ASCE Engineering Mechanics Institute 2023 Conference

Atlanta, Georgia | June 6 – 9, 2023

Book of Abstracts

Table of Contents

Plenary Lecture Abstracts

Nurturing Augmented Twins; From First Principles, to Learning, to Real-time Virtualization

Eleni Chatzi, Ph.D., M.ASCE, Eidgenössische Technische Hochschule (ETH) Zürich(Switzerland)

Abstract Modern engineering structures form complex assemblies that operate under highly varying loads and adverse environments. To ensure a resource-efficient and resilient operation of such systems, it is imperative to understand their performance as-is; a task which can be effectuated through Structural Health Monitoring (SHM). SHM comprises a hierarchy across levels of increasing complexity aiming to i) detect, ii) localize and iii) quantify damage, and iv) finally offer a prognosis over the system's residual life. When considering higher levels in this hierarchy, including damage assessment and even performance prognosis, purely data-driven methods are found to be lacking. For higher-level SHM tasks, or for furnishing a digital twin of a monitored structure, it is necessary to integrate the knowledge stemming from physics-based representations, relying on the underlying principles of mechanics/dynamics. This talk discusses implementation of such a hybrid approach to SHM aiming to tackle the aforementioned challenges for robust simulation and monitoring of engineered systems. It offers a view to establishing augmented twin representations, capable of representing the structure as-is, anticipating performance under future stressors, and advising on preventive and remedial actions.

Biographical Sketch Eleni Chatzi is an Associate Professor and Chair of Structural Mechanics and Monitoring at the Department of Civil, Environmental and Geomatic Engineering of ETH Zurich, Switzerland. Her research interests include the fields of Structural Health Monitoring (SHM) and structural dynamics, nonlinear system identification, and intelligent life-cycle assessment for engineered systems. She has authored more than 300 papers in peer-reviewed journals and conference proceedings, and further serves as an editor for international journals in the domains of Dynamics and SHM. She led the recently completed ERC Starting Grant WINDMIL on the topic of "Smart Monitoring, Inspection and Life-Cycle Assessment of Wind Turbines". Her work in the domain of self-aware infrastructure was recognized with the 2020 Walter L. Huber Research prize, awarded by the American Society of Civil Engineers (ASCE).

Shape Memory Alloy Structures: Modeling, Simulation, and Experiments

Chad M. Landis, Ph.D., University of Texas at Austin

Abstract In this lecture I will present work with my colleague, Prof. Stelios Kyriakides, and our students on our recent investigations of the physical response of shape memory alloy structures, under a wide range of thermal and mechanical loadings that link careful experiments with detailed numerical simulations. The first part of the talk will focus on the structure of a newly devised constitutive modeling framework describing the thermomechanical response of SMAs. As the ultimate goal of the model is its implementation within finite element calculations of SMA structures, it is a phenomenological model with a small set of internal variables, specifically the transformation strains and the transformation entropy that is directly related to the martensite volume fraction. The construction of the model is based on a usual flow-theory plasticity framework with kinematic hardening. One novelty of the approach is that a *single* transformation, i.e. yield, surface in effective stress and effective temperature space is introduced, and an associated flow rule then governs the evolution of the transformation strain and entropy. To capture the multitude of SMA behaviors, a transformation potential function is introduced in transformation strain and entropy space for the derivation of the back stresses and back temperatures that define the kinematic hardening behavior. It is this potential function that governs all the important behaviors within the model. The model is capable of capturing the asymmetries in tension versus compression for transformation strain, transformation stress, and in the hardening in tension versus compression with softening allowed in tension along with hardening in compression. The second part of the talk will describe the implementation of the model for the simulation of SMA strips and tubes subjected to a wide range of thermomechanical loadings (tension, compression, bending, iso- and non-isothermal). Meticulously devised experiments were performed that show that these structures exhibit instabilities, e.g. buckling in compression and Lüders-like bands in tension due to softening, that are all reproduced in the simulations. Finally, I will discuss our work on a transformation strain gradient enhancement of the model for incorporating the material length scale associated with the macroscopic interface between austenite and martensite in these structures, and how that length scale can be determined by linking careful experiments to detailed numerical simulations.

Biographical Sketch Professor Landis has a broad range of interests in the mechanics of materials, including fracture mechanics, plasticity, micromechanics, composites, and finite element methods. He has made contributions to the constitutive modeling and fracture mechanics of ferroelectrics, ferromagnetic materials, and shape memory alloys. He has also made significant contributions to phase-field modeling of fracture where he has applied and extended this approach to dynamic crack propagation, ductile failure, hydraulic fracture, and fatigue crack growth. His work is highly collaborative and he is always looking to cooperate with other researchers both in his own department, nationally, and internationally. Professor Landis serves as an Associate Editor for the International Journal of Solids and Structures, a Regional Editor for the International Journal of Fracture, Associate Editor for the Journal of the American Ceramics Society, and in the past as Associate Editor for the Journal of Applied Mechanics. He also serves on the Editorial Board of Computational Methods in Theoretical and Applied Mechanics. Additionally, he is as a member of the U.S. National Committee for Theoretical and Applied Mechanics, and in the summer of 2022, he served as the co-Chair of the 19th U.S. National Congress on Theoretical and Applied Mechanics.

Particle Scale Modelling of Clay: Opportunities and Challenges

Catherine O'Sullivan, Ph.D., Imperial College London (UK)

Abstract Understanding of the mechanical behaviour of granular materials, including sand, has been greatly improved thanks to our ability to use the discrete element method to develop numerical models that explicitly consider the individual particles and their interactions. In many civil engineering projects the more significant geotechnical challenges are posed by clay deposits. In contrast to sand grains, clay particles are platy, the electrostatic forces between them influence their movement, and the interactions are sensitive to the pore water chemistry. This means we cannot directly apply software and algorithms developed for sand to clay; instead the modelling toolkit needs adaptation and extension to enable us to address problems that can have a real impact on civil engineering practice. In other words, the models are, by necessity, significantly more complex. This presentation will lay out the argument in favour of the development of particle-based models of clay. Then, drawing on her own experience, the speaker will lay out the key challenges that must be addressed to develop useful particle-based models of clay. This discussion will encompass the particle interaction models (potential functions) required including their calibration, interparticle friction, system size effects, and the anisotropy of the particle surface charge. The arguments will largely be supported by considering data from recent molecular dynamics simulations of systems of kaolinite particles, however many of the points made are applicable to other mineralogies and other colloidal materials.

Biographical Sketch Catherine O'Sullivan is a Professor in Particulate Soil Mechanics at Imperial College London. Originally from Ireland, she obtained her PhD from the University of California at Berkeley in 2002. Her research has examined soil behaviour focussing on the particulate scale. Catherine has authored a textbook on the use of discrete element modelling in geomechanics and has authored/co-authored over 100 contributions to international journals. In 2015 she delivered the Géotechnique lecture. Funding for her post-graduate studies and research has been provided by the Fulbright Programme, the O'Reilly Foundation, IRCSET, the EPSRC, the ICE, the Leverhulme Trust and ARUP. Catherine is currently a member of the editorial boards of Soils and Foundations, Computers and Geotechnics, Granular Matter and an Editor of the ASCE Journal of Geotechnical and Geoenvironmental Engineering.

Recent Advances and Breakthroughs in the Modeling and Simulation of Extreme Events

Yuri Bazilevs, Ph.D., A.M.ASCE, Brown University

Abstract In this presentation we'll first give a broad discussion of computational Fluid-Structure Interaction (FSI), focusing on several classes of problems and the corresponding numerical formulations that deliver efficient, accurate and practical solutions. Next, we'll discuss a new class of formulations for the immersed coupling of Isogeometric Analysis (IGA) and Meshfree Methods for the simulation of FSI with applications to extreme events. We'll focus on air- and water-blast FSI applications, and address the computational challenges of immersed FSI methods in the simulation of fracture and fragmentation by developing strongly and weakly volume-coupled FSI formulations and showing these in action. In the present work, we employ *Peridynamics-as-a-discretization* as a meshfree methods of choice, however, the proposed approach works just as easily with other meshfree methods. We show the mathematical formulations and present several numerical examples in 2D and 3D, and with experimental validation, of inelastic ductile, brittle and quasi-brittle solids under blast loading that clearly demonstrate the power and robustness of the proposed methodologies.

Biographical Sketch Yuri Bazilevs is the E. Paul Sorensen Professor in the School of Engineering at Brown University, where he was the Lead and Executive Committee representative of the Mechanics of Solids and Structures group. He was previously a Professor and Vice Chair in the Structural Engineering Department at the University of California, San Diego. Yuri's research interests lie in the broad field of computational science and engineering, with emphasis on the modeling and simulation in solids and structures, fluids, and their coupling in HPC environments. For his research contributions Yuri received many awards and honors, including the 2018 Walter E. Huber Research Prize from the ASCE, the 2020 Gustus L. Larson Award from the ASME, the inaugural 2021 Centennial Mid-Career Award from the Materials Division of the ASME, and the Computational Mechanics Award from the International Association for Computational Mechanics (IACM). He is included in the lists of Highly Cited Researchers, both in the Engineering (2015-2018) and Computer Science (2014-2019) categories. Yuri recently completed his service as the President of the US Association for Computational Mechanics (USACM) and as the Chairman of the Applied Mechanics Division of the ASME. He currently serves on the US National Committee for Theoretical and Applied Mechanics (USNCTAM).

Engineering Mechanics Role in Robot-enabled Infrastructure Preservation

Genda Chen, Ph.D., P.E., F.ASCE, Missouri Science & Technology University

Abstract More than 42% of over 617,000 U.S. bridges are 50 years (design life) or older. It is thus imperative to meet more frequent and more rigorous preservation needs to ensure that the aging infrastructure is safe during everyday operations and resilient to catastrophic events. Drones and structural crawlers, or robots in general, are efficient and effective platforms that can be rapidly deployed to support sensor installation, visual inspection, nondestructive evaluation, and preventive maintenance of bridges. This presentation will provide an overview of engineering mechanics problems and solutions to platform dynamics, the probability of deterioration detection, aerial testing and evaluation, and machine learning for data-driven asset management enabled by the INSPIRE University Transportation Center partners. For example, control design equations of structural crawlers and/or drones with robotic arms will be established and solved to support bridge inspection and maintenance tasks. Given k robots, a NP-hard min-max k-Chinese postman problem will be formulated to generate optimal inspection routes using generic algorithms. Aerial impact-echo tests for delamination detection and/or ultrasonic metal thickness measurement will show their superior performance that is comparable to ground-based nondestructive tests. Mathematically rigorous approaches to evaluate the level of deterioration based on the data taken from in-situ sensors will be presented to shed light on the unconservative nature of traditional statistical analysis. Explainable artificial intelligence will engage inspectors at two levels: (1) inspectors-in-the-loop during training and testing of semi-supervised deep learning algorithms and (2) sensitivity analysis to understand the effect of individual key factors to a desirable prediction from neural additive models. This presentation will conclude with a few key challenges and research opportunities in robot-enabled infrastructure preservation.

Biographical Sketch Dr. Genda Chen is Professor and Abbett Distinguished Chair in Civil Engineering, Director of the Center for Intelligent Infrastructure, and Director of INSPIRE University Transportation Center at Missouri University of Science and Technology. He has authored or co-authored over 400 technical publications and delivered 28 keynote/invited presentations at international conferences. He received the international 2019 Structural Health Monitoring Person of the Year Award and the 1998 National Science Foundation CAREER Award. He is a Fellow of American Society of Civil Engineers and the International Society for Structural Health Monitoring of Intelligent Infrastructure. He serves as Vice President of the U.S. Panel on Structural Control and Monitoring.

Decision-Oriented Sensitivity Analysis with Applications to Engineering Mechanics

Daniel Straub, Ph.D., Technical University of Munich (Germany)

Abstract In engineering, models are created and employed to support decision making. Consider a structural engineering model that serves to determine the materials, shapes and dimensions of structural members. Or a fracture mechanics model that is established to assess the safety of a mechanical component against fatigue, to decide if the component can be safely continued in operation. As engineers are aware, such models and their predictions are subject to uncertainty, which must be considered when making decisions based on the model output, e.g., by using safety factors. Sensitivity analysis can be employed to better understand the effect of specific input uncertainties on the model outcome. There exist a myriad of sensitivity measures that can be employed, which can be confusing. Since the engineering model is ultimately used for decision making, what measure could be better suited than one that directly quantifies the effect of the uncertainty on the decision, i.e., a measure of decision sensitivity? Such measures have been around for a while, but have received no attention in the engineering community. They measure the importance of a specific input uncertainty by quantifying how likely this uncertainty causes a change in the decision, and how much can be gained by an improved decision. As I will show in this talk, they are easier to interpret than other sensitivity measures and their computation is not necessarily more demanding than that of other commonly used measures, such as the Sobol' index. I start out the talk with a brief introduction to sensitivity analysis and its goals. This includes a discussion of uncertainty in engineering models and their treatment in decision support. I then present the decision-theoretic background (which is less complicated than it sounds) and show the derivation of decision sensitivity measures. Since the measures depend on the decision context, I propose a categorization of decisions encountered in engineering mechanics and derive the proper sensitivity measures for these different decision categories. Along the way, the relation to other commonly used sensitivity measures are highlighted – which also helps to better interpret those measures. This is followed by a presentation of different computational strategies to evaluate these sensitivity measures. I show that often the measures can be obtained by a mere post-processing of results obtained from a standard uncertainty or reliability analysis. Throughout the talk, application examples illustrate the concepts and methods and demonstrate their easy interpretability. The talk ends with a discussion of lessons learnt from real-life applications and remaining challenges.

Biographical Sketch Daniel Straub is Associate Professor for engineering risk and reliability analysis at Technical University of Munich (TUM). He develops physics-based stochastic models and methods for decision support and safety analysis of engineering systems, with a particular focus on Bayesian techniques and AI methods. Daniel obtained his Dipl.-Ing. degree in civil engineering in 2000 and his PhD in 2004 from ETH Zürich and was a postdoc and adjunct faculty at UC Berkeley before joining TUM in 2009. He is also active as a consultant to the industry on reliability and risk assessments and decision making under uncertainty. His awards include the ETH Silbermedaille, the Early Achievement Research Award of IASSAR and the SAE Ralph H. Isbrandt Automotive Safety Engineering Award.

List of Mini-Symposia and Associated Abstracts

MS101: Mechanics, Physics, and Chemistry for Sustainable and Resilient Civil, Energy, and Bio-related Infrastructures and Materials - In honor of the NAE Recognition of Prof. Franz-Josef Ulm.

Organizer(s): Ange-Therese Akono, Mohammad Javad Abdolhosseini Qomi, Matthieu Vandamme

- ID 118: Sustainable and Resilient Coastal Infrastructure Amidst A Sea Level Rise and Coastal Storm Environment. *Author(s): George Deodatis, Kyle Mandli, Yuki Miura*
- ID 126: Are Configurational Forces Real Forces. *Author(s): Roberto Ballarini, Gianni Royer-Carfagni*
- ID 200: Thermo-poro-mechanical couplings from molecular fluctuations and application to cellulose. *Author(s): Laurent Brochard*
- ID 225: Leapfrog in Computational Fracture Mechanics Empowered by Curvature-Limiting Sprain as Damage Localization Limiter. *Author(s): Zdeněk Bažant, Houlin Xu, A. Abdullah Dönmez, Anh Nguyen, Yupeng Zhang*
- ID 291: Viscous behavior of shale rocks due to dissolution and precipitation processes. *Author(s): Ravi Prakash, Arash Noshadravan, Sara Abedi*
- ID 333: The Physics of Urban Flooding. *Author(s): Sarah Balaian, Brett Sanders, Mohammad Javad Abdolhosseini Qomi*
- ID 389: Chemo-mechanical homogenization applied to climate and energy geomechanics. *Author(s): Chloe Arson*
- ID 520: Engineering now! Are we ready?. *Author(s): Franz-Josef Ulm*
- ID 537: A Machine-learning approach to development of Microtexture-Effective Property relationship. *Author(s): Xuejing Wang, Mazdak Tootkaboni, Arghavan Louhghalam*
- ID 567: Falling Weight Deflectometer tests on multi-layered pavements: design and evaluation of innovative experiments. *Author(s): Rodrigo Díaz Flores, Valentin Donev, Mehdi Aminbaghai, Lukas Eberhardsteiner, Luis H. Zelaya-Lainez, Raphael Höller, Christian Hellmich, Ronald Blab, Martin Buchta, Bernhard L.A. Pichler*
- ID 611: Reducing Thermal Conductivity of Calcium Silicate Hydrates: New Technological Opportunities provided by Cross-Linking with Organic Molecules. A*uthor(s): Amir Moshiri, Ali Morshedifard, Damian Stefaniuk, Santiago EL Awad, Kamil Krzywinski, Debora Frigi Rodrigues, Tejasree Phatak, Mohammad Abdolhosseini Qomi, Konrad Krakowiak*
- ID 619: Molecular simulations study of freezing of water confined in C-S-H, and implications for the cryo-suction process. *Author(s): Xinping ZHU, Laurent Brochard, Matthieu Vandamme*
- ID 630: Elastic and Plastic Characteristics of Lithium-Graphite Intercalation Phase. *Author(s): Edris Akbari, George Z. Voyiadjis*
- ID 780: Enhance Structures' Resilience with Particle Physics: a Statistical Approach of Quasi-Static Brittle Fracture.. *Author(s): Ariel Attias, Franz-Josef Ulm*
- ID 824: Hidden environmental footprint of roadway network: when mechanistic models meet data analytics. *Author(s): Mazdak Tootkaboni, Meshkat Botshekan, Franz Ulm, Arghavan Louhghalam*
- ID 826: Forces between Calcium-Silicate-Hydrate Surfaces: A Density Functional Approach. *Author(s): Thomas Petersen*
- ID 886: Multi-scale Toughness via Scratch Testing: From QuasiBrittle to Ductile Materials. *Author(s): Ange-Therese Akono*
- ID 890: Carbon-cement supercapacitors: A scalable bulk energy storage solution. *Author(s): Damian Stefaniuk, Nicolas Chanut, James C. Weaver, Yang Shao-Horn, Franz-Jozef Ulm, Admir Masic*
- ID 903: Analytical solution for a poroelastic inclusion embedded within an elastoplastic matrix. *Author(s): Yidi Wu, Amin Mehrabian, Shengli Chen, Younane Abousleiman*
- ID 923: Mesoscale logic mediates microscale chatter and scientific discovery. *Author(s): Roger Ghanem, Zheming Gou*
- ID 973: Fluctuation-based fracture and healing of materials and structures in the semi-grand canonical ensemble. *Author(s): Nima Rahbar*

MS104: Advanced Engineering Concepts, Designs, and Technologies for Aerospace and Extraterrestrial Applications (Sponsored by ASCE Aerospace Division).

Organizer(s): Ramesh Malla, Ph.D., F. ASCE, F. EMI, Robert Mueller, Kris Zacny, Hongyu (Nick) Zhou

- ID 253: Incorporating a Finite Element-Based Structural model within a System of Systems Modeling Framework to Analyze Smart Habitats in Deep Space Environments. *Author(s): Adnan Shahriar, Arsalan Majlesi, David Avila, Arturo Montoya*
- ID 260: Machinability Characteristics of Cu-Al-Mn and NiTi Shape Memory Alloys and Common Steels. *Author(s): Huanpeng Hong, Bora Gencturk*
- ID 274: Risks and Challenges of Using Earth Rock Mass Classification System on the Moon. *Author(s): Roberto Mendonca de Moraes, Antonio Bobet*
- ID 345: Vibration effects on assisting penetration into granular materials. *Author(s): Mahdi Alaei, Pooneh Maghoul, Nan Wu*
- ID 388: Experimental investigation on the in-plane compressive behavior of curved steered fiber laminated panels. *Author(s): Avinkrishnan Ambika Vijayachandran, Shiyao Lin, Anthony Waas*
- ID 415: Sintering for ISRU-Oriented Lunar Regolith Densification: Multiscale Characterization and Multiphysics Computational Modeling. *Author(s): Shayan Gholami, Young-Jae Kim, Xiang Zhang, Yong-Rak Kim, Bai Cui, Hyu-Soung Shin, Jangguen Lee*
- ID 554: Temperature Profile on a Lunar Habitat Structure Covered with Regolith Protective Layer. *Author(s): Sachin Tripathi, Ramesh Malla*
- ID 564: A Stabilized Interface Method for 3D Printing: Terrestrial and Extraterrestrial Applications. *Author(s): Arif Masud, Ignasius Wijaya, Eric Kreiger*
- ID 682: Discrete Element Method for Regolith-Tool Interaction Modeling of RASSOR Collection System. *Author(s): Daniel Gaines, Qiushi Chen, Laura Redmond*
- ID 728: Considering the non-linear behavior of materials in the design of lunar habitats. *Author(s): Arsalan Majlesi, Amir Behjat, Adnan Shahriar, David Avila, Arturo Montoya, Shirley Dyke, Julio Ramirez*
- ID 793: Seismic Regolith-Structure Interaction on Proposed Martian Habitats. *Author(s): Hamed Seifamiri, Pooneh Maghoul, Roberto de Moraes, Ramesh B. Malla*
- ID 811: Micromechanics-guided design of functional cementitious composites for 3D printing. *Author(s): Hongyu Zhou, Adam Brooks, Zhenglai Shen*
- ID 816: Industrialized and Robotic Construction Advances in Terrestrial Construction and Opportunities in Space Construction. *Author(s): Naveen Kumar Muthumanickam*

MS201: Physics-Based Data-Driven Modeling and Uncertainty Quantification in Computational Materials Science and Engineering.

Organizer(s): Johann Guilleminot, Michael Shields, Lori Graham-Brady, Kirubel Teferra

- ID 312: Probabilistic Gait Parameters from Floor Vibrations. *Author(s): Yohanna MejiaCruz, Juan M. Caicedo, Zhaoshuo Jiang, Jean Franco Lozada*
- ID 334: Multi-fidelity Physics-informed Generative Adversarial Network for Solving Partial Differential Equations. *Author(s): Mehdi Taghizadeh, Mohammad Amin Nabian, Negin Alemazkoor*
- ID 375: Quantification of the effect of uncertainty in noise on posterior probability values. *Author(s): Yupeng Zhang, Jeffrey Hart*
- ID 410: Multi-scale stochastic modeling and uncertainty quantification of rare events using the switching diffusion model. *Author(s): Zheming Gou, Xiaohui Tu, Sergey Lototsky, Roger Ghanem*
- ID 450: Reconstruction of 3D microstructures from 2D images by using a pre-trained deep neural network in a gradient-based sequential optimization approach. *Author(s): Ashwini Gupta, Noah Wade, Lori Graham-Brady*
- ID 498: Data-driven projection pursuit adaptation in polynomial chaos expansion for high-dimensional problems. *Author(s): Xiaoshu Zeng, Roger Ghanem*

- ID 638: Constitutive Relationship Exploration in A fiber-reinforced Composite Material with Uncertainty. *Author(s): Zhengtao Yao, Roger Ghanem, Venkat Aitharaju, Jay Mahishi*
- ID 789: Manifold Learning to Map Amorphous Microstructural Features to Local Yield Stress. *Author(s): Rahul Meena, Spencer Fajardo, Michael D. Shields, Michael L. Falk, Dimitris Giovanis, Thomas J. Hardin, Michael Chandross, Yannis Kevrekidis*
- ID 818: Prediction of Microstructure Evolution with Physics-Constrained Bayesian Neural Networks. *Author(s): Luka Malashkhia, Dehao Liu, Anh Tran, Yanglong Lu, Yan Wang*
- ID 840: Error quantification of wind tunnel-informed stochastic wind model based on the translation processes for simulation of non-Gaussian wind pressures on buildings. *Author(s): Thays Duarte, Srinivasan Arunachalam, Arthriya Subgranon, Seymour Spence*
- ID 868: A First-Order formulation with exact imposition of boundary conditions for physics-informed neural networks. *Author(s): Rini J. Gladstone, Mohammad A. Nabian, Hadi Meidani*

MS202: Structural Identification and Damage Detection.

Organizer(s): Eleni Chatzi, Costas Papadimitriou, Babak Moaveni

- ID 248: Sensitivity Analysis of Model-Assisted Probability of Detection for Guided-Wave-Based Structural Health Monitoring Systems. *Author(s): Juan David Navarro, Juan Camilo Velasquez-Gonzalez, Mauricio Aristizabal, Harry Millwater, Arturo Montoya, David Restrepo*
- ID 249: Rapid performance evaluation of building structures under seismic excitations based on prior dynamic testing. *Author(s): Luji Wang, Jiazeng Shan*
- ID 268: Framework for Near-real-time Seismic Damage Detection of Structural Systems using Structural-mode-based Graph Neural Network. *Author(s): Minkyu Kim, Junho Song*
- ID 305: Dual state-parameter estimation of continuous structural systems using Adaptive Physics-informed parallel neural networks. *Author(s): Rui Zhang, Gordon P. Warn, Aleksandra Radlińska*
- ID 310: Operational Modal Analysis of Two Offshore Wind Turbines in CVOW Wind Farm. *Author(s): Burak Bagirgan, Babak Moaveni, Eric Hines*
- ID 351: Model-based Unknown Input Estimation via Partially Observable Markov Decision Processes. *Author(s): Wei Liu, Zhilu Lai, Charikleia Stoura, Kiran Bacsa, Eleni Chatzi*
- ID 397: Kernel ridge regression based force identification in the time domain. *Author(s): Shuo HAO, Su-Mei WANG, Yi-Qing NI*
- ID 434: Transfer Learning Enhanced Neural ODEs for Adaptive Digital Twin Modeling. *Author(s): Yujie GAN, Zhilu LAI*
- ID 510: Identification of Fractional Dynamical Systems using Recursive Nonlinear Stochastic Filtering Methods. *Author(s): Kalil Erazo, Alberto Di Matteo*
- ID 518: Environmental Effects on Output-Only Vibration Parameters of Reinforced Concrete Systems. *Author(s): Maya Rao, Riley Brown, Karl Gaebler, Carol Shield, Lauren Linderman*
- ID 552: Unsupervised Damage Detection for Smart Extraterrestrial Habitats Using Autoencoders and Information Fusion. *Author(s): Zixin Wang, Mohammad Jahanshahi, Ilias Bilionis, Amin Maghareh, Yuguang Fu, Shirley Dyke*
- ID 592: State-Input-Parameter Identifiability in Output Only Structural Identification. *Author(s): Adrita Kundu, Suparno Mukhopadhyay*
- ID 598: Strain Transfer Mechanisms of Fiber Optic Sensors and Recent Applications of Distributed Fiber Optic Sensing on Structural Component Testing. *Author(s): Shenghan Zhang, Matthew DeJong*
- ID 634: The Impact of Modelling Error when estimating the foundation parameters of Offshore Wind Turbines through Bayesian Model Updating. *Author(s): Harry Simpson, Imad Abdallah, Costas Papadimitriou, Eleni Chatzi, Manolis Chatzis*
- ID 662: Wind Load Estimation of an Operational 6 MW Offshore Wind Turbine: a comparison of physics-based vs. data-driven approaches. *Author(s): Azin Mehrjoo, Finn Rüdinger, Ross McAdam, Babak Moaveni, Eric Hines*

- ID 690: Digital Twinning and Wind Load Estimation of Block Island Offshore Wind Turbines Using One Year of Data. *Author(s): Babak Moaveni, Eric Hines*
- ID 707: A Transfer Learning Strategy for Virtual Sensing in Offshore Wind Farms. *Author(s): Eleonora Maria Tronci, Anna Haensch, Babak Moaveni, Eric Hines*
- ID 710: Finite element model updating of non-proportional non-viscous damping systems using complex eigenvalues and eigenvectors. *Author(s): Yu Otsuki, Yang Wang*
- ID 734: Physics-informed machine learning for hidden crack localization in concrete structure: Experimental evaluation of multi-fidelity transfer learning approaches. *Author(s): Sarah Miele, Pranav Karve, Sankaran Mahadevan*
- ID 747: Output-Only Bayesian System Identification for Digital Twinning of Floating Offshore Wind Turbines. *Author(s): Martin Masanes Didyk, Vahid Bagherian, Saeed Eftekhar Azam, Mohsen Ebrahimzadeh Hassanabadi, Babak Moaveni*
- ID 761: A framework for design allowables accounting for paucity of data and errors in complex models. *Author(s): Philippe Hawi, Roger Ghanem*
- ID 804: Supervised Learning with GPR A-scans for Material Property Prediction in Building Envelopes. *Author(s): Ahmed Nirjhar Alam, Wesley Reinhart, Rebecca Napolitano*

MS203: Computational Methods for Stochastic Engineering Dynamics.

Organizer(s): Ketson Dos Santos, Vasileios Fragkoulis, Ioannis Kougioumtzoglou, Antonina Pirrotta

- ID 150: A Bayesian compressive sampling approach for modeling, analysis and diagnostics of dynamic cerebral autoregulation in cardiovascular disease. *Author(s): Maria Katsidoniotaki, Leonidas Taliadouros, Ioannis Kougioumtzoglou, Eliza Miller, Randolph Marshall*
- ID 159: Dynamics and extreme response probability distributions of linear elastic structures subjected to harmonizable loads. *Author(s): Zifeng Huang, Michael Beer*
- ID 205: Performance Enhancement of Vibro-Impact Targeted Energy Transfer Within a Random Environment. *Author(s): Rahul Kumar, Daniil Yurchenko, Rachel Kuske*
- ID 269: Response statistics of vibro-impact system via the Step Matrix Multiplication based on Path Integration method. *Author(s): Henrik Tamás Sykora, Rachel Kuske, Daniil Yurchenko*
- ID 327: The Emergence of an Inherent Urban Resilience to Natural Hazards. *Author(s): Nicos Makris, Tue Vu, Gholamreza Moghimi, Georgios Chatzikyriakidis, Eric Godat*
- ID 439: Response evolutionary power spectrum determination of nonlinear oscillators endowed with fractional derivative elements. *Author(s): Vasileios Fragkoulis, Ioannis Kougioumtzoglou, Athanasios Pantelous, Michael Beer*
- ID 446: Efficient Wiener path integral most probable path determination based on extrapolation. *Author(s): Ilias Mavromatis, Ioannis Kougioumtzoglou*
- ID 465: A Rayleigh-Ritz solution approach for determining the Wiener path integral technique most probable path with mixed fixed/free boundaries. *Author(s): Ketson Roberto Maximiano dos Santos, Ioannis A. Kougioumtzoglou*
- ID 480: Hierarchical Bayesian Approach for Electromechanical Properties Updating in Piezoelectric Energy Harvesters. *Author(s): Rafael Ruiz, Alejandro Poblete, Gaofeng Jia*
- ID 582: First-passage stochastic incremental dynamics methodology for nonlinear structural systems with fractional derivative elements. *Author(s): Peihua Ni, Ioannis Mitseas, Vasileios Fragkoulis, Michael Beer*
- ID 718: Combination of Statistical Linearization and Harmonic Balance for non-stationary random vibration analyses. *Author(s): Beatrice Pomaro, Pol D. Spanos*

MS204: Machine learning innovations towards long-term safety, performance, and serviceability assessment of civil infrastructure.

Organizer(s): Mauricio Pereira, Branko Glisic

- ID 316: Structural Dynamics Learning using a Supervised Variational Auto-Encoder (SVAE). *Author(s): Kiran Bacsa, Wei Liu, Eleni Chatzi*
- ID 649: Prediction of long-term time-dependent behavior in prestressed concrete structures. *Author(s): Mauricio Pereira, Branko Glisic*
- ID 671: Machine Learning Algorithm to Predict Axial Stress in Continuous Welded Rails. *Author(s): Matthew Belding, Alireza Enshaeian, Piervincenzo Rizzo*
- ID 732: Machine Learning- Based Virtual Buoys Model for Live Prediction of Wave Height. *Author(s): Eleonora Maria Tronci, Matteo Vitale, Therese Patrosio, Seixas Aldrich, Anela Bajric, Babak Moaveni, Usman Khan*

MS205: Innovations and Advances in Passive, Active, and Semi-active Structural Control.

Organizer(s): Nicholas Wierschem, P. Scott Harvey

- ID 125: Control Perfromance of Sloped Rolling-type Bearings with an Added Rotational Inerter. *Author(s): Shiang-Jung Wang, Yi-An Lai, Chung-Han Yu, Yu-Wen Chang, Ting-Yu Hsu*
- ID 199: Active Control of Equipment Seismic Isolation System by Output Feedback Skyhook Algorithm. *Author(s): Yong-An Lai, Po-Yen Wu*
- ID 278: Deep reinforcement learning strategies for structural control devices with variable inerter. *Author(s): Takehiko Asai, Yuto Inaba*
- ID 359: Tuned-inerter dampers in vibration control of semi-submersible offshore wind platforms to improve system lifespan and energy harvesting. *Author(s): Lauren Hall, Duncan Lambert, Ryan Okuda, Lei Zuo, Biao Fang, Yifan Luo, Javad Javaherian*
- ID 557: Inerters: Mapping the Multiple Mechanisms for Magnifying Mass. *Author(s): Jonathan Shell, Nicholas Wierschem*
- ID 559: A Numerical Study of Clutching Inerter Dampers for Mitigating the response of Multi-degree-of-freedom Base-Isolated Structures. *Author(s): Wyatt Cupp, Nicholas Wierschem*
- ID 561: Seismic Performance of Multi-degree-of-freedom Structures with Variable Inertia Rotational Mechanisms. *Author(s): Anika Sarkar, Nicholas Wierschem*
- ID 607: Semi-active cam-lever friction device for structural control of buildings subjected to natural hazards. *Author(s): Alejandro Palacio-Betancur, Mariantonieta Gutierrez Soto*
- ID 674: Application of Fe-SMA Bars as Self-Centering Elements in Bridge Piers to Improved Seismic Resilience. *Author(s): Masood Vahedi, Hamed Ebrahimian, M. Saiid Saiidi*
- ID 781: On the effect of vertical flexibility in objects isolated on pendulum-type systems. *Author(s): Mia Griffin, P. Scott Harvey*
- ID 832: Experimental Testing of T-FLC Yielding Element with Non-Degrading Hysteretic Profile to Limit Floor Accelerations in SMF-Spine Systems. *Author(s): Jessica Duke, Richard Sause, James Ricles, Larry Fahnestock, Barbara Simpson, Bryam Astudillo, Zhuoqi Tao*

MS206: Infrastructure assessment automation with robotics, deep learning and digital twins.

Organizer(s): Vedhus Hoskere, Jian Li, Wei Song

- ID 322: Autonomous Defect Detection in Bolted Connections of Highway Ancillary Structures Using Deep Learning. *Author(s): Faezeh Jafari, Sattar Dorafshan*
- ID 329: An image-based modeling-to-simulation framework for hazard vulnerability assessment of unreinforced masonry structures. *Author(s): Mohammad Abu-Haifa, Seung Jae Lee*
- ID 352: Towards real-time digital twins for post-earthquake damage assessment of masonry buildings. *Author(s): Bryan German Pantoja-Rosero, Radhakrishna Achanta, Katrin Beyer*

- ID 547: Monitoring Infrastructure using Augmented Reality in a Network of Microrobots with Visual Data Analysis. *Author(s): Alireza Fath, Nicholas Hanna, Yi Liu, Scott Tanch, Tian Xia, Dryver Huston*
- ID 627: Addressing Structural Health Monitoring Uncertainty in a Deep Learning-based Anomaly Detection System. *Author(s): Kareem Eltouny, Xiao Liang*
- ID 753: Autonomous Crack Sealing Robot for Infrastructure Maintenance using Reinforcement Learning. *Author(s): Joshua Genova, Subin Varghese, Vedhus Hoskere*
- ID 756: Insights on Hyperparameter Importance in Crack Segmentation DCNNs. *Author(s): Carlos Canchila, Shanglian Zhou, Wei Song*
- ID 829: Agile Simulation of Structural Systems within a Digital Twin Framework. *Author(s): Zahra Zhiyanpour, Ayatollah Yehia, Mehrdad Shafiei Dizaji, Devin Harris*
- ID 853: The role of digital twins for predictive maintenance of concrete deck bridges. *Author(s): Manuel Salmeron, Xin Zhang, Shirley Dyke, Julio Ramirez*
- ID 865: Bridge Deck Underside Condition Assessments with UAS Acoustic Sensor. *Author(s): Damien Garland, Tian Xia, Dryver Huston*
- ID 932: Digital twins for inspections of reinforced concrete bridges. *Author(s): Asad ur Rahman, Deepank Kumar Singh, Subin Varghese, Vedhus Hoskere*

MS207: Recent Advances in Hybrid Simulation and Real-time Hybrid Simulation.

Organizer(s): Wei Song, Richard Christenson

- ID 116: Hybrid Simulation with Combined Displacement and Force Based Experimental Control Points. *Author(s): Claudio Sepulveda, Gilberto Mosqueda, Chia-Ming Uang, Chung-Che Chou, Kung-Juin Wang*
- ID 171: Investigation of the Effect of Dynamic Axial Force on the Lateral Response of RC Columns Using Real-Time Hybrid Simulation. *Author(s): Yunbyeong Chae, Jamin Park, Minseok Park, Chul-Young Kim*
- ID 217: Real-time hybrid simulation test of mast structure considering fluid-structure interaction. *Author(s): Yucai Chen, Xiaojun Zheng, X. Shawn Gao, Kun Wang, Jiurong Wu , Huimeng Zhou, Pin Tan*
- ID 230: Application of Hydro-Real-Time Hybrid Simulation to Examine the Response of Offshore Wind Turbines. *Author(s): Akiri Seki, Jonah Gadasi, Cameron Irmas, Bret Bosma, Shangyan Zou, Michael Devin, Barbara Simpson, Bryson Robertson, Bryony DuPont, Ted Brekken, Andreas Schellenberg, Pedro Lomonaco*
- ID 276: Modeling of the Dynamic Interaction between the NHERI@UCSD 6-DOF Large High-Performance Outdoor Shake Table and TallWood Building Specimen. *Author(s): Chin-Ta Lai, Joel Conte*
- ID 602: Multi-directional Behavior of a Tall Building Equipped with Damped Outriggers using 3D Real-Time Hybrid Simulation. *Author(s): Safwan Al-Subaihawi, James Ricles, Thomas Marullo, Liang Cao*
- ID 664: A Real-Time Hybrid Simulation Platform for Monopile Offshore Wind Turbines. *Author(s): Wei Song, Chao Sun, Santiago Ruiz*
- ID 778: Revisiting Hybrid Simulation with a Cost-Effective Hardware-Software Platform. *Author(s): Juan Meriles, Khalid M. Mosalam*
- ID 796: Multi-Axis Shake Table Real-time Hybrid Simulations of Buildings with Floor Isolation Systems. *Author(s): James Ricles, Liang Cao, Esteban Villalobos Vega, Scott Harvey, Thomas Marullo, Faisal Malik*
- ID 798: Thermomechanical Real-Time Hybrid Simulation: Identification, Control, and Experimental Implementation. *Author(s): Herta Montoya, Christian Silva, Shirley Dyke, Manuel Salmeron*
- ID 880: Experimental Validation of Real-Time Hybrid Substructuring for a Seismically Excited Building using an Inertial Shaker Transfer System. *Author(s): David Vanasse, Sergio Lobo-Aguilar, Richard Christenson*

MS208: Advances in bridge health monitoring: Data-driven and machine learning methods, indirect monitoring, crowdsourced mobile sensing.

Organizer(s): Debarshi Sen, Basuraj Bhowmik, Shamim Pakzad

- ID 107: A Decision Tree-based Neural Network Approach for Railroad Bridge Event Classification. *Author(s): Omobolaji Lawal, Shaik Althaf V. Shajihan, Kirill Mechitov, Billie Spencer*
- ID 140: Bridge health monitoring using WIM-data driven reliability assessment. *Author(s): Mi G. Chorzepa, Ananta Sinha*
- ID 637: Structural Vibration Monitoring Via Mobile LiDAR. *Author(s): Adriana Trias Blanco, John Vrabel*
- ID 709: Field implementation of indirect strain sensing using acceleration response of bridges. *Author(s): Soheila Eshkevari, Soheil Eshkevari, Debarshi Sen, Iman Dabbaghchian, Shamim Pakzad*
- ID 711: Wavelet-based modal identification of bridges using field mobile sensing data. *Author(s): Liam Cronin, Debarshi Sen, Shamim Pakzad*

MS209: Advances in probabilistic and data assimilation approaches for assessment and mitigation of climatological hazards.

Organizer(s): Michele Barbato, Alexandros Taflanidis, Tracy Kijewski-Correa

- ID 280: Assessment of the combined effects of climate change and structural aging on the hurricane-induced losses for typical US wooden single-family homes. *Author(s): Michele Barbato*
- ID 283: Statistical Comparison of Resilience for Civil Infrastructure Systems and Application for Rural Distribution System subject to Hurricane Hazards. *Author(s): ZhiQiang Chen, Prativa Sharma*
- ID 363: Multi-fidelity Monte Carlo for real-time probabilistic storm surge predictions. *Author(s): WoongHee Jung, Alexandros Taflanidis*
- ID 657: Resilience of Gulf Coast communities under a changing climate. *Author(s): Mohamed Abdelhafez, Hussam Mahmoud, Bruce Ellingwood*
- ID 749: Development and Uncertainty Analysis of Probabilistic Vulnerability Model for Mid/High-Rise Buildings. *Author(s): Zhuoxuan Wei, Jean-Paul Pinelli, Kurtis Gurley, Christian Bedwell*
- ID 755: Text mining to predict the impact of wind disasters. *Author(s): Huy Pham, Monica Arul Jayachandran*
- ID 768: Digital twin for damage diagnosis in steel framed structures. *Author(s): GBANDI NIKABOU, JingWen Du, Pranav M. Karve, Sankaran Mahadevan*
- ID 779: Knowledge Discovery from Post-Storm Reconnaissance Data: From Frequentist Inference to Bayesian Knowledge Graphs. *Author(s): Jordan Nakayama, Daniel Yahya, David Roueche*
- ID 863: Tiered Infrastructure Performance Assessment Framework for Field Reconnaissance of Built Environment Across Hazards (Seismic, Windstorm, and Coastal) and Infrastructure Typologies. *Author(s): Mohammad Alam, Tracy Kijewski-Correa, Khalid Mosalam, Ian Robertson, David Prevatt, David Roueche*
- ID 889: The utility of visual document understanding in regional building inventory generation. *Author(s): Rachel Hamburger, Tracy Kijewski-Correa*

MS210: Integration of Physics-based Models with Data for Identification, Monitoring, Estimation, and Uncertainty Quantification.

Organizer(s): Hamed Ebrahimian, Babak Moaveni, Haeyoung Noh, Yang Wang

- ID 123: Finite Element Model Updating through Global Optimization of Smooth Nonconvex Problems. *Author(s): Trent Schreiber, Yang Wang*
- ID 294: Normalizing Flow-based Deep Variational Bayesian Network for Seismic Multi-hazards and Impacts Estimation from InSAR Imagery. *Author(s): Xuechun Li, Susu Xu*
- ID 443: Dynamic response prediction of nonlinear MDOF systems by neural-network-augmented physics models. *Author(s): Jaehwan Jeon, Junho Song*

- ID 471: DISPLACEMENT-BASED STRUCTURAL IDENTIFICATION USING DIFFERENTIABLE PHYSICS. *Author(s): Borna Rahnamay Farnod, Wesley Reinhart, Rebecca Napolitano*
- ID 528: Axial stress measurement in continuous welded rails using impact-driven vibrations. *Author(s): Alireza Enshaeian, Matthew Belding, Piervincenzo Rizzo*
- ID 563: Learning nonlinear material constitutive models using machine-infused mechanics-based model training. *Author(s): Mohammad Valikhani, Kasra Shamsaei, Hamed Ebrahimian*
- ID 635: TelecomTM: A Fine-grained and Ubiquitous Traffic Monitoring System Using Pre-Existing Telecommunication Cables as Sensors. *Author(s): Jingxiao Liu, Siyuan Yuan, Yiwen Dong, Biondo Biondi, Hae Young Noh*
- ID 641: Efficient Combination of Modal Data for Structural Parameter Estimation Using Artificial Neural Networks. *Author(s): Milad Mehrkash, Erin Bell*
- ID 670: Bayesian Inversion for Soil-Structure System Identification. *Author(s): Abdelrahman Taha, Hamed Ebrahimian*
- ID 714: Physics-Constrained Dictionary Learning with Sensor Fusion for Machine Health Monitoring. *Author(s): Sungjin Hong, Yanglong Lu, Sung-Hoon Ahn, Yan Wang*
- ID 782: Operational Health Monitoring of Bridges Using Bayesian Model Updating and Computer Vision Techniques. *Author(s): Niloofar Malekghaini, Farid Ghahari, Hamed Ebrahimian, Vinayak Sachidanandam, Eric Ahlberg, Matthew Bowers, Ertugrul Taciroglu*
- ID 950: Scaled Spherical Simplex Filter for finite-element model updating and system identification. *Author(s): Mariyam Amir, Konstantinos G. Papakonstantinou, Gordon P. Warn*

MS211: Complex Dynamics and Vibration Control of Infrastructure Exposed to Single/Multiple Hazards.

Organizer(s): Chao Sun, Mariantonieta Gutierrez Soto , Lin Chen

- ID 266: Global Motions of a Floating Platform with Tuned Liquid Damper in Waves. *Author(s): Wen-Huai Tsao, Ying-Chuan Chen, Christopher Kees, Lance Manuel*
- ID 289: A New Macro Model for Steel-Concrete Shear Walls using CSI PERFORM-3D. *Author(s): Nakisa Haghi, siamak Epackachi, Steve Efe*
- ID 381: Numerical Evaluation of Dynamic Responses of Oregon Bridge Rail under Multi-level Vehicular Impacts. *Author(s): Howie Fang, Qian Wang*
- ID 539: Investigation on the performance of a rolling pendulum isolation system subject to 3D seismic excitations. *Author(s): Esteban Villalobos Vega, Erika Vanderheiden, P. Scott Harvey*
- ID 668: Assessment of ship impact force on offshore structures with varying collision scenarios. *Author(s): Hyunjoong Kim*

MS212: Probabilistic assessment, data-driven inference, and optimization for decision-making under uncertainty.

Organizer(s): Kostas Papakonstantinou, Charalampos Andriotis, George Deodatis, Mariyam Amir, Pablo Morato

- ID 223: Mapping component reliabilities to system reliability in flange-angle partially restrained steel moment connections. *Author(s): Trisha Chakravorty, Aritra Chatterjee, Baidurya Bhattacharya*
- ID 224: Threat-independent progressive collapse analysis to identify dominant failure sequences and estimate system failure probability. *Author(s): Trisha Chakravorty, Minangshu Baidya, Aritra Chatterjee, Baidurya Bhattacharya*
- ID 235: Bayesian Model Calibration Under Statistical and Model Errors Based on Polynomial Chaos Methodologies. *Author(s): Zhiheng Wang, Roger Ghanem*
- ID 301: Data-driven non-homogeneous Markov deterioration models for bridges. *Author(s): Min Li, Gaofeng Jia*

- ID 366: Knowledge transfer for life-cycle optimization: Applications to the management of bridge networks and ship structures. *Author(s): Jianda Cheng, Minghui Cheng, Yan Liu, Jun Wu, Wei Li, Dan M. Frangopol*
- ID 509: Rare Event Uncertainty Quantification Using Hamiltonian MCMC and Inverse Importance Sampling Approaches. *Author(s): Kostas G. Papakonstantinou, Elsayed Eshra, Hamed Nikbakht*
- ID 542: Discrete optimization of structures through a sequential decision process: benchmarking and validation. *Author(s): Maximilian Ororbia, Gordon Warn*
- ID 566: Truncated Unscented Kalman Filter for Incorporating Constraints in Joint State-Parameter Estimation. *Author(s): Adrita Kundu, Suparno Mukhopadhyay*
- ID 576: POMDP inference and solution of railway optimal maintenance and comparisons with deep reinforcement learning. *Author(s): Giacomo Arcieri, Cyprien Hoelzl, Oliver Schwery, Daniel Straub, Konstantinos G. Papakonstantinou, Eleni Chatzi*
- ID 678: Copula-based Quadratic Point Estimate Method under Incomplete Probability Information. *Author(s): Minhyeok Ko, Kostas Papakonstantinou*
- ID 681: Transportation Asset Management With Incorporation Of Traffic Operations Adaptation Using Deep Reinforcement Learning. *Author(s): Mohammad Saifullah, Kostas Papakonstantinou, Shelley Stoffels, Weiwen Zhou, Elise Miller-Hooks*
- ID 720: A Novel Fragility Framework for Assessing the Performance of Marine Vessels. *Author(s): Aws Idris, Mohamed Soliman*
- ID 733: Bayesian fragility estimation for risk assessment of structures within the setting of generalized stratified sampling. *Author(s): Srinivasan Arunachalam, Seymour Spence*
- ID 741: Rapid Uncertainty Propagation by LSTM Networks and Knowledge Transfer in High-dimensional Nonlinear System subject Stochastic Excitation. *Author(s): Bowei Li, Seymour Spence*
- ID 760: A sequential decision process for the multi-objective design optimization of structural systems based on life cycle costs. *Author(s): Aditya Sharma, Gordon Warn*
- ID 831: Performance-based design optimization of uncertain wind-excited systems under life-cycle loss constraint with climate change considerations. *Author(s): Thays Duarte, Imad Alhayik, Arthriya Subgranon*
- ID 835: A Novel Approach to Computing Generalized Variability Response Functions for Structures with Random Parameters. *Author(s): Manuel Miranda*
- ID 934: Development of an integrated platform for probabilistic risk assessment using fault tree analysis. *Author(s): Nailah Afshan, Saran Srikanth Bodda, Abhinav Gupta, Kevin Han*

MS213: Smart sensing and artificial intelligence for civil infrastructure monitoring.

Organizer(s): Jian Li, Yuguang Fu

- ID 232: Impact Detection and Localization Using Deep Learning and Information Fusion. *Author(s): Yuguang Fu, Zixing Wang, Amin Maghareh, Shirley Dyke, Mohammad Jahanshahi*
- ID 271: Measuring 3D Torsional Displacement of Structures by Computer Vision. *Author(s): Mohammad Vasef, Mostafa Iraniparast, Lin Chen, Peng "Patrick" Sun*
- ID 296: Bridge pier structural performance prediction framework driven by scour monitoring and extreme event forecasting. *Author(s): Neandro DeMello, Jennifer A. Bridge*
- ID 461: Simultaneous seismic input and state estimation with optimal sensor placement for building structures using incomplete acceleration measurements. *Author(s): Jian Li, Sdiq Taher, Huazhen Fang*
- ID 536: Prototyping of An Edge-Intelligence-Enabled Smart Adaptive Triggering Mechanism for Wireless Vibration-based Structural Health Monitoring. *Author(s): Shuaiwen Cui, Yuguang Fu*
- ID 772: Investigation of heterogeneous strain data fusion for output-only system identification. *Author(s): Tahsin Afroz Hoque Nishat, Hongki Jo, Jian Li, Simon Laflamme, Austin Downey, Caroline Bennette, William Collins, Sdiq Taher, Han Liu*

MS214: Data-driven Methods for Uncertainty Quantification: Improvements and New Approaches.

Organizer(s): Subhayan De, Ruda Zhang

- ID 275: Improving Accuracy and Computational Efficiency of Optimal Design of Experiment via Greedy Backward Approach. *Author(s): Mehdi Taghizadeh, Dongbin Xiu, Negin Alemazkoor*
- ID 326: Modeling Degrading Hysteretic Systems under Unceratinty with a Bi-fidelity DeepONet. *Author(s): Subhayan De, Patrick Brewick*
- ID 472: Probabilistic Operator Learning via Stochastic Processes with Implicit Kernels. *Author(s): Ruda Zhang*
- ID 970: Whitening-curvelet-based Filter for SNR Enhancement of Distributed Acoustic Sensing Data. *Author(s): Naveed Iqbal, Sikandar Khan*

MS215: Probabilistic Learning, Stochastic Optimization, and Digital Twins.

Organizer(s): Amir H Gandomi, Roger Ghanem, Christian Soize

- ID 442: Bayesian deep learning for probabilistic virtual load monitoring of offshore wind farms. *Author(s): Nandar Hlaing, Pablo G. Morato, Francisco de Nolasco Santos, Wout Weijtjens, Philippe Rigo, Christof Devriendt*
- ID 481: Quantifying Uncertainty in Quantum Approximate Optimization Algorithms. *Author(s): Jungin Kim, Yan Wang*
- ID 512: Surrogate Modeling of Highway Bridge Column Earthquake Response Using Probabilistic Learning on Manifolds (PLoM). *Author(s): Peter Lee, Kuanshi Zhong, Sanjay Govindjee, Gregory Deierlein*
- ID 661: Rare-events simulation using normalizing flows. *Author(s): Agnimitra Dasgupta, Erik Johnson*
- ID 803: Probabilistic digital twin for damage-adaptive rotorcraft control. *Author(s): William Sisson, Pranav Karve, Sankaran Mahadevan*
- ID 879: A data-driven statistical inverse identification method for phase field modeling of fracture in random heterogeneous elastic media. *Author(s): Florent Pled, Christophe Desceliers*

MS216: Advances in Computer Vision, Deep Learning, & Artificial Intelligence for Structural Health Monitoring & Inspections.

Organizer(s): Mohammad Jahanshahi, Vedhus Hoskere, Jian Li, Arash Noshadravan

- ID 101: Automated Multi-Damage Detection on Historic Buildings in Post-Disaster Areas Using Image Segmentation. *Author(s): Joe Kallas, Rebecca Napolitano*
- ID 216: Roadmap for fully autonomous robotic visual inspection of bridges. *Author(s): Yasutaka Narazaki*
- ID 251: High-fidelity Seismic-induced Failure Mode Prediction for RC Bridge Columns Using Generative Adversarial Networks. *Author(s): Ting-Yan Wu, Rih-Teng Wu, Ping-Hsiung Wang, Tzu-Kang Lin, Kuo-Chun Chang*
- ID 254: A Novel Multi-scale Branch Fusion Network for Tile Spalling Segmentation Using Limited Samples. *Author(s): Hai-Wei Wang, Rih-Teng Wu*
- ID 270: Multi-Vision System for Full-field Strain Measurement and Crack Tracking on UHPC Beams. *Author(s): Mostafa Iraniparast, Seyed Sina Shid-Moosavi, Peng "Patrick" Sun, Tiancheng Wang, Georgios Apostolakis, Kevin Mackie*
- ID 281: Multi-view deep learning for post-hurricane damage assessment of buildings. *Author(s): Asim Khajwal , Chih-Shen Cheng , Arash Noshadravan*
- ID 385: Can you trust your AI crack detection model in the wild: benchmarks & enhancement strategies. *Author(s): Chen ZHANG, Jize ZHANG*
- ID 402: Methods of Inspection of Deteriorated Steel Beam Ends using LiDAR & 3D Scanning. *Author(s): Aidan Provost, Shahrukh Islam, Georgios Tzortzinis, Chengbo Ai, Simos Gerasimidis*

- ID 462: Automated image localization to support rapid building reconnaissance in a large-scale area. *Author(s): Xiaoyu Liu, Shirley Dyke, Ali Lenjani, Ilias Bilionis, Xin Zhang, Jongseong Choi*
- ID 525: A Deep Learning-Based Data Fusion Model to Predict Building Attributes Using Google Street View Images, Census Block Group Characteristics, and Real-Estate Data. *Author(s): Abhishek Subedi, Mohammad R. Jahanshahi, David Johnson*
- ID 548: Active Perception Based on Deep Reinforcement Learning for Autonomous Robotic Inspection. *Author(s): Wen Tang, Mohammad Jahanshahi*
- ID 553: Autonomous Pavement Surface Evaluation and Rating (PASER) Condition Assessment Using a Cost-effective RGB-D Data Acquisition System. *Author(s): Yu-Ting Huang, Nikkhil Vijaya Sankar, Mohammad Reza Jahanshahi, Fangjia Shen*
- ID 606: RGB-D Fusion through Depth Hallucination for Enhanced Deep Learning-based Damage Segmentation. *Author(s): Tarutal Ghosh Mondal, Mohammad Jahanshahi*
- ID 679: Super-sensitivity full-field displacement measurements. *Author(s): Shanwu Li, Yongchao Yang*
- ID 683: Unpaired Image-to-Image Translation of Structural Damage. *Author(s): Subin Varghese, Vedhus Hoskere*
- ID 830: Photogrammetric Reconstructions for Bridge Inspections: Establishing Performance Metrics for Automated Drone Acquisition Algorithms. *Author(s): Emilie Hollingsworth, Ishan Pradhan, Michael Sanchez, Rodrigo Sarlo*
- ID 848: General, unsupervised structural health monitoring based on generative adversarial networks. *Author(s): Mohammad Hesam Soleimani-Babakamali, Ismini Lourentzou, Korosh Nasrollahzadeh, Rodrigo Sarlo*
- ID 872: Integrating image and LiDAR data for measuring road and roadside objects on hillside streets. *Author(s): Sven Malama, Debasish Jana, Sriram Narasimhan, Ertugrul Taciroglu*

MS217: Infrastructure Health Condition Evaluation Using Emerging Sensor and AI Technologies.

Organizer(s): Mohamad Alipour, Yichang (James) Tsai

- ID 145: Self-Powered Sensors for Sustainable Condition Monitoring of Bridges under Traffic-Induced Vibration. *Author(s): Mohsen Amjadian, Anil Kumar Agrawal, Hani Nasif*
- ID 292: A Generalized digital image correlation Using Attention-based Deep Learning Architecture to Extract Full-field Subpixel Displacement Measurements from Limited Data Using Transfer Learning. *Author(s): Mehrdad Shafiei Dizaji, Devin Harris*
- ID 344: Automatic Segmentation and Measurement of Surface Concrete Spalling for Structural Members. *Author(s): Luis Espinola-Diaz, Smith Huamani-Rojas, Luis Alberto Bedriñana*
- ID 368: Machine Learning with Microtexture Feature Extraction for Automated Pavement Raveling Classification. *Author(s): Haolin Wang, Yi-Chang (James) Tsai*
- ID 373: Autonomous delamination detection in reinforced concrete bridge decks using infrared thermography and an encoder-decoder-type DCNN model. *Author(s): Eberechi ICHI, Sattar Dorafshan*
- ID 513: Performance-based UAS path planning for automated infrastructure inspection. *Author(s): Yuxiang Zhao, Binyao Guo, Mohamad Alipour*
- ID 631: Gaze informed path optimization of building inspection for automated damage diagnostics. *Author(s): Muhammad Rakeh Saleem, Rebecca Napolitano*
- ID 684: Pavement Crack Detection Using Machine Learning and a Fusion of 2D & 3D Data. *Author(s): Paul Roeser, Yi-Chang (James) Tsai*
- ID 713: Optimized Correlation Between Mean Profile Depth and Pavement Friction. *Author(s): Pavan Chandrasekar, Yichang James Tsai*

MS301: Advances and Applications of Elasticity within Applied Mechanics.

Organizer(s): John C Brigham, Ney Dumont, Evgueni T. Filipov, Euclides Mesquita, Sonia Mogilevskaya, Anil C Wijeyewickrema

- ID 212: TRANSIENT RESPONSE OF FRAME STRUCTURES INTERACTING WITH SOIL PROFILES BY MODIFIED MODAL BASIS. *Author(s): Amauri Ferraz, Lucas Pacheco, Ronaldo Carrion, Euclides Mesquita*
- ID 239: A Transfer Matrix Approach for the Simulation of 2D Rainbow Traps. *Author(s): Prasannakumar Salasiya, Bojan Guzina*
- ID 257: Analytical solution for Mode I stress intensity factor in aviation pavement reflection cracking model. *Author(s): Kairat Tuleubekov, David Brill*
- ID 293: Two dimensional problem of an elastic matrix containing multiple Gurtin-Murdoch material surfaces along straight segments. *Author(s): Rohit S Patil, Sofia G Mogilevskaya*
- ID 357: Simulation of a hot forming tool with a thermoelastic boundary element formulation. *Author(s): Michael Leitner, Martin Schanz*
- ID 589: Eshelby Tensor in Integral Nonlocal Elasticity: Theoretical Formulation and Numerical Validation. *Author(s): Wei Ding, Fabio Semperlotti*
- ID 590: The response of multi-span railway bridges accounting for dynamic soil-structure interaction. *Author(s): Pieter Reumers, Geert Lombaert, Geert Degrande*
- ID 593: Biaxial testing and elastic characterization of a laminated membrane composite. *Author(s): Steven Palkovic, Andrew Sarawit, Mehdi Zarghamee*
- ID 648: Machine-precision, complex-variable implementation of the consistent boundary element method in two-dimensional elasticity. *Author(s): Ney Dumont*
- ID 726: Tailorable thermoelectricity of cubic lattice-based cellular and granular materials by the configuration stress. *Author(s): Chao Liu, Huiming Yin*
- ID 821: A NOVEL ANALYTICAL APPROACH FOR CYLINDRICAL CAVITY EXPANSION/ CONTRACTION PROBLEMS IN MOHR-COULOMB MATERIALS. *Author(s): Shengli Chen, Xu Wang, Yanhui Han, Younane Abousleiman*
- ID 837: Mechanics of nanomaterials from first principles. *Author(s): Phanish Suryanarayana*

MS302: Challenges and Advances in Material Damage Modeling.

Organizer(s): Mostafa Mobasher, Lampros Svolos, Alessandro Fascetti, Haim Waisman, Ravindra Duddu, Somnath Ghosh

- ID 124: Understanding the training dynamics of PINNs for the non-local gradient damage equation. *Author(s): Panos Pantidis, Mostafa Mobasher*
- ID 133: A displacement-controlled Arc Length scheme for Continuum Damage Mechanics problems. *Author(s): Roshan Philip Saji, Mostafa Mobasher*
- ID 304: Density-Driven Damage Model (D3M)of Concrete Structures. *Author(s): Yingbo Zhu, Zachary Grasley, Alessandro Fascetti*
- ID 427: Mechanistic Mapping of Random Fields for Stochastic FE Simulations of Quasibrittle Fracture. *Author(s): Josh Vievering, Jia-Liang Le*
- ID 486: Adaptive domain decomposition using image detection for local and nonlocal damage formulations. *Author(s): Cornelius Otchere, Panos Pantidis, Mostafa Mobasher*
- ID 574: Fracture mode investigation in the Brazilian splitting test using a micromechanics-based variational phase-field model. *Author(s): Mina Sarem, Nuhamin Eshetu Deresse, Jaincto Ulloa, Els Verstrynge, Stijn François*
- ID 596: An efficient computational framework for the damage assessment of multistory steel frames. *Author(s): Jade Cohen, Filip Filippou*
- ID 762: A virtual element method for the fourth-order phase-field equation with application to fracture modeling in materials with microstructure. *Author(s): Lampros Svolos, Gianmarco Manzini, Hashem Mourad*

- ID 808: Physics and chemistry-based constitutive framework for thermo-chemically aged elastomer using phase-field approach. *Author(s): Aimane Najmeddine, Maryam Shakiba*
- ID 847: Preventing cracks in continuously reinforced concrete with peridynamic models: temperature/shrinking effects in early-age CRCP, and corrosion-induced fracture. *Author(s): Yupeng Liu, Ziguang Chen, Jiangming Zhao, Florin Bobaru*

MS303: Multiscale Behavior of Damage and Failure Mechanics.

Organizer(s): Leong Hien Poh, Oliver Giraldo-Londono, Lizhi Sun, Jiann-Wen Ju, George Z. Voyiadjis, Glaucio H. Paulino

- ID 152: Computationally Efficient Modeling of Microstructurally Short Cracks in Polycrystalline Materials. *Author(s): Damin Xia, Caglar Oskay*
- ID 180: Prediction and Multi-objective Optimization of the Three-Phase Particulate Concrete Parameters with Artificial Neural Network and Particle Swarm Optimization. *Author(s): YIJIE CHEN, Sze Dai Pang*
- ID 215: Multiscale Phase Field formulation for capturing Anisotropy in Network Response of Rubber-like materials. *Author(s): Prajwal Kammardi Arunachala, Matthias Neuner, Christian Linder*
- ID 234: Strong and tough fibrous hydrogels reinforced by multiscale hierarchical structures with multimechanisms. *Author(s): Huajian Gao*
- ID 236: Molecular Dynamics Study of the Impact Response of Architected Metallic Foam Nanocomposites. *Author(s): Mohammed Saffarini, Tommy Sewell, Zhen Chen*
- ID 241: A Micromorphic Filter for Determining Stress and Deformation from Grain-Resolving DNS. *Author(s): Nathan Miller, Farhad Shahabi, Joseph Bishop, Richard Regueiro*
- ID 284: A Machine Learning-Aided Digital Twin for Damage Sensing based on a Multiphysics-Multiscale Computational Modeling Framework using Piezoelectric Composites. *Author(s): Saikat Dan, Preetam Tarafder, Somnath Ghosh*
- ID 353: A simple implementation of localizing gradient damage model in Abaqus for the dynamic fracture. *Author(s): Guangyuan Yang, Leong Hien Poh*
- ID 474: A phase-field formulation for fracture modeling of rate- and temperature-dependent materials. *Author(s): Rogelio Muñeton-Lopez, Oliver Giraldo-Londoño*
- ID 599: Modeling Frictional Contact Between a Blunt Tool and Rock With Anisotropic Damage. *Author(s): Yaneng Zhou, George Z. Voyiadjis*
- ID 842: Modeling fatigue overload behavior in microstructurally short cracks: connecting initiation and long crack behavior. *Author(s): Robert Fleishel, Stephanie TerMaath*

MS305: Quasibrittle Fracture of Heterogenous Composites: Modeling and Characterization.

Organizer(s): Kedar Kirane, Marco Salviato, Jia-Liang Le

- ID 132: Size effect and failure behavior of woven composites under biaxial flexure. *Author(s): Felix Liu, Kedar Kirane*
- ID 177: Multi-scale characterization of mode-II interlaminar fracture in scaled stitched resin-infused composites using digital image correlation. *Author(s): Jackob Black, Wayne Huberty, Christopher Bounds, Han-Gyu Kim*
- ID 346: Size Effect on Random Structural Strength of Prenotched Quasibrittle Structures. *Author(s): Jia-Liang Le, Jan Eliáš*
- ID 774: Use of characteristics method for fragmentation analysis of 1D heterogeneous quasi-brittle materials. *Author(s): Reza Abedi, Giang Hyunh*

MS307: Structural instabilities: From failure to function.

Organizer(s): Stylianos Yiatros, Hayder Rasheed, C. W. Lim, Nöel Challamel, Rainer Groh, M. Ahmer Wadee

- ID 121: Thin rectangular plate behavior under in-plane harmonic compression. *Author(s): Mehdi Bohlooly Fotovat, Przemyslaw Perlikowski, Tomasz Kubiak*
- ID 175: Buckling of Short Beams Considering Warping with Application to Fiber-Reinforced Elastomeric Isolators. *Author(s): Eduardo Montalto, Dimitrios Konstantinidis*
- ID 298: Inelastic Buckling of Hybrid FRP-Metal Long Tubes under External Pressure. *Author(s): Hayder Rasheed*
- ID 369: Insight into the stability and load carrying capacity estimations of double curved shells. *Author(s): Adrian Gliszczyński*
- ID 379: Interactive buckling in thin-walled steel angle columns leading to a more consistent structural design methodology. *Author(s): Behnam Behzadi-Sofiani, Leroy Gardner, Ahmer Wadee*
- ID 515: Stability of Thin Cylindrical Shells Under Combined Bending and Torsion. *Author(s): Victoria Ding, Shahab Torabian, Sandor Adany, Xiang Yun, Ben Schafer*
- ID 545: POST-BUCKLING CAPACITY OF OF CORRODED STEEL BRIDGE BEAMS UNDER REPETITIVE MONOTONIC LOADING. *Author(s): Shahrukh Islam, Aidan Q. Provost, Simos Gerasimidis*
- ID 645: Stochastic Buckling Analysis of Geometrically Imperfect Spherical Shells. *Author(s): Zheren Baizhikova, Jia-Liang Le, Roberto Ballarini*
- ID 738: Static friction models for a rod deforming on a cylinder. *Author(s): Gert van der Heijden, Rehan Shah*
- ID 809: Comparison of stiffness reduction factors for rotary-straightened and hot-rolled W-shape members. *Author(s): Hyeyoung Koh, Barry Rosson, Hannah Blum*
- ID 815: Stability of a novel all-steel modular floor assembly. *Author(s): Rajshri Chidambaram Muthu Kumar, Sandor Adany, Benjamin Schafer*
- ID 961: Lowerbound buckling loads of cylindrical shells with periodic imperfections. *Author(s): Rainer Groh*
- ID 967: Progressive Wrinkling and Collapse of Lined Pipe due to Cyclic Bending and Reeling. *Author(s): Stelios Kyriakides, Emile Naous*

MS308: Machine Learning in Mechanics, Materials, and Structures.

Organizer(s): Christos Athanasiou, Miguel Bessa, Kai Guo, Vikas Srivastava, Jan Fuhg

- ID 194: Transfer Learning Genetic Expression Programming for Reduced Data Modeling of Civil Engineering Systems. *Author(s): Jacob Murphy*
- ID 382: Characterization of the Damage Tolerance of Composite Overlays through Subspace Evaluation. *Author(s): Corey Arndt, Stephanie TerMaath*
- ID 433: How can graph neural networks help in the analysis and design of structures. *Author(s): Kai Guo*
- ID 441: A conditional Variational AutoEncoder-boosted Reduced Order Model for multi-parametric dependencies in nonlinear dynamics. *Author(s): Kontantinos Vlachas, Thomas Simpson, Anthony Garland, Carianne Martinez, Eleni Chatzi*
- ID 459: Predicting Fracture Paths in Heterogeneous Brittle Materials using Deep and Probabilistic Learning. *Author(s): Yen Peng (Ariana) Quek, Jin Yi Yong, Johann Guilleminot*
- ID 477: Multiscale mechanics modeling by transferring knowledge across scales using a deep convolutional network. *Author(s): Ashwini Gupta, Lori Graham-Brady*
- ID 565: Prestressed Concrete Beam Shear Capacity Prediction Models based on Regression and Genetic Programming. *Author(s): Wonsuh Sung, Suhaib Alfaris, Nikhil Potnuru, Stephanie Paal, Maria Koliou, Petros Sideris, Anna Birely, Mary Beth Hueste, Stefan Hurlebaus*
- ID 603: Investigating large language models' understanding of mechanics. *Author(s): Mohd Zaki, N. M. Anoop Krishnan*

- ID 628: Predicting floor response of RC buildings under near-field ground motions using convolutional neural network. *Author(s): Iqra Latif, Arnab Banerjee, Mitesh Surana*
- ID 706: Knowledge extraction and transfer in data-driven fracture mechanics. *Author(s): Xing Liu, Christos Athanasiou, Nitin Padture, Brian Sheldon, Huajian Gao*
- ID 807: Artificial language and machine learning-integrated approach for understanding and designing concrete with consideration of physiochemical properties. *Author(s): Soroush Mahjoubi, Rojyar Barhemat, Weina Meng, Yi Bao*
- ID 896: Optimization of vascular structure of self-healing concrete using generative deep neural network (GDNN). *Author(s): Zhi Wan, Yading Xu, Ze Chang, Branko Šavija*

MS309: Modeling of Materials with Interfaces and Scales Using Physics-Based and Machine-Learning Methods.

Organizer(s): Xiang Zhang, Pinlei Chen, Ravindra Duddu, Soheil Soghrati, Timothy Timothy Truster

- ID 109: Micromechanical Analysis of Materials with Complex Microstructures: Automated Modeling and Deep Learning Algorithms. *Author(s): Soheil Soghrati, Salil Pai, Pengfei Zhang, Balavignesh Vemparala*
- ID 178: Computation Infrastructure for Modeling Discontinuities within Materials: DEIP, BEAVER and MOOSE. *Author(s): Timothy Truster, Sunday Aduloju, Amirfarzad Behnam*
- ID 193: Prediction of Kink Bands and Splitting in Multidirectional Double-edge Notch Compression Specimens. *Author(s): Alexander Faupel, Caglar Oskay*
- ID 252: A paradigm for fast exploring of material repones space considering microstructure statistics and application to particulate composites. *Author(s): Min Lin, Xiang Zhang*
- ID 400: The Effect of Disorder on the Dynamic Properties of One-Dimensional Metamaterials. *Author(s): Ali Heidari Shirazi, Reza Abedi*
- ID 411: Novel Lagrange Multiplier Formulation for Imposing Displacement and Traction Discontinuities in Material Microstructures. *Author(s): ARIFUL HASAN, Timothy Truster*
- ID 423: A Combined Variational Multiscale and Phase Field Approach for Coupled Thermomechanical Problems with Interface Separation, Crack Propagation, and Heat Transport. *Author(s): Pinlei Chen, Wan Wan*
- ID 524: Physics-Informed Neural Network-based computational Solid Mechanics Model for Problems with Material Heterogeneity. *Author(s): Hyeeun Kong, Pinlei Chen*
- ID 625: Peridynamics with stochastic bond strengths for determination of final failure in composite laminates. *Author(s): Ernest Ytuarte, Hossam Ragheb, Adam Sobey, Stephanie TerMaath*
- ID 639: Self-limited dynamics and patio-temporal complexity of crustal seismicity enabled by elasto-plastic fracture meahanics. *Author(s): Ahmed Elbanna, Md Shumon Mia, Mohamed Abdelmeguid*
- ID 705: Shape Dependence of Diffusion Creep Behavior in Polycrystalline Materials with Two Strength-Contrasting Phases. *Author(s): Heechen Cho*
- ID 791: Characterizing the elasto-adhesive length of polymeric materials. *Author(s): A. Derya Bakiler, Berkin Dortdivanlioglu*
- ID 861: On the modeling of interfaces with resultant-based formulations in composite materials. *Author(s): Ghadir Haikal*

MS310: Maximizing information content for data-scarce engineering mechanics applications.

Organizer(s): Audrey Olivier, Michael Shields, Lori Graham-Brady

- ID 324: A knowledge transfer LSTM model to predict the seismic response of structures. *Author(s): Hongrak Pak, Stephanie German Paal*
- ID 399: From partial and limited structural health data to optimal management of engineering systems. *Author(s): Pablo G. Morato, Charalampos P. Andriotis, Konstantinos G. Papakonstantinou*

- ID 514: A multifidelity control variates formulation for rare event simulation when model covariance estimation is infeasible. *Author(s): Promit Chakroborty, Michael Shields, Somayajulu Dhulipala*
- ID 584: Fisher Information based Optimal Sensor Locations for Structural Identification: Non-Stationary Inputs and Non-Classically Damped Systems. *Author(s): Dhiraj Ghosh, Suparno Mukhopadhyay*
- ID 712: Bayesian Neural Networks with Physics-Aware Regularization For Travel Time Modeling from Imbalanced Data. *Author(s): Audrey Olivier, Sevin Mohammadi, Andrew Smyth, Matt Adams*
- ID 794: Heterogenous Sensor Placement Under Uncertainty Considering Sensor Failure. *Author(s): Amin Jabini, Erik Johnson*
- ID 810: The impact of data-driven design approaches on shear connector reliability. *Author(s): Hyeyoung Koh, Hannah Blum*
- ID 883: Evaluation of Feature Selection Methods for the Shear Failure Mode Prediction of Prestressed Concrete Beams. *Author(s): Luis Alberto Bedriñana, Jhon Tovar, Christian Malaga-Chuquitaype*

MS311: Phase-field models of fracture.

Organizer(s): Aditya Kumar, Haim Waisman

- ID 147: Phase-field modelling of fatigue fracture in anisotropic aluminium sheets. *Author(s): Martha Kalina, Markus Kästner*
- ID 222: Role of strength and toughness in the indentation problem. *Author(s): Aditya Kumar, Oscar Lopez-Pamies*
- ID 267: A thermodynamical phase field fracture modeling of concrete structures. *Author(s): Sina Abrari Vajari, Matthias Neuner, Christian Linder*
- ID 502: A Phase field model for anisotropic incompressible materials at finite strains. *Author(s): Wenyuan Xue, Prajwal Kammardi Arunachala, Sina Abrari Vajari, Christian Linder*
- ID 708: Working towards a modular, fully-coupled phase field fracture model integrating elasticity, plasticity, and damage. *Author(s): Chiraag Nataraj, Andrew Stershic*

MS312: Surrogate modeling for uncertainty quantification, optimization, and statistical inference in engineering applications.

Organizer(s): Gaofeng Jia, Abdollah Shafieezadeh

- ID 153: Discrete Wavelet Transform Based Earthquake Data Augmentation for Training Surrogate Models of Nonlinear Structures. *Author(s): Siddharth Parida, Christina Bocirnea, Supratik Bose, Georgios Apostolakis*
- ID 209: Non-Deterministic Kriging for Systems with Mixed Continuous and Discrete Input Variables. *Author(s): J Heeralu P Ravindu Jayasekara , Sabarethinam Kameshwar*
- ID 264: Physics-Informed Machine Learning for Structural Metamodeling of Nonlinear Structures. *Author(s): Robert Bond, Pu Ren, Hao Sun, Jerome Hajjar*
- ID 341: Augmented sample-based approach for multi-fidelity uncertainty quantification. *Author(s): Leila Naderi, Gaofeng Jia*
- ID 342: Physics-constrained Gaussian Process Model for Prediction of Power Generation in Wave Energy Converter Arrays. *Author(s): Suraj Khanal, Gaofeng Jia*
- ID 354: The Application of Surrogate Modelling Methods to the Calibration of Crystal Plasticity Finite Element Models. *Author(s): Hugh Dorward, Matthew Peel, Mahmoud Mostafavi*
- ID 384: Scalable Bayesian Optimization with Metaheuristics for Efficiency and Exploitation. *Author(s): Ibrahim Aydogdu, Michaela Kempner, Yan Wang*
- ID 495: Advances in node condition classification within storm surge surrogate modeling framework. *Author(s): Christopher Irwin, Alexandros Taflanidis*
- ID 695: Deep Learning-based Integrated Probabilistic Cost Analysis for Future Decarbonized Hurricane-Prone Power Systems. *Author(s): Kamiar Khayambashi, Andrés Clarens, William Shobe, Negin Alemazkoor*

- ID 698: Adaptive Surrogate Improvement for High-dimensional Problems. *Author(s): Yulin Guo, Paromita Nath, Sankaran Mahadevan*
- ID 722: Efficient Bayesian Posterior Sampling Aided by Kriging Surrogate Model. *Author(s): Aakash Bangalore Satish, Sang-ri Yi, Alexandros Taflanidis*
- ID 758: Quantifying the Fatigue Reliability of Ship Hulls with Long Propagating Cracks. *Author(s): Mohamed Soliman, Mohammad F. Tamimi, Somayeh Shojaeikhah*
- ID 771: Enhanced Support Vector Machine for efficient reliability analysis of offshore wind turbines. *Author(s): Xukai Zhang, Asim Khajwal, Arash Noshadravan*

MS313: 7th Mini-Symposium on 4M (Modeling of Multiphysics-Multiscale-Multifunctional) Engineering Materials and Structures.

Organizer(s): Yong-Rak Kim, Xiaoyu Song, Chung Song, Huiming Yin, Qiming Wang, Congrui Grace Jin

- ID 90: Experimental Investigation on Enhancing Tube Energy Absorption Capacity by Orifice Effect. *Author(s): Farhad Farzaneh, Sungmoon Jung*
- ID 183: Optical Properties of Topological Semimetals MX (M = Ti, Zr, Hf, and X = S, Se, Te) Family by DFT Approach. *Author(s): Sami Ullah, Sikandar Khan, Firoz Khan*
- ID 314: Harnessing Carbon Sequestration to Manufacture Coral-Inspired Extremely Tough Materials. *Author(s): Haoxiang Deng, Yuyan Gao, Haixu Du, Ketian Li, Yanchu Zhang, Kyunghoon Lee, Qiming Wang*
- ID 348: Modeling of the environment-dependent microstructure of hydrogel-based concrete (HBC) - for Mars application. *Author(s): Ning Liu, Jishen Qiu*
- ID 412: Inverse Determination of Shrinkage and Fracture Properties of Engineered Buffer Materials for Geological Repositories of Nuclear Waste Using an Integrated DIC-FEM Approach. *Author(s): Mohammad Rahmani, Abdullah Azzam, Julia Grasley, Yong-Rak Kim, Jongwan Eun, Seunghee Kim*
- ID 413: Use of Alkali-activated Slag Binder and Shape-stabilized Phase Change Material to Develop an Energy-efficient Multifunctional Cementitious Composite in Buildings. *Author(s): In Kyu Jeon, Abdullah Azzam, Hussein Al Jebaei , Yong-Rak Kim, Ashrant Aryal, Juan Carlos Baltazar*
- ID 458: Parametric Study to Determine Hydrodynamics Input Parameters in FLOW-3D-Hydro for Crushed Limestones in Nebraska. *Author(s): Basil Abualshar, Chung Song*
- ID 470: AI- Approach to Predict the Erosion Resistance of Highway Shoulder Gravels. *Author(s): Bashar Al-Nimri, Aiman Tariq, Basil Abualshar, Chung Song, Babur Deliktas*
- ID 511: Harnessing microorganisms to manufacture engineered living materials with environmentally friendly, low-cost, mechanically strong, and fire-resistant performance. *Author(s): Yuyan Gao, Audie Lee, Qiming Wang*
- ID 571: A GID-OpenSEES framework for the structural fire analysis of reinforced concrete structures. *Author(s): Anand Kumar, P. Ravi Prakash, Mohamed Anwar Orabi*
- ID 610: The effect of wrapping force on the transverse stiffness of packed bridge cables: an elastoplastic analysis. *Author(s): Linda Teka, Huiming Yin*
- ID 618: Stress and Fracture Analysis of a Perforated Spherical Container under Internal Pressure. *Author(s): Xin He, Huiming Yin*
- ID 646: The Green's function based thermoelastic analysis of spherical geothermal tanks in a semi-infinite domain. *Author(s): Chunlin Wu, Tengxiang Wang, Huiming Yin*
- ID 654: Thermoelastic Model of Cubic Crystals for Structural Metals. *Author(s): Byung-Wook Kim, Chao Liu, Huiming Yin*
- ID 694: Size effect on the thermoelastic behavior of a particulate composite beam - a comparative study of micromechanical models and numerical simulation. *Author(s): Jinming Zhang, S.H. Chu, Chunlin Wu, Huiming Yin*
- ID 729: Bspline material point method for strongly coupled poroelastic materials. *Author(s): Ashkan Ali Madadi, David Garza, Berkin Dortdivanlioglu*

- ID 860: Digital Twin of Foamed Concrete toward Design and Development of High Performance Building Envelope. *Author(s): S.H. Chu, J.M. Zhang, H.M. Yin*

MS314: Mechanics of Wood and Wood Based Materials.

Organizer(s): Markus Lukacevic, Josef Füssl

- ID 286: Phase field method-based modeling of wood fracture. *Author(s): Sebastian Pech, Markus Lukacevic, Josef Füssl*
- ID 336: Experimental Evaluation of Post-Tensioning Losses in Mass Timber Wall Panels. *Author(s): Jacob Gesh, Esther Baas, Mariapaola Riggio, Andre R. Barbosa, Lech Muszynski, Gabriele Granello*
- ID 360: Microprestress Theory for the Simulation of Mechanosorptive Effects in Wood. *Author(s): Susan Alexis Brown, Danyang Tong, Hao Yin, Gianluca Cusatis*
- ID 451: Energy Dissipation Mechanisms in Cross-Grain Fracture of Spruce. *Author(s): Parinaz Belalpour Dastjerdi, Eric Landis*
- ID 595: Size effect of glued laminated timber beams predicted by numerical simulations. *Author(s): Markus Lukacevic, Christoffer Vida, Josef Füssl*
- ID 751: A Probabilistic Model for the Spatial Variation of Eastern Hemlock Tensile Strength. *Author(s): Fiona O'Donnell*
- ID 757: A Probabilistic Modeling Approach for Wind Uplift Resistance in Wood-Frame Load Paths. *Author(s): Brandon Rittelmeyer, David Roueche*
- ID 902: Computational Evaluations of the Flexural Behavior of Steel-CLT Composite Floor Members. *Author(s): Megan Potuzak, Kadir Sener, David Roueche*

MS315: Meshfree, Peridynamic, and Particle Methods: Contemporary Methods and Applications.

Organizer(s): Mike Hillman, J. S. Chen, Foster John, Pablo Seleson, Sheng-Wei Chi

- ID 317: Simulation of vehicle impact with barriers based on the Discrete Element Method. *Author(s): Abinet K. Habtemariam, Kai Fischer, Luis Brunnabend, Alexander Stolz*
- ID 499: CabanaPD: A meshfree GPU-enabled peridynamics code for exascale fracture simulations. *Author(s): Pablo Seleson, Sam Reeve*
- ID 508: Naturally Stabilized Conforming Nodal Integration with Novel Stress Update. *Author(s): Mike Hillman, Jiarui Wang, Dominic Wilmes, Joseph Magallanes*
- ID 522: Concurrent Semi-Lagrangian Reproducing Kernel Formulation and Stability Analysis. *Author(s): Mohammed Atif, Sheng-Wei Chi*
- ID 647: Investigation of Damage and Crack Propagation in Quasi-Brittle Materials via Peridynamics. *Author(s): Semsi Rakici, Bora Pulatsu, Ece Erdogmus*
- ID 822: A Coupled Lagrangian and Semi-Lagrangian RKPM with Smooth Contact for Penetration Problems. *Author(s): Ryan Schlinkman, Jonghyuk Baek, Frank Beckwith, Stacy Nelson, Jiun-Shyan Chen*
- ID 849: Partition of Unity Neural Network-enhanced Reproducing Kernel Particle Method for Localization Modeling. *Author(s): Jonghyuk Baek, J. S. Chen*
- ID 866: Maximum principle preserving meshfree methods for linear elliptic equations via nonlocal relaxation. *Author(s): Xiaochuan Tian, Qihao Ye*
- ID 965: Multiphase dissipative particle dynamics modeling of dynamic spreading of molten sand droplet on porous surfaces. *Author(s): Zhen Li, Rahul Koneru, Alison Flatau, Luis Bravo, Muthuvel Murugan, Anindya Ghoshal, George Karniadakis*

MS401: Design optimization of long span bridges and tall buildings.

Organizer(s): Santiago Hernandez

- ID 135: Advances in aero-structural optimization techniques for long-span bridges. *Author(s): Miguel Cid Montoya, Santiago Hernández, Ahsan Kareem*
- ID 176: Tall Building Optimization in Regions of High Seismicity: Balancing Stiffness and Ductility Requirements. *Author(s): Abel Diaz, David Shook*
- ID 181: MULTIDISCIPLINARY APPROACH FOR THE CROSS-SECTION SHAPE OPTIMIZATION OF HIGH-RISE BUILDINGS. *Author(s): Felix Nieto, Santiago Hernandez, Miguel Cid-Montoya*
- ID 839: Multi-fidelity Sequential Design with CFD Applications of Twisted Building Design. *Author(s): Fei Ding, Jize Zhang, Ahsan Kareem*

MS402: Topology Optimization: from Algorithmic Developments to Applications.

Organizer(s): Mazdak Tootkaboni, Alireza Asadpoure, Josephine Carstensen , James Guest

- ID 173: Exploiting Buckling and Contact: Exploring a New Approach for Tackling Shape and Topology Optimization With Challenging Solid Mechanics Behavior. *Author(s): Ryan Alberdi, Craig Hamel, Kevin Long, Aabhas Singh, Adam Cook*
- ID 188: Material design for thermal regulation in vascular systems using topology optimization. *Author(s): Kripa Adhikari, Kalyana Babu Nakshatrala*
- ID 475: Embodied Carbon Optimization of Multi-Material Truss Structures Subjected to Manufacturability Constraints. *Author(s): Zane Schemmer, Josephine Carstensen*
- ID 541: Discrete topology optimization of structures through deep reinforcement learning. *Author(s): Maximilian Ororbia, Gordon Warn*
- ID 601: Addressing the issue of parameter tuning in topology optimization algorithms. *Author(s): Dat Ha, Josephine Carstensen*
- ID 622: Stress-constrained topology optimization of anisotropic structures. *Author(s): Oliver Giraldo-Londono, Rogelio Muneton-Lopez, Chadwick Bettale*
- ID 701: Fiber Orientation and Topology Optimization of Tow-Steered Composite Laminates with Manufacturability Control. *Author(s): CHUAN LUO, James Guest*
- ID 769: Finite Strain Robust Topology Optimization Considering Multiple Uncertainties. *Author(s): Nan Feng, Shiyao Sun, Guodong Zhang, Kapil Khandelwal*
- ID 775: Multiphysics topology optimization of heat sinks considering additive manufacturing constraints. *Author(s): Ardalan Nejat, James Guest*
- ID 777: Efficient reliability-based topology optimization via polynomial chaos expansion: A multi-fidelity, greedy-Kaczmarz approach. *Author(s): Alberto Torres, James Guest, James Warner, Mazdak Tootkaboni*
- ID 894: Development of Material Property Feasibility Constraints for a Multiscale Topology Optimization Framework Using Radial Basis Function Interpolations. *Author(s): Brent Bielefeldt, Richard Beblo, Eddie Meixner, Robert :Lowe*
- ID 946: A Smooth Maximum Regularization Approach for Robust Topology Optimization in the Ground Structure Setting. *Author(s): Emily Alcazar, Lorran Foliveira, Fernando Vasconcelos Da Senhora, Adeildo Ramos, Glaucio Paulino*
- ID 968: Embodied carbon-based topology and sizing optimization of seismic retrofit for non-conforming RC structures. *Author(s): Fabio Di Trapani, Antonio P. Sberna, Josephine V. Carstensen, Giuseppe C. Marano*

MS403: Origami/Kirigami Inspired Structures and Metamaterials.

Organizer(s): Evgueni Filipov, John Brigham, Pradeep Pratapa, Mark Schenk, Martin Walker

- ID 98: REPROGRAMMING THE ENERGY LANDSCAPE OF META-STRUCTURES FOR TUNABLE MULTI-STABILITY. *Author(s): Giada Risso, Max Kudisch, Paolo Ermanni, Chiara Daraio*
- ID 142: Multifunctional magnetic origami robots. *Author(s): Renee Zhao*
- ID 190: Phononic Bandgap Programming and Fine-Tuning in Stretched Kirigami. *Author(s): Hesameddin Khosravi, Suyi Li*
- ID 287: Homogeneous lattice modes of Miura-ori tessellations with voids. *Author(s): Anandaroop Lahiri, Phanisri Pradeep Pratapa*
- ID 300: Origami Metamaterials with Near-Constant Poisson Functions over Finite Strains. *Author(s): Siva Poornan Vasudevan, Phanisri Pradeep Pratapa*
- ID 303: Geometric mechanics of random kirigami. *Author(s): Lauren Niu, Gaurav Chaudhary, Qing Han, Marta Lewicka, Lakshminarayanan Mahadevan*
- ID 390: Additively Manufactured Multi-material Monolithic Self Deployable Spacecraft Structures containing Hinges. *Author(s): Colin Hunter, Avinkrishnan Ambika Vijayachandran, Anthony Waas*
- ID 457: Evaluation of kirigami-inspired faÃ§ade concepts to improve building energy performance. *Author(s): Rodrigo Arauz, Aminallah Pourasghar, John Brigham*
- ID 529: Cable-Actuated Prestressed Origami Tubes. *Author(s): Megan Ochalek, Manan Arya*
- ID 577: Folding Polygonal Kirigami Tubes. *Author(s): Martin Walker*
- ID 609: Hybrid Origami Patterns. *Author(s): Kevin T. Liu, Glaucio H. Paulino*
- ID 612: Design of Thick Origami for Reusable and Deployable Load Carrying Structures and Infrastructure. *Author(s): Yi Zhu, Evgueni Filipov*
- ID 687: Holistic inverse design of origami using interpretable machine learning. *Author(s): Yi Zhu, Evgueni Filipov*
- ID 736: Coarse graining planar kirigami, Part 2: A Mechanism Gradient Theory. *Author(s): Ian Tobasco, Paul Plucinsky*
- ID 737: Coarse graining planar kirigami, Part 1: Continuum PDE description. *Author(s): Paul Plucinsky, Ian Tobasco*
- ID 750: Structural morphing surfaces based on self-standing, snap-through building blocks. *Author(s): Asifur Rahman, Samuele Ferracin, Sujata Tank, Paolo Celli*
- ID 754: Multi-Objective Optimisation of Origami Bellows. *Author(s): Mengzhu Yang, Fabrizio Scarpa, Mark Schenk*
- ID 786: A nonlinear iterated map for a graded Waterbomb origami tube. *Author(s): Americo Cunha Jr, Glaucio Paulino*
- ID 792: Tube-Based Multifunctional 3D Origami-Architected Metamaterials. *Author(s): Hannah Kim, Glaucio H. Paulino*

MS501: Computational/Experimental Fluid Dynamics and Fluid-Structure Interaction.

Organizer(s): Georgios Moutsanidis, Ning Zhang, Jinhui Yan

- ID 226: Recent Advances on Multiscale Simulations of Multiphase Interactions under Extreme Loadings with Continuum- and Particle-Based Methods. *Author(s): Zhen Chen, Andrew Bowman, Mohammed Saffarini, Hani Salim*
- ID 231: Multiphase Fluid-Structure Interaction in Deformable Porous Media at Multiple Scales. *Author(s): Samuel Fagbemi, Pejman Tahmasebi, Mohammad Piri*
- ID 358: HYBRID RANS-LES SIMULATION OF TURBULENT HEAT TRANSFER IN A BACKWARD-FACING STEP FLOW. *Author(s): Olalekan Olubunmi Shobayo, Dibbon Keith Walters, Samuel Ruegsegger*

- ID 516: Reducing Drag, Improving Performance: A Study of V-Shaped Riblets on Shipping Vessel Hulls. *Author(s): Nathaniel Werner, Katherine Rioux, Ryan Pritzkau*
- ID 549: High Fidelity Modeling of Fracture Under Extreme Hydrodynamic Events: A Coupled SPH-Phase-Field FSI Approach. *Author(s): Mohammad Naqib Rahimi, Georgios Moutsanidis*
- ID 617: An Enriched Immersed Boundary Method for Solidification and Melting Problems in Additive Manufacturing. *Author(s): Ze Zhao, Jinhui Yan*
- ID 699: Heat and mass transfer analysis for nanofluid flows in a channel. *Author(s): Gabriella Bognar*

MS502: New advances in tropical cyclone induced winds, surge-wave, and flooding.

Organizer(s): Chao Sun, Grace Yan, Celalettin Ozdemir

- ID 210: Fragility assessment of bottom plate and shell of above ground storage tanks during flood events using finite element analysis. *Author(s): Md Manik Mia, Sabarethinam Kameshwar*
- ID 555: Investigation of Hurricane Wind Effects on Solitary Wave Energy Dissipation in a Storm Surge. *Author(s): Hunter Boswell, Grace Yan, Wouter Mostert*
- ID 605: Large Eddy Simulation of Wind Loading on Elevated Low-rise Buildings. *Author(s): Xiangjie Wang, Chao Sun, Chunsheng Cai*
- ID 689: Large Eddy Simulation of Wind Turbulences Over Non-breaking and Breaking Waves. *Author(s): Tianqi Ma, Chao Sun*
- ID 801: Analysis of the Non-Linear Tide-River Flow Interactions of the Lower Mississippi and Atchafalaya Rivers in the Low-Lying Louisiana Coastline. *Author(s): Sayed Omar Hofioni, Peter Bacopoulos, Jin Ikeda, Celalettin Emre Ozdemir*
- ID 918: The Role of Turbulence and Roughness Length Parameterizations in Improving Major Hurricane Simulations in Weather Forecasting Models. *Author(s): Mostafa Momen, Leo Matak, Meng Li*

MS601: 2nd Annual Mini-Symposium: Resilience of Coastal Structures, Systems, and Community Subjected to Hazards.

Organizer(s): Wei Zhang, Jamie Padgett, Andre Barbosa

- ID 189: Prestressed Concrete Piles with GFRP Spirals against Corrosion Hazard. *Author(s): Olayiwola Adegbulugbe, Sungmoon Jung*
- ID 261: Long-term Salt Spray and Electrochemical Corrosion Behavior of Cu-Al-Mn Shape Memory Alloys and Steel Rebar. *Author(s): Huanpeng Hong, Bora Gencturk*
- ID 331: Past hurricane performance of above-ground storage tanks and their future risk considering sea level rise and subsidence scenarios. *Author(s): Santosh Ghimire, Sabarethinam Kameshwar*
- ID 377: Design Targets to Achieve Community Resilience Metrics in a Changing Climate. *Author(s): Jiate Li, John van de Lindt*
- ID 403: Progressive Failure of Low-rise Buildings Considering Internal Wind Pressure Change. *Author(s): Zhixia Ding, Wei Zhang, Dongping Zhu, William Hughes*
- ID 633: Probabilistic Analysis of Hurricane-Induced Debris Impacts towards Enhancing Coastal Community Resilience. *Author(s): Kooshan Amini, Jamie Padgett*
- ID 650: Investigation of Vegetation Shielding Effects on Structural Vulnerability. *Author(s): Aikaterini (Katerina) P. Kyprioti, Joaquin P. Morris Barra, Chris Irwin, Alexandros A. Taflanidis, Andrew B. Kennedy*
- ID 667: Analysis of the equity in post hurricane access to emergency services. *Author(s): Naqib Mashrur, Sabarethinam Kameshwar*
- ID 703: The Evaluation of Explicit Parameters on Eulerian-Lagrangian Simulations of Wave Impact on Coastal Bridges. *Author(s): Arsalan Majlesi, Adnan Shahriar, Arturo Montoya, Ao Du, Adolfo Matamoros*

MS602: Advanced Analysis for Earthquake Engineering: 7th Edition.

Organizer(s): Steven McCabe, Ting Lin, Kevin Wong

- ID 155: Seismic retrofit of low-rise reinforced concrete buildings typical to Haiti using a deterministic and a probabilistic approach. *Author(s): Marc-Ansy Laguerre, Reginald DesRoches, Mohammad Salehi*
- ID 371: A versatile Python-based framework for EDP seismic response estimation using reduced order structural models. *Author(s): Parisa Toofani Movaghar, Alexandros Taflanidis*
- ID 476: Realistic Out-Of-Plane Shear Strength of Reinforced Concrete Walls and Slabs for Seismic Probabilistic Risk Assessment Applications. *Author(s): Siavash Dorvash, Greg S. Hardy, John Richards, Tim Graf*
- ID 588: Rocking of Deformable Bodies on Flexible Ground. *Author(s): Mohammad Daud, Suparno Mukhopadhyay*
- ID 788: Structural Behavior of 3D Printed Concrete Buildings Subjected to Seismic Loads: Numerical Modeling. *Author(s): Hao Chen, Mohammad Aghajani Delavar, Sumedh Sharma, Petros Sideris*
- ID 909: A multiaxial plasticity model to represent softening in steel hollow square beam-columns under monotonic loading. *Author(s): Diego I. Heredia Rosa, Albano de Castro e Sousa, Dimitrios G. Lignos, Arka Maity, Amit Kanvinde*
- ID 972: Distribution of Seismic Demand and Damage During the 2015 Gorkha Earthquake. *Author(s): Raymond Hilly, Supratik Bose, Andreas Stavridis, Yingjie Hu*

MS603: Machine Learning Applications in Wind Engineering.

Organizer(s): Sungmoon Jung, Pedro Fernandez-Caban

- ID 127: Experimental study on the effect of complex heterogeneous terrain on wind pressure in low-rise building. *Author(s): Lee Sak An, Sungmoon Jung*
- ID 128: Physics-informed few-shot learning for wind pressure prediction of low-rise buildings. *Author(s): Yanmo Weng, Stephanie Paal*
- ID 151: Producing Heterogeneous Upwind Terrain Dataset for Wind Tunnel Testing Using Image Classification Method. *Author(s): Nasrollah Alinejad, Sungmoon Jung*
- ID 201: A data-driven DNN model for wind load prediction based on inflow turbulence and minor architectural features of low-rise building roof systems. *Author(s): Nasreldin Mokhktar, Pedro Fernández-Cabán*
- ID 244: Prediction of pressure coefficients on roof soffits and walls of low-rise building using artificial neural networks and ensemble methods. *Author(s): Karim Mostafa, Ioannis Zisis, Amal Elawady*
- ID 328: Machine Learning-Enabled Parameterization Scheme for Aerodynamic Shape Optimization of Wind-Sensitive Structures. *Author(s): Shaopeng Li, Brian Phillips, Zhaoshuo Jiang*
- ID 387: Physics-Informed Deep Learning for Wind Load Identification on Nonlinear Structures. *Author(s): Haifeng Wang*
- ID 394: Prediction of Wind Profile in Heterogeneous Terrain using Artificial Neural Network. *Author(s): Zihan Mahmood Nahian, Lee-Sak An, Sungmoon Jung*
- ID 507: Data-driven Modeling of Urban Wind Field Using Conditional Generative Adversarial Networks. *Author(s): yue dong, yanlin guo*

MS604: Recent Advances in Response Modification Devices and Strategies.

Organizer(s): Nicos Makris, Kostas Kalfas

- ID 325: Design and component testing of pressurized sand-dampers: Effects of the design parameters. *Author(s): Konstantinos Kalfas, Nicos Makris*
- ID 505: Seismic Response of Core Wall Building with Force-Limiting Connections. *Author(s): Kyoungyeon Lee, Georgios Tsampras*
- ID 506: Structural connection with predetermined discrete variable friction forces for high-performance earthquake-resistant buildings. *Author(s): Kaixin Chen, Georgios Tsampras*

- ID 558: Scaled Experimental Investigation of the Sensitivity of Strongback Performance to Location of Supplemental Dampers and Stiffness Irregularities. *Author(s): Sima Abolghasemi, Nicholas Wierschem, Mark Denavit*
- ID 616: Real-time Hybrid Simulation of a CLT Rocking Wall System equipped with Pressurized Sand Dampers for Seismic Hazard Mitigation. *Author(s): Liang Cao, Kostas Kalfas, Nicos Makris, James Ricles*
- ID 752: Multi-Hazard Analysis of Multi-Story Frames with Viscoelastic Semi-Rigid Connections. *Author(s): Alessandro Palmeri, Mariateresa Lombardo*

MS605: Analysis of Heritage Structures: Tools and Methods for Assessing Unknowns in Historic Monuments and Structures.

Organizer(s): Rebecca Napoiltano, Linda Seymour, Brank Glisic, Admir Masic

- ID 136: Looking into the Void: Detecting and Evaluating Voids Beneath Concrete Slabs-On-Grade. *Author(s): Linda Seymour*
- ID 256: Nonlinear dimensionality reduction to identify building attributes that influence tornado damage for historic buildings. *Author(s): Saanchi Singh Kaushal, Mariantonieta Gutierrez Soto, Rebecca Napolitano*
- ID 519: Image-based 3D Modeling as a Damage Tool Prioritization in Post-Disaster Areas. *Author(s): Joe Kallas, Rebecca Napolitano*
- ID 642: Assessing Vulnerability of Historic Midwestern U.S. Timber Barns under Severe Windstorms. *Author(s): Moriah Hughes, Branko Glisic*
- ID 744: Discrete, nonlinear, FE model for structural analysis of adobe piers at Huaca de la Luna. *Author(s): Cristiana Riccio, Anna Remus, Selman Tezcan, Luis C. Silva, Gabriele Milani, Renato Perucchio*

MS606: Wildfire Engineering: Research and practice in wildland and wildland-urban-interface.

Organizer(s): Hamed Ebrahimian, Erica Fischer, Hussam Mahmoud, Negar Elhami-Khorasani

- ID 191: Mapping wildfire ignition probability with ensemble-based machine learning models. *Author(s): Qi Tong, Thomas Gernay*
- ID 320: A Physics-Based Model for Predicting Diurnal and Seasonal Changes in the Ignition Potential of Complex Landscapes and Fuels. *Author(s): Saurabh Saxena, Ritambhara Dubey, Neda Yaghoobian*
- ID 321: Investigation of the Impact of Dynamic Fuel Moisture on Fire and Plume Behavior. *Author(s): Ritambhara Dubey, Neda Yaghoobian*
- ID 356: The Influence of Urban Landscape on Firebrand Spotting. *Author(s): Iago Dal-Ri dos Santos, Neda Yaghoobian*
- ID 544: An Integrated Network Approach for Managing Wildfire Risk to Communities. *Author(s): Hussam Mahmoud, Akshat Chulahwat*
- ID 643: Modeling Wildfire Propagation: A Stochastic Level-Set Formulation. *Author(s): Sourangshu Ghosh, Armin Tabendah, Paolo Gardoni*
- ID 672: A Preliminary Analysis of the Wildfire Hazard in Oklahoma. *Author(s): Richard Campos, P. Scott Harvey, Kanthasamy Muraleetharan*
- ID 731: WRF-Fire for Landscape-Scale Wildfire Simulation: Sensitivity Analysis, The Role of Fuel Characteristics and Fire Spotting, and Data Assimilation. *Author(s): Kasra Shamsaei, Timothy W. Juliano, Matthew Roberts, Hamed Ebrahimian, Branko Kosovic, Neil P. Lareau*
- ID 806: Artificial Intelligence-based wildfire community risk assessment considering physical and social impacts. *Author(s): Abdur Rasheed, Do-Eun Choe*
- ID 910: Long term slope stability after the 2019 Williams Flats wildfire. *Author(s): Mustafa Demir, Idil Deniz Akin*

MS607: Advances in Resilience Analytics and Quantitative Sustainability.

Organizer(s): Arghavan Louhghalam, Mazdak Tootkaboni, Mohammad Javad Abdolhosseini Qomi, Hadi Meidani, Franz-Josef Ulm, Roger Ghanem

- ID 174: Handling High-dimensional Data through Basis Reduction via Interactive Decomposition: Application to Smart Meter Big Data. *Author(s): Esmaeil Rezaei, Mohammad Pourghasemi Saghand, Yanlai Chen, Arghavan Louhghalam, Mazdak Tootkaboni*
- ID 332: A Potential of Mean Force-Based Lattice Element Method for Modeling Progressive Collapse of Structures. *Author(s): Shayan Razi, Mazdak Tootkaboni, Arghavan Louhghalam*
- ID 469: A Dynamic Potential of Mean Force Approach to Lattice Element Method for Estimation of Damage Under Extreme Events. *Author(s): Soolmaz Khoshkalam, Shayan Razi, Mazdak Tootkaboni, Arghavan Louhghalam*
- ID 483: The Impact of Urban Texture on Flood Hazards. *Author(s): Sarah Balaian, Brett Sanders, Mohammad Javad Abdolhosseini Qomi*

MS608: Analysis and Prediction of Wind Effects on the Built Environment.

Organizer(s): Teng Wu, Catherine Gorle, Marco Giometto, Panneer Selvam

- ID 172: Advancements in the Physical Simulation of Atmospheric Surface Layer Flows using Synthetic Turbulence Modulation in a Large Boundary Layer Wind Tunnel. *Author(s): Ryan Catarelli, Yutiwadee Pinyochotiwong, Forrest Masters, Brian Phillips, Tai-An Chen, Jennifer Bridge, Kurtis Gurley*

ID 262: Computation of Building Corner Peak Pressure Using CFD. Author(s): Rathinam Selvam

ID 447: Application of Incremental Dynamic Analysis to Performance-Based Wind Design. Author(s): Baichuan Deng, Teng Wu

- ID 482: Performance-Based Wind Design of Tall Buildings: Challenges of Implementation. *Author(s): Teng Wu, Baichuan Deng*
- ID 527: Investigating the Accuracy of Wind Tunnel Simulations for Wind Profiles over Heterogeneous Terrain: A Comparison Study with Field Measurements. *Author(s): Sejin Kim, Nasrollah Alinejad, Sungmoon Jung, Pedro Fernández-Cábán*
- ID 608: Assessment of Wind Hazard Mitigation on a Tall Building equipped with Performance Control Devices using 3D Real-Time Aeroelastic Hybrid Simulation. *Author(s): Liang Cao, Haitham Ibrahim, Thomas Marullo, James Erwin, James Ricles, Amal Elawady, Arindam Chowdhury*
- ID 693: An LES-based neural network multi-fidelity framework for wind loading predictions. *Author(s): Mattia Fabrizio Ciarlatani, Themistoklis Vargiemezis, Catherine Gorlè*
- ID 697: Comparison of full-scale measurements and large-eddy simulations of wind pressures on a high-rise building. *Author(s): Jack Hochschild, Catherine Gorle*
- ID 783: CFD-enabled surrogate modeling of self-excited forces for single-box deck bridges. *Author(s): Sumit Verma, Miguel Cid Montoya, Ashutosh Mishra*
- ID 844: Database-enabled surrogate-assisted investigation on the interference effects of two adjacent buildings. *Author(s): Fei Ding, Sang-ri Yi, Alexandros Taflanidis, Ahsan Kareem*
- ID 858: Comparison of LES and wind tunnel tests of wind loads on a low-rise building in an urban area. *Author(s): Themistoklis Vargiemezis, Catherine Gorlé*
- ID 891: Large-Scale Open-Jet Testing to Meet Field Pressures on a Flat-Roof Building. *Author(s): Aly Mousaad Aly, Faiaz Khaled*

MS609: Geometries & Design: Opportunities for Sustainable Construction.

Organizer(s): Ann Sychterz, Mija Hubler, Jiaolong Zhang

- ID 144: Effect of stamped dimples on the stiffness of plates under uniaxial compression. *Author(s): Isabel de Oliveira, Jun Sato, Sigrid Adriaenssens*
- ID 290: A new method for fast testing of the shear strength of the interface between artificial rock and printed concrete at super-early ages. *Author(s): Jiao-Long Zhang, Yong Yuan, Xiaoyun Wang, Yaxin Tao, Kim Van Tittelboom, Luc Taerwe, Geert De Schutter*
- ID 302: Analysis of Coreless Filament Wound Structures Using Alternative Performance Indicators. *Author(s): David Forster, Ann Sychterz, Manfred Bischoff*
- ID 318: Automated planning for the construction of laterally resistant masonry walls using irregular stones. *Author(s): Qianqing Wang, Bryan German Pantoja Rosero, Ketson Roberto Maximiano dos Santos, Katrin Beyer*
- ID 490: Tensile Behavior of Multi-layered Randomized Architected Material (MLRAM). *Author(s): Sagnik Paul, Ann Christine Sychterz*

MS610: Objective Resilience: Balancing Portfolio of Actions Across Mitigation and Recovery to Enhance Resilience in an Uncertain Environment.

Organizer(s): Alice Alipour, Paolo Gardoni

- ID 139: Sensitivity analysis for the development of class fragility models of transmission towers under hurricanes. *Author(s): Xinyue Wang, Paolo Bocchini*
- ID 143: Hindcasting Residential Building Damage and Predicting Recovery for the Mayfield, Kentucky December 2021 Tornado. *Author(s): Wanting (Lisa) Wang, John W. van de Lindt, P. Shane Crawford, Blythe Johnston, Guirong Yan*
- ID 184: Risk Communication of Urban Flood Hazards and Damaging Effects through Augmented Reality. *Author(s): ZhiQiang Chen, Molan Zhang, Chengye Li*
- ID 192: A dynamic Bayesian network approach to assess resilience to cascading events in industrial facilities. *Author(s): QI TONG, Thomas Gernay*
- ID 238: Ensemble-based time series analysis considering lag information and feature importance to predict power outages during winter storms. *Author(s): Jangjae Lee, Stephanie Paal*
- ID 453: Multi-Stage Optimization of Mitigation and Response to Enhance Resilience of Infrastructure Systems. *Author(s): Alice Alipour, Ning Zhang*
- ID 517: Optimal Strategies for Enhancing Healthcare Resilience Under Mainshock-Aftershock Events. *Author(s): Emad Hassan, Hussam Mahmoud*

MS611: Objective Resilience: From Performance-Based Engineering to Community Resilience.

Organizer(s): Alice Alipour, Paolo Gardoni

- ID 255: Multi-Disciplinary Simulation-Based Model for Interdependent Seismic Resilience Assessment of Communities. *Author(s): Omar Sediek, Milad Roohi, John van de Lindt, Nathanael Rosenheim, Sara Hamideh*
- ID 742: An Objective-based Framework for Linking Reconnaissance Data to Performance-based Engineering and Community Resilience Performance Metrics. *Author(s): Amir Safiey, David Roueche*
- ID 759: Enhancing Community Resilience with Minimal Instrumentation and Performance-based Seismic Monitoring of Buildings. *Author(s): Milad Cheraghzade, Milad Roohi*
- ID 920: Cascade failure analysis of transmission tower systems. *Author(s): Saransh Dikshit, Alice Alipour*

MS612: Mechanics and Impacts of Wind-borne Debris.

Organizer(s): David Roueche, Franklin Lombardo, Gregory Kopp, Nigel Kaye, Seymour Spence, Yanlin Guo

- ID 95: Validation of an analytical model for estimating debris trajectories in a tornadic wind field. *Author(s): Connell Miller, Gregory Kopp*
- ID 137: Predicting Wildfire Ignition and Windborne Ember Accumulation on Roofs via Deep Learning (DL). *Author(s): Mohammad khaled al-Bashiti, Dac Nguyen, Nigel B Kaye, M.Z Naser*
- ID 138: Experimental Study of Roof Gravel Motion Initiation. *Author(s): Md Safwan Ahsanullah, Nigel Kaye*
- ID 158: A tornadic field retrieval method based on wind-induced debris video-analysis. *Author(s): Guangzhao Chen, Franklin Lombardo, David Roueche*
- ID 179: Wind-Borne Debris FaÃ§ade Impact Design: Validation of a 2D Monte Carlo Numerical Model. *Author(s): Angela Mejorin, Gregory Kopp*
- ID 330: Impact of Tall Building Cluster Layout on Urban Wind Field and Debris Flight Trajectory. *Author(s): Shaopeng Li, Yue Dong, Kimia Yousefi Anarak, Yanlin Guo, Kurtis Gurley, John van de Lindt, Ryan Catarelli*
- ID 550: A physics-based approach to estimate wind speed from wind-borne debris flight trajectory. *Author(s): Daniel Yahya, David Roueche, Franklin Lombardo, Guangzhao Chen*
- ID 745: An AI-based framework for damage estimation of hurricane-impacted residential communities through CFD simulations. *Author(s): Segin Kim, Fei Ding, Seymour Spence*

MS613: Scientific computing for regional risk assessment and performance/resiliency based design.

Organizer(s): Seymour Spence, Alexandros Taflanidis, Andre Barbosa

- ID 258: Leveraging Automation and Surrogate Modeling to Quantify Post-Earthquake Functional Recovery Performance at the Regional Scale. *Author(s): Laxman Dahal, Henry Burton*
- ID 265: Spatial and Computational Analysis to Prioritize Green and Grey Flood Infrastructure under Uncertainty to Increase Resilience. *Author(s): Michelle Reckner, Iris Tien*
- ID 273: Computational tool for community-level probabilistic building performance assessment under excavation-induced ground settlements. *Author(s): Jinyan Zhao, Matthew DeJong*
- ID 311: Informed post-earthquake building inspection planning using adaptive batch-mode active learning. *Author(s): Amirhossein Cheraghi, Ge Ou, Yinhu Wang, Nikola Markovic*
- ID 398: Computational tsunami risk management. *Author(s): Cláudia Reis, André R. Barbosa*
- ID 426: Adaptive importance sampling for efficient probabilistic storm surge estimation. *Author(s): WoongHee Jung, Alexandros Taflanidis, Aikaterini Kyprioti*
- ID 556: Life-cycle assessment of long-span bridge's wind resistant performance considering multi-source time-variant effects and uncertainties. *Author(s): Xiaolei Chu, Wei Cui, Lin Zhao, Yaojun Ge*
- ID 735: A Multi-fidelity Bayesian-based framework for collapse reliability analysis under hurricane hazards. *Author(s): Liuyun Xu, Srinivasan Arunachalam, Seymour Spence*
- ID 799: Propagation of modeling uncertainty in the seismic behavior of specimens employing spines. *Author(s): Bryam Astudillo, Barbara Simpson*
- ID 825: Error quantification and guidance on the use of wind tunnel-informed stochastic wind load models for the applications of performance-based wind engineering. *Author(s): Thays Duarte, Srinivasan Arunachalam, Arthriya Subgranon, Seymour Spence*
- ID 827: Accounting for Cascading Failure of Interdependent Civil Infrastructure in Seismic Resilience Modeling of Communities. *Author(s): Saeid Ghasemi Gavabar , Milad Roohi*
- ID 843: Stochastic emulation of seismic structural response using enhanced partial replication strategy. *Author(s): Sang-ri Yi, Alexandros Taflanidis*
- ID 864: Graph Neural Networks for Efficient Assessment of Transportation Network Response to Disasters. *Author(s): Tong Liu, Hadi Meidani*

- ID 948: Seismic reliability-based retrofitting optimization of non-ductile reinforced concrete frame structures. *Author(s): Antonio Pio Sberna, Angshuman Deb, Fabio Di Trapani, Joel P. Conte*

MS614: Sustainable and Resilient Infrastructure Using Lightweight Materials.

Organizer(s): Fariborz Tehrani

- ID 103: What Goes Up On a Roof Can Come Down … But It Will Cost You. Understanding the Sustainable Design Indent of Green Roof Growing Media. *Author(s): Chuck Friedrich, PLA, GRP*
- ID 361: Asphalt Chip Seal: An Alternative to Sealcoating. *Author(s): Steven Hoard*
- ID 492: Applied Development of Environmental Declarations for Rotary-Kiln Manufactured Expanded Aggregates. *Author(s): Fariborz Tehrani*
- ID 615: Sustainable Biobased Coatings for In-situ Repair of Damaged Coated Rebars. *Author(s): Sher Afgan, Ravi Kiran*
- ID 727: Contributions of Internally-Cured Concrete to Sustainability and Resilience of Pavements. *Author(s): Daron Brown*

MS615: Assessing Human-Infrastructure Interactions and their Performance.

Organizer(s): Fernando Moreu, Hae Young Noh, Ken Loh

- ID 240: Understanding Gait Biomechanics through Structural Mechanics: Foot-Floor Contact Modeling using Footstep-induced Structural Vibrations. *Author(s): Yiwen Dong, Hae Young Noh*
- ID 376: Theory and Computational Framework for Quantifying Social Capital Derived from Human-Human and Human-Infrastructure Interactions. *Author(s): Maral Doctor Arastoo, Katherine Flanigan, Mario Bergés*
- ID 532: A novel approach for repairing corroded structural steel bridge structures using plasma arc additive manufacturing. *Author(s): Rajat Kawalkar, Shengbiao Zhang, John Hart, Wen Chen, Simos Gerasimidis*
- ID 740: Emotion Recognition Using Footstep-Induced Floor Vibration Signals. *Author(s): Yuyan Wu, Yiwen Dong, Hae Young Noh*
- ID 800: {Gait Speed Estimations Using the Change of Amplitude of Vibration Signals. *Author(s): Jean Michel Franco Lozada, Yohanna MejiaCruz, Juan M. Caicedo, Zhaoshuo Jiang*
- ID 823: Exploring Interaction Methods for Human Machine Collaboration in Bridge Inspection via Augmented Reality. *Author(s): Alan Smith, Eric Bianchi, Kyle Tanous, Joseph Gabbard, Rodrigo Sarlo*
- ID 935: Enhancing the Blind-with-Buildings Interaction Using a Digital Controller with Augmented Auditory Feedback. *Author(s): Kaveh Malek, Fernando Moreu*
- ID 936: Enhanced Human Interfaces for Rebar Inspection using RGBD-equipped UAV - Field Application. *Author(s): Mahsa Sanei, Ali Mohammad khorasani, Fernando Moreu*

MS616: CIVIC Transportation and Resilient Solutions Towards Smart and Connected Communities.

Organizer(s): Fernando Moreu, Su Zhang

- ID 852: Route Travel Time Prediction and Uncertainty Quantification using Hierarchical Bayesian Regression. *Author(s): Sevin Mohammadi, Audrey Olivier, Andrew Smyth*
- ID 854: Application of GNN for edge ranking in Transportation systems. *Author(s): Debasish Jana, Sven Malama, Sriram Narasimhan, Ertugrul Taciroglu*
- ID 942: Human-disaster interfaces enabled by Low-cost Efficient Wireless Intelligent Sensors (LEWIS). *Author(s): Fernando Moreu, Ali Khorasani, Kaveh Malek*

MS701: Computational Geomechanics.

Organizer(s): Qiushi Chen, Xiaoyu Song, Steve Waiching Sun, Shabnam Semnani, Majid Manzari, Jose Andrade, Ronaldo Borja, Jinhyun Choo

- ID 167: A domain reduction approach for moving loads on half-space and its implementation to ABAQUS. *Author(s): Yufeng Dong, Ertugrul Taciroglu, Wenyang Zhang, Ahmad Dehghanpoor, Anoosh Shamsabadi, Li Shi*
- ID 182: Yielding and fracture in the nucleation of frictional slip. *Author(s): Miguel Castellano, Flavio Lorez, David Kammer*
- ID 208: Direct Numerical Simulation (DNS) of Binder-Grain Composite Materials Using Pure Discrete Element Method (DEM) Modeling. *Author(s): Beichuan Yan, Richard Regueiro*
- ID 350: Numerical implementation and validation of an advanced Thermo-Elasto-Viscoplastic (TEVP) constitutive model for saturated frozen geomaterials. *Author(s): Dana Amini, Pooneh Maghoul, Amade Pouya*
- ID 362: Modeling fracture propagation in porous media with assumed enhanced strain method. *Author(s): Fushen Liu*
- ID 395: Homogenization model for layered media: the coupling effect of bedding direction and mineral fabric. *Author(s): Tingting Xu, Chloé Arson*
- ID 396: Multiscale modeling of flowslide triggering and runout by accounting for hydro-mechanical feedbacks and granular dynamics. *Author(s): Ming Yang, Giuseppe Buscarnera*
- ID 425: Data-driven breakage mechanics for granular media. *Author(s): Jacinto Ulloa, Anna Gorgogianni, Michael Ortiz, José E. Andrade*
- ID 464: Formulation of a nonlocal gradient enhanced numerical model for geomaterials guided by controllability criteria. *Author(s): Dawei Xue, Xilin Lu, Giuseppe Buscarnera*
- ID 484: Effect of anisotropic consolidation on cyclic liquefaction of granular materials: insights from 3D-DEM modeling. *Author(s): Ming Yang, Mahdi Taiebat*
- ID 521: A New Assumed Deformation Gradient Approach for Mitigating Volumetric Locking in Explicit Material Point Methods. *Author(s): Yidong Zhao, Chenfanfu Jiang, Jinhyun Choo*
- ID 526: Modeling of high strain rate impact of single crystal silica cubes using phase field fracture formulation. *Author(s): Shank Kulkarni, Timothy Truster, Ibraheem Gharaibeh, Khalid Alshibli, Daniel Casem*
- ID 546: Anisotropic bounding surface model for clay under monotonic and cyclic loading conditions. *Author(s): Yang Yu, Zhongxuan Yang*
- ID 572: Reaction cross-diffusion and the long-term behaviour of bio-geomaterials. *Author(s): Manman Hu, Klaus Regenauer-Lieb*
- ID 636: Numerical Study on Phase Transformation Induced Material Fracture. *Author(s): S. Sindhusuta, Sheng-Wei Chi, Craig Foster*
- ID 746: Finite element model of fault zone of northeast Japan subduction zone for intermediate depth earthquake initiation. *Author(s): Ashay Panse, Craig Foster, Shen Wei Chi, Fnu Sindhusuta*
- ID 875: Physics-informed Machine Learning for Porous Media. *Author(s): Ruofan Wu, Shabnam Semnani*
- ID 907: Implementation of a fabric driven mobilized friction angle to improve estimated K0 in Norsand. *Author(s): Mason Ghafghazi, Wyatt Handspiker*
- ID 917: Neural network-encoded signed distance field for shape representation and computational particle mechanics of granular materials. *Author(s): Zhengshou Lai*
- ID 928: Discrete element modeling and design optimization of bio-inspired drilling into the lunar regolith. *Author(s): Liang Zhang, Lei Wang, Quan Sun, Jesus Badal, Qiushi Chen*
- ID 930: Nano-scale soil-water retention mechanism through MD and machine learning. *Author(s): Zhe Zhang, Xiaoyu Song*
- ID 945: On the effects of fabric on the instability onset under constant shear drained loading. *Author(s): Srinivas Vivek Bokkisa, Jorge Macedo, Alexandros Petalas*

- ID 976: Extension of the novel Line Element-less Method for plates shaped with re-entrant angles. *Author(s): Antonina Pirrotta, Carsten Proppe*

MS702: Characterization and modeling of physical processes in porous materials across scales.

Organizer(s): Mostafa Mobasher, Pania Newell, Jean-Michel Pereira, Giuseppe Buscarnera, Sara Abedi, Manolis Vevakis

- ID 111: Unified surface poromechanics theory capturing condensation-induced contraction of mesoporous materials. *Author(s): Yida Zhang, Mohammadali Behboodi*
- ID 207: Bound Preserving Numerical Methods for Infiltration in Porous Media. *Author(s): Arnob Barua, CE Kees*
- ID 338: Porohyperlastic modeling of high-dose subcutaneous injection of monoclonal antibodies using data-driven tissue geometries. *Author(s): Mario de Lucio, Yu Leng, Atharva Hans, Ilias Bilionis, Melissa Brindise, Arezoo M. Ardekani, Pavlos P. Vlachos, Hector Gomez*
- ID 367: Classical density functional theory for nanoconfined inhomogeneous water-Co2 mixture on mineral surfaces. *Author(s): Ali Morshedifard, Mohammad Javad Abdolhosseini Qomi*
- ID 391: Finite Element Analysis for Predicting greenhouse gas emissions in riparian and hyporheic zones. *Author(s): Chengwu Jiang, Martial Taillefert, Chloe Arson*
- ID 407: Simulation of spontaneous excess pore pressure development during compaction band formation in saturated porous rock. *Author(s): Divyanshu Lal, Giuseppe Buscarnera*
- ID 573: Reactive chemo-hydro-mechanics for modelling aggressive fluid injection. *Author(s): Xiaojie Tang, Manman Hu*
- ID 575: Multiscale modeling of heterogeneous porous solids saturated by a thermoviscous fluid: beyond longwave homogenization. *Author(s): Renan Liupekevicius, Hans van Dommelen, Marc Geers, Varvara Kouznetsova*
- ID 600: Particle Scale Assessment of Strain Localization in Saturated Sheared Sand. *Author(s): Mohammed Elnur, Khalid Alshibli*
- ID 644: Influence of Micro- and Crystalline-Scale Properties on the Fracture of Silica Sand Particles Using 3D Finite Element Analysis. *Author(s): Wadi Imseeh, Mohammad Safi, Khalid Alshibli*
- ID 838: Poroelastic Spherical Indentation for Material Characterization. *Author(s): Ming Liu, Haiying Huang*
- ID 862: Computation of per atom strain in classical molecular dynamics simulations. *Author(s): Ranganathan Parthasarathy, Andrew Mikhaeil*
- ID 953: Surface and size effect in nanoporous materials. *Author(s): Gilles Pijaudier-Cabot, Dono Toussaint, Gyorgy Hantal, Romain Vermorel*
- ID 974: Phase-Field Fracture Modeling Informed by Molecular Dynamics Simulation for Investigating Hierarchical Porous Structures. *Author(s): Pania Newel, Bang He*

MS703: Porous flow and geomechanics of CO2 storage - high fidelity physics and surrogate modeling approaches.

Organizer(s): Dakshina Valiveti, Xiao-Hui Wu, Matthias Imhof, Yanhui Han

- ID 99: Coupled Reservoir-Geomechanical Analysis and CO2 Leakage Modeling during CO2 Injection into the Hanifa Reservoir: A Study Focused on Climate Change Mitigation. *Author(s): Sikandar Khan, Abdullatif Al-Shuhail*
- ID 117: Uncertainty Quantification of CO2 Leakage and Risk Analysis of Induced Seismicity for Large-scale Geological CO2 Sequestration. *Author(s): Hannah Lu, Lluis Salo Salgado, Ruben Juanes, Youssef Marzouk*
- ID 146: Surrogate Model for CO2 Storage with Coupled Flow and Geomechanics and Its Use in MCMC-based Data Assimilation. *Author(s): Yifu Han, Francois Hamon, Su Jiang, Louis Durlofsky*
- ID 206: Uncertainty-aware time-lapse monitoring of geological carbon storage with learned surrogates. *Author(s): Ziyi Yin, Rafael Orozco, Mathias Louboutin, Ali Siahkoohi, Felix Herrmann*

- ID 307: Simulation of large-scale geological carbon sequestration in the Gulf of Mexico using fully coupled flow and geomechanics. *Author(s): Yanhua Yuan, Kevin Dugan, Prasanna Krishnamurthy, Stephen Morgan, Josh White*
- ID 309: Fourier-enhanced multiple-input neural operators for accurate and efficient surrogate modeling for geological carbon sequestration. *Author(s): Zhongyi Jiang, Min Zhu, Lu Lu, Dongzhuo Li, Yanhua Yuan, Qiuzi Li, Kun Wang*
- ID 424: Characterizing the geomechanical constraints of long-term CO2 injection and storage through fully coupled 3D fluid flow, geomechanics and hydraulic fracture simulations. *Author(s): Ankush Singh, Mark McClure, Garrett Fowler*
- ID 435: FluidFlower concept for visualizing and studying CO2 storage: From lab experiments to quantitative imaging. *Author(s): Jakub W. Both, Martin A. Fernø, Jan M. Nordbotten*
- ID 908: Anomaly detection for CO2 capture and sequestration monitoring. *Author(s): Jose Hernandez Mejia, Matthias Imhof, Michael Pyrcz*

MS704: Data-Driven Approaches and Digital Twins for Solid and Geological Mechanics.

Organizer(s): Qizhi He, WaiChing Sun, Jiun-Shyan Chen, Xiaolong He

- ID 319: Microstructure transitions from stress field latent features extracted by a Variational Autoencoder. *Author(s): Daniel Chou, Chloe Arson*
- ID 409: Deep Learning models for subterranean navigation and soil characterization. *Author(s): Sanshrit Singhai, Chloé Arson*
- ID 870: Multi-Resolution Physics-Informed Machine Learning Approaches for Digital Twin Applications. *Author(s): Karan Taneja, Xiaolong He, Qizhi He, J. S. Chen*
- ID 874: High-dimensional symbolic regression via neural feature polynomials for interpretable machine learning plasticity. *Author(s): Bahador Bahmani, Hyoung Suk Suh, WaiChing Sun*

MS705: Mechanics and Physics of Granular Materials.

Organizer(s): Yida Zhang, Payam Poorsolhjouy, Marcial Gonzalez

- ID 96: In-Situ Measurements of Stresses and Kinematics in Triaxial Tests. *Author(s): Ryan Hurley, Ghassan Shahin, Ye Tian, Oyvind Torgersrud, Eleni Stavropoulou, Edward Ando, Andrew King*
- ID 110: Fabric characteristics of jammed and unjammed granular materials. *Author(s): Yida Zhang, Yuxuan Wen*
- ID 195: Fracture and damage mechanics on sea ice floes using LS-ICE DEM. *Author(s): Rigoberto Moncada Lopez, Jacinto Ulloa, Mukund Gupta, Andrew Thompson, Jose Andrade*
- ID 202: The effect of drained cyclic loading on changes in fabric anisotropy using DEM. *Author(s): Tara Sassel, Catherine O'Sullivan*
- ID 204: Particle-scale kinematics and kinetics of particle rearrangement in granular materials. *Author(s): Kwangmin Lee, Ryan Hurley*
- ID 374: Evolution of Stress Tensor in terms of Multivariate Probability Distributions using Internal State Variable Theory. *Author(s): Abhinav Ramkumar, Marcial Gonzalez*
- ID 455: A nonlinear elastic constitutive framework for anisotropic granular materials based on particle-scale mechanics. *Author(s): Shubjot Singh, Giuseppe Buscarnera*
- ID 523: Particle shape effect on granular materials mechanics under high strain rate. *Author(s): Dawa Seo, Nitin Pandurang Daphalapurkar, Darby Jon Luscher*
- ID 604: Influence of Loading Rate and Crystal Structure on Constitutive Anisotropy of Silica Cubes. *Author(s): Ibraheem Gharaibeh, Daniel Casem, Wadi Imseeh, Khalid Alshibli, Peter Kenesei, Hemant Sharma*
- ID 624: Multiscale analysis of fiber-reinforced 3D printed concrete. *Author(s): Pouriya Pirmoradi, Payam Poorsolhjouy, Akke Suiker*
- ID 704: A unified descriptive framework for co-evolving particle shape and size in comminution. *Author(s): Priya Tripathi, Seung Jae Lee, Moochul Shin, Chang Hoon Lee*

- ID 723: Continuum stress and strain analysis of the Discrete Element Method (DEM) as applied to shear loading of cuboidal grain assemblies. *Author(s): Yu-Hsuan Lee, Beichuan Yan, Zhou Lei, Richard Regueiro*
- ID 850: An experimental investigation of the transient friction of granular materials at low sliding velocities and pressures. *Author(s): Aizhan Zhakupova, Behrooz Ferdowsi*
- ID 869: Micromechanics based homogenization of truss lattices with experimental validation. *Author(s): Kehinde Omotayo, Samal Aminashairi, Ranganathan Parthasarathy*
- ID 952: Predicting the yield limit of sandstones. *Author(s): Julien Khoury, Sébastien Boutareaud, Gilles Pijaudier-Cabot*

MS706: Understanding the mechanics of induced seismicity.

Organizer(s): Xiao Ma, Dakshina Valiveti, Yang Chen

- ID 148: The influence of fluid injection on energy partitioning during the earthquake cycle. *Author(s): Maryam Alghannam, Hector Gomez, Ruben Juanes*
- ID 156: Scale dependence of frictional rupture prestress: Implications for earthquake statistics and inferences of fault stress. *Author(s): Valère Lambert, Nadia Lapusta, Daniel Faulkner*
- ID 468: How well do we really know the b-value? New estimates of earthquake magnitude for the Delaware Basin and the effect of magnitude uncertainty on induced seismic hazard estimates. *Author(s): Sydney Gable, Yihe Huang, David Shelly*
- ID 659: Role of fault zone complexity in modulating injection-induced seismicity. *Author(s): Md Shumon Mia, Mohamed Abdelmeguid, Chunhui Zhao, Ahmed Elbanna*

MS707: Mechanics of Nonconventional Granular Materials.

Organizer(s): Wencheng Jin, Yidong Xia, Mehari Tekeste, Hariswaran Sitaraman

- ID 113: Smoothed particle hydrodynamics development for modeling granular biomass handling. *Author(s): Yumeng Zhao, Whencheng Jin, Sheng Dai*
- ID 130: Impacts of moisture content on the flowability of milled biomass. *Author(s): Yimin Lu, Wencheng Jin, Jordan Klinger, Hariswaran Sitaraman, Sheng Dai*
- ID 165: Quantitative Assessment of Particle Characteristics Impact on the Flowability of Granular Biomass in Handling and Feeding Units. *Author(s): Ahmed Hamed, Yidong Xia, Nepu Saha, Jordan Klinger, David Lanning, Jim Dooley, Neal Yancey*
- ID 187: Shear Characterization of Particulate Rigid Plastics From Non-recyclable Municipal Solid Waste. *Author(s): Abdallah Ikbarieh, Yimin Lu, Sheng Dai*
- ID 259: Discrete particle simulation of granular pine residues in an FT4 powder rheometer. *Author(s): Zakia Tasnim, Dr. Qiushi Chen, Dr. Yidong Xia, Dr. Ahmed Hamed*
- ID 372: Topological Interlocking Materials with Tunable Mechanical Properties. *Author(s): Ziran Zhou, Tracy Lu, Anna Gorgogianni, Chiara Daraio, Jose Andrade*
- ID 503: A material-point-method based model for the flow behavior of biomass particles with varying moisture content. *Author(s): Yudong Li, Nicholas Deak, Yimin Lu, Hariswaran Sitaraman*
- ID 719: What is shape? Characterizing particle morphology with genetic algorithms and deep generative models. *Author(s): Robert Buarque de Macedo, Slavish Monfared, Konstantinos Karapiperis, Jose Andrade*

MS708: Bio-inspired geotechnics: learning from nature to solve geotechnical challenges.

Organizer(s): Julian Tao, Alejandro Martinez, J. David Frost

- ID 161: Bio-inspired Horizontal Burrowing Robot by Breaking Symmetries in Granular Media. *Author(s): Yi Zhong, Julian Tao*
- ID 488: Numerical Analysis of Sequential Tunnel Excavation Inspired by Ants. *Author(s): Meron Belachew, Karie Yamamoto, Chloé Arson, David Frost*

- ID 491: Investigation of densification effect and anti-scour potential using mangrove-inspired pile group. *Author(s): Xiwei Li, Leon van Paassen, Junliang Tao*
- ID 578: Optimal design and mechanical behaviour of root-inspired anchors under combined loading. *Author(s): Fernando Patino-Ramirez, Catherine O'Sullivan*
- ID 882: How fracture properties of sediments influences bioturbation: A discrete numerical approach. *Author(s): Xuejing Wang, Sanjay Arwade, Kelly Dorgan, Arghavan Louhghalam*
- ID 916: Stability of kangaroo rat burrows in the Sonoran Desert: initial evidence of bio-cementation. *Author(s): Sera Tirkes, Duygu Aydin, Haluk Beyenal, Clint Collins, Idil Deniz Akin*
- ID 924: Investigating Changes to Seabed Properties Due to Biogenic Processes in the York River Estuary, Chesapeake Bay. *Author(s): Chesna Cox, Kelly Dorgan, Nina Stark, Grace Massey, Carl Friedrichs , Adrian Rodriguez-Marek, Eric Hunstein, Md Rejwanur Rahman*
- ID 929: From Geo to Bio and back - Learning from Multiphysics processes in porous media to explore the evolution of branched biological networks. *Author(s): Nariman Mahabadi, Benjamin Blonder*

MS709: Recent Advances in Unsaturated Poromechanics.

Organizer(s): Xiaoyu Song, Ning Lu, Marte Gutierrez

- ID 487: 2D stochastic analysis of Vette fault stability in potential CO2 storage site Smeaheia, offshore Norway. *Author(s): Xiongyu Hu, Marte Gutierrez, Nazmul Haque Mondol, Md Jamilur Rahman*
- ID 931: Nonlocal micro-polar poromechanics for shear bands and cracks in porous media under dynamic loads. *Author(s): Xiaoyu Song, Hossesin Pashazad*

MS802: Integrated Computational Materials Engineering (ICME).

Organizer(s): Mohammadreza Yaghoobi, George Z. Voyiadjis

- ID 676: Crystal plasticity modeling for material strengthening effects of multilayered copper-graphene nanopillar compression. *Author(s): George Z. Voyiadjis, Juyoung Jeong*

MS803: Coupled chemical, physical and mechanical processes in porous heterogeneous materials - From additive manufacturing to long term deterioration.

Organizer(s): Mohammed Alnaggar, Gianluca Cusatis, Giovanni Di Luzio, Roman Wan-Wendner, Jan Elias

- ID 288: Charactering the basic creep behavior of 3D printed concrete with layered structures. *Author(s): Mohammadhossein (Mahan) Kosarimovahhed, Qian Zhang, Sungmoon Jung*
- ID 493: Poly-Material Lattice Discrete Particle Model (P-LDPM) for the Multiscale Prediction of Concrete Mechanical Behavior. *Author(s): Matthew Troemner, Elham Ramyar, Gianluca Cusatis*
- ID 543: Computational Modelling of Flow-induced Fiber Orientation for Ultra-high-performance Concrete Flow. *Author(s): Tathagata Bhaduri, Shady Gomma, Mohammed Alnaggar*
- ID 580: Thermal stability and degradation kinetics of polystyrene-layered double hydroxide composites. *Author(s): Farrukh Shehzad, Sikandar Khan, Mamdouh Al-Harthi*
- ID 696: Stochastic Lattice Discrete Particle Modeling of Fracture in Pervious Cementitious Composites. *Author(s): Alessandro Fascetti, John Bolander*
- ID 906: Coupling between ion irradiation-induced expansion and mechanical stress: An irradiation-induced flow phenomenon. *Author(s): Mohammed Alnaggar, Yann Le Pape*
- ID 922: Microstructure and mechanical properties of brucite recovered from reject brine via different precipitating agents. *Author(s): Inderjeet Singh, Rotana Hay, Kemal Celik*
- ID 939: Study of Effect of Oxide Layer on the Strength of the Cold Spray Layer. *Author(s): Mobin Vandadi, Nima Rahbar, Winston Soboyejo*

- ID 957: Investigation of Scaling-Up Cement Paste Rheological Measurement to Fresh State Behavior of Concrete. *Author(s): Raul Marrero Rosa, Ayesha Ahmed, Elmer Irizarry, Liza Dill, Nasser Nduhi, David Corr, Gianluca Cusatis*
- ID 975: Osmotic Ion Concentration Control of Steady-State Subcritical Fracture Growth in Shale. *Author(s): Anh Tay Nguyen, Hoang T Nguyen, Zdeněk P. Bažant*

MS804: Mechanics of Pavements and Pavement Materials.

Organizer(s): Zhanping You, Linbing Wang, Shane Underwood

- ID 306: Acceleration Monitoring for Pavements. *Author(s): Linbing Wang, Zhoujing Ye*
- ID 308: Use of time-temperature shift factors for waveform-based viscoelastic measures in asphalt binder systems. *Author(s): Saqib Gulzar, Shane Underwood*
- ID 851: Computational Modeling of Skid Resistance of Aircraft Tire on Wet Runway Pavement. *Author(s): Baiyu Jiang, Hao Wang*
- ID 895: Modeling Plastic Deformation of Granular Materials in Pavements Using the Modified Drucker-Prager Cap (MDPC) Model. *Author(s): Mohammad Rahmani, Santosh Kommidi, Yong-Rak Kim, Dallas Little, John Rushing*
- ID 898: Strain Field Distribution in Asphalt Mixes Using Digital Image Correlation. *Author(s): Babak Asadi, Ramez Hajj*

MS805: Self-healing infrastructure materials and systems.

Organizer(s): Ali Ghahremaninezhad

- ID 272: Crack-healing in reinforced concrete beams with engineered aggregates. *Author(s): Xiaoying Pan, Bora Gencturk, Hadi Aryan*
- ID 587: Towards self-healing concrete using protein encapsulated hydrogels. *Author(s): Elvis Baffoe, Ali Ghahremaninezhad*
- ID 926: Development of a damage-responsive self-healing system using bio-inspired polymeric fiber (BioFiber) for incorporation into infrastructure materials. *Author(s): Mohammad Houshmand Khaneghahi, Divya Kamireddi, Seyed Ali Rahmaninezhad, Aidan Cotton, Caroline L. Schauer, Christopher M. Sales, Ahmad Najafi, Reeva Street, Amirreza Sadighi, Yaghoob (Amir) Farnam*

MS806: Small Scale Phenomena in Sustainable & Complex Materials.

Organizer(s): Nishant Garg, Claire White

- ID 279: INDENTATION SIZE EFFECT IN CARBONITRIDED AISI 1045 STEEL. *Author(s): TABIRI KWAYIE ASUMADU, Dr. Kwadwo MENSAH-DARKWA, Dr. Emmanuel Gikunoo, Dr. Desmond Klenam, Mobin Vandadi, Prof. Samuel Kwofie, Prof. Nima Rahbar, Prof. Winston Wole Soboyejo*
- ID 370: CO_2 mineralization of silicate minerals and the potential inhibiting effect of amorphous silica-rich surface layers. *Author(s): Kumaran Coopamootoo, Claire E. White*
- ID 531: Molecular insight on creep of cement-based systems from in situ neutron total scattering experiments. *Author(s): Nishant Garg, Brendan Kehoe, Daniel Olds, Joseph Vocaturo, Michelle Everett, Katharine Page, Joerg Neuefeind, Claire White*
- ID 540: Composition-structure-reactivity relationship for aluminosilicate glasses in alkaline environment. *Author(s): Kai Gong, Claire White, Elsa Olivetti*
- ID 691: Dissolution kinetics of silica fume in alkaline solutions. *Author(s): Yoonjung Han, Jonathan Lapeyre, Umme Zakira, Mine G. Ucak-Astarlioglu, Jedadiah F. Burroughs, Jeffrey W. Bullard*
- ID 784: Influence of Gypsum on Tricalcium Silicate in Blended System: in situ X-ray Total Scattering Study. *Author(s): Hyeonseok Jee, Chirayu Kothari, Nishant Garg*
- ID 812: FROM SMALL SCALE FRACTURE TESTS TO OPEN METROLOGY. *Author(s): Christos Athanasiou*

- ID 884: Using Nanomaterials to Improve the Performance of Recycled Aggregate Concrete. *Author(s): Nathanial Buettner, Ange-Therese Akono*
- ID 885: Novel Polymer-Ceramic Nanocomposites Using Advanced Electrospinning Methods. *Author(s): Yunzhi Xu, Ping Guo, Ange-Therese Akono*
- ID 899: Tracking Spatiotemporal Evolution of Cementitious Carbonation via Raman Imaging. *Author(s): Nishant Garg*

MS807: Innovations in advanced cementitious materials and low-carbon concrete.

Organizer(s): Jianqiang Wei

- ID 416: Commercial and Sustainable Hydrogels for Internal Curing and Shrinkage Control in Concrete. *Author(s): Asif Jalal, Ravi Kiran*
- ID 569: Experimental study of the effect of single fiber pullout behavior of recycled steel fiber on the performance of fiber reinforced concrete. *Author(s): Md. Mashfiqul Islam, Qian Zhang*
- ID 817: Influence of carbonation on alkali-silica reaction. *Author(s): Dayou Luo, Jianqiang Wei*
- ID 836: Phase and Property Evolutions of Alkali-silica Reaction Gels Under Carbonation. *Author(s): Arkabrata Sinha, Jianqiang Wei*
- ID 845: Understanding the role of magnesium in modifying structure and properties of calcium silicate hydrate. *Author(s): Amirhossein Madadi, Jianqiang Wei*
- ID 859: Data-driven design of low-carbon concrete mixture for additive construction. *Author(s): Chaofeng Wang, Jianhao Gao*

MS808: Cementitious Materials: Experiments and Modeling Across the Scales.

Organizer(s): Bernhard Pichler, Franz-Josef Ulm, Günther Meschke, Christian Hellmich, Gilles Pijaudier-Cabot

- ID 122: Modeling the chloride ingress in well cement due to the carbonation reaction underground. *Author(s): Jinliang Liu, Yuxiang Jing, Linfei Li*
- ID 169: A framework for predicting tensile strength of cement paste using multi-scale micro-CT and nanoindentation. *Author(s): Tong-Seok Han, Se-Yun Kim, Donghwi Eum*
- ID 355: Multiscale modeling of thermal Young's modulus degradation of concrete at elevated temperatures. *Author(s): Simon Peters, Günther Meschke*
- ID 414: Multiscale Characterization to Examine Carbonation of Alkali-Activated Binders in Cementitious Materials. *Author(s): Shayan Gholami, Yong-Rak Kim, Dallas Little, Sukmin Kwon, Jong Suk Jung*
- ID 452: Viscoelastic properties of an LC3-paste: ultrasound pulse transmission and hourly repeated minute-long creep testing. *Author(s): Sophie J. Schmid, Luis Zelaya-Lainez, Olaf Lahayne, Martin Peyerl, Bernhard L.A. Pichler*
- ID 466: Measurements of Rate Effects on Damage and Fracture of Different Ultra-High Performance Concretes. *Author(s): Aidan Carlson, Eric Landis*
- ID 467: Seasonal variation of FWD test results of a concrete-over-asphalt composite pavement: asphalt-related temperature correction of measured deflections. *Author(s): Rodrigo Diaz Flores, Valentin Donev, Mehdi Aminbaghai, Lukas Eberhardsteiner, Luis Zelaya-Lainez, Raphael Höller, Christian Hellmich, Martin Buchta, Bernhard L.A. Pichler*
- ID 485: A Numerical Investigation of Gas Migration in Wellbore Cementing Processes using the Lattice Boltzmann Method. *Author(s): Carlos Garcia Verdugo, Ping Lyu, Eilis Rosenbaum, Julie Vandenbossche, Anthony Iannacchione, John Brigham*
- ID 501: Carbon nanotube (CNT) reinforced cementitious composites using carboxymethyl cellulose (CMC) treatment for enhanced dispersion, mechanical, and piezoresistive properties. *Author(s): Dawei Zhang, Ying Huang, Wenjie Xia, Leonard Chia*
- ID 819: Raman Imaging of Alkali Silica Reaction Product Formed Under Accelerated Conditions. *Author(s): Chirayu Kothari, Nishant Garg*

- ID 887: Carbon sequestration in cementitious materials: Characterizing the hydration processes in early-stage carbonated concretes. *Author(s): Marcin Hajduczek, Damian Stefaniuk, James C. Weaver, Franz-Josef Ulm, Admir Masic*

MS809: Mechanics of Sustainable Alternative Pavement Materials.

Organizer(s): Ramez Hajj, Shane Underwood, Hao Wang, Amit Bhasin

- ID 428: How Does Chemical Makeup of Recycling Agents and Antioxidants Affect the Long-Term Performance of Recycled Asphalt Binder Blends? *Author(s): Hamzeh Haghshenas, David Mensching, Michael Elwardany, Panos Apostolidis*
- ID 591: On the Use of Alternative Paving Materials: a RILEM research from TC 279 WMR. *Author(s): Augusto Cannone Falchetto, Lily Poulikakos, Emiliano Pasquini, Di Wang, Marjan Tušar, Jorge Pais, Fernando Moreno-Navarro, Davide Lo Presti, Ana Jiménez del Barco Carrión*
- ID 888: Investigation of the Reactivity in Epoxy-Modified Asphalt (EMA) as an Alternative Paving Material for Durable Open-Graded Friction Course (OGFC). *Author(s): Michael Elwardany, Adrian Andriescu, Hamzeh Haghshenas, Panos Apostolidis, Raj Dongré, David Mensching, Jack Youtcheff*
- ID 933: Rheological modeling of recycled asphalt binder blends as fluid mixtures. *Author(s): Saqib Gulzar, Andrew Fried, Jaime Preciado, Shane Underwood, Cassie Castorena*

MS810: Advanced Design and Manufacturing of Programmable Matter.

Organizer(s): Jochen Mueller, Wesley Reinhart, Amir Alavi

- ID 168: Development of a custom metal DED 3D printer for real-time printing quality control. *Author(s): Subin Shin, Sangjun Kim, Hoon Sohn*
- ID 220: Architected materials with effective water intake, storage, and release properties inspired by the feathers of namaqua sandgrouse (Pterocles namaqua). *Author(s): Jochen Mueller, Lorna Gibson*
- ID 419: Automated Design and Discovery of Mechanical Metamaterials. *Author(s): Qianyun Zhang, Kaveh Barri, Wenyun Lu, Jianzhe Luo, Amir Alavi*
- ID 787: Evaluating Regression and Generative Modeling Paradigms for Materials Design. *Author(s): Arindam Debnath, Wesley Reinhart*
- ID 790: Studying Neural Network Constitutive Models in Open-Source Finite Element Analysis Software. *Author(s): Nilay Upadhyay, Wesley Reinhart*
- ID 949: Universal principles of flexible mechanical metamaterials. *Author(s): Zeb Rocklin*
- ID 956: Pathways to Manufacturing Mechanical Metamaterials by Examining Auxeticity in Nonwoven Fiber Networks. *Author(s): Prateek Verma, Anselm Griffin, Meisha Shofner*

MS811: Architected Materials.

Organizer(s): Stavros Gaitanaros

- ID 106: Auxetic confinement of steel-reinforced concrete members with architected truss lattices. *Author(s): Thomas Vitalis, Andrew Gross, Georgios Tzortzinis, Brian Schagen, Simos Gerasimidis*
- ID 141: Superkagome: a framework for augmented topological lattices. *Author(s): Mohammad Charara, Stefano Gonella*
- ID 149: Fragile topology and corner modes in elastic self-dual kagome metamaterials. *Author(s): Pegah Azizi, Siddhartha Sarkar, Kai Sun, Stefano Gonella*
- ID 166: Stress focusing and damage protection in topological Maxwell metamaterials. *Author(s): Caleb Widstrand, Chen Hu, Xiaoming Mao, Joseph Labuz, Stefano Gonella*
- ID 233: Study of architected materials exhibiting simultaneously negative Poisson's ratio and negative thermal expansion. *Author(s): Yunche Wang, Tsechun Liso*

- ID 237: Arbitrary-Order Sensitivity Analysis in the Wave Propagation Behavior of Architected Materials Using HYPAD-FEM. *Author(s): Juan David Navarro, Juan Camilo Velasquez, Arturo Montoya, Harry Millwater, David Restrepo*
- ID 245: Dynamics of bilayer topological Maxwell lattices and the quest for omnimodal polarization. *Author(s): Mohammad Charara, James McInerney, Kai Sun, Xiaoming Mao, Stefano Gonella*
- ID 337: Healable Magneto-elastic Networks from Self-assembly with Tunable Network Patterns and Mechanical Properties. *Author(s): Xinyan Yang, Junqing Leng, Cheng Sun, Sinan Keten*
- ID 378: Irregular architected materials with programmable properties. *Author(s): Ke Liu, Rachel Sun, Chiara Daraio*
- ID 392: Design and 3D-Printing of Woven Textiles. *Author(s): Tian Chen*
- ID 420: Nanogenerator Mechanical Metamaterial Concrete Systems. *Author(s): Amir Alavi, Kaveh Barri, Qianyun Zhang, Wenyun Lu, Jianzhe Luo*
- ID 504: Acoustic metasurface for wavefront manipulation of ultrasound waves. *Author(s): Xhorxha Kuci, Marc G.D. Geers, Varvara G. Kouznetsova*
- ID 530: Enhanced Mechanical Properties of Marine sponges Inspired Tubular Metamaterials. *Author(s): Zhennan Zhang, Yanyu Chen*
- ID 663: Effects of granular media on energy absorption of architected lattices under dynamic loading. *Author(s): Luis Baldelomar Pinto, Kathryn Matlack*
- ID 666: Time Domain Analysis of Resonant Microstructured Media under Impact Loading. *Author(s): Erdem Caliskan, Willoughby Cheney, Weidi Wang, Reza Abedi, Alireza Amirkhizi*
- ID 677: Light stiff instability-tolerant lattice architectures: the topological efficiency of deep sea sponges. *Author(s): Mazdak Tootkaboni, Ladan Salari , Lorenzo Valdevit, Ardalan Nejat, Alireza Asadpoure*
- ID 716: A Data-Driven Framework for Structure-Property Correlation in Ordered and Disordered Cellular Metamaterials. *Author(s): Shengzhi Luan, Enze Chen, Stavros Gaitanaros*
- ID 721: Mechanics of bioinspired and hierarchical tape-springs. *Author(s): Kristiaan Hector, Phani Saketh Dasika, Adwait Trikanad, Julian Rimoli, Nilesh Mankame, Pablo Zavattieri*
- ID 763: Tension-Compression Asymmetry and Failure of Lattice Metamaterials. *Author(s): Enze Chen, Shengzhi Luan, Stavros Gaitanaros*
- ID 846: Phase Transforming Cellular Materials under Concentrated Loading Conditions. *Author(s): Yunlan Zhang, Phani Saketh Dasika, Nilesh Mankame, Pablo Zavattieri*
- ID 857: Evaluating and tailoring stiffness of lattices for various states. *Author(s): Yash Agrawal, Gabriel Dreisbach, James Guest*
- ID 925: Experimental investigation of nature-inspired nano-architected porous materials. *Author(s): Seo Young Ahn, Pania Newell*
- ID 938: Computational Modeling of Tensegrity Metamaterials. *Author(s): Julian Rimoli, Kevin Garanger, Julie Kraus*
- ID 943: Influence of Carbon Nanofibers and Multiwalled Carbon Nanotubes on the Elastic and Creep Properties of Metakaolin - Based Geopolymers. *Author(s): Ange-Therese Akono, Yunzhi Xu, Haklae Lee, Nathanial Buettner*
- ID 969: Dispersive engineering of metasurfaces for directional and omnidirectional band gaps. *Author(s): Heedong Goh, Ke Ma, Loukas Kallivokas*

MS901: Biomechanics of Human Movement, Performance, and Training.

Organizer(s): J. Brent Knight, John C. Brigham, Amir H. Alavi

- ID 160: Effect of occupant position on ejection and injury mitigation during the rollover of cutaway buses. *Author(s): Mohamad Alagheband, Sungmoon Jung, MohammadReza Seyedi*
- ID 418: In-Vitro Assessment of Lumbar Spinal Fusion in Human Cadaver Models Using Self-powered Sensors. *Author(s): Amir Alavi, Kaveh Barri, Jianzhe Luo*
- ID 653: Neuromechanical Approaches for Improving Human Movement. *Author(s): Minoru Shinohara*

- ID 685: Robotic System to Enable Active and Passive Embodiment for Hand Rehabilitation. *Author(s): Joshua Posen, Joshua Lee, Frank Hammond III, Minoru Shinohara*
- ID 959: Motion Tape Sensors and the Warfighter Digital Twin for Enhancing Physical Performance. *Author(s): Ken Loh*

MS902: 21st Symposium on Biological and Biologically Inspired Materials and Structures.

Organizer(s): Dinesh Katti, Christian Hellmich

- ID 112: Bio-inspired silica coating for steel fibers. *Author(s): Jialai Wang*
- ID 114: Soft Solid-Liquid Composites in Biomedical Applications: Understanding the Size Effect. *Author(s): Karthik Kundapur, Vinu Unnikrishnan*
- ID 115: Modeling of Heat Flow in the Eye. *Author(s): Dipika Gongal, Craig Foster*
- ID 456: The Effect of Intraocular and Intracranial Pressure Gradient on Lamina Cribrosa Biomechanics for Subjects with and without Glaucoma. *Author(s): Soumaya Ouhsousou, Lucy Q. Shen, Amin Pourasghar, Chhavi Saini, Mengyu Wang, John C. Brigham*
- ID 494: Actin Dynamics at Cancer Metastasis to Bone. *Author(s): Dinesh Katti, Sharad Jaswandkar, Kalpana Katti*
- ID 497: Horizontal flow bioreactor for mimicking the migration of late-stage prostate cancer cells to bone. *Author(s): Sharad Jaswandkar, Haneesh Jasuja, Kalpana Katti, Dinesh Katti*
- ID 614: Viscoelastic characteristics of nacre-like materials. *Author(s): Li-Wei Liu, Yuan-Jyun Shih*
- ID 621: Inducing Bone Regeneration in Critical Bone Defects using "LegoBlocks" and Bone Morphogenic Proteins. *Author(s): kalpana katti, Krishna Kundu, Dinesh Katti*
- ID 717: A bone organoid to simulate human bone formation. *Author(s): Elisa Budyn*
- ID 725: On the mechanics of the tooth-stylus-radula systems of chitons: a soft conveying-belt for efficient force transduction. *Author(s): John Connolly, Phani Saketh Dasika, Jungeun Lee, Taifeng Wang, David Kisailus, Pablo Zavattieri*
- ID 878: Nanoindentation and micromechanics of dental cement paste. *Author(s): Petr Dohnalik, Bernhard Pichler, Gilles Richard, Christian Hellmich*
- ID 892: Nanomechanical Characterization of Bacterial Biofilms via Bioindentation and Nanoscratch Tests. *Author(s): Haklae Lee, Ange-Therese Akono*

MS903: Eighth Symposium on Molecular Scale Modeling and Experimentation.

Organizer(s): Dinesh Katti, Sinan Keten, Nima Rahbar, Kalpana Katti, Steve Cranford, Wenjie Xia

- ID 405: Coarse-Graining of Thermomechanical Behaviors of Functional Polymer via Energy Renormalization. Author(s): Zhaofan Li, Wenjian Nie, Dawei Zhang, Wenjie Xia
- ID 496: The mechanics and adhesion of αvβ3 integrin on biomaterials using steered molecular dynamics simulations. *Author(s): Hanmant Gaikwad, Sharad Jaswandkar, Kalpana Katti, Dinesh Katti*
- ID 534: Exploring the Thermomechanical and Interfacial Behaviors of Nano-Clay Using Molecular Modeling. *Author(s): Sarah Ghazanfari, Wenjie Xia*
- ID 562: Optimization and machine-assisted Δ-learning for multiscale modeling of polymer nanocomposites. *Author(s): Hamid Ghasemi, Hessam Yazdani*
- ID 813: Compress Au Nanoparticle towards 2-Dimensional Extreme: A Molecular Dynamics Study. *Author(s): Tanuj Gupta, Michael Cai Wang, Huijuan Zhao*

Poster Presentations

- ID 134: Machine-learning based optimum retrofit scheme development of FRP column jacketing system for seismically-vulnerable RC building structures. *Author(s): Jiuk Shin*

- ID 242: Learning and prediction of structure-property relationships of cracked metamaterials via deep neural networks. *Author(s): Yunche Wang, Yichen Hong, Weilun Hsieh*
- ID 295: Experimental Validation real-time, weighted control algorithm on civil infrastructure. *Author(s): Courtney Peckens, Clara Voskuil, Dylan Clem*
- ID 335: 3D Boundary Kinematic Phenomena Observed on a Series of Sand Specimens. *Author(s): Yichuan Zhu, Zenon Medina-Cetina*
- ID 339: DEM-MBD Coupled Simulation of a Dual-auger Burrowing Robot in Dry Sand. *Author(s): Sarina Shahhosseini, Mohan Parekh, Junliang Tao*
- ID 347: ASCE Student Steel Bridge Optimized Design and Modeling. *Author(s): Brayden Shaver, Paul Pike, Kyle Branning, Ignatius Fomunung, Joseph Owino, Weidong Wu*
- ID 421: Reducing Heavy Fuel Oil Consumption in Shipping: The Impact of V-Shaped Riblets on Hull Drag. *Author(s): Nathaniel Werner, Katherine Rioux, Ryan Pritzkau*
- ID 463: Deep learning-based bridge corrosion detection using UAV images. *Author(s): Zahra Ameli, Eric Landis*
- ID 473: CFD analysis of materials surface roughness changes on heat transport in multi-layer walls. *Author(s): Arkadiusz Urzedowski, Joanna Styczen*
- ID 551: DEM Simulations of the Seismic Response of Tunnels in Deep Granular Deposit. *Author(s): Ahmed Khamiss, Usama El Shamy*
- ID 568: Thermo-Hydro-Mechanical-Bio (THMB) Modeling of Microbially-Induced Calcite Precipitation (MICP) Technique for Ground Improvement in Cold Regions. *Author(s): Sophie Jung, Pooneh Maghoul, Amade Pouya*
- ID 570: Multiband Red/NIR/SWIR synthesis of MgGeO3:Pr3+ persistent phosphor material. *Author(s): Syed Niaz Ali Shah, Sikandar Khan*
- ID 658: Numerical Simulations of Particle Behavior and Breakage within a Pressurized Sand Damper Subjected to Cyclic Loading. *Author(s): Mehrdad Karimipetanlar, Usama El Shamy, Konstantinos Kalfas, Nicos Makris*
- ID 914: Development of Johnson-Holmquist-Beissel Model in Discontinuous Deformation Analysis and its Application in Projectile Penetration. *Author(s): Chenghao Li, Rui Li, Junjie Chen, Jianjun Ma, Linchong Huang*

Presentation Abstracts

2D stochastic analysis of Vette fault stability in potential CO2 storage site Smeaheia, offshore Norway

Xiongyu Hu; Colorado School of Mines; United States
Marte Gutierrez; Colorado School of Mines; United States
Nazmul Haque Mondol; University of Oslo; Norway
Md Jamilur Rahman; University of Oslo; Norway

This paper presents the results of the coupled H-M (hydro mechanical) modeling of the two-fluid phase fluid flow and geomechanics of CO2 injection in the Smeaheia, Norway, CO2 Geological Sequestration (GS) Project. Due to the the uncertainties associated with the subsurface fault properties (i.e., fault rock lithologies and strength, etc.), assessing the fault stability in the Smeaheia area is a challenge. This study employs a computational stochastic approach combined with the two-fluid coupled modeling to predict the effects of supercritical CO2 injectivity on the Vette fault stability. By carrying out a large number of Monte Carlo Simulations in FLAC (Fast Lagrangian Analysis of Continua), with random input of fault rock lithologies and strength, the Vette fault stability is assessed. Results show that the Vette fault's system shows a good reliability. The fault is more prone to shear failure than tensile failure. Overall, the Smeaheia area is predicted to provide CO2 sealing and likely act as potential barriers to prevent leakage of the sequestered CO2 injection.

3D Boundary Kinematic Phenomena Observed on a Series of Sand Specimens

Yichuan Zhu; Temple University; United States
Zenon Medina-Cetina; Texas A&M University; United States

Strain localization, associated with non-homogeneous deformation phenomenon, is commonly seen in granular material when subjected to compressive or tensile stress. Despite many experimental and numerical studies have been conducted during the last two decades to explore the characteristics of localization effects on sand, no 3D experimental kinematic analysis has been performed on sands to study the localization phenomena that can directly relate the impact of a specimen's initial and boundary conditions to a failure mechanism during a triaxial test. In this research, we introduce a full set of 3D kinematic operators under cylindrical coordinates to assess the boundary localization effects of deforming sand specimens under triaxial loading conditions. Furthermore, a set of experiments were carried out under varying experimental conditions to study the impact of variability in these localization effects. Results show that patterns of kinematic effects are quantifiable and can be used to assess likely failure-influencing factors, such as confining pressure, initial density, sample geometry, and sample heterogeneity, in the development of specific failure mechanisms. Spatio-temporal interdependencies between localization effects, such as the interactions between shear, expansion, and compaction bands observed during the specimen's shearing process, were also studied. We therefore hypothesize that the proposed framework will serve as the basis for quantifying the uncertainty associated with the development of localization effects over the boundary of sand-deforming specimens.

A Bayesian compressive sampling approach for modeling, analysis and diagnostics of dynamic cerebral autoregulation in cardiovascular disease

Maria Katsidoniotaki; Columbia University; United States
Leonidas Taliadouros; Columbia University; United States
Ioannis Kougioumtzoglou; Columbia University; United States
Eliza Miller; Columbia University Irving Medical Center; United States
Randolph Marshall; Columbia University Irving Medical Center; United States

Dynamic cerebral autoregulation (DCA) refers to the normal physiological capacity for cerebral arterioles to rapidly adjust caliber in response to blood pressure (BP) shifts, thereby ensuring constant cerebral blood flow (CBF) over a wide range of BP values. DCA dysfunction is associated with a number of cardiovascular diseases, and thus, devising precise and accurate techniques for DCA analysis, monitoring and control is of growing importance to patient care. This may allow for targeted and personalized management of blood pressure in patients with acute cardiovascular disease.

Current state-of-the-art methods for DCA modeling and analysis typically employ continuous bedside monitoring of BP and CBF to identify an input-output relationship between the two variables (e.g., [1]). However, most of these methods rely on strong and often unrealistic assumptions (such as linearity of the input-output relationship and stationarity of the measured data), and/or lack any predictive capabilities, and/or employ exceedingly large and complex parameterizations that reduce the interpretability of the model and provide limited insight regarding the autoregulation mechanism. Overall, there is a critical need for better methods to provide precise, accurate, real-time, and easily interpretable quantification of impaired DCA function in a wide range of cardiovascular diseases.

In this paper, a data-driven technique based on Bayesian compressive sampling [2] is developed to be used both for sparse modeling of dynamic cerebral autoregulation (DCA) and for rapid diagnosis and control of impaired DCA function. The proposed technique exhibits significant novelty and advantages compared to current state-of-the-art approaches, including (1) Predictive capabilities used for rapid, real-time, and accurate diagnosis and control of impaired DCA; (2) Uncertainty quantification of the model predictions, providing clinicians with a measurable confidence degree when employing the methodology as a diagnostic tool for assessing DCA performance; (3) Precision by tailoring the model to a specific patient/disease; (4) Robustness subject to incomplete data, allowing for reliable predictions even if the measured BP-CBF time-histories have missing data.

[1] Miller E., Dos Santos K. R. M., Marshall R. S., Kougioumtzoglou I. A., 2020. Joint time-frequency analysis of dynamic cerebral autoregulation via generalized harmonic wavelets, Physiological Measurement, vol. 41: 024002: 1-11.

[2] Kougioumtzoglou I. A., Petromichelakis I., Psaros A. F., 2020. Sparse representations and compressive sampling approaches in engineering mechanics: A review of theoretical concepts and diverse applications, Probabilistic Engineering Mechanics, vol. 61, 103082: 1-20.

A bone organoid to simulate human bone formation

Elisa Budyn; Ecole Normale Superieure Paris-Saclay; France

We present a bone-on-chip as a physiologically relevant 3D environment in which human bone can be formed in vitro and test regenerative treatments. Our bone-on-chip is composed of one or multiple decellularized bones recellularized with human primary Mesenchymal Stem Cells (MSCs) of different age from fetal to adult individuals. The MSCs became stem cell derived osteocytes (SCDOs) and formed new bone composed of oriented layers of collagen fibers of alternating orientations of 45o and could be cultured up to 26.5 months. Compressive mechanical stimulation was applied to mimic human walk. The stiffness of the new bone was tested using 3-point bending tests. Numerical twins of the cells and tissues indicated pico-Newton force stimulations around the cells. The cell differentiation was measured by in situ live histology under fluorescent confocal microscopy to visualize secreted E11 and SOST. MSCs differentiated into early osteocytes as soon as 15 days and then mature osteocytes at 30 days, identified by qPCR of the mRNA of RUNX2, SP7 and PDPN expressed by the cells. The results shows that cells become more specialized with age and that the stem cell reservoir tends to diminish. The chemical constituents in the new mineralized collagen matrix were also measured using FTIR. The cell reorganization created a fibrous extracellular matrix able to assemble multiple bone chips and revealed topological cues sensed by the cells within minutes of seeding with the attempt to reform the Haversian network. The new results confirmed the influence of age on stem cell ability to produce higher quality bone that is richer in lipid and minerals at the fetal stage compared to adult cells. Our bone-on-chip was successful to assess cell differentiation, mechanobiology and bone quality and assembly with respect to parameters like mechanical stimulation and cell age. Acknowledgments: The author is grateful to NSF CMMI BMMB 1214816 EAGER award, CNRS, the Farman Institute, and Synchrotron 20191708 and 20201633 awards, the support of Rush University. Human materials were obtained from the Anatomical Gift Association of Illinois.

REFERENCES

[1] E. Budyn et al., Human Stem Cells Derived Osteocytes in Bone-on-Chip, MRS Advances, 3(26), 1443-1455, 2018

A Combined Variational Multiscale and Phase Field Approach for Coupled Thermomechanical Problems with Interface Separation, Crack Propagation, and Heat Transport

Pinlei Chen; Penn State University; United States
Wan Wan; Penn State University; United States

In this work, we propose a computational framework for coupled thermomechanical analysis of interface separation, crack propagation, and heat transport in composites. This method treats the tensile debonding and compressive frictional contact in a unified way while considering the interaction between load and heat transfer. Two methods are adopted simultaneously: Variational Multiscale Discontinuous Galerkin (VMDG) method [1] for interface separation and the phase field method [2] for crack propagation. To model the interfaces and the corresponding failure modes, a Discontinuous Galerkin (DG) framework with the jump of both displacement and temperature field at the contact interfaces is proposed. Because of the naturally derived interface terms, the formulation is easily extended to accommodate tensile, contact and frictional debonding at the contact interfaces due to both thermal and mechanical loadings without the loss of numerical stability. On the other hand, the phase field method can represent arbitrary crack geometry without an explicit representation of the crack surface. The distinguishable feature of the proposed phase field method in moding frictional contact problems is that the formulations are presented for incorporating the phase field damage parameter to accommodate different thermal conductance conditions. In particular, we consider a pressure-dependent thermal conductance model which is fully coupled with the mechanical phase in the frictional contact case. For the tensile case, the interface conductance consists of the conductance of connective bond, air, and contact. The potential of the proposed formulation is showcased by several benchmark problems. We gained insights into the role of the temperature field affecting the mechanical field. Several 2D boundary value problems are addressed, demonstrating the capabilities of the model to capture cracking phenomena with the effect of the thermal field. We compare our results with the discrete methods and phase field methods, and a very good agreement is achieved.

A conditional Variational AutoEncoder-boosted Reduced Order Model for multi-parametric dependencies in nonlinear dynamics

Kontantinos Vlachas; ETH Zurich; Switzerland
Thomas Simpson; ETH Zurich; Switzerland
Anthony Garland; Applied Machine Intelligence, Sandia National Laboratories; United States
Carianne Martinez; Applied Machine Intelligence, Sandia National Laboratories; United States
Eleni Chatzi; ETH Zurich; Switzerland

Physics-based Reduced Order Models (ROMs) can be used as surrogates of dynamical systems via the use of projection-based reduction that relies on Proper Orthogonal Decomposition (POD) or similar approaches. However, deriving physics-based ROMs for nonlinear problems with parametric dependencies requires additional treatment, mainly due to the linear nature of the respective operators. This is typically addressed via the use of local reduction bases, and thus local ROMs. Such approaches assemble a pool of projection bases to inject parametric traits or address localized phenomena, and, when needed, they select the suitable subspace via clustering or interpolation strategies. Our work explores the potential of employing Variational Autoencoders (VAEs) to perform a more accurate mapping of the parametrized subspaces, in place of the utilized clustering or interpolation. The derived ROM still relies on projection bases from response data, thus retaining the imprinted physical connotation. However, it additionally formulates a matrix of coefficients that relates the local sample dynamics to the global phenomena and applies a VAE scheme to approximate those coefficients for any input state. This attempts to define a nonlinear approach to approximating the respective subspaces, leading to more accurate and generalized approximations. The proposed pROM is evaluated in a published benchmark example featuring a shear frame with hysteretic links under stochastic ground motion and multi-parametric dependencies, and on a large-scale wind turbine tower with model uncertainties and plasticity.

A Coupled Lagrangian and Semi-Lagrangian RKPM with Smooth Contact for Penetration Problems

Ryan Schlinkman; University of California San Diego; United States
Jonghyuk Baek; University of California San Diego; United States
Frank Beckwith; Sandia National Laboratories; United States
Stacy Nelson; Sandia National Laboratories; United States
Jiun-Shyan Chen; Sandia National Laboratories; United States

We present a Coupled Lagrangian/semi-Lagrangian (L-SL) [1] reproducing kernel particle method (RKPM) with a smooth contact algorithm [2] for modelling problems involving projectile penetration into soil. Due to the extreme deformation of the soil in the form of fracture, fragmentation, and perforation, the semi-Lagrangian formulation [3], which updates the model approximation every time step using the current, deformed configuration as reference, is utilized only in the areas of extreme deformation while a Lagrangian description, which references the undeformed configuration, is used elsewhere. The result is an efficient algorithm that minimizes runtime and maximizes accuracy. This formulation is combined with a smooth contact algorithm that, due to the high level of continuity in the RK approximation, is capable of approximating higher order derivatives terms in a continuous contact force vector and consistent tangent. The result of this combination of methods is the ability to accurately model problems involving projectile penetration into soft targets. We demonstrated the effectiveness of our formulation by modelling the penetration of an ogive projectile into soil at different impact angles with comparison to experimental data.

A data-driven DNN model for wind load prediction based on inflow turbulence and minor architectural features of low-rise building roof systems

Nasreldin Mokhktar; FAMU-FSU College of Engineering; United States
Pedro Fernández-Cabán; FAMU-FSU College of Engineering; United States

Wind mitigation strategies for reducing roof suction loads (e.g., porous parapets, spoilers, barriers, screens, etc.) have been experimentally evaluated and have shown promising results in alleviating uplift roof pressures for a limited number of idealized wind flow conditions (e.g., open terrain simulation). However, it is well-established that both the magnitude and spatial distribution of peak loads near separated flow regions (e.g., roof edges/corners) are strongly linked to the small- and large-scale turbulent eddies embedded in the oncoming wind flow. Further, physical simulation of the complete turbulent wind spectra (including both large and small-scale turbulence) for large-scale testing of scaled low-rise building models has not yet been achieved in traditional boundary layer wind tunnels (BLWTs). This presentation will illustrate the development of a supervised deep neural network (DNN) to accurately predict wind pressure statistics (i.e., mean, RMS, peaks) based on approach flow and geometric roof building parameters. An extensive series of aerodynamic BLWT experiments will offer large volumes of high-quality training data necessary to reliably calibrate, validate, and test the DNN model. The input parameters for the DNN will resemble approach flow inputs required to set up the turbulent inflow conditions of numerical CFD-based models (e.g., RANS and LES). Flow parameters will include turbulence intensity, integral-length scales, and small-scale turbulence parameters (e.g., S-parameter) in the three orthogonal directions (i.e., longitudinal, lateral, and vertical components of the wind velocity). For minor aerodynamic mitigation techniques that are Reynolds number dependent (e.g., porous parapets), the mean wind velocity will also serve as an input to the DNN model. Other input parameters such as wind direction and geometric properties of the wind mitigation elements (e.g., parapet wall height) will also be considered. The proposed DNN model will dramatically augment existing aerodynamic BLWT datasets and help map highly complex input-output functional relationships between inflow conditions and extreme aerodynamic envelope loading. The DNN model will also assist in predicting the performance of roof wind mitigation strategies for unexplored BLWT testing configurations, which will be used in the following task to calibrate the inflow turbulence properties of CFD-based models.

A Data-Driven Framework for Structure-Property Correlation in Ordered and Disordered Cellular Metamaterials

Shengzhi Luan; Johns Hopkins University; United States
Enze Chen; Johns Hopkins University; United States
Stavros Gaitanaros; Johns Hopkins University; United States

One of the most promising recent developments in materials science and engineering is the concept of exploiting "architecture" ─ the combination of topology and solid(s) distribution ─ as a means to generate materials with properties that are unattainable by traditional monolithic solids. Lightweight architected materials, such as additively manufactured micro-lattices and random foams, are excellent candidates for a plethora of engineering applications ranging from space structures to battery electrodes and biomedical implants. To date, a wide range of strut- and shell-based architected metamaterials with unique effective properties have been successfully designed and synthesized. Despite their significance, however, a rigorous framework for associating specific mechanical properties of these material systems to key features of their complex microstructure remains an open challenge. We present here a data-driven framework that allows structure-property correlation for both ordered and disordered cellular solids. Representative lattice microstructures are first generated by solid distribution on k-uniform tilings and Laguerre tessellations with large variations of topological characteristics. A set of deterministic and stochastic morphological descriptors is used to perform microstructure quantification for all designs. Finite element simulations, validated by experiments on additively manufactured specimens, are then performed to predict the macroscopic elastic modulus for different sets of material designs. The numerical data are introduced in machine learning algorithms to develop a surrogate model with the ability to (a) predict macroscopic properties and (b) correlate them to the key morphological descriptors. Results will be presented for 2D materials, including identification of the microstructural descriptors with the largest effect on their effective stiffness. We will further show how this framework can be used to design materials with specific mechanical properties that are also imperfection-insensitive.

A data-driven statistical inverse identification method for phase field modeling of fracture in random heterogeneous elastic media

Florent Pled; Université Gustave Eiffel; France
Christophe Desceliers; Université Gustave Eiffel; France

This research work is concerned with the data-driven statistical inverse identification of a phase field model for fracture in random heterogeneous elastic materials. Within the framework of linear elasticity theory and probability theory, a stochastic model for almost surely (a.s.) isotropic random elastic materials adapted to standard phase field models for brittle fracture is proposed and constructed using the maximum Entropy (MaxEnt) principle. A sensitivity analysis is carried out to study the influence of some fracture properties (fracture toughness) and random spatially-varying elastic material properties on the crack path and the global force-displacement response. Finally, a data-driven statistical inverse identification method based on a nonparametric Bayesian approach is proposed to estimate the posterior probability distribution of the random fracture toughness. The proposed approach is illustrated on two classical benchmark problems for brittle fracture, namely a mode I fracture problem (uniaxial tension test) and a mode II fracture problem (pure shear test) of a two-dimensional single-edge notched/cracked square specimen.

A Decision Tree-based Neural Network Approach for Railroad Bridge Event Classification

Omobolaji Lawal; University of Illinois at Urbana-Champaign; United States
Shaik Althaf V. Shajihan; University of Illinois at Urbana-Champaign; United States
Kirill Mechitov; University of Illinois at Urbana-Champaign; United States
Billie Spencer; University of Illinois at Urbana-Champaign; United States

Railroad bridges are a vital part of the United States' freight network, which according to the Bureau of Transportation statistics transported $186.5 billion worth of goods in 2021. A good number of these bridges are low clearance, thus making them prone to impacts from over-height vehicles which may cause damage and lead to unwanted interruption in their usage. While there has been some previous studies on bridge impact detection, most approaches utilize the more expensive traditional wired sensors and threshold-based detection. The challenge is that the use of vibration thresholds may not be able to accurately distinguish between impacts and other events such as train crossings that occur on railroad bridges. In this work, an approach for accurate impact detection using event-triggered wireless sensors and an artificial neural network is developed. Specifically, responses from events are collected from two instrumented railroad bridges and key features are extracted to train a neural network classifier. A classification accuracy of 97% is achieved, while the false positive rate is only 1.56%. Finally, a framework for on-edge event classification is also proposed.

A Deep Learning-Based Data Fusion Model to Predict Building Attributes Using Google Street View Images, Census Block Group Characteristics, and Real-Estate Data

Abhishek Subedi; Purdue University; United States
Mohammad R. Jahanshahi; Purdue University; United States
David Johnson; Purdue University; United States

Knowledge of a structure's physical attributes is critical for analyzing the risks associated with natural disasters such as floods and hurricanes. However, collecting these data over a wide geographical area is a difficult task because it often requires manual labor. Even in Louisiana, which is at considerable risk for flood-related natural disasters, the state government has sparse data about the composition of building type, number of stories, foundation type, foundation height, presence of a basement, and presence of a garage, of individual structures, all of which are significant predictors of flood risk in many flood risk assessment methods. In this study, we present an automated model to predict these six attributes by utilizing a data fusion-based methodology. The model extracts features from the building's Google Street View (GSV) image through a Convolutional Neural Network (CNN) architecture. Likewise, an Artificial Neural Network (ANN) architecture is employed to extract features from community data taken at the census-block-group level. Another ANN is used to extract features from structure-level data obtained through a real estate database. These three feature streams are then concatenated and processed with a four-layered perceptron fusion module to predict a building's attributes needed for flood risk assessment. Through this technique, we achieve accuracies close to or surpassing 90% on all five classification tasks. Likewise, the Mean Absolute Error (MAE) for foundation height estimation is small enough to make usable improvements to flood risk estimates over existing data sources and modeling assumptions. We also conduct systematic ablation studies to demonstrate the improvements because of fusion. All the experiments are performed in the context of flood risk assessment in Louisiana, but the framework can be easily applied to other natural disasters and geographical regions.

A displacement-controlled Arc Length scheme for Continuum Damage Mechanics problems

Roshan Philip Saji; New York University Abu Dhabi; United Arab Emirates
Mostafa Mobasher; New York University Abu Dhabi; United Arab Emirates

We present a framework for displacement-based arc-length method for damage mechanics problems. The arc-length method has established its capability to handle critical non-linear equilibrium paths in various classes in problems. Yet, the available arc-length algorithms still encounter challenges in displacement-loading scenarios. The displacement-based arc-length method was recently introduced to address these challenges in geometric non-linearity scenarios. In the presented work, we adapt the displacement-based arc-length method to material non-linearity problems, specifically, to continuum damage problems. The presented algorithm covers both local and non-local gradient damage. The algorithm is derived from the linearization of the non-linear system of equations leading to a setup that resembles mixed finite elements. Three variations of the algorithm are proposed to solved the mixed finite element system, and the adequacy of each algorithm is discussed. User-defined stabilization parameters are introduced to enhance the robustness and efficiency of the proposed algorithm. The proposed algorithms are applied to benchmark numerical examples that prove the capabilities of the proposed algorithm and demonstrate the influence of various stabilizing parameters used.

A domain reduction approach for moving loads on half-space and its implementation to ABAQUS

Yufeng Dong; University of California, Los Angeles; United States
Ertugrul Taciroglu; University of California, Los Angeles; United States
Wenyang Zhang; Texas Advanced Computing Center, University of Texas at Austin; United States
Ahmad Dehghanpoor; University of California, Los Angeles; United States
Anoosh Shamsabadi; California High-Speed Rail Authority; United States
Li Shi; College of Civil Engineering, Zhejiang University of Technology; China

Vibrations induced by dynamic vehicle loads on bridges, culverts, embankments, and other support structures are routine considerations in the design of transportation infrastructure, especially in the design of flexible bridges and high-speed train applications. However, current modeling approaches are either based on severe simplifications (e.g., dynamic load increase factors) or mostly analytical, which can only handle a few specific configurations. This naturally limits their applicability. A purely numerical (e.g., finite element) approach is not straightforward either, as it requires careful treatment of the far-field problem involving the inbound moving load. One approach is to use a vast domain, so the system reaches a steady state before the moving loads start interacting with any local scatterer(e.g., a culvert). This increases the computational burden to impractically high levels. In this study, we devise an approach that combines the Domain Reduction Method (DRM) and Perfectly-Matched-Layers (PMLs), which enables drastic reductions in domain size while retaining accuracy. The effective nodal forces are computed analytically from the far-field problem and consistently injected into the local domain through DRM. The PMLs absorb the outbound/scattered waves. The entire scheme is implemented to work with ABAQUS to enhance its utilization in practical applications. The method's accuracy is verified against known solutions, and a parametric study involving different load speeds, scatterer geometries, and embedment depths is presented to demonstrate its application.

A dynamic Bayesian network approach to assess resilience to cascading events in industrial facilities

QI TONG; Johns Hopkins University, Department of Civil and Systems Engineering, Baltimore, USA; United States
Thomas Gernay; Johns Hopkins University, Department of Civil and Systems Engineering; United States

Facilities in the process industry, which are commonly used to process, store, and transfer flammable, explosive, or toxic materials, are vulnerable to cascading accidents. These accidents occur when a failure in one unit triggers the failure of other units, leading to further disruptions and damage. Resilience assessments through performance metrics are useful to evaluate the ability of industrial facilities to withstand and recover from accidents, as well as to assess the effectiveness of mitigation measures, but such assessments must account for the uncertainties and the interdependency between the units which leads to complex and computationally costly models. To address this problem, this study proposes a framework based on Dynamic Bayesian Network to calculate the probabilities of the evolution scenarios for the cascading accidents. The possible spatial and temporal evolution scenarios are identified with their uncertainties in evolution paths and the resilience is evaluated considering the stages of absorption, adaptation, investigation, and restoration associated with the scenarios. The framework is then applied to a case study of a storage tank farm. The resilience of the tank farm against fire hazard is quantified, and the results are used to evaluate the cost effectiveness of different protection measures and determine the optimal strategy for enhancing fire resilience of the facility. The study also includes a sensitivity analysis and break-even point analysis to understand how changes in certain critical parameters affect the resilience assessment. This research provides a step forward in the evaluation of resilience in the process industry, taking into account the uncertainties and interdependencies that can lead to cascading accidents. The proposed framework could then be used to support decision making about implementation of mitigation measures and minimization of the impact of disruption on the performance of facilities in the process industry.

A Dynamic Potential of Mean Force Approach to Lattice Element Method for Estimation of Damage Under Extreme Events

Soolmaz Khoshkalam; UmassD; United States
Shayan Razi; UmassD; United States
Mazdak Tootkaboni; UmassD; United States
Arghavan Louhghalam; UmassD; United States

Damage assessment tools as a crucial component of resilience analytics must be computationally efficient for modeling structural and non-structural elements simultaneously and robust to discontinuity that is the nature of damage and failure. Recently, A potential of mean force approach to lattice element method is developed and used for simulating fracture of heterogenous materials subject to a quasi-static loading [1, 2]. The method is adapted for simulation of response of structural systems [3]. The advantage of PMF-based LEM is its versatility to model linear and different non-linear behaviors. Given the dynamic nature of natural hazards, here we extend LEM for modeling dynamic response of structural systems. Our goal is to leverage the advances in Molecular Dynamics (MD) simulations and integrate that with PMF-based LEM to devise an efficient tool for modeling dynamic response of buildings comprised of structural and non-structural components. More specifically, we use the integration algorithms in MD to capture the displacement of the inertial degrees of freedom. To be consistent with the classical structural dynamics approaches, one needs to account only for the translational inertia and disregard the rotational inertia of particles that do not significantly contribute to the overall dynamic performance of the system. To this end, we develop an energy-base framework for static condensation, where we only account for the translational degrees of freedom in MD simulations, while ensuring that the entire system satisfies the minimum potential energy theorem. We verify the proposed framework via comparison to benchmark problems and demonstrate the accuracy and efficiency of our framework through its application to several structural members and systems subject to different dynamic loadings.

References

1. Laubie, H., Monfared, S., Radjaï, F., Pellenq, R., & Ulm, F. J. (2017). Effective potentials and elastic properties in the lattice-element method: Isotropy and transverse isotropy. Journal of Nanomechanics and Micromechanics, 7(3), 04017007.

2. Wang, X., Botshekan, M., Ulm, F. J., Tootkaboni, M., & Louhghalam, A. (2021). A hybrid potential of mean force approach for simulation of fracture in heterogeneous media. Computer Methods in Applied Mechanics and Engineering, 386, 114084.

3. Razi. S, Tootkaboni. M and Louhghalam. A, "An Energy-Based Lattice Element Method for Assessment of Functionality of Buildings", Engineering Mechanics Institute Conference 2021, Columbia University, New York.

A First-Order formulation with exact imposition of boundary conditions for physics-informed neural networks

Rini J. Gladstone; University of Illinois at Urbana-Champaign; United States
Mohammad A. Nabian; Nvidia; United States
Hadi Meidani; University of Illinois at Urbana-Champaign; United States

The exact imposition of boundary conditions in physics-informed neural networks is an open problem. As a solution for this problem, we propose FO-PINNs, physics-informed neural networks that are trained using the first-order formulation of the Partial Differential Equation (PDE) losses. We show that FO-PINNs first offer significantly higher accuracy in solving parameterized systems compared to traditional PINNs, and reduce time-per-iteration by removing the extra backpropagations needed to compute the second or higher-order derivatives. Additionally, unlike standard PINNs, FO-PINNs can be used with exact imposition of boundary conditions using approximate distance functions, and can be trained using Automatic Mixed Precision (AMP) to further speed up the training. Through two Helmholtz and Navier-Stokes examples, we demonstrate the advantages of FO-PINNs over traditional PINNs in terms of accuracy and training speedup.

A framework for design allowables accounting for paucity of data and errors in complex models

Philippe Hawi; University of Southern California; United States
Roger Ghanem; University of Southern California; United States

A-basis and B-basis design allowables are predicated on estimating the statistical confidence in a computed probability of failure. This "uncertainty on the uncertainty" can be sensitive to a whole slew of errors, omissions, or simplifications accumulated in the process of model synthesis. We develop a novel procedure for the construction and characterization of A-basis and B-basis design allowables. We address the following key challenges in correctly characterizing these design allowables: 1) computational models are expensive to run, therefore hampering the estimation of tail probabilities, 2) experimental data are not sufficient, neither in number nor in content, to construct a credible prior or inform a posterior probability model, 3) uncertainties in mechanistic models have significant consequences on the credibility of associated inferences. We tackle these challenges as follows. 1) The computational cost of stochastic models is addressed by relying on adapted polynomial chaos (PCE) construction that scales the cost of a full stochastic simulation linearly with the number of stochastic variables. 2) Prior models are construed to be random, with their parameters treated as random variables, thus extending the stochastic dimension of the problem. This allows to simultaneously explore a whole family of prior models. A relationship is constructed between the probability distributions of the solution, treated as a random function, and the polynomial chaos coefficients of this solution, allowing us to efficiently evaluate the sensitivity of tail probabilities with respect to missing data, model errors, and aleatoric variables. Further, by introducing new random variables that indexes the parameters of probabilistic models, we rely on the same PCE machinery to propagate the effect of these variables on predicted quantities of interest (QoI), and for assessing the sensitivity of the QoI to these variables. This has significant implications for both convergence analysis and software development (reusing theory and reusing code). It is important to mention that the probabilistic model for the parameters of the prior can be obtained in one of two ways: first, a joint Gaussian model can be associated with these parameters, which is consistent with properties of Maximum-Likelihood estimators; this would lead to a first order PCE approximation of these hyperparameters. Alternatively, a higher order PCE for these parameters can be constructed by executing a Rosenblatt transformation on a Bayesian posterior or an uninformed prior. 3) Complex models, and specifically multiscale or multiphysics models, have particular structure that we leverage. Thus, several mechanistic parameters for any given scale, or physics, are themselves evaluated as the output of other physics submodels. Any uncertainty in these submodels would therefore manifest itself as uncertainty in these "upscaled" parameters. Thus, we account for submodel uncertainties by endowing the upscaled parameters with probabilistic attributes, in the form of a PCE along a new stochastic dimension (that is independent of the previous dimensions relevant to data and aleatoric variables). This assumption of independence is potentially over-reaching and could merit further investigation, but is not scrutinized in this paper. Here again, by relying on new "dimensions" to introduce this uncertainty in submodels, we can reuse the PCE machinery in order to propagate the effect of these uncertainties to the tail of the QoI. It is worth noting that our approach to model error is not comprehensive, in the sense that it does not tackle model-form error. But, as model error (including model form) gets smaller, our model yields a correct representation of the physics. We thus claim that the sensitivities obtained from our construction provide accurate guidelines for remedial actions aimed at ensuring A- or B-allowables. We show how the framework is put to good use characterizing and analyzing A-basis and B-basis design allowables.

A framework for predicting tensile strength of cement paste using multi-scale micro-CT and nanoindentation

Tong-Seok Han; Yonsei University; South Korea
Se-Yun Kim; Yonsei University; South Korea
Donghwi Eum; Yonsei University; South Korea

A synergic tool of combining experiment and simulation for predicting mechanical properties of new and existing materials can expedite the material design and performance evaluation processes. In this study, a framework for evaluating macroscale tensile strength of cement paste using microscale characteristics and properties is proposed. The splitting tests of cement paste are simulated using microstructures obtained from micro-CT, where the input modeling material parameters for phase field fracture model are determined from microscale micro-CT and nanoindentaion test results. A scale-linking strategy between microstructural characteristics between microscale and macroscale micro-CT measurements is discussed as well as the issues on modeling parameter determination and resolution of microstructures from micro-CT. It is confirmed that the proposed framework can predict tensile strength of cement paste compared with experimental results, and shows a feasibility of accelerating new material design and property evaluation of existing materials.

A Generalized digital image correlation Using Attention-based Deep Learning Architecture to Extract Full-field Subpixel Displacement Measurements from Limited Data Using Transfer Learning

Mehrdad Shafiei Dizaji; University of Virginia; United States
Devin Harris; University of Virginia; United States

In the physical infrastructure domain, experimental techniques such as DIC are becoming more widespread, as this technique provides a non-contact measurement strategy in complex environments, creating an opportunity to measure operational response without service disruptions. However, the experimental solutions from DIC are computationally expensive and challenging for real-time applications. In recent works, the authors utilized three-dimensional DIC (3D-DIC) within a topology optimization framework to identify unseen damage at the element level within a simple structural member. This work is analogous to a component-level digital twin and illustrates the potential for describing operational performance, damage in this case; however, the computation expense of solution time was on the order of hours and in the current form creates a barrier to adaptation towards the real-time feedback requirements of a true digital twin. To avoid the computationally-expensive process of using DIC for calculating structural deformation fields from image sequences, a deep learning approach is proposed to re-formulate the problem. Therefore, a deep convolutional neural network (CNN) capable of learning the correlation between sequences of DIC speckle pattern images and the corresponding deformation fields is developed. The proposed CNN will first be developed for 2D speckle patterns and the corresponding in-plane deformation field and then extended to 3D, which requires adaptation to stereo-paired speckle image pairs for correspondence with in-plane and out-of-plane deformation fields. To tackle the challenges associated with the massive size of the data required to train the proposed deep learning models, we propose to leverage a combination of artificially-curated speckle pattern image pairs with pre-defined deformation patterns as well as real-world speckle datasets DIC experiments.

A GID-OpenSEES framework for the structural fire analysis of reinforced concrete structures

Anand Kumar; Indian Institute Of Technology, Jodhpur; India
P. Ravi Prakash; Indian Institute Of Technology, Jodhpur; India
Mohamed Anwar Orabi; The Hong Kong Polytechnic University; China

Structural fire design of reinforced concrete (RC) structures is usually done using experimental methods, codified methods and structural fire analysis. Given the limitations in codified and experimental methods in terms of cost, time and replicating realistic scenarios, computational structural fire analysis has been gaining popularity among researchers and practitioners. Structural fire analysis involves the numerical multi-physics simulation of the thermo-mechanical response history of structures by coupling thermal and mechanical numerical models. This study presents a GID-OpenSEES integration-based finite element (FE) modelling framework for structural fire analysis of RC structures. GID is a pre and post-processing toolkit, whereas OpenSEES is an open-source FE modelling software. The GID-OpenSEES framework follows a computationally efficient two-level discretization, where the structure is discretized into line elements, and the cross-sections of the elements are further discretized into fibres using fiber sections. The thermomechanical analysis considers the response of the line elements, whereas the thermal analysis is performed on two-dimensional heat transfer models of the fiber sections. For the line elements, the force deformation relations are derived from the classical Euler-Bernoulli beam-column theory and duly incorporate the effects of temperature-dependent material degradation, large deformations, yielding in steel and cracking and crushing in concrete. The efficacy of the GID-OpenSEES framework will be demonstrated by comprehensive verification and validation studies. Also, a detailed thermo-mechanical response history demonstration will be performed on an RC frame for chosen input parameters, namely a) compressive strength of concrete, b) yield strength of steel and c) type of fire exposure.

A knowledge transfer LSTM model to predict the seismic response of structures

Hongrak Pak; Texas A&M University; United States
Stephanie German Paal; Texas A&M University; United States

A novel deep learning framework is proposed to rapidly and accurately predict the seismic response of a structure. By adopting transfer learning and unsupervised learning, only two temporal ground motion records and the corresponding structural displacements are required to train and test a deep learning model. The proposed framework consists of four parts: 1) The seismic history is employed to build a database for a specific structure, consisting of important values extracted from earthquake ground motions. 2) The Structural Seismic Response (SSR) net is established on previously recorded earthquake ground motions and displacements. Instead of training the full set of ground motions on a single LSTM model, the SSR net is composed of multiple LSTM models trained independently on a specific earthquake and the corresponding displacements. Each LSTM model tries to understand how to predict the time history of dynamic displacements based on a single earthquake ground motion. 3) The unsupervised nearest neighbor algorithm aims to identify the most relevant previous earthquake when a new earthquake occurs. 4) In the knowledge transfer strategy, knowledge acquired from the most relevant previous earthquake will be transferred to predict the structural displacement caused by a new earthquake. To validate the novel framework proposed in this study, ground motion data and field structural response data measured from a building and bridge is utilized. The results show that the proposed framework can predict reliable seismic structural responses without excessive training procedures and offer significant potential in advancing seismic fragility analysis and reliability assessment.

A Machine Learning-Aided Digital Twin for Damage Sensing based on a Multiphysics-Multiscale Computational Modeling Framework using Piezoelectric Composites

Saikat Dan; Johns Hopkins University; United States
Preetam Tarafder; Johns Hopkins University; United States
Somnath Ghosh; Johns Hopkins University; United States

This work develops a digital twin for predicting damage in composite structures. It is based on a two-way (bottom-up and top-down) multiscale modeling framework coupling deformation, damage, and electric fields. The bottom-up or hierarchical multiscale modeling is achieved by developing a Parametrically Upscaled Coupled Constitutive Damage Model (PUCCDM). The PUCCDM is a thermodynamically consistent, reduced-order structural scale multi-physics constitutive damage model that has explicit dependence on its underlying material microstructure [1]. The microstructure for these structures consists of unidirectional piezoelectric fibers distributed nonuniformly in a passive epoxy matrix that can undergo different damage mechanisms such as interfacial debonding, crack kinking, propagation into the matrix, etc. [2]. The PUCCDM incorporates the nonuniform microstructural morphology in its coefficients through Representative Aggregated Microstructural Parameters or RAMPs. Optimal expressions for RAMPs are determined through principal component analysis of the two-point correlation functions. The PUCCDM coefficients in terms of the RAMPs are determined using machine learning tools operating on data generated by micromechanical analysis. The developed PUCCDM is used for structural scale analysis of composite structures for understanding concurrent damage and failure at multiple scales.

From analysis using PUCCDM it is observed that due to the electromechanical coupling in the piezo composites, damage states in the structures are strongly correlated with its electrical response. Therefore, an electric signal can be used as a proxy indicator of the damage state. This leads to the top-down modeling framework that can quantitatively predict microstructural damage mechanisms from the measurement of a macroscopic electric signal and its corresponding RAMPs. An advanced machine learning model (ConvLSTM) based on the combination of a convolutional neural network (CNN) and a recurrent neural network (RNN) is developed for this purpose. This augmented neural network is advantageous over conventional machine learning models due to its capability in treating path-dependent nonlocal material response data. The trained machine learning model shows good damage prediction capabilities and good generalization characteristics with respect to validation and test data. Thus, the digital twin model can be used as a quantitative global damage indicator in near-real time rather than a location-specific qualitative damage measure.

[1] X. Zhang, D. J. O’Brien, and S. Ghosh (2021), “Parametrically homogenized continuum damage mechanics (PHCDM) models for unidirectional composites with nonuniform microstructural distributions”, J. of Comput. Physics, Vol. 435, pp. 110268

[2] P. Tarafder, S. Dan and S. Ghosh (2023) "Cohesive Zone Phase Field Model for Electromechanical Fracture in Multiphase Piezoelectric Composites." J. of Composite Mat., Vol. 0(0)

A Machine-learning approach to development of Microtexture-Effective Property relationship

Xuejing Wang; UMass Dartmouth; United States
Mazdak Tootkaboni; UMass Dartmouth; United States
Arghavan Louhghalam; UMass Dartmouth; United States

Design and development of fracture-resistant materials is of interest for many different applications in civil, mechanical, and aerospace engineering. It is also well known that the microscopic characteristics of materials is a key driver of the effective elastic and fracture properties. In this presentation, we first describe a novel hybrid energy-based approach we developed to efficiently model the fracture behavior in heterogeneous materials. Our model is based on the potential-of-mean-force (PMF) formulation of the lattice element method (LEM) and the direct application of the Griffith fracture criteria [1]. We then leverage the approach we developed to evaluate the macroscopic response of random porous materials subject to external loading. We perform statistical analysis on a large set of realizations of two-phase porous materials with the goal of establishing a relationship between microstructural properties and macroscopic response. To this end, we define and examine a wide range of geometric descriptors to characterize the micro-texture. These features include the porosity and its local variability, modes of the autocorrelation functions of the random media, and different graph-theoretical features describing the connectivity of the pore network. We use Bayesian machine learning techniques, namely Bayesian Additive Regression Tree (BART) and Gaussian Process Regression (GPR) to build predictive tools for the macroscopic response of the porous materials. Finally, we leverage the feature selection through BART to determine the key dominant features impacting the elastic and fracture properties.

[1] Wang, X., Botshekan, M., Ulm, F.-J., Tootkaboni, M., & Louhghalam, A. (2021). A hybrid potential of mean force approach for simulation of fracture in heterogeneous media. Computer Methods in Applied Mechanics and Engineering, 386, 114084. doi:10.1016/j.cma.2021.114084

A material-point-method based model for the flow behavior of biomass particles with varying moisture content

Yudong Li; National Renewable Energy Laboratory; United States
Nicholas Deak; National Renewable Energy Laboratory; United States
Yimin Lu; National Renewable Energy Laboratory; United States
Hariswaran Sitaraman; National Renewable Energy Laboratory; United States

Lignocellulosic biomass is a renewable resource for producing biochemicals and biofuels and is especially important for the advancement of sustainable aviation fuels. The handling of the milled biomass particles, including bulk transport and feeding, poses significant risk to the reliable operation of biorefinery plants. A predictive understanding of granular flow is therefore essential to derisk feedstock handling operations. Currently, the bulk particle flow and transport are mostly simulated using discrete element methods (DEM). Scaling particle resolved DEM simulation from pilot scale to full size industrial plant with a large throughput of a thousand ton/day requires the use of 100 million to a billion non-spherical particles and is therefore challenging to simulate, due to high computational costs.

Continuum approaches offer considerable improvement in computational efficiency but require closure models for the stress tensor unlike the first-principles discrete-element approach, wherein models for inter-particle and particle-wall collisions are the only requirements. Mesh-based approaches using Finite-Element-Method to solve the continuum mechanics equations have shown great successes in simulating biomass granular flows [1]–[4], but numerical instabilities exist when simulating flow with complex contact behaviors. In this study, we present an alternate numerical approach using the material point method (MPM) to simulate variable biomass particle flow with constitutive models that account for inherent moisture content.

MPM is a hybrid Lagrangian-Eulerian method wherein the material is treated as a collection of material points. The material point data (such as mass, velocity) are interpolated onto a uniform background grid. The grid velocity data provides an accurate way to calculate deformation gradients which are then interpolated back to the material points using suitable basis functions (linear hat or splines in this work).MPM therefore offers several advantages such as the treatment of large deformation and can support a wide range of constitutive models.

We implemented a hypoplastic model in this work to capture both the quasi-static shear and dynamic flow behaviors of the bulk biomass transport process in our in-house open-source MPM solver. The implementation uses data structures from performance portable mesh/particle library, AMReX [5]. The performance of our solver on graphics-processing-units (GPU) accelerated compute nodes is presented along with experimental validation of biomass flow with moisture content on an inclined plane and in a wedge-shaped hopper.

[1] W. Jin et al., "On the Fidelity of Computational Models for the Flow of Milled Loblolly Pine: A Benchmark Study on Continuum-Mechanics Models and Discrete-Particle Models," Front. Energy Res., vol. 10, Jun. 2022, doi: 10.3389/fenrg.2022.855848.

[2] Y. Lu, W. Jin, N. Saha, J. L. Klinger, Y. Xia, and S. Dai, "Wedge-Shaped Hopper Design for Milled Woody Biomass Flow," ACS Sustain. Chem. Eng., vol. 10, no. 50, pp. 16803–16813, Dec. 2022, doi: 10.1021/acssuschemeng.2c05284.

[3] Y. Lu, W. Jin, J. Klinger, T. L. Westover, and S. Dai, "Flow characterization of compressible biomass particles using multiscale experiments and a hypoplastic model," Powder Technol., vol. 383, pp. 396–409, May 2021, doi: 10.1016/j.powtec.2021.01.027.

[4] Y. Lu, W. Jin, J. Klinger, and S. Dai, "Flow and Arching of Biomass Particles in Wedge-Shaped Hoppers," ACS Sustain. Chem. Eng., vol. 9, no. 45, pp. 15303–15314, Nov. 2021, doi: 10.1021/acssuschemeng.1c05628.

[5] W. Zhang et al., "AMReX: a framework for block-structured adaptive mesh refinement," J. Open Source Softw., vol. 4, no. 37, p. 1370, May 2019, doi: 10.21105/joss.01370.

A Micromorphic Filter for Determining Stress and Deformation from Grain-Resolving DNS

Nathan Miller; Los Alamos National Laboratory; United States
Farhad Shahabi; University of Colorado Boulder; United States
Joseph Bishop; Sandia National Laboratories; United States
Richard Regueiro; University of Colorado Boulder; United States

A micromorphic filter is presented for upscaling stress and deformation measures from underlying Direct Numerical Simulation (DNS) of grain-scale mechanical response. The filter follows the micromorphic continuum theory of Eringen & Shuhubi 1964, and allows for the upscaling of DNS "data" to generate higher order constitutive models which are more computationally efficient than the DNS itself, yet resolve more of the grain-scale mechanics than classical continuum theory. The filter adopts aspects of overlap coupling techniques for atomistic-continuum scale-bridging to update the nodal degrees of freedom of a finite-element-based filter. No restrictions on the type of grain-resolving DNS are imposed, provided that the required quantities at the grain-scale (Cauchy stress, position, etc.) are provided. Various small-scale finite-element-based DNS are filtered as examples to demonstrate when the micromorphic degrees of freedom become active, or not.

A Multi-fidelity Bayesian-based framework for collapse reliability analysis under hurricane hazards

Liuyun Xu; University of Michigan; United States
Srinivasan Arunachalam; University of Michigan; United States
Seymour Spence; University of Michigan; United States

To maximize the benefit of performance-based wind engineering, a key challenge is related to the efficient estimation of reliabilities associated with inelastic/collapse-level limit states under long-duration wind loads from site-specific hurricane events. Notwithstanding the potential of high-fidelity models for accurately capturing essential features of inelastic wind behavior, they quickly turn computationally infeasible when adopted within modern probabilistic hurricane assessment frameworks/practices that require a considerable number of nonlinear analyses. A multi-fidelity Bayesian framework is proposed to efficiently estimate fragility functions as well as small probabilities of failure associated with rare events. In this approach, an informative prior distribution on the fragility model parameters is constructed using low-fidelity structural analyses, which are cheap but may be biased. Subsequently, a limited number of structural analyses on a high-fidelity model is performed and a Bayes update integrates this data and the prior. To tackle the computational limitation of running long-duration nonlinear analyses, critically truncated wind load time histories are identified that essentially capture the progression of inelasticity and damage through high-fidelity simulation. The framework is illustrated on a full-scale case study building where it is demonstrated to be computationally efficient for simultaneously estimating fragility functions for a wide variety of limit states as well as failure probabilities through convolution with the site-specific hazard curve.

A multiaxial plasticity model to represent softening in steel hollow square beam-columns under monotonic loading

Diego I. Heredia Rosa; École Polytechnique Fédérale de Lausanne (EPFL); Switzerland
Albano de Castro e Sousa; École Polytechnique Fédérale de Lausanne (EPFL); Switzerland
Dimitrios G. Lignos; École Polytechnique Fédérale de Lausanne (EPFL); Switzerland
Arka Maity; University of California Davis; United States
Amit Kanvinde; University of California Davis; United States

In the context of finite element simulations, there is a growing interest in the development of alternatives to computationally expensive modelling approaches, that can still provide sufficiently accurate structural responses. Such models should be able to represent the post-yield hardening behavior of different steel materials, as well as the deterioration in strength and stiffness due to local buckling. The present paper proposes a modeling approach to simulate the nonlinear response of steel beam-columns with hollow square sections (HSS). For this purpose, a novel multiaxial plasticity formulation is proposed that is assigned to a fiber cross-section of a 3-dimensional force-based beam-column element. The developed constitutive model follows the framework of rate-independent metal plasticity. An initial yield surface is selected, and evolution rules are formulated for its evolution during the different loading stages. In the pre-peak domain, and for tensile loading, the material model follows J2 plasticity, with isotropic and kinematic hardening rules. Following the onset of local buckling, the proposed formulation is based on a suitable yield line mechanism that was deduced from buckling analysis conducted on steel plates with representative boundary conditions of those in plates composing HSS sections. The proposed constitutive model is general, and can be extended to the modeling of other softening phenomena. The ability of the proposed modeling approach in simulating the response of HSS beam-columns under monotonic loading is demonstrated through comparisons with prior experimental work.

A multifidelity control variates formulation for rare event simulation when model covariance estimation is infeasible

Promit Chakroborty; Johns Hopkins University; United States
Michael Shields; Johns Hopkins University; United States
Somayajulu Dhulipala; Idaho National Laboratory; United States

Monte Carlo simulation is one of the most widely used techniques for estimating the statistical properties of systems. However, large numbers of samples are often required to bring the estimate variance within acceptable limits, making the process inefficient. This is especially true for the reliability analysis of real-world systems where the failure domain is complex, or the failure probability is small. In such cases, variance reduction schemes are used; one of the most common schemes applied is the control variates framework. Unfortunately, this is often not enough due to the high computational cost of evaluating the system response for each sample, which is necessary to estimate whether failure has occurred. This makes reliability analysis infeasible even with the incorporation of a variance reduction scheme. Multifidelity modeling is one way to reduce this cost, where accurate but costly High Fidelity (HF) model evaluations are replaced with relatively less accurate but cheaper Low Fidelity (LF) models. We propose the Simple Multifidelity Approximate Control Variates (SMACV) framework, which uses LF models as the control variate to create a more efficient failure probability estimator. The framework addresses some of the practical challenges of the control variates method, such as the necessity to know the true mean of the control variate itself or the need to estimate the covariance between the original estimator and the control variate. The associated SMACV algorithm also provides a natural sample allocation strategy. Additionally, it allows for a diagnostic that indicates both the efficiency of the algorithm as well as the quality of the control variate. Finally, the performance of the algorithm is explored through analytical examples.

A New Assumed Deformation Gradient Approach for Mitigating Volumetric Locking in Explicit Material Point Methods

Yidong Zhao; KAIST; South Korea
Chenfanfu Jiang; University of California, Los Angeles; United States
Jinhyun Choo; KAIST; South Korea

The material point method (MPM) has been widely used for large deformations in (nearly) incompressible materials such as water and undrained soils. For such materials, however, standard MPMs suffer from volumetric locking, manifesting overly stiff behavior with oscillations in the stress and strain fields. Although several methods have been proposed to mitigate volumetric locking in MPM, they are either difficult to implement—requiring significant modifications of the standard calculation procedure—or limited to specific MPM basis functions. Here, we present a simple and efficient approach for circumventing volumetric locking in standard explicit MPM schemes. The approach applies the assumed deformation gradient (F-bar) method, which was originally developed for finite elements [1], with a volume-averaging operation based on the standard particle-grid projection scheme in MPM. When applied to explicit MPMs, this approach leads to a simple algorithm for updating the deformation gradient, without any need to modify the governing equation, the basis function, or the time integration scheme. Also, the approach can be applied to any type of nearly incompressible materials, without being limited to a specific constitutive relation. Implementing the approach in two popular MPM schemes (the generalized interpolation material point method and B-splines MPM), we demonstrate the performance of the approach for alleviating volumetric locking in a variety of nearly incompressible materials exhibiting geometric and/or material nonlinearity.

REFERENCES

[1] de Souza Neto, E. A., Perić, D., Dutko, M., and Owen, D. Design of simple low order finite elements for large strain analysis of nearly incompressible solids. Int. J. Solids Struct. (1996) 33(20-22), 3277-3296.

A New Macro Model for Steel-Concrete Shear Walls using CSI PERFORM-3D

Nakisa Haghi; Morgan State University; United States
siamak Epackachi; Amirkabir University of Technology; Iran
Steve Efe; Morgan State University; United States

Although several macro models exist to simulate the global response of steel plate and reinforced concrete shear walls, no robust macro model has been developed yet for the simulation of the cyclic inelastic response of steel-concrete (SC) composite shear walls. Herein, a novel macro model is proposed for steel-concrete shear walls in order to expand the application of such systems to the building industry and infrastructures. The proposed model is implemented in the CSI PERFORM-3D program to simulate the nonlinear seismic response of the SC shear walls. The proposed model is validated using 17 available test data of SC wall specimens consisting of various geometries. This new model is proven to appropriately predict the global response of SC shear walls including the initial stiffness, peak shear strength and associated displacement, stiffness and strength degradation, and pinching behavior.

A new method for fast testing of the shear strength of the interface between artificial rock and printed concrete at super-early ages

Jiao-Long Zhang; Tongji University; China
Yong Yuan; Tongji University; China
Xiaoyun Wang; Tongji University; China
Yaxin Tao; Ghent University; Belgium
Kim Van Tittelboom; Ghent University; Belgium
Luc Taerwe; Ghent University; Belgium
Geert De Schutter; Ghent University; Belgium

Replacement of the shotcrete of tunnel linings by 3D printed concrete reduces the rebound loss to zero. The shear strength of the interface between rock and printed concrete at several-minutes ages is one of the most important parameters for the evaluation of the bond properties. Fast-hardening at super-early age of 3D printed concrete renders the traditional direct shear test inapplicable, because it is time-consuming. In this contribution, a new method for fast testing of the shear strength of the interface is proposed. It is based on pushing the printed concrete out of holes in an artificial rock which is made of ultra-high performance concrete (UHPC). A test is performed in 1 minute during which ageing of concrete is insignificant. Another 2 minutes are required for preparing the next test. 72 tests were carried out. They differed in the composition and the age of the printed concrete as well as the interface roughness. A dimensionless formula for the shear strength of the interface is deduced. It was validated by comparing the calculated and the experimental results.

A nonlinear elastic constitutive framework for anisotropic granular materials based on particle-scale mechanics

Shubjot Singh; Northwestern University; United States
Giuseppe Buscarnera; Northwestern University; United States

It is widely accepted that the macroscopic response of granular media, including their anisotropic properties, is a product of micromechanical interactions mediated by the material microstructure (e.g., distribution of inter-particle contacts, magnitude of contact forces, particle shape and orientation). Often, these microstructural characteristics are encapsulated into non-isotropic second-order tensors referred to as fabric state variables. While these variables are often found to evolve in response to changing stress conditions (so-called induced anisotropy), evidence from small strain probing on sand has also shown traits of elastic stiffness anisotropy (e.g., Hoque and Tatsuoka (2004)1 and Ezaoui and Benedetto (2009)2). The possibility for this stress-induced anisotropy to emerge even without major changes in particle arrangement suggests that these effects may in part originate from grain-to-grain contact nonlinearity. In this work, discrete element simulations are performed to examine the microscopic origin of stress-induced anisotropy within the small-strain deformation regime. The analyses are conducted by inhibiting grain rearrangement in accordance with simulation strategies previously proposed by Calvetti (2003)3. The preliminary results indicate that, when the granular system is forced to behave elastically, the sole action of contact nonlinearity results into evolving anisotropic elastic characteristics, with a magnitude and orientation that can be correlated to the applied stress state. Such effect, offers opportunities to augment existing constitutive laws (e.g., Houlsby et. al (2009)4) by allowing for the elastic fabric to adapt even without inelastic effects. To account for this effect, a fabric-enriched continuum framework inspired by the above-mentioned DEM simulations is proposed which considers adaptive fabric contributions under purely elastic conditions. Examples of simulations conducted with the proposed enhanced constitutive law are presented, pointing out its ability to capture the macroscopic trends observed in experiments and simulated through discrete element computations.

[1] Hoque, E., & Tatsuoka, F. (2004). Effects of stress ratio on small-strain stiffness during triaxial shearing. Géotechnique, 54(7), 429-439

[2] Ezaoui, A., & Benedetto, H. D. (2009). Experimental measurements of the global anisotropic elastic behaviour of dry Hostun sand during triaxial tests, and effect of sample preparation. Géotechnique, 59(7), 621-635.

[3] Calvetti, F., Viggiani, G., & Tamagnini, C. (2003). A numerical investigation of the incremental behavior of granular soils. Rivista italiana di geotecnica, 37(3), 11-29.

[4] Houlsby, G. T., Amorosi, A., & Rollo, F. (2019). Non-linear anisotropic hyperelasticity for granular materials. Computers and Geotechnics, 115, 103167.

A nonlinear iterated map for a graded Waterbomb origami tube

Americo Cunha Jr; Rio de Janeiro State University; Brazil
Glaucio Paulino; Princeton University; United States

The classic Waterbomb tube is a periodic three-dimensional origami, with a complex geometry capable of exhibiting wave-like behavior along its longitudinal axis, which originates from a tessellation of degree 6 vertex. It is an attractive pattern with potential applications in several fields such as metamaterials, energy harvesting and medical implants. Due to its rich mathematical structure, a recent approach has explained its wave property as a quasi-periodic solution of a discrete two-dimensional dynamical system associated with the origami geometry. Such dynamics is defined by a nonlinear recurrence relation (iterated map) involving distances between the vertices in different rings of the origami tube. Building on this idea, the present study investigated gradation of the unit cells along the tessellation lines, giving rise to a graded origami structure with similar unit cells along horizontal rings but with different rings along the longitudinal direction of the tube. This dynamical system is non-autonomous and is accessed for different grading patterns, following deterministic and stochastic rules, which generate ordered and disordered origami tubes, respectively. The systems are studied and the respective properties reported in this presentation.

A NOVEL ANALYTICAL APPROACH FOR CYLINDRICAL CAVITY EXPANSION/ CONTRACTION PROBLEMS IN MOHR-COULOMB MATERIALS

Shengli Chen; Louisiana State University; United States
Xu Wang; Louisiana State University; United States
Yanhui Han; Aramco Americas Company; United States
Younane Abousleiman; The University of Oklahoma; United States

The cavity expansion/contraction in an infinite/finite medium is a fundamental problem in the field of applied mechanics involving the elasticity, poroelasticity, and plasticity theories. It provides a versatile and reasonably accurate approach/model for the study of many important problems across various disciplines within the physical and engineering sciences, including geomechanics, civil/geotechnical engineering, as well as petroleum, mining, and mechanical engineering. This work develops a complete analytical solution for the cylindrical cavity expansion and contraction in non-associated Mohr-Coulomb materials, by using a novel graphical approach and Lagrangian formulation of the cavity boundary value problem (through tracing the responses of a single material point at the cavity wall). The novelty of the new solution framework lies in that, through unique and rigorous geometrical analysis, the stress path pertinent to the cavity problems will become essentially trackable. This hence allows for the determination of the flow rule/stiffness matrix that in general vary with the continued cavity loading/unloading, a real difficulty inherent with the cornered Mohr-Coulomb model that has remained unsolved to date. Following the graphical solution procedure, the radial and tangential strain increments pertaining to the respective cavity expansion or contraction conditions result in the unique determination of the elastoplastic stress trajectory in the deviatoric plane. With the incorporation of the radial equilibrium condition, the cavity problems are formulated to solve a single first-order differential equation for the internal cavity pressure with respect to a pivotal auxiliary variable. Some selected results are presented here based on the analytical solutions proposed to illustrate the influences of the Mohr-Coulomb parameters on the cavity expansion/contraction curves as well as on the calculated limit cavity pressure for the expansion case.

A novel approach for repairing corroded structural steel bridge structures using plasma arc additive manufacturing

Rajat Kawalkar; University of Massachusetts, Amherst; United States
Shengbiao Zhang; University of Massachusetts, Amherst; United States
John Hart; Massachusetts Institute of Technology; United States
Wen Chen; University of Massachusetts, Amherst; United States
Simos Gerasimidis; University of Massachusetts, Amherst; United States

Wire arc additive manufacturing (WAAM) has evolved through the last years to be one of the most promising consistent additive manufacturing (AM) techniques for metal printing; however, its performance for WAAM produced steel composites repair works still remains unexplored. In this study, WAAM method was used to repair corroded A36 structural steel substrate with maraging steel 250 grade feedstock wire to assess its feasibility in bridge repair applications. The study involves preparation of tensile and compressive test samples made from WAAM printed specimens. Thereafter, optical microscopy (OM) and scanning electron microscopy (SEM) analysis was carried out for understanding the behavior of individual materials within the fractured surfaces. Additionally, computational modelling of sample data was done for validating the experimental values with theoretical data for interpreting the behavior of composite material.

A Novel Approach to Computing Generalized Variability Response Functions for Structures with Random Parameters

Manuel Miranda; Hofstra University; United States

A major issue in stochastic structural mechanics is the difficulty in validating the probabilistic description of the random system parameters assumed in many studies. Investigations usually require extensive sensitivity analyses with respect to these parameters, and this can lead to prohibitive computational cost and possible loss of insight on their relative effect.

In order to address the issues mentioned above, the concept of the Variability Response Function (VRF) has been proposed in the past as a means of systematically capturing the effect of the spectral characteristics of the random system parameters [1]. The existence of the classical VRF can been rigorously derived only for the case of linear elastic, statically determinate structures; on the other hand, for many other structural mechanics problems, the derivations require the assumption of small parameter variability. Either way, the classical VRF is a purely deterministic function that is independent of the probabilistic characteristics of the system parameters.

To overcome the restrictions of the classical VRF approach, a Generalized VRF formulation was introduced, and was successfully applied to structures with linear and nonlinear constitutive laws [2,3,4,5]. In the present work, we present an alternate approach to computing Generalized VRFs. We believe this novel methodology has greater applicability, is more versatile, and shows less dependence on the probabilistic characteristics of the random parameters than previous efforts along these lines. Numerical examples are also presented to illustrate these ideas.

[1] Shinozuka, M. (1987). "Structural Response Variability." Journal of Engineering Mechanics, 113(6), 825–842.

[2] Miranda, M., and Deodatis, G. (2012). "Generalized Variability Response Functions for Beam Structures with Stochastic Parameters." Journal of Engineering Mechanics, 138(9), 1165–1185.

[3] Teferra, K., and Deodatis, G. (2012). "Variability Response Functions for Beams with Nonlinear Constitutive Laws." Probabilistic Engineering Mechanics, 29, 139–148.

[4] Teferra, K., Arwade, S. R., and Deodatis, G. (2014). "Generalized Variability Response Functions for Two-Dimensional Elasticity Problems." Computer Methods in Applied Mechanics and Engineering, 272, 121–137.

[5] Papadopoulos, V., and Giovanis, D. G. (2017). Stochastic Finite Element Methods: An Introduction. Mathematical Engineering, Springer International Publishing, Cham, Switzerland.

A Novel Fragility Framework for Assessing the Performance of Marine Vessels

Aws Idris; Oklahoma State University; United States
Mohamed Soliman; Oklahoma State University; United States

Ships face threats from natural and/or human-induced sources such as storms and ice impact, collision, and grounding. These hazards can cause damage to the structural and non-structural systems of the ship, leading to potentially significant consequences including capsizing or sinking. The quantitative assessment of the susceptibility to damage under hazards can be utilized to improve the safety and integrity of marine vessels. Moreover, understanding the fragility of the system can inform the design process to improve its robustness to hazards; in addition, it can assist in developing optimized maintenance and management plans to improve the system resilience. This paper presents a comprehensive framework for quantifying the fragility of ship hulls and evaluating their performance under operational hazards. It also proposes a systematic definition of the damage states of the ship hulls, taking into consideration the actual operational environment and hull girder characteristics. The analysis is conducted by integrating high-fidelity nonlinear finite element analysis, which accounts for both geometric and material nonlinearity, into probabilistic Monte Carlo simulation to estimate the ultimate flexural capacity of the ship hull. Artificial neural networks are utilized to surrogate the structural model which allows for the proper treatment of uncertainty associated with material properties and hull geometry. This approach will help maintain an acceptable risk level under different operational hazards and assist in improving the resilience of the vessels.

A Novel Multi-scale Branch Fusion Network for Tile Spalling Segmentation Using Limited Samples

Hai-Wei Wang; Department of Civil Engineering, National Taiwan University; Taiwan
Rih-Teng Wu; Department of Civil Engineering, National Taiwan University; Taiwan

The exterior walls of buildings often experience unexpected surface damage like tile spalling induced by aging effects and environmental conditions. These spallings may fall and therefore pose severe safety issues to pedestrians and automobiles on the sidewalks. However, the current inspection process of the exterior walls relies on visual inspections conducted by trained engineers, which is time-consuming and labor-intensive. In recent years, deep learning-based approaches have been developed rapidly, and they are widely incorporated in autonomous condition assessments of buildings due to their ability in learning representative features. However, training a supervised learning model usually requires a large labeled dataset, which is typically not available for a new task of interest. Besides, tile spalling varies significantly in shape and size, leading to challenges for damage segmentation especially with limited training samples. In this study, we propose a novel multi-scale branch fusion UNet (MBF-UNet) to aggregate various feature levels for semantic segmentation of tile spalling. MBF-UNet contains extra branches with different receptive fields and self-attention mechanisms in order to extract meaningful representations of surface damage. To minimize the bias caused by the small dataset, we conducted seven repeated trials to evaluate the performance of the proposed network using only a total of 364 labeled images. Statistical measures have demonstrated that the proposed MBF-UNet achieves a mean intersection over union (mIoU) of 0.53, which is 5.1% superior to the state-of-the-art segmentation models.

A Numerical Investigation of Gas Migration in Wellbore Cementing Processes using the Lattice Boltzmann Method

Carlos Garcia Verdugo; University of Pittsburgh; United States
Ping Lyu; University of Pittsburgh; United States
Eilis Rosenbaum; National Energy Technology Laboratory; United States
Julie Vandenbossche; University of Pittsburgh; United States
Anthony Iannacchione; University of Pittsburgh; United States
John Brigham; University of Pittsburgh; United States

The most common approach in well completion to achieve zonal isolation is to place cement as a barrier between the well casing and formation, filling the annulus. This cement barrier prevents annular gas migration between zones and avoids possible damage to the well and/or environment due to corrosive gasses and water. However, there can be instances where gas is able to migrate through the cement barrier, creating a potential hazard itself as well as providing pathways for future unwanted fluid migration. As such, there is substantial interest in minimizing the occurrence of gas migration during wellbore cementing processes. To do so, it is first necessary to better understand the processes that lead to gas migration in cement between the point of first placement until the cement has developed sufficient mechanical strength to fully resist formation of gas sources. Towards addressing this need, an approach using the multi-component lattice Boltzmann method (LBM) will be presented to represent cementing processes in the presence of formation gas sources. The LBM was chosen as the approach to simulate the multicomponent fluid-gas interaction that occurs during gas migration, due to LBM's capability to capture the behavior of such complex systems with relative computational efficiency and flexibility. The specific LBM implementation to be presented uses the multicomponent model presented by Shan and Chen (1993), because of its efficiency to capture fluid interaction. This approach will be applied to investigate the effects of the properties of the cement slurry and conditions of the wellbore on the potential for and form of gas migration. In addition to evaluating the feasibility of the LBM approach in this context, a computational case study of a representative wellbore segment will be presented. This case study will examine how the material properties of the cement slurry, which vary as the cement hydrates, and the size and depth of the wellbore segment affect the gas migration process within the wellbore segment.

A Numerical Study of Clutching Inerter Dampers for Mitigating the response of Multi-degree-of-freedom Base-Isolated Structures

Wyatt Cupp; University of Tennessee; United States
Nicholas Wierschem; University of Tennessee; United States

Base isolation systems (BIS) are commonly used to isolate sensitive equipment, machinery, or larger structures from vibration sources; however, the reduction in transmitted loads with the BIS can come at the cost of large isolation layer displacements. Proposals have been made to hybridize the BIS with other vibration control technologies in order to improve its isolation performance and simultaneously decrease the associated base displacements. The clutch inerter damper (CID) is one such device proposed to be coupled with the BIS, and its performance in the literature is thus far promising. The CID acts as a linear inerter when in its engaged state, adding effective mass in the form of rotational inertance to oppose a system's motion, and when disengaged it can idle freely and dissipate its rotational energy without directing this energy back into the system. Previous studies on the CID in base isolated multi-degree-of-freedom (MDOF) structures are fairly limited and focus heavily on the time history analyses of seismic or harmonic loadings. Furthermore, much of the research on this topic considers an ideal CID where all rotation is damped out between engagements with the structure, which cannot be considered physically realistic in many circumstances. This work numerically investigates the performance of a base isolated MDOF system with a CID subjected to white noise loading primarily from a frequency domain perspective and employs a more realistic numerical model of the CID's dynamics. Several indices, such as the H2 and H∞ norms of the system's displacement and acceleration frequency response functions, are analyzed to evaluate the response of the system. The performance of the MDOF base isolated structure with the CID is evaluated in comparison to a BIS with a linear inerter, a BIS without a CID or inerter, and the structure without base isolation. Results indicate that the CID in a base isolated MDOF structure outperforms the other configurations for several key indices and that the CID behaves similarly to an additional damper between the ground and isolation layer. The analysis also reveals that the CID's ability to improve system performance diminishes at higher levels of rotational inertance. The performance of the CID as is presented in this work illustrates it potential for effective use as a part of isolation systems for MDOF structures.

A paradigm for fast exploring of material repones space considering microstructure statistics and application to particulate composites

Min Lin; University of Wyoming; United States
Xiang Zhang; University of Wyoming; United States

It is well recognized that manufacturing process generally introduces variation in the material microstructures, and inherently delivers material microstructure with certain statistical features. In composites, this could be the size distribution of the reinforcement phase (e.g., fiber or particle diameter distribution), nearest neighbor distance distributions, or the phase or interfacial properties (i.e., distribution of the modulus of the fibers, or the cohesive stiffness of the interfaces). There is a strong need to obtain the stress-strain response of a large number of similar microstructures (e.g., different instances of the same statistics), either to probe the spreading of the response of materials from a manufacturing process or providing training data for the development of other data-driven methods. While this could be accomplished straightforwardly by using high-performance computing resources, and the easy-parallel nature of those individual direct numerical simulations (DNS, oftentimes finite element-based methods), computational cost can still be a limiting factor if the number of DNS is substantially large. We propose a paradigm for fast evaluation of many similar microstructures (i.e., instances of microstructures from a single statistical description) based on the eigendeformation-based reduced-order homogenization model (EHM). EHM partitions the microstructure into a few sub-domains (also known as parts) and precomputes coefficient tensors including each part's localization tensor and the interaction tensors between parts. By assuming a uniform response over each part, a reduced-order nonlinear system can be derived from the microscale equilibrium and solved for the part-wise responses to replace the full field microscale problem, achieving high computational efficiency for moderately low levels of error. Prior efforts of EHM development include the speed up of the ROM solving stage, as well as the incorporation of different deformation mechanisms and coupled physics and the preprocessing stage is normally conducted for a single microstructure and then used in different simulations, where the non-linear solving process is generally 2-5 orders of magnitude faster than DNS. In the current case, different microstructures are considered, and the pre-processing stage need to be conducted for each microstructure, posing a need to accelerate the pre-processing stage. While the pre-processing stage normally use FE-based methods to solve influence functions (i.e., numerical green's function) and the computational cost scales linearly with the number of microstructure evaluation, we propose to use physics-informed neural networks (PINN) are adopted to solve the influence functions. We extend the publicly available PINN and further include material or geometry parameters as input, which once trained, can provide fast evaluation of the coefficient tenors of a many new microstructures. The coefficient tensors are compared with those from the FE simulations, and the subsequent nonlinear stress-strain response are compared with both DNS and conventional EHM. The verified model is then adopted to study the response space of a particulate composite considering the material and geometry variation.

References

[1] Zhang, Xiang, and Caglar Oskay. "Eigenstrain based reduced order homogenization for polycrystalline materials." Computer Methods in Applied Mechanics and Engineering 297 (2015): 408-436.

[2] Brandyberry, David R., Xiang Zhang, and Philippe H. Geubelle. "A GFEM-based reduced-order homogenization model for heterogeneous materials under volumetric and interfacial damage." Computer Methods in Applied Mechanics and Engineering 377 (2021): 113690.

A Phase field model for anisotropic incompressible materials at finite strains

Wenyuan Xue; Stanford University; United States
Prajwal Kammardi Arunachala; Stanford University; United States
Sina Abrari Vajari; Stanford University; United States
Christian Linder; Stanford University; United States

In the past few decades, the mechanical modeling of fracture in biological materials has been a promising field of research as it has been found to benefit disease prevention and surgical treatments, and improve our understanding and prediction of the failure mechanisms of injuries. However, accurate prediction of the behavior of many biological tissues requires modeling their anisotropic and incompressible behaviors. Additionally, such models have also been found to be applicable to many engineering materials like fiber-reinforced composites, which exhibit similar characteristics. In recent years, the phase field method has been a rapidly developing approach for modeling fracture, where the cracks are approximated by a smooth auxiliary scalar field [1,2]. Based on such a framework, various formulations of crack evolution equation and failure criteria for anisotropic materials have been proposed. However, few researchers account for the incompressibility constraint in their models, due to its numerical complexities. Therefore, a three-field mixed formulation coupled with the phase field approach is proposed in this study for modeling such materials. Anisotropy is incorporated using an energy-based failure criterion and a strain energy function [3] which assumes two families of fibers in a hyperelastic medium. Assuming an incompressible behavior, a decoupled deformation formulation is employed, with the volumetric and isochoric parts of the free energy degraded by different degradation functions for numerical stability. Furthermore, the augmented Lagrangian procedure is implemented to enforce the incompressibility constraint in the undamaged regions. The performance of the proposed model is validated by comparison with available test results.

[1] S. Abrari Vajari, M. Neuner, P.K. Arunachala, A. iccarelli, G. Deierlein, C. Linder, A thermodynamically consistent finite strain phase field approach to ductile fracture considering multi-axial stress states, Computer Methods in Applied Mechanics and Engineering 400 (2022): 115467.

[2] P.K. Arunachala, S. Abrari Vajari, M. Neuner, C. Linder, A multiscale phase field fracture approach based on the non-affine microsphere model for rubber-like materials, Computer Methods in Applied Mechanics and Engineering (Submitted).

[3] G. A. Holzapfel, T. C. Gasser, R. W. Ogden, A new constitutive framework for arterial wall mechanics and a comparative study of material models, Journal of elasticity and the physical science of solids 61 (2000): 1-48.

A phase-field formulation for fracture modeling of rate- and temperature-dependent materials

Rogelio Muñeton-Lopez; University of Missouri; United States
Oliver Giraldo-Londoño; University of Missouri; United States

The phase-field method is becoming one of the most promising numerical techniques for modeling brittle and quasi-brittle fracture. Using appropriate geometric degradation functions, we recently recast the Park-Paulino-Roesler (PPR) cohesive zone model within the phase-field modeling framework, allowing us to model fracture for a wide variety of materials characterized by either convex or concave traction-separation relationships. The new phase-field model, herein referred to as the regularized PPR model, is designed for rate- and temperature-independent materials, yet several engineering materials (e.g., asphalt) are viscoelastic and therefore highly sensitive to loading rate and temperature. To overcome this limitation, we extend the regularized PPR model to account for thermoviscoelasticity. Specifically, we consider a weakly coupled thermoviscoelastic problem tailored to isotropic linear viscoelastic media and solve for the effective stresses via an incrementalization approach, such that the stresses at the current time step can be computed recursively based on the stresses at the previous time step. The derivation of the recursive relationship relies on a Dirichlet–Prony series representation for the shear and bulk modulus of the bulk material. In this presentation, we will discuss the derivation of the new thermoviscoelastic phase-field model and will discuss several numerical examples to show the ability of the model to simulate complex crack topologies for structures subjected to complex thermomechanical loads.

A physics-based approach to estimate wind speed from wind-borne debris flight trajectory

Daniel Yahya; Auburn University; United States
David Roueche; Auburn University; United States
Franklin Lombardo; University of Illinois at Urbana-Champaign; United States
Guangzhao Chen; University of Illinois at Urbana-Champaign; United States

Non-synoptic wind events, including thunderstorms, downbursts, and tornadoes, account for most weather-related fatalities in the United States and cost billions of dollars in property damage each year. Despite advancements in incorporating non-synoptic winds into wind design codes and standards, there remains a significant gap in understanding the near-surface wind and debris characteristics of these events. However, with the advent of smartphones, video monitoring systems, and remote sensing technologies, a wealth of media now exists that capture the real-time dynamics of non-synoptic storms, including the motion of wind-borne debris, which could be a useful source of data. This study aims to establish a framework for inferring near-surface wind characteristics from debris speed and other debris attributes captured by videos and other media during these events. The proposed framework involves three key steps: (1) accurate extraction of debris trajectories from videos in 2D or 3D space as a function of time, (2) estimation of debris attributes relevant to debris-flight motion (e.g., mass, area, aerodynamic coefficients) from the video, and (3) application of equations of motion to (1) and (2) to infer background wind flow characteristics. The proposed framework is demonstrated using a high-resolution video that captured a tornado which struck Andover, KS, USA, on April 29, 2022. The wind-borne debris was manually identified and tracked using the Computer Vision Annotation Tool (CVAT), and the real coordinates of the debris trajectory relative to a reference point in the flight video were estimated using principles of lens optics, the known tornado path, and the known location of fixed reference points captured in the video. For simplicity in demonstrating the framework, two-dimensional motion of a compact (spherical) debris object is considered in this preliminary study. The flight of wind-borne debris is defined by Newton's second law of motion. The results from the framework were compared to the actual wind speed estimate of the event based on the observed damage and the Enhanced Fujita Scale. The study shows that the framework can give reasonable estimates, but the estimates are sensitive to assumptions about debris geometry and mass. Overall, this study shows the possibility and necessity of utilizing a physics-based approach to estimate wind speed at specific points of a flow field. Analyzing the trajectory of wind-borne debris objects within the flow field extracted from existing debris flight media can therefore provide an opportunity to gain a deeper understanding of near-surface wind and debris characteristics.

A Physics-Based Model for Predicting Diurnal and Seasonal Changes in the Ignition Potential of Complex Landscapes and Fuels

Saurabh Saxena; Florida State University; United States
Ritambhara Dubey; Florida State University; United States
Neda Yaghoobian; Florida State University; United States

Wildfires and wildland-urban interface fires have become more frequent and severe in the United States and around the world. One of the primary causes of the severity and extensive destruction during such events is the fuel ignition potential or the vulnerability of fuels to fire and embers. Understanding the impact of the entire environmental mosaic, including but not limited to the local weather conditions, geographic location, topographical features, fuel material properties, and the associated energy and moisture exchanges are critical in determining the ignition potential of fuels. A better understanding of the fuel ignition potential will aid in mitigating the adverse effects of wildfires and helps to recognize the necessary defensive actions. This study develops a novel coupled water and energy balance model that considers all the important factors in predicting the temperature and moisture content evolution of complex fuels/landscapes in a high spatial and temporal resolution under diurnally variable environmental conditions. Some examples of such complex settings range from densely packed fuels in hilly terrains to intermix communities composed of natural and manmade random-shaped objects. This research presents the model theory, validates the model, and seeks to explain the influence of some conventional terrains on ignition potentials. The model is versatile and can be used in various fuel condition problems and due to its high spatiotemporal resolution, can be coupled with computational fluid dynamics simulations when coupled physics is desired.

A Potential of Mean Force-Based Lattice Element Method for Modeling Progressive Collapse of Structures

Shayan Razi; University of Massachusetts Dartmouth; United States
Mazdak Tootkaboni; University of Massachusetts Dartmouth; United States
Arghavan Louhghalam; University of Massachusetts Dartmouth; United States

Natural hazards such as windstorms, earthquakes, and floods can exert significant stresses on buildings and infrastructure that could cause failure of the structural and non-structural components and consequently overall damage to the entire building. The significance of economic repercussions of such events calls for a reevaluation of engineering approaches to resilience assessment and examination of functional integrity of civil infrastructures. To implement such an assessment, it is crucial to establish accurate yet computationally efficient frameworks for predicting the failure of building systems that incorporate both structural and non-structural elements. To this end, we employ a potential-of-mean-force (PMF) approach to lattice element method (LEM) to capture the mechanical response of structural systems. The proposed framework discretizes the system into a set of particles that interact through prescribed potential functions, to represent the mechanical properties of members. Due to its discrete nature, PMF-based LEM is well-suited for damage assessment and overcomes the limitations of continuum mechanics methods in simulating discontinuity. The framework is capable of simulating the linear and nonlinear behavior of structural components by incorporating harmonic and non-harmonic effective interaction potentials, respectively. Here we use both harmonic and non-harmonic potential and model failure by breaking bonds between particles according to an energy-based failure criterion. The calibration procedure for the harmonic potential parameters is carried out via a handshake with continuum mechanics theories, i.e., the Timoshenko beam theory for one-dimensional and Kirchhoff-Love plate theory for two-dimensional members. Such calibration is applied to non-harmonic potentials adopting section properties that encapsulate the nonlinear stress-strain responses of the materials, e.g., nonlinear moment-curvature relations. The efficiency and accuracy of the proposed method are explored through its application to quasi-static simulation of large-scale buildings subjected to various loading conditions. We then extend the analysis to the simulation of large-scale failure of structures due to the propagation of local structural damage.

A Preliminary Analysis of the Wildfire Hazard in Oklahoma

Richard Campos; The University of Oklahoma; United States
P. Scott Harvey; The University of Oklahoma; United States
Kanthasamy Muraleetharan; The University of Oklahoma; United States

Wildfires in the Southern Great Plains have devastated millions of acres in the past decade destroying land and infrastructure resulting in millions of dollars in damage and repairs. The increase in wildfire frequency has been attributed to changes in climate, land cover, and socioecological conditions. Climate change has exacerbated the frequency and size of wildfires where climatic changes such as hot/dry/windy weather conditions have worsened. Recent wildfires and megafires (i.e., more than 100,000 acres burned) in northwest Oklahoma have raised concerns, and this work is part of an effort (Oklahoma NSF EPSCoR) to improve Oklahoma's infrastructure and community resilience. The ability to model these wildfires and the Eastern redcedar (Juniperus virginiana L.) encroachment dynamics at the wildland-urban interface analytically will play a crucial role in the development of resiliency strategies through risk and fragility analysis of infrastructure components. In order to create representative wildfire models for Oklahoma, critical model input components must first be identified. In this study, up-to-date (1992–2020) wildfire data from Oklahoma was analyzed using the random forest machine learning algorithm to determine critical factors for future wildfire modeling efforts that may be affected by climate change and possible fuel changes due to emerging encroachment dynamics. Grassland and forest fire data was acquired through various public database sources such as the National Interagency Fire Center and Fire Program Analysis Fire Occurrence Database. Initial results show that there is an increase in large wildfires and a decrease in the total number of annual wildfires. Further, results also show that 94% of the wildfire ignitions were human-caused ignitions. Additionally, a preliminary wildfire hazard map was developed, and resilient mitigation strategies for Oklahoma were proposed. With the results of this research, a preliminary characterization of wildfires in Oklahoma was achieved which allows for informed decisions with regards to wildfire modeling, hazard characterization, and fragility analysis of infrastructure in Oklahoma.

A Probabilistic Model for the Spatial Variation of Eastern Hemlock Tensile Strength

Fiona O'Donnell; Swarthmore College; United States

The natural growth of wood leads to significant variation in the mechanical properties of dimension lumber, which is used as constituent lumber in CLT fabrication. Understanding the influence of constituent board material properties on Cross Laminated Timber (CLT) performance is essential for the efficient use of wood material in mass timber construction. Great strides have been made in recent years to understand the influence of constituent board stiffness properties on CLT displacement response. This work characterizes and models this relationship at the strength scale, aiming to bridge the gap between constituent board strength properties and CLT panel performance. Strength varies due to the presence of features, such as knots, but also due to natural variation in clear wood. An experimental program was performed to 1) characterize the longitudinal spatial variation in clear wood tensile strength and 2) evaluate the influence of knot features on Modulus of Rupture in Eastern hemlock dimension lumber. Spatial distribution of clear wood tensile strength was modelled by a continuous random variable with an autocorrelation function calibrated to the experimental results. The influence of knots on spatial variation in tensile strength was considered using the Knot Area Ratio (KAR). A transfer function that maps KAR onto a cross-sectional tensile strength reduction factor was developed and calibrated to the experimental results. A model for the location and geometry of knot features in Eastern hemlock was previously developed by O'Donnell (2021). The tensile strength spatial variation in Eastern hemlock dimension lumber was simulated by applying the Monte Carlo method and superimposing the spatial variation in clear wood with the tensile strength reduction factor and the probabilistic geometry of knots. As such, synthetic Eastern hemlock boards with spatially varying tensile strength can be simulated. This enables the opportunity to perform computational analyses, such as reliability studies, for novel CLT layups before largescale experimental testing. While this work was calibrated to Eastern hemlock, the developed model can be calibrated to any softwood species of interest.

Citations O'Donnell, Fiona, "Material Property Heterogeneity in Dimensional Lumber and its Relationship to Mass Timber Performance" (2021). Doctoral Dissertations. 2207. https://doi.org/10.7275/21482531.0

A Probabilistic Modeling Approach for Wind Uplift Resistance in Wood-Frame Load Paths

Brandon Rittelmeyer; Auburn University; United States
David Roueche; Auburn University; United States

Past failure risk analyses of wind-impacted wood-frame structural load paths have tended to consider simplified resistance models that account for a few key load path connections, in which connection capacity distributions are generally based on benchmark experimental results. This study presents a novel approach for modeling wind uplift resistance in wood-frame load paths that includes a more exhaustive set of potential failure points yet is computationally efficient and readily adaptable to various load paths composed of different assemblages of structural members and connections. In this framework, ultimate capacities of connections and wood members are either based on design equations provided in the National Design Specification for Wood Construction or another applicable standard or computed from a comparable mechanics-based model. Analytical capacity estimates for roof sheathing, roof-to-wall connections, and wall-to-slab-foundation connections accord well with the range of published experimental results for these connections. Capacities of connections that act in parallel are summed to transform the load path into an analogous load chain of series components. System-level wind uplift resistance, defined by the weakest component in series, is evaluated by Monte Carlo simulation. By providing a more complete description of resistance than previous simplified models have done while avoiding the expense of a detailed finite-element or other solid mechanics model, the method proposed here holds promise as a rapid, consistent, and accurate way to quantify wind resistance in any arbitrary wood-frame load path, with applications including hybrid data science frameworks utilizing post-storm reconnaissance data and estimation of hazard intensity from structural damage observations.

A Rayleigh-Ritz solution approach for determining the Wiener path integral technique most probable path with mixed fixed/free boundaries

Ketson Roberto Maximiano dos Santos; Department of Civil, Environmental, and Geo-Engineering, University of Minnesota; United States
Ioannis A. Kougioumtzoglou; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States

The Wiener path integral (WPI) technique has been pioneered recently in the field of engineering mechanics (e.g., [1-2]) for determining the stochastic response of diverse dynamical systems. Notably, the technique has exhibited both high accuracy and low computational cost in a wide range of engineering applications. In fact, a variational formulation with mixed fixed/free boundary conditions was developed in [3] that renders the associated computational cost independent of the total number of stochastic dimensions of the problem. Remarkably, any lower-dimensional joint response probability density function (PDF) corresponding to a subset of the degrees-of-freedom of the system can be determined directly, in a computationally efficient manner. The technique, which can be construed as an approximation-free dimension reduction approach, leads to a functional minimization problem that yields a system of Euler-Lagrange equations to be solved numerically for the most probable path, and eventually, for obtaining the system joint response PDF. In this paper, an alternative solution treatment is pursued, and an appropriate Rayleigh-Ritz approach is developed for treating the functional minimization problem directly. This renders the technique less intrusive, while the potentially cumbersome task of formulating and solving the Euler-Lagrange equations is circumvented. An indicative numerical example is considered for demonstrating the reliability of the technique. Comparisons with pertinent Monte Carlo simulation data are included as well.

[1] Kougioumtzoglou I. A., Spanos P. D., 2012. An analytical Wiener path integral technique for non-stationary response determination of nonlinear oscillators, Probabilistic Engineering Mechanics, vol. 28: 125-131.

[2] Kougioumtzoglou I. A., 2017. A Wiener path integral solution treatment and effective material properties of a class of one-dimensional stochastic mechanics problems, ASCE Journal of Engineering Mechanics, vol. 143 (6), 04017014: 1-12.

[3] Petromichelakis I., Kougioumtzoglou I. A., 2020. Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries, Proceedings of the Royal Society A, vol. 476: 20200385.

A Real-Time Hybrid Simulation Platform for Monopile Offshore Wind Turbines

Wei Song; University of Alabama; United States
Chao Sun; Louisiana State University; United States
Santiago Ruiz; University of Alabama; United States

The performance assessment of offshore wind turbine (OWT) structure is a challenging task due to the combined wind-wave actions and the difficulties in reproducing such loading conditions in laboratory. Real-time hybrid simulation (RTHS), combining physical testing and numerical simulation in real-time, offers a new venue to study the structural behavior of OWTs. It overcomes the scaling incompatibilities in OWT scaled model testing by replacing the rotor components with an actuation system, driven by an aerodynamic simulation tool running in real-time. In this study, a RTHS framework for monopile OWTs is proposed. A set of sensitivity analyses is carried out to evaluate the feasibility of this RTHS framework and determine possible tolerances on its design. By simulating different scaling laws and possible error contributors (delays and noises) in the proposed framework, the sensitivity of the OWT responses to these parameters are quantified. An example using a National Renewable Energy Lab (NREL) 5-MW reference OWT system is simulated in this study to demonstrate the proposed RTHS framework and sensitivity analyses. The sensitivity results show that the delays in the RTHS framework significantly impact the performance on the response evaluation, higher than the impact of noises.

A sequential decision process for the multi-objective design optimization of structural systems based on life cycle costs

Aditya Sharma; The Pennsylvania State University; United States
Gordon Warn; The Pennsylvania State University; United States

Traditionally, the different phases of a structure's life cycle are managed by independent teams with little interaction. Optimizing resource allocation during individual design, construction, and maintenance phases might not translate into optimal life cycle costs due to the inherent dependency and interaction between the different phases. This study presents a sequential decision process (SDP) framework for optimizing the design of structures based on the probabilistic life-cycle costs associated with construction, maintenance, and the risk of failure, while considering the uncertainty and non-stationarity in the life cycle demands. The SDP is a set-based design approach, whereby many design concepts are generated, evaluated, and carefully eliminated throughout the process, allowing for significant freedom in the early stages of designs. Efficiency in the SDP is achieved by first using low-fidelity model evaluations of the design alternatives to return imprecise yet bounded estimates of the decision criteria, including life cycle costs, which are used to filter out dominated designs. The sub-set of non-dominated design alternatives is further evaluated with increasingly higher-fidelity modeling and analysis efforts to tighten the bounds on the decision criteria, hence revealing more dominated design alternatives. Mean-risk analysis and stochastic dominance rules are used to identify and eliminate dominated designs, sequentially culling the set of design alternatives assuming a risk-averse decision-maker. The SDP framework is applied for the multi-objective design optimization of a (i) two bar truss and a (ii) truss bridge structure. For both applications, uncertainty in the material properties, external loading, and corrosion of the truss elements due to a non-stationary deterioration process are taken into consideration. For this initial demonstration, a condition-based maintenance policy is adopted whereby elements reaching a prescribed cross-sectional loss threshold are replaced to maintain system reliability. The results demonstrate the ability of the SDP to explore large sets of design alternatives, while efficiently arriving at a set of global pareto optimal designs when considering multiple probabilistic life cycle decision criteria for structural systems operating in non-stationary environments under uncertainties.

A simple implementation of localizing gradient damage model in Abaqus for the dynamic fracture

Guangyuan Yang; National University of Singapore; Singapore
Leong Hien Poh; National University of Singapore; Singapore

With the localizing gradient enhancement, a damage model for quasi-brittle materials is able to achieve regularized softening responses, with localized damage profiles corresponding to the development of macroscopic cracks. Focusing on the finite element (FE) package Abaqus, a user element subroutine is required to define the finite elements with additional degrees of freedom for the nonlocal field. In this contribution, a simple implementation of the localizing gradient damage model is elaborated, with a focus on the dynamic fracture of quasi-brittle materials. By utilizing the in-built coupled thermo-mechanical elements in Abaqus, the user only needs to define the material constitutive laws. Post-processing of results can be done directly in Abaqus. The applicability and ease of implementation are demonstrated via several examples.

A Smooth Maximum Regularization Approach for Robust Topology Optimization in the Ground Structure Setting

Emily Alcazar; Princeton University; United States
Lorran Foliveira; Universidade Federal de Alagoas; Brazil
Fernando Vasconcelos Da Senhora; Georgia Institute of Technology; United States
Adeildo Ramos; Universidade Federal de Alagoas; Brazil
Glaucio Paulino; Princeton University; United States

A robust topology optimization framework using the ground structure method is presented to handle the uncertainty of point load direction and design for the worst case compliance scenario. The deterministic optimization framework is formulated by two objective functions and set of design variables; the first to determine the critical load angle corresponding to the worst case compliance and the latter to design the topology for compliance minimization. The worst case compliance objective for the unconstrained, continuously rotating point load is an eigenvalue problem which obtains instances of non-smoothness which causes major difficulties in the gradient-based optimization. Here we propose a method to treat the non-differentiability of the eigenvalue optimization problem by a smooth maximum regularization function hence achieving converged solutions to the robust topology optimization problem resulting in designs that have greater stiffness and are thus robust in all possible loading directions.

A Stabilized Interface Method for 3D Printing: Terrestrial and Extraterrestrial Applications

Arif Masud; University of Illinois at Urbana-Champaign; United States
Ignasius Wijaya; University of Illinois at Urbana-Champaign; United States
Eric Kreiger; . Army Engineer Research and Development Center; United States

This talk presents a stabilized interface method for layered printing with cementitious material where the mechanical properties continuously evolve as a function of chemical curing. The goal is to analyze the feasibility of 3D printing of a structure in a virtual environment, while accounting for a variety of conditions that arise in terrestrial application, extraterrestrial exploration under reduced gravity, and construction in extreme environments. The method is extended to account for material and geometric nonlinearity that may be triggered by the geometric design, printing speed, and material evolution due to curing. To model the mechanical behavior of the printed concrete, Drucker-Prager plasticity model is employed. Incorporating plasticity model allows for analysis of two main modes of failure, namely (i) elastoplastic buckling, and (ii) plastic collapse. The material parameters evolve as a function of time to model chemical curing of the layered cementitious material. The evolution of material parameters gives rise to the bounce-back phenomenon where the deformation under constant load decreases as a result of increasing stiffness in the material model. This numerical manifestation of curing induced deformation contradicts the experimental observation of the behavior of printed cementitious materials that gain strength at an almost constant deformation. An algorithm is presented that prevents the non-physical bounce-back via enforcing a constraint on the Drucker-Prager model in the material space. An algorithm that simulates the process of 3D layered printing is presented. The model and method are validated with experimental data, and several interesting test cases are presented.

A thermodynamical phase field fracture modeling of concrete structures

Sina Abrari Vajari; Stanford University; United States
Matthias Neuner; Stanford University; United States
Christian Linder; Stanford University; United States

Concrete due to its complex heterogeneous internal structure, exhibits an involved quasi-brittle response with a gradual decrease in the material integrity. This behavior is in sharp contrast to brittle fractures where the load-carrying capacity of the solid drops abruptly. In real-life applications, concrete structures are frequently subjected to loading conditions that may lead to involved mixed-mode I-II or I-III fracture patterns. As a result, the prediction of failure in concrete structures is a challenging task. Computational fracture modeling of concrete structures, due to the high cost associated with experimental testing, has attracted significant attention in the past decades. Among many computational techniques, the phase field approach is a well-established formulation to simulate complex fracture phenomena such as crack nucleation, propagation, branching, and merging [1]. In the phase field approach, propagation of a crack surface is tracked implicitly through the evolution of an additional independent field. As a result, unlike discrete crack models, the tedious task of tracking the fracture surface is avoided, and the approach naturally fits the framework of the finite element method. However, unlike well-established phase field formulations for brittle fractures, their application to complex quasi-brittle fracturing mechanisms of concrete have received far less attention. Therefore, this work aims at developing a phase field model for capturing the quasi-brittle response of concrete. Following a thermodynamically consistent approach, a phase field framework is derived, investigating different decompositions of the strain energy leading to various crack driving forces. These driving forces are studied for capturing the complex quasi-brittle crack response of concrete. Furthermore, we discuss how the pressure dependency of strength can be accounted into the formulation. For validation, we apply the proposed approach to different benchmark examples, investigating mixed-mode I-II or I-III failures. A comparison with experimental results confirms the good performance of the model.

References:

[1] S. Abrari Vajari, M. Neuner, P. K. Arunachala, A. Ziccarelli, G. Deierlein, and C. Linder, "A thermo-dynamically consistent finite strain phase field approach to ductile fracture considering multi-axial stress states," Computer Methods in Applied Mechanics and Engineering, vol. 400, p. 115467, 2022.

A tornadic field retrieval method based on wind-induced debris video-analysis

Guangzhao Chen; University of Illinois Urbana-Champaign; United States
Franklin Lombardo; University of Illinois Urbana-Champaign; United States
David Roueche; Auburn University; United States

In a tornado case, the windborne debris is commonly observed and recorded as videos. Considering the intensity and randomness of the tornado events, it is challenging to directly obtain tornadic fields from measuring instruments such as an anemometer. However, the wind-induced debris trajectories provide an indirect observing method for tornadoes field. The windborne debris trajectories, which can be recognized through in-situ videos, can act as a probe in the wind field and reflect the physical information. This paper raised a novel model identifying windborne debris trajectories from the in-situ videos during a tornado with image analysis and simulated the streamlines of the event. Furthermore, a numerical 3D wind field model is established based on the debris information and can be applied to reconstruct the tornadic field. After comparing with the practical data, a best-fit parameter set for the vortex model is developed. As an example, the model fitting and approximation process with the Andover, KS, 2022 tornado is shown.

A Transfer Learning Strategy for Virtual Sensing in Offshore Wind Farms

Eleonora Maria Tronci; Tufts University; United States
Anna Haensch; Tufts University; United States
Babak Moaveni; Tufts University; United States
Eric Hines; Tufts University; United States

Worldwide there is a pressing need to accelerate the evolution to green and clean energy solutions and offshore wind is set to play an important role in this transition. To make this transition easier, it is fundamental to improve the strategies to guarantee turbines' structural integrity and reliability, reducing maintenance costs. The installation of a dense monitoring network of sensors (accelerometers, strain gauges, etc.) on offshore wind turbines can be challenging and costly, given the complex accessibility of these structures. Therefore, there is a demanding requirement to optimize the sensor and monitoring resources for wind farms. Transfer learning (TL) has recently gained much acclaim in different research fields. They provide a low-cost and efficient way of taking advantage of learned information gained thanks to rich and robust datasets. In the present work, a Hidden Markov Model TL strategy for virtual sensing is addressed to infer quantities of interest using simultaneous physical measurements of diverse signals. This approach can be used for sensing wind field properties when a dense sensor network is not directly available on all the turbines in a wind farm. This approach will enable the data from one unit turbine to infer information on the neighboring ones. The framework is validated using the experimental data collected on two instrumented Offshore Wind Turbines located in the Coastal Virginia Offshore Wind (CVOW) farm. This study focuses on implementing the strategy considering the two identical 6 MW turbines belonging to the CVOW farm.

A Transfer Matrix Approach for the Simulation of 2D Rainbow Traps

Prasannakumar Salasiya; University of Minnesota, Twin Cities; United States
Bojan Guzina; University of Minnesota, Twin Cities; United States

In many applications such as vibration isolation and energy harvesting, the phenomenon of rainbow trapping provides an effective means to achieve broadband stoppage, i.e. reflection, of propagating energy via passive devices. The latter are typically designed as functionally-graded layered structures, where (i) each layer represents a periodic assembly of the unit cells, and (ii) the unit cells constituting various layers are designed so that the union of their individual band gaps (computed via the Floquet-Bloch analysis which assumes quasi-periodic boundary conditions) gives rise to the sought broadband energy stoppage. Typically, rainbow traps are designed by gradually varying the material properties of the unit cell from one layer to another, which (implicitly) allows for a smooth shift in the neighboring band gaps and uninterrupted coverage of the broadband energy filter. Given the fact that the band gaps characterizing individual layers are computed under the premise of an infinite periodic medium, however, it is not at all clear whether (i) the global band gap is in fact (at least approximately) the union of the individual layers' band gaps, and (ii) how a given rainbow trap (RT) can be effectively optimized given the computational complexity of the wave transmission problem. To tackle these challenges, a novel semi-analytical method to analyze 2D rainbow traps via the transfer matrix approach is proposed. The configuration includes a RT sandwiched in between two homogenous half spaces and a time-harmonic plane wave impinging (at some angle) upon the RT. The dispersion analysis for individual unit cells is performed via the Floquet-Bloch theorem. Thanks to the fact that the component of the wave vector that is tangential to the interface must be preserved throughout the composite system (in order to satisfy the interfacial conditions), this leads to a quadratic eigenvalue problem (QEP) for each unit cell at a prescribed frequency and angle of incidence. The solution of the QEP produces eigenvalues and eigenfunctions that can be interpreted as either left/right propagating, evanescent, or decaying waves depending on the nature of the corresponding eigenvalue. Once the relevant Floquet-Bloch eigenfunctions for each unit cell are identified, they can be used to: (i) relate the ``left'' and ``right'' Cauchy data at the boundaries of each layer, and (ii) construct computationally-effective solution of the global transmission problem in the spirit of the transfer matrix approach. This in turn allows for highly effective optimization of the RT via e.g. permutation of the participating layers or variation of their individual thicknesses. The proposed analysis is supported by numerical examples which (a) demonstrate high fidelity of the transfer-matrix approach by comparison with finite element simulations, and (b) illustrate computationally-effective optimization of 2D rainbow traps.

A unified descriptive framework for co-evolving particle shape and size in comminution

Priya Tripathi; Florida International University; United States
Seung Jae Lee; Florida International University; United States
Moochul Shin; Western New England University; United States
Chang Hoon Lee; Western New England University; United States

This study presents a new descriptive framework that can systematically relate the extent of co-occurring abrasion and breakage to co-evolving particle shape and size. This approach is important as it unifies the concepts of abrasion and breakage that may co-occur due to friction and collision between particles under loading. To this end, this study leverages a power-law relation between particle surface-area-to-volume ratio (A/V) and particle volume (V) that is realized as a linear graph in a log-log space (i.e., power regression). The proposed framework is powerful in the sense that it can present a complete picture of co-evolving particle shape and size by both abrasion and breakage. Transformative concepts of breakage line, sphere line, and average shape-conserving line are discussed to characterize limit states and a special comminution process. In addition, using the A/V and V space, all geometric features including particle volume V, surface area A, size D, and shape angularity β can be entirely presented in a single space, which is unprecedented. Besides, this study evidences the scale-invariance of co-evolving particle shape and size in the comminution process. This will be an exciting discovery for the granular materials research community as scale-invariance is a fundamental property observed in many natural phenomena. This study will help develop a comprehensive understanding of particle geometry change during comminution processes that cause both abrasion and breakage. This presentation will highlight the key features of this new framework.

A versatile Python-based framework for EDP seismic response estimation using reduced order structural models

Parisa Toofani Movaghar; University of Notre Dame; United States

Alexandros Taflanidis; University of Notre Dame; United States

Utilizing high-fidelity finite element models (FEMs) for establishing EDP predictions within seismic risk assessment applications (nonlinear time-history analysis) entails a significant computational burden. Recent efforts have explored the calibration and use of reduced order models (ROMs) to establish a reduction of this burden. These ROMs represent dynamical system models with hysteretic characteristics, developed so that they (approximately) match the original high-fidelity FEM. Past work has leveraged the graphical models (block-diagram representation) within the Simulink computational environment for establishing and analyzing the corresponding dynamical systems. This work presents an extension considering the development of a versatile python-based framework to replace the original Simulink implementation for the ROM deployment. A code generation platform provided by Simulink is first used to produce the C code from a developed graphical ROM model for the specific target environment. The generated codes are deployed in the target environment using pre-compiled shared libraries that include the ROMs' information. Such shared libraries help to translate the constructed model information to the Python environment. Different architectures are then developed to facilitate the Python implementation. The accuracy and computational efficiency of the models are assessed by comparing the Simulink- and Python-based models.

A virtual element method for the fourth-order phase-field equation with application to fracture modeling in materials with microstructure

Lampros Svolos; Los Alamos National Laboratory; United States
Gianmarco Manzini; Los Alamos National Laboratory; United States
Hashem Mourad; Los Alamos National Laboratory; United States

Modeling fracture in materials with microstructure is of great importance to study the effects of texture on damage evolution and prevent catastrophic failure associated with a sudden loss of load-carrying capacity. Second-order phase-field fracture models have gained popularity due to their capability to capture complex fracture patterns (e.g., crack merging and branching) and their aptness for implementation using the finite element method. High-order phase-field models have also been proposed to increase the regularity of the exact solution and thus increase the spatial convergence rate of its numerical approximation. However, specialized numerical techniques are required for the solution and their high-order terms lack physical interpretation.

In this talk, we present a two-dimensional conforming virtual element method for a fourth-order phase-field fracture model and provide a physical interpretation of the higher-order terms within the context of continuum damage theories for materials with microstructure. Specifically, we show the convergence behavior of the proposed method by deriving error estimates in different norms. The numerical approximation relies on the design of an arbitrary-order accurate, virtual element space with C1 global regularity. Such regularity is guaranteed by taking the values of the virtual element functions and their full gradient at the mesh vertices as degrees of freedom. High-order accuracy requires also edge polynomial moments of the trace of the virtual element functions and their normal derivatives. A set of problems is presented to assess the behavior of the proposed method.

Acceleration Monitoring for Pavements

Linbing Wang; University of Georgia; United States
Zhoujing Ye; University of Science and Technology Beijing; China

Pavement vibration amplitude and frequency are indicative of traffic and pavement health conditions. Monitoring of pavement vibration, especially, acceleration will provide information for both pavement health conditions and traffic conditions. This presentation will present recent developments on monitoring both rigid and flexible pavements and the traffic of actual newly built roads.

Accounting for Cascading Failure of Interdependent Civil Infrastructure in Seismic Resilience Modeling of Communities

Saeid Ghasemi Gavabar; University of Nebraska-Lincoln; United States
Milad Roohi; University of Nebraska-Lincoln; United States

The cascading failure of interdependent civil infrastructure is a major factor to consider when evaluating the seismic resilience of communities. It is important to understand how a severe earthquake or other natural hazards may cause failure in one or multiple infrastructure components, resulting in the failure of multiple related infrastructure components and thus leading to a “cascade” of failure. Thus, it is necessary to consider how these cascading failures can affect a community's infrastructure and its ability to recover quickly following an earthquake.

This paper address the need from the previous exposition by developing a methodology for modeling the seismic resilience of interdependent civil infrastructure by accounting for the interdependency between these systems. The method of approach consists of 1) characterizing the built environment by collecting the required data and information for resilience modeling, 2) developing a network model of the interdependent infrastructure using fundamental graph theory, 3) performing seismic hazard analysis for the networked infrastructure, 4) performing probabilistic damage analysis and quantify the functionality of individual infrastructure systems, 5) simulating the cascading failure of the networked infrastructure using an input-output analysis to quantify the functionality of the infrastructure system. A case study of a US community's buildings and lifeline systems subject to a long return period seismic event is presented to demonstrate the proposed methodology. The outcome of this analysis can help engineers identify key nodes in the infrastructure systems that are particularly vulnerable to failure if an earthquake should occur. Local governments and planners can use this information to develop detailed emergency response plans and infrastructure-strengthening initiatives that address vulnerabilities in the civil infrastructure and improve the resilience of seismic-prone communities.

Acoustic metasurface for wavefront manipulation of ultrasound waves

Xhorxha Kuci; Eindhoven University of Technology; Netherlands
Marc G.D. Geers; Eindhoven University of Technology; Netherlands
Varvara G. Kouznetsova; Eindhoven University of Technology; Netherlands

Acoustic metasurfaces, a relatively new class of 2D metamaterials with subwavelength thickness [1], have attracted a lot of interest in recent years, due to their extraordinary properties for enhanced wavefront manipulation, which cannot be realized by their 3D counterparts. By introducing suitable phase modulations along the acoustic path, metasurfaces provide an unprecedented way to control the direction of reflected and refracted waves, even going to negative angles, thus opening new possibilities in designing metasurfaces for many practical applications in wave engineering. In this work, locally resonant acoustic metamaterials (LRAMs) [2] are considered as the building units of the metasurface, which owe their favorable properties to the localized resonances at the microstructural level. Anomalous and negative reflection phenomena for ultrasound waves are demonstrated numerically by means of a finite-element analysis for a fluid-metasurface-solid structure. A thorough analysis of the influence of the constituent material parameters of the metasurface, incident angles, and operating frequencies on the phase shift of the reflected waves is performed. In addition, a new extension for the classical computational homogenization framework [3] is developed that relaxes the restriction on the long-wavelength regime for the host medium of the unit cell. The results of this study provide new insights and detailed guidelines to design and model metasurfaces for controllable acoustic wave reflection in an accurate and efficient way.

References

[1] Assouar, B., Liang, B., Wu, Y., Li, Y., Cheng, J.-C., Jing, Y., "Acoustic metasurfaces", Nat Rev Mater, 3, 460–472 (2018).

[2] Liu, Z., Zhang, X., Mao, Y., Zhu, Y., Yang, Z., Chan, C., Sheng, P., "Locally resonant sonic materials", Science, 289, 1734–1736 (2000).

[3] Sridhar, A., Kouznetsova, V.G. & Geers, M.G.D. "Homogenization of locally resonant acoustic metamaterials towards an emergent enriched continuum", Comput Mech 57, 423–435 (2016).

Actin Dynamics at Cancer Metastasis to Bone

Dinesh Katti; North Dakota State University; United States
Sharad Jaswandkar; North Dakota State University; United States
Kalpana Katti; North Dakota State University; United States

Breast cancer and prostate cancer have the propensity to metastasize to bone. At the bone site, the cancer cells colonize, proliferate, and adversely impact the bone. We have built the first in vitro testbeds for breast cancer and prostate cancer metastasis to bone. Our studies on cancer progression at the bone metastases site reveal extreme morphological changes of the cancer cells as cells cluster and form a tumor and are related to the cancer phenotype. Also, depending on the phenotype, the mechanical properties of the cancer cells extracted from the tumors are dramatically altered. Associated with the observed changes, we witness significant changes to gene expressions related to actin and actin depolymerization factor cofilin (ADF/cofilin). Confocal imaging of cancer tumors during cancer progression reveals significant actin dynamics, both quantitatively and spatially. Label-free discrimination of cancer progression using Raman imaging and cluster analysis also reveals actin dynamics and changes to actin-related bands, which could serve as spectral biomarkers for cancer progression at the bone site. Steered molecular dynamics simulations of actin and actin with ADF/cofilin describe the mechanisms of the resilience of actin molecules and depolymerization of actin by ADF/cofilin, critical players in the actin dynamics during the cancer progression.

Active Control of Equipment Seismic Isolation System by Output Feedback Skyhook Algorithm

Yong-An Lai; National Central University, Department of Civil Engineering; Taiwan
Po-Yen Wu; National Central University, Department of Civil Engineering; Taiwan

The high-tech factory buildings in seismic hazard region often adopt seismic resistant design due to anti-microvibration requirements. Although the safety of the building structure can be guaranteed by proper seismic resistant design, the equipment inside the structure might still have a large base excitation induced by floor acceleration. Therefore, the seismic isolation system that can protect the internal equipment is an important issue. The conventional skyhook control principle imitates the damper force for disturbance rejection from a virtual damper one end of which is connected to an undisturbed sky point. Therefore, the control effect of conventional skyhook control depends on the accuracy of the absolute velocity signal feedback. In this study, the skyhook control methodology is modified and practiced to an active isolation system to protect equipment from seismic disturbances. Instead of using absolute velocity signal feedback, the proposed configuration measures the absolute acceleration of the base to integral for feedthrough control and the relative velocity to the base for feedback control. These modifications not only improve the convenience of signal measurement, but also increase the stability by the feedback signal. The active isolation system will not easily react by unexpected external forces. The modified skyhook active isolation system has two gain parameters, not full-state feedback, so that these two gain parameters are optimized by using the direct output feedback to minimize the absolute acceleration of the equipment. The frequency response function analysis shows that the skyhook active isolation system is more effective than the passive isolation system, especially for the significant frequency range of common earthquakes. The shaking table experiments verify that the proposed skyhook active isolation system suitable for both near-fault and far-field earthquakes.

Active Perception Based on Deep Reinforcement Learning for Autonomous Robotic Inspection

Wen Tang; Purdue University, Lyles School of Civil Engineering; United States
Mohammad Jahanshahi; Purdue University, Lyles School of Civil Engineering; United States

In this study, an artificial intelligence framework is developed to facilitate the use of robotics for autonomous inspection. Current practices for civil infrastructure condition assessment are manual and, therefore, labor-intensive and time-consuming. The use of inspection robots equipped with optical sensors is a promising alternative to manual visual inspection for quantitative, rapid, and safe condition assessments. While considerable progress has been achieved by utilizing state-of-the-art computer vision approaches for damage detection, these approaches are still far away from being used for autonomous robotic inspection systems due to the existence of uncertainties in data collection and data interpretation. To address this gap, this study proposes a multi-paradigm framework based on computer vision, stochastic control process, and decision and information theories combined with novel computer graphics methods that will enable robots to select the best course of action (e.g., move to the right, left, up, down, etc.) for active perception (i.e., information gathering) while searching for defective regions and accounting for existing uncertainties and constraints (e.g., the robot's battery life). By doing so, the required information is collected efficiently for a better understanding of damage severity and, hence, more reliable decision-making. More specifically, the proposed framework for decision-making under uncertainty is developed by formulating the active perception as a Partially Observable Markov Decision Process (POMDP). To this end, a deep reinforcement learning (DRL) agent is generated to learn the optimal policy for the proposed decision-making framework. As a test case, the proposed framework is rigorously evaluated for autonomous assessment of cracks on metallic surfaces to demonstrate the capabilities as well as the limitations of the proposed solution.

Adaptive domain decomposition using image detection for local and nonlocal damage formulations

Cornelius Otchere; Johns Hopkins University; United States
Panos Pantidis; New York University Abu Dhabi; United Arab Emirates
Mostafa Mobasher; New York University Abu Dhabi; United Arab Emirates

In this work, we propose a framework which combines image-segmentation and domain decomposition for the purpose of automatically reducing the cost of the non-linear continuum damage mechanics simulations. In this hybrid formulation which models the damage response of quasi-brittle materials, we generate damage contours and apply an image segmentation algorithm to detect the presence of damage. The algorithm identifies polygonal shapes that bound the damaged regions, scales them by a user-defined factor, and divides the domain into healthy domain and damaged subdomains. Since damage is highly localized, the iterative solution is sought for only within the damaged region through a Schur complement approach. We have applied the proposed framework across several 2D benchmark models. Compared to the single-domain benchmark FEM problem, the proposed framework realizes a reduction in the total computational cost by several multiples across all the investigated cases while maintaining the accuracy of physical predictions. The proposed approach scales well and is expected to lead to further computational cost reductions. The ongoing work focuses on extending this framework to 3D geometries. In addition to cost reduction, the proposed approach can be readily integrated with other sources of images, e.g. CT and ultrasound scans, for the automated analysis of damage propagation.

Adaptive importance sampling for efficient probabilistic storm surge estimation

WoongHee Jung; University of Notre Dame; United States
Alexandros Taflanidis; University of Notre Dame; United States
Aikaterini Kyprioti; University of Oklahoma; United States

During landfalling tropical storms, probabilistic predictions of the storm surge constitute important products for guiding emergency response decisions. The probabilistic formulation for these predictions is established by considering historical forecast errors for the intensity, size, cross- and along-track variability of the National Hurricane Center (NHC) advisories. These errors quantify ultimately uncertainties in storm features, serving as input to a numerical model for predicting storm surge, while propagation of the uncertainties provides the desired statistical products. This probabilistic estimation is repeated whenever the NHC updates the storm advisory. Monte Carlo (MC) simulation is considered for facilitating the uncertainty propagation in this paper, and in order to improve computational efficiency, the implementation of adaptive importance sampling (IS) across the storm advisories is introduced, using simulation results from the current advisory to select the optimal IS density to use for the next advisory. The requirement to estimate the storm surge across a large geographic domain, leading to the definition of a large number of quantities of interests (QoIs), poses a significant challenge, since these quantities typically represent competing IS choices. Principal component analysis (PCA) is utilized for dimensionality reduction to establish a compromising solution with a reduced computational burden. An adaptive selection of the IS characteristics is discussed, utilizing an efficient estimation of the anticipated IS accuracy and a defensive IS scheme is introduced to guarantee robustness.

Adaptive Surrogate Improvement for High-dimensional Problems

Yulin Guo; Vanderbilt University; United States
Paromita Nath; Vanderbilt University; United States
Sankaran Mahadevan; Vanderbilt University; United States

Surrogate models are often employed in engineering analysis to replace detailed models with complicated geometry, loading, material properties and boundary conditions, in order to achieve computational efficiency in iterative calculations such as model calibration or design optimization. The accuracy of the surrogate model depends on the quality and quantity of data collected from the expensive physics-based model. We present a novel approach to efficiently construct and improve surrogate models for high dimensional problems in both the input and output spaces.

In the proposed method, the principal components and corresponding features in the output field quantity are first identified. Mapping between inputs and each feature is then considered, and the active subspace methodology is used to capture the relationship in a low-dimensional subspace in the input domain. Thus dimension reduction is accomplished in both the input and output spaces, and surrogate models are built within the reduced spaces. A new low-dimensional adaptive learning strategy is proposed in this work to improve the surrogate model. With multiple iterations of this adaptive learning procedure, the optimal surrogate is achieved without intensive model simulations.

In contrast to existing adaptive learning methods which focus on scalar output or a limited number of output quantities, we address adaptive learning for both high-dimensional input and output, with a novel learning function balancing exploration and exploitation. The adaptive learning is based on the active variables in the low-dimensional space and once the newly-added training sample is selected, it can be easily mapped back to the original space for running the physics-based model. The proposed method is demonstrated on an additively manufactured component, with a high-dimensional field output quantity of interest, namely the residual stress in the component that has spatial variability due to the stochastic nature of multiple input variables (including process variables and material properties).

Additively Manufactured Multi-material Monolithic Self Deployable Spacecraft Structures containing Hinges

Colin Hunter; University of Michigan; United States
Avinkrishnan Ambika Vijayachandran; University of Michigan; United States
Anthony Waas; University of Michigan; United States

Origami, the Japanese art form of paper folding, has been extensively referenced for the design of deployable structures for medical devices, impact absorption devices, robots, and spacecraft structures. They have been widely used in space for solar arrays, reflector arrays, and satellite antennas. Traditionally, such structures are designed as components that are stowed during launch, and then deployed in-orbit using springs or other actuator mechanisms. The design of deployable structures needs to maintain high resilience to extreme conditions, contain reliable deployment methods, and have the smallest possible volume of compaction. Traditional deployment methods require the use of motors, actuators, and batteries which can add unnecessary weight and take up vital space in a rocket's payload. These mechanisms are for one-time use in general, thus remaining as parasitic mass after deployment. Two solutions to this problem are spring-loaded hinges and structures that can store strain energy due to deformation and can self-deploy in space using that strain energy. The availability of multi-material additive manufacturing allows these deployable mechanisms to be designed and manufactured as one monolithic structure. In this paper, we create a framework for unidirectional and bidirectional hinges in combination with rigid plates for use in deployable structures. We propose a set of designed hinges that store strain energy when deformed and self-deploy to a flat surface. The hinge properties are then sequenced by varying dimensional values. A large origami-inspired deployable structure with a Repeating Unit Cell is then created to demonstrate the compatibility of our hinges with popular deployable structure patterns.

Addressing Structural Health Monitoring Uncertainty in a Deep Learning-based Anomaly Detection System

Kareem Eltouny; University at Buffalo; United States

Xiao Liang; University at Buffalo; United States

The exponential advancement in machine learning and computer hardware has led to many developments in vibration-based structural health monitoring (SHM) in the past few decades. Yet, it is important to note that machine learning models, in general, are susceptible to errors. It is therefore vital to exercise caution when relying on the damage detection models' predictions given the disastrous consequences of incorrect decisions. This study presents an anomaly detection-based SHM system that relies on a variational convolutional-recurrent hybrid neural network to provide a stochastic damage index and a measure of uncertainty. The system is also designed to operate in near real-time monitoring with an implemented early warning system that can provide alarms and decision confidence as tools for engineers to better assess the situation. With a focus on seismic damage detection, we test the validity and practicality of the system on three real structures from the California Strong Motion Instrumentation Program, including two that were damaged during the 1994 Northridge earthquake. Results indicate that the anomaly detection system can provide accurate and uncertainty-aware warning signals with the onset of damage in a continuous monitoring scheme.

Addressing the issue of parameter tuning in topology optimization algorithms

Dat Ha; MIT; United States
Josephine Carstensen; MIT; United States

Topology optimization offers a new paradigm for engineers to arrive at novel and innovative solutions, which can perform better than conventional designs. This design technology can thus leverage the rapidly developing computation and manufacturing possibilities. A notable research trend in recent years has been to increase the realism of topology optimization problems, by adding more complex mechanics and constraints. To run these algorithms, new design parameters are typically required as input. The parameters or problem settings referred to herein are most frequently introduced to stabilize the convergence and do not as such describe the physics of the design problem. In density-based topology optimization, simple examples include settings of the gradient-based optimizer, penalty settings for intermediate densities, and function parameters for nonlinear filtering operations. The main purpose of these parameters is to guide the designs towards a high-performance solution, but the design results are often highly dependable on their specific settings. For some design problems, even very small changes of the settings can be detrimental for the quality of the results. Currently, users and researchers rely almost exclusively on previous experience and manual tuning to find parameter combinations that give desirable results. Very few automated alternatives have been suggested thus far. As the number of input parameters grow, the tuning task can become particularly challenging, as the amount of possible combinations that must be tested manually becomes exponentially large. This work addresses the issue of manual tuning in current topology optimization algorithms by developing an automated tuning framework. To increase the computational efficiency of the new tuning algorithm, surrogate modeling is utilized. Surrogate models are simple analytical models that simulate the input/output response of systems whose behaviors are computationally expensive to analyze. Developing a surrogate model requires performing computationally expensive simulations at a set of carefully selected sample points. The surrogate model then approximates the behavior of the underlying complex simulations while being computationally cheaper to evaluate. For the context herein, the surrogate model approximates the design's dependency on the parameter settings by fully designing with topology optimization for carefully selected parameter combinations. The design variables now include the input parameters to be tuned in addition to the distribution of material in the design domain. The objective function of the surrogate model is set to consider not only the desired performance, but also the quality of the design. Penalties are introduced for having too many grey elements or getting stuck at the initial guess. Furthermore, the user can customize the range of parameters as they wish, and the algorithm can adjust accordingly. The computational and optimization efficiency of the new automated tuning algorithm is discussed. It is tested on benchmark problems with various numbers of tuning parameters.

Advancements in the Physical Simulation of Atmospheric Surface Layer Flows using Synthetic Turbulence Modulation in a Large Boundary Layer Wind Tunnel

Ryan Catarelli; University of Florida; United States
Yutiwadee Pinyochotiwong; University of Florida; United States
Forrest Masters; University of Florida; United States
Brian Phillips; University of Florida; United States
Tai-An Chen; University of Florida; United States
Jennifer Bridge; University of Florida; United States
Kurtis Gurley; University of Florida; United States

This work presents continued advancements in the development of a high-performance multi-fan array in a large boundary layer wind tunnel (BLWT) with the goal of improving the physical simulation of complex turbulent flows observed in the atmospheric surface layer (ASL). Traditional BLWT flow simulations are known to be deficient in low frequency energy content for large model scales, which may affect the separation zones on model structures and introduce errors in the estimation of peak wind loading. Generating the necessary low frequency energy content at model-scale requires physical simulation equipment capable of rapidly modulating wind speed and turbulence characteristics to achieve kinematic similitude with full-scale wind phenomena. In addition, flow control software capable of converging on simultaneous simulation targets, such as the profiles of mean, turbulence, and integral length scales, as well as longitudinal turbulence spectra, is critical. To achieve this, turbulence was synthetically generated using spectral models and injected into the flow using the multi-fan array. Errors between input target spectra and measured output spectra were iteratively reduced using spectral warping techniques. A governing convergence algorithm (GCA) was used to balance the control inputs to the main BLWT fans, multi-fan array, and automated roughness grid. Simulation targets in this study were generated from profiles of marine, open, and suburban exposures since the characteristics of these flows are well understood.

The multi-fan array, referred to as the Flow Field Modulator (FFM), consists of 319 individually controlled shrouded propeller assemblies driven by 800-Watt brushless DC motors with electronic speed controllers. The system was designed and fabricated at the University of Florida (UF) Experimental Facility within the NSF Natural Hazards Engineering Research Infrastructure (NHERI) program. The FFM produces rapid velocity changes and generates profile shapes that vertically extend and/or deviate from neutral boundary layer profiles naturally grown over grid roughness.

The ultimate goal for this system is to reproduce the relevant characteristics of time-varying non-synoptic flow fields either as-measured in-situ or modeled by potential users of the NHERI shared-use facility at UF. For example, implementing this new control system in conjunction with the previously developed GCA permits the investigation of wind loads on scale-model structures produced by non-stationary and/or non-neutral flows for comparison with stationary, neutrally stratified boundary layer wind loading. The EMI presentation will address the continued development and current capabilities of this system, and present new high-throughput flow measurement tools that will accelerate the rate of experimental discovery.

Advances in aero-structural optimization techniques for long-span bridges

Miguel Cid Montoya; Texas A&M University-Corpus Christi; United States
Santiago Hernández; University of La Coruña; Spain
Ahsan Kareem; University of Notre Dame; United States

Aero-structural optimization techniques have been developed during the last couple of decades in the aerospace engineering field, motivated by the multi-disciplinary nature of aircraft design. In the case of long-span bridges, several kinds of natural hazards must be considered along with the classical self-weight and traffic-induced loads to achieve safe and resilient designs, including earthquake and wind-induced loads. Furthermore, several aeroelastic phenomena must be considered when conducting comprehensive wind-resistant bridge designs, from those typically related to service limit states, such as buffeting and VIV, to instabilities associated with ultimate limit states, i.e., flutter and aerostatic instability. The deck cross-section is a key parameter to handle all these responses. However, the inherent bluffness of bridge decks and the challenges in assessing fluid-structure interactions of innovative geometries in complex flows require transformative developments in this field. Hence, advanced optimization formulations are required to adequately address all these issues and consider many design constraints from multiple disciplines. This presentation summarizes the author's efforts in the last years to implement aero-structural optimization approaches in designing long-span bridges by developing multidisciplinary optimization frameworks driven by gradient-based optimization algorithms. Current developments, challenges, and future directions for further improvements will be discussed.

Advances in node condition classification within storm surge surrogate modeling framework

Christopher Irwin; University of Notre Dame; United States
Alexandros Taflanidis; University of Notre Dame; United States

Surrogate models have emerged as attractive data-driven, predictive models for storm surge estimation. They are calibrated based on an existing database of synthetic storm simulations, and can provide fast-to-compute approximations of the expected storm surge. Recent work has demonstrated the need to integrate a node classification metamodel within this formulation, providing binary predictions for the wet/dry condition for nearshore and inland nodes that have remained dry in some of the synthetic storm simulations. One of the challenges of this classification problem is that the number of nodes that need to be accommodated is very large (hundreds of thousands) creating a high-dimensional QoI setting. Past work has leveraged logistical principal component analysis (LPCA) and logistic regression to establish a computationally efficient classification metamodel. This implementation does not incorporate any explicit information for the spatial correlation. While the averaging established through the LPCA facilitates well average accuracy, the implementation may provide predictions with lower accuracy for certain groups of problematic nodes. This work examines a more sophisticated approach relying on bootstrap aggregating (i.e. bagging) to make wet/dry predictions specifically for these groups. As the number of these nodes becomes smaller, development of classification regression with higher complexity is utilized, explicitly using spatial node information. The predictions of the original and new classification approaches are optimally combined to support greater classification accuracy.

Agile Simulation of Structural Systems within a Digital Twin Framework

Zahra Zhiyanpour; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States
Ayatollah Yehia; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States
Mehrdad Shafiei Dizaji; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States
Devin Harris; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States

The concept of a digital twin (DT) provides an update to the framework of structural health monitoring (SHM) by placing models and simulations at the forefront of decision processes. These DTs ultimately need to be agile and designed to allow for direct integration of measured results into an iterative feedback loop with the model representations of the structure. Within a classical SHM framework, finite element (FE) models have been widely used for characterizing structural behavior; however, these FE models often do so with a significant computational cost that constrains two-way interaction between measured data and simulations. Having real-time analysis of a structure circumvents solving the equations of complex systems and this can be conducted through non-physics-based representations of structures using deep learning approaches. In this study, deep convolutional neural networks (CNNs) are used to predict Von Misses stress, strain, and displacement distributions. These CNNs were designed with the goal of serving as a surrogate of the physics-based representations of structural behavior traditionally derived from FE models. For this purpose, two different CNNs (SCSNet and StressNet) were trained and tested on four types of datasets of 2D plate systems subjected to in-plane loads and boundaries. A convolutional autoencoder with constant CNN layers was used in SCSNet, whereas StressNet utilized residual blocks capable of adaptively selecting the layer's depth. SCSNet consisted of a single input while StressNet consisted of multi-channel input with an enhanced architecture. This study extended previous works by Nei et. al [1], and included the addition of random loading, boundary, and discontinuities in the model training. The resulting models were developed to increase robustness, improve applicability to a wider range of scenarios, test scenarios that could be compared with classical solutions. For both CNNs, the input required for the 2D plates was comprised of information on geometry, boundary conditions, and the magnitude and location of the load, but different in the structure of the input format. Results from the improved model demonstrated that the multi-channel input CNN (StressNet) performs better than the single-channel CNN (SCSNet) with a mean relative error of 0.72% on the test dataset. The performance of the networks demonstrates the deep learning model is a promising alternative to the conventional finite element analysis methods and provides a foundation for extending these findings to three dimensional models.

AI- Approach to Predict the Erosion Resistance of Highway Shoulder Gravels

Bashar Al-Nimri; University of Nebraska Lincoln; United States
Aiman Tariq; Bursa Uludag University; Turkey
Basil Abualshar; University of Nebraska Lincoln; United States
Chung Song; University of Nebraska Lincoln; United States
Babur Deliktas; Bursa Uludag University; Turkey

Evaluation of the erosion behavior of soils and rocks is an extremely complicated task due to its natural characteristics, which are coupled with hydrodynamics and natural materials with unknown hydrodynamic characteristics. This study adopted an ANN-based AI method to overcome these inherent difficulties to predict the erosion characteristics of crushed rocks applied on highway shoulders. To achieve this task, the researchers conducted large-scale erosion tests (UNLETB) for various crushed rocks. Then, the team utilized half of the results for training the AI system and another half to verify(test) the trained AI system. Throughout the training and verifying process, this study utilized five gradation parameters (D10, D30, D60, Coefficient Curvature, and Coefficient of Uniformity), and the AI system showed a higher than 97% probability range. Then, the researchers realized that the coefficient of curvature and coefficient of uniformity are also functions of D10, D30, and D60 and deleted these two parameters. With only D10, D30, and D60, the AI predicted the erosion susceptibility of gravels with an accuracy higher than 99%.

An AI-based framework for damage estimation of hurricane-impacted residential communities through CFD simulations

Segin Kim; University of Michigan; United States
Fei Ding; University of California Berkeley; United States
Seymour Spence; University of Michigan; United States

This study presents an improved methodology for estimating damage caused by wind-induced debris, taking into account the unique geometric characteristics of individual buildings. The methodology is based on simulating full hurricane tracks through parametric models while explicitly capturing debris generation and flight through debris trajectory models that are coupled with models that capture the damage susceptibility of buildings to peak pressures as well as debris impact. In particular, Computational Fluid Dynamics (CFD) large eddy simulations are performed in OpenFoam to obtain cluster-specific peak pressure distributions on the surface of each building utilizing detailed 3D building models constructed from Google Earth polygon data. Additionally, the Artificial Intelligence (AI) scheme, BRAILS (Building Recognition using AI at Large-Scale) developed by the SimCenter, was employed to automatically detect the damageable components, e.g., windows and doors, of each building of the community from street-view images. As a case study, the proposed framework was applied to a cluster of eight buildings in a residential area in Atlantic City, NJ. CFD simulations were conducted for 36 different wind directions and combined with the hurricane tracks, therefore, providing track-specific peak pressure distributions on the AI-identified damageable components of each building. By propagating uncertainty with Monte Carlo methods while explicitly modeling debris generation and impact, the probabilistic performance of the building cluster was estimated. The proposed methodology was then compared to existing frameworks that only consider a single building archetype, highlighting the importance of considering the unique characteristics of each building in a residential area.

An efficient computational framework for the damage assessment of multistory steel frames

Jade Cohen; Exponent; United States
Filip Filippou; University of California, Berkeley; United States

The failure analysis and probabilistic risk assessment of structures require the use of sophisticated numerical models for locating and quantifying the level of damage under a given excitation. The accuracy of these numerical models is important for assessing the performance of the structure in a way that agrees with experimental observations. Yet, in the context of large-scale simulations under multiple loading scenarios, it is of equal importance that these numerical models are computationally robust and efficient.

The objective of this study is the development of efficient analytical capabilities for the simulation of the inelastic response of steel frames under the strength and stiffness deterioration they experience when subjected to extreme events. To this end, the study presents a family of three-dimensional frame elements based on damage-plasticity. The strength and stiffness of these models degrade continuously as a function of one or more damage indices making them suitable for the damage assessment of multistory steel frames up to incipient collapse. The damage evolution function accounts for low-cycle fatigue and the different rate of damage accumulation in primary and follower deformation cycles. The function also accounts for the fact that the behavior in one loading direction may be affected by the damage accumulated in the opposite direction.

The damage model operates as an independent wrapper of the effective force-deformation relation of the element, section or material and returns the true forces or stress resultants and the true tangent stiffness of the force-deformation relation under damage. With this modular formulation, it is possible to generate a family of deteriorating frame elements based on resultant plasticity or distributed plasticity with different degrees of accuracy and complexity.

The study compares the response of the proposed frame elements against available experimental data from the degrading hysteretic uniaxial and biaxial bending response of steel columns under constant and variable axial force. These comparisons lead to recommendations on a consistent set of damage parameter values for typical steel members.

The study concludes with the seismic response analysis of a three-dimensional irregular six-story steel frame under a strong ground acceleration in both principal directions at the base. The inelastic response history evaluates the effect of the damage evolution on the collapse risk assessment of the frame.

An Enriched Immersed Boundary Method for Solidification and Melting Problems in Additive Manufacturing

Ze Zhao; University of Illinois Urbana Champaign; United States
Jinhui Yan; University of Illinois Urbana Champaign; United States

Solidification and melting are fundamental physical phenomena with essential roles in additive manufacturing. Accurate simulation of solidification or melting processes directly affects the prediction quality of structural mechanical performance. Traditional numerical methods dependent on smeared interfaces usually have high requirements on mesh resolution to resolve the fluid-solid interface, which leads to high computational costs, especially in cases with large temperature gradients and latent heat.

Based on the assumption that interfaces have zero thickness, we propose an enriched finite element framework where the fluid-solid interface is immersed in the computational domain with an implicit representation. Meanwhile, the solution can retain C-1 smoothness in the weak sense across the interface by duplicating degrees of freedom in the elements containing both phases.

Evaluations from multiple aspects justify the outstanding performance of the enriched immersed boundary method. The case “1-D solidification of aluminum” compares the accuracy against other popular approaches, including the theoretical solution. Additionally, we simulate the laser scanning process in additive manufacturing, and the results show remarkable agreement with the experimental measurement.

An experimental investigation of the transient friction of granular materials at low sliding velocities and pressures

Aizhan Zhakupova; University of Houston; United States
Behrooz Ferdowsi; University of Houston; United States

In this work, we use a customized rheometer to investigate the nature of the transient friction of granular materials under perturbations (±1-3 orders of magnitude) in sliding velocity (the velocity-step loading protocol). We also investigate the stress relaxation and healing behaviors of the materials in periods of halting and restarting of shear, respectively (the slide-hold-slide protocol). Our work and questions are in part motivated by previous studies in earthquake physics and friction mechanics, where scientists observed that localized shear zones (at the center of tectonic faults) exhibit a curious transient response to perturbations in sliding velocity, which includes an immediate change ("direct effect") in friction upon perturbations, followed by a gradual evolution of friction toward its steady-state at the new velocity. This response is commonly referred to as "Rate- and State-dependent Friction" (RSF), and it controls the initiation of numerous instabilities with a frictional origin. It has been long argued that the transients originate from contact-scale processes at asperities. Indeed, recent experimental studies have shown that an RSF-like behavior is at work at the scale of single asperities. However, the underlying physics of the transients, as observed at the macroscopic scale, continues to be debated. Further, no physics-based model has been able to capture and explain the most commonly observed features in transient friction.

More recently, one of the authors developed a set of numerical simulations using the Discrete Element Method (DEM) and showed that much of the RSF-like behavior can originate from the rearrangement of granular materials in the absence of any rate- and time-dependence at the grain scale. It is noteworthy that most shear zones are also filled with granular materials as the product of wear and fragmentation of sliding surfaces. However, the possibility that the transients can be a granular physics phenomenon has not been previously appreciated. We use the rheology experiments described earlier to examine how much of the transient friction of granular materials looks like the expectations of classical RSF, and to what degree they defer from the RSF. The experiments are performed on both idealized and synthetic materials (silica powder and glass microspheres) as well as on naturalistic materials (obtained from the shear zone of the Oak Ridge earthflow, near San Jose, California), at low (relevant to Earth's near-surface) confining stresses and low sliding velocities (Inertial numbers ≤1e-8). Our current results indicate that at least the magnitude of the RSF direct effect for the tested granular materials at low pressures is within the range previously observed for earthquake fault zones, in rock friction experiments that ran at tectonic stresses. Further, the sheared materials show stress relaxation and healing behaviors qualitatively similar to tectonic fault zones. A detailed and quantitative comparison of the response of our experiments with RSF constitutive relations (Aging or Dieterich and Slip or Ruina laws) is underway and will be reported in the presentation.

An image-based modeling-to-simulation framework for hazard vulnerability assessment of unreinforced masonry structures

Mohammad Abu-Haifa; Florida International University; United States
Seung Jae Lee; Florida International University; United States

Masonry structures represent a significant subpopulation of our built environment as well as the historic heritage. Many of the structures are unreinforced and are vulnerable to various natural hazards including earthquakes, thermal stresses, foundation settlements, etc. The damage accumulation is even accelerating due to the impact of changing climate that transforms the hazard type and intensity. Therefore, it is important to predict the aggravating impact on the structures. This study presents an 'image-based modeling-to-simulation' framework to address this challenge, which seamlessly integrates visual imaging with computational analysis to assess the hazard vulnerability of the unreinforced masonry structures. Masonry images are used as input for 3D polyhedral discrete element modeling and simulation. The interactions between individual bricks are explicitly modeled, for which the bricks in the images are segmented, and the geometric features are extracted using a bespoke algorithm. Segmented bricks are approximated into n-sided polygons for a computationally manageable discrete element simulation. The polygons are extruded to realistically model a 3D masonry structure with a consideration for adjoining wythe (i.e., structural interlocking at the corners). Rigid body discrete element simulation of the 3D model is performed using an impulse-based dynamics engine for anticipated hazard scenarios. This presentation will discuss the innovative features of the imaging-based modeling-to-simulation framework as a model of vision-based health monitoring.

An Integrated Network Approach for Managing Wildfire Risk to Communities

Hussam Mahmoud; Colorado State University; United States
Akshat Chulahwat; Colorado State University; United States

With the advent of climate change, all regions across the globe are experiencing sporadic growth in wildfire events that are expected to further increase in the future. The increasing urban development at the fringes of native ecosystems, also referred to as the Wildland Urban Interface (WUI) regions, is expected to significantly increase wildfire exposure. To better prepare communities for future wildfire events, an understanding of the efficacy of current fire mitigation policies is required. The development and evaluation of such policies necessitate the use of tools that can determine the spatial distribution of wildfire damage at a community scale. Current wildfire spread models focus primarily on the wildland. Moreover, existing community level models pertain to localized areas of communities due to their computational demand. In this presentation, a new community level wildfire model will be discussed and the application of the model to predicting damage during recent wildfire events will be demonstrated. The presentation will conclude with how the new model can be used to establish effective policies towards adapting communities to wildfire events.

An LES-based neural network multi-fidelity framework for wind loading predictions.

Mattia Fabrizio Ciarlatani; Stanford University; United States
Themistoklis Vargiemezis; Stanford University; United States
Catherine Gorlè; Stanford University; United States

This study evaluates the use of a multi-fidelity (MF) model based on large-eddy simulations (LESs) to predict wind loading on a high-rise building. The model combines data from low-resolution LESs at 10 wind directions, regarded as low-fidelity (LF) model, with data from high-resolution LESs at 5 wind directions, regarded as high-fidelity (HF) model, to provide accurate multi-fidelity wind loading predictions for all wind directions. To build the multi-fidelity model, we leverage neural networks to reconstruct the discrepancy between HF and LF data using LF LES features as input. The neural network is trained with data from the five wind directions for which we have both LF and HF data. Subsequently, the network is used to predict the HF-LF model discrepancy at the other five wind directions, I.e. the wind directions for which HF data was withheld when training the model. Finally, the multi-fidelity model capability to accurately predict the HF model response is evaluated by comparing the predictions to the withheld HF data. To further evaluate the neural network model results, we also compare the predictions to results from a Co-Kriging framework previously developed for the same task. The results show that the proposed neural network framework significantly outperforms Co-Kriging in terms of predictive capability, yielding satisfactory wind loading predictions over most of the building façade. The use of the neural network model for wind loading predictions would allow a 50% cost reduction for a full wind rose evaluation while retaining an accuracy close to that of the HF model.

An Objective-based Framework for Linking Reconnaissance Data to Performance-based Engineering and Community Resilience Performance Metrics

Amir Safiey; Auburn University; United States
David Roueche; Auburn University; United States

Recent investments in extreme events reconnaissance research have vastly expanded the ability of the research community to collect perishable data following disasters. These building- and community-scale assessments of structural performance following extreme events can be invaluable for developing and validating performance-based engineering and community resilience frameworks. For example, the Structural Extreme Events Reconnaissance (StEER) network is funded by NSF to coordinate the collection of perishable data related to structural performance in the immediate aftermath of extreme hazard events, including hurricane, tornadic, coastal, and seismic events. StEER has coordinated 24 on-site post-disaster event assessments (and over 16 virtual assessments) in recent years, leading to collections of curated datasets of the perishable data from such events published on the Design Safe cyberinfrastructure. These past assessments have relied upon hazard-specific performance rating systems (e.g., ATC 20 or FEMA HAZUS), but there is a need for frameworks to explicitly link the reconnaissance data to a broader suite of appropriate performance metrics such as those commonly used in building- or community-scale resilience assessments. To meet this need, this study presents a framework for performance assessments that will facilitate capturing perishable data on building performance that explicitly links to multiple established performance and functionality metrics. The efforts are focused on (1) the identification of necessary base performance measures (e.g., roof cover loss and characteristics of cracks in reinforced concrete) needed to inform common performance metrics (e.g., safety tags or economic losses) across multiple hazards and building types, (2) the development of transfer functions to facilitate the mapping of common base performance measures to multiple performance metrics, and (3) a downscaling exercise, focused on the base performance measures and performed via sensitivity analysis, to balance the efficiency of field reconnaissance studies with the need for accurate assignment of performance metrics for model validation. A key aspect of the sensitivity analysis is the development of performance metric emulators, formulated as decision trees that define performance metrics using rule-based procedures acting on the base performance measures captured in reconnaissance datasets. Sensitivity analysis is conducted on the emulators to rank the relative importance of the various inputs (typically perishable data) to the output performance metrics. The presentation will include several specific examples, in addition to discussing the studies' modeling aspects, to showcase the methodology.

Analysis of Coreless Filament Wound Structures Using Alternative Performance Indicators

David Forster; University of Stuttgart, Institute for Structural Mechanics; Germany
Ann Sychterz; University of Illinois Urbana Champaign; United States
Manfred Bischoff; University of Stuttgart, Institute for Structural Mechanics; Germany

Due to the shortage of raw material resources and the lack of productivity in the building sector, the Cluster of Excellence EXC IntCDC at the University of Stuttgart is working on the development of coreless filament wound structures on a multidisciplinary basis. Engineers and architects, as the classical participants of creating the built environment are collaborating with experts from the fields of manufacturing, material science and geodesy to embed their methods into a computational co-design framework, presented by Gil Pérez et al. (2022). The close collaboration of the above-mentioned disciplines enables an efficient collection of data during the overall process of the development of a structural system. For instance, laser scanning of robotically assembled specimens provides cross-sectional data. In structural engineering, alternative measures for structural assessment can then be used with this input in order to inform the design process and all other disciplines with structural insight beyond stresses and displacements. Classical formulas, see Maxwell (1864), capture the degree of static indeterminacy as an integer number. In contrast to that, the redundancy matrix provides a quantitative measure about its distribution throughout a structure, see Bahndorf (1991). A detailed description of the concept can be found in von Scheven et al. (2021). Various applications of using the redundancy distribution as an alternative measure for structural assessment already exist, for example designing robust structures or adaptive structures, see Kou et al. (2017) and Wagner et al. (2018). In this paper, a thorough analysis of the data from smallscale sample testing is presented, showing significant deviations in the redundancy distribution within the same type of specimen. This shows quantitatively, that the above-mentioned manufacturing process is very sensitive, and even specimens that look alike have different structural properties. In addition to that, the redundancy matrix is used to detect critical elements with a rather small contribution to the overall degree of static indeterminacy. This means that little opportunity for the redistribution of forces in case of failure of such an element is present. Different approaches to change the redundancy distribution within a structure exist, e.g., topological changes or the reinforcement of certain elements. One additional potential application could be to inform the decision-making process of placing sensors for maintenance of building structures. The overarching goal of the presented method is to improve the design and analysis process and ultimately reduce the safety factors of such kinds of structural systems.

References

Bahndorf, J. (1991). Zur Systematisierung der Seilnetzberechnung und zur Optimierung von Seilnetzen. In English: To systematize the calculation of rope nets and to optimize rope nets. Ph. D. thesis, University of Stuttgart, Stuttgart. Gil Pérez, M., C. Zechmeister, F. Kannenberg, P. Mindermann, L. Balangé, Y. Guo, S. Hügle, A. Gienger, D. Forster, M. Bischoff, C. Tarín, P. Middendorf, V. Schwieger, G. T. Gresser, A. Menges, and J. Knippers (2022). Computational co-design framework for coreless wound fibre–polymer composite structures. Journal of Computational Design and Engineering 9(2), 310–329. Kou, X., L. Li, Y. Zhou, and J. Song (2017). Redundancy Component Matrix and Structural Robustness. International Journal of Civil and Environmental Engineering 11(8), 1155–1160. Maxwell, J. C. (1864). On the calculation of the equilibrium and stiffness of frames. The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science 27(182), 294–299. von Scheven, M., E. Ramm, and M. Bischoff (2021). Quantification of the redundancy distribution in truss and beam structures. International Journal of Solids and Structures 213, 41–49. Wagner, J. L., J. Gade, M. Heidingsfeld, F. Geiger, M. von Scheven, M. Böhm, M. Bischoff, and O. Sawodny (2018). On steady-state disturbance compensability for actuator placement in adaptive structures. at - Automatisierungstechnik 66(8), 591–603.

Analysis of the equity in post hurricane access to emergency services

Naqib Mashrur; Louisiana State University; United States
Sabarethinam Kameshwar; Louisiana State University; United States

This study quantified equity in the loss of connectivity to essential service facilities due to storm9 surge induced flooding considering climate change in Southeast part of Louisiana. At present limited studies10 have focused on equity in post-event connectivity to essential facilities. For this purpose, a general11 framework was established that included steps for: data collection, model formulation, connectivity analysis12 and data analysis. The framework was applied to study the impact of hurricane induced flooding and13 consequent islanding of different demographic groups based on race, age and economic factors. Herein, the14 effects of climate change and sea level rise were incorporated by using storm surge induced flooding15 predictions for return periods ranging from 10 to 500 years for future years up to 2065. The results showed16 that in the case study region over 70% could lose access to emergency service facilities such as hospitals17 during a 100-year hurricane induced flood event. The Native American and Hispanic populations in the18 region was disproportionately affected as over 85% become disconnected. People over the age of 60 were19 also found to be at higher risk. Due to climate change, storm surge induced flood events are expected to20 cause complete loss of connectivity to hospitals for flood projections in the year 2065. The results also21 show that Louisiana’s coastal master plan implemented by the Coastal Protection and Restoration Authority22 slightly improves connectivity to essential service facilities in the case study region and could be ineffective23 in the long term. Future research can expand this to other hazard categories and include the different failure24 modes of bridges in a road network.

Analysis of the Non-Linear Tide-River Flow Interactions of the Lower Mississippi and Atchafalaya Rivers in the Low-Lying Louisiana Coastline

Sayed Omar Hofioni; Louisiana State University; United States
Peter Bacopoulos; Louisiana State University; United States
Jin Ikeda; Louisiana State University; United States
Celalettin Emre Ozdemir; Louisiana State University; United States

The Mississippi and the Atchafalaya River basins play a significant role in the Gulf Coast by providing economic activities, sediment loads, and ecosystem services. The flow to the Atchafalaya River is controlled at the Old River Control Structure, and it receives 30 % of the combined flows of the Mississippi and Red Rivers, where the rest 70 % continues down the Mississippi River. This management of the Mississippi River by the floodgate system results in two different river systems where Atchafalaya resembles an uncontrolled and natural river, whereas Mississippi is a controlled and engineered river. The natural and engineered river basins will potentially respond differently to tidal influence for different river discharges, starting from the river mouth to inland, due mainly to basin characteristics and control structures. Especially increasing river discharge may nonlinearly increase the water levels, putting pressure on infrastructure and causing flood hazards on low-lying coastal land-margins. This study investigates the potential non-linear interaction between the river and tidal flows in the Mississippi and Atchafalaya rivers. The ADvanced CIRCulation (ADCIRC) model with unstructured meshes will be used to model the two river systems and the tides. Various realistic and hypothetical scenarios would be considered: floods of different return periods and hydrographs of varying duration and intensity. To identify and analyze the non-linear tide-river flow interactions, non-stationary tidal analysis and non-linear time series analysis methods such as wavelet transforms, Short-Time Fourier Transforms (STFT) will be used in this study.

Analytical solution for a poroelastic inclusion embedded within an elastoplastic matrix

Yidi Wu; Pennsylvania State University; United States
Amin Mehrabian; Pennsylvania State University; United States
Shengli Chen; Louisiana State University; United States
Younane Abousleiman; University of Oklahoma; United States

This work presents a time-dependent and coupled analytical solution to undrained elastoplastic stress of a fluid-saturated matrix when subjected to fluid injection at the center of an embedded porous, fluid-saturated, elastic inclusion. The solution is spherically symmetric and considers full poroelastic coupling in the inclusion while solving for the surrounding matrix stress using a Lagrangian formulation of the corresponding elastoplastic deformations. The plastic part of the solution applies a Drucker-Prager formulation of plastic flow with strain-hardening. The obtained solution is used as a proxy model to study caprock stress evolution upon subsurface fluid injection or withdrawal. Results indicate that the (poro)elastic models which are predominantly utilized in the existing studies of the subject could substantially underestimate the caprock failure threshold. A considered case study shows an increase of the inclusion fluid volume injectivity by 50% when allowable plastic strain increases by less than 2%. The presented solution would further serve as a rigorous benchmarking tool for related numerical solvers.

Analytical solution for Mode I stress intensity factor in aviation pavement reflection cracking model

Kairat Tuleubekov; Applied Research Associates; United States
David Brill; Federal Aviation Administration; United States

In 2020, the Federal Aviation Administration (FAA) developed a two-dimensional model of its full-scale, indoor reflection cracking test equipment at the National Airport Pavement Test Facility (NAPTF), William J. Hughes Technical Center, Atlantic City International Airport, NJ. The analytical model represents two jointed concrete slabs with a continuous hot mix asphalt overlay, and with a single, preexisting vertical crack in the overlay centered on the joint. An analytical series is shown to be a solution to the simplified model where it is assumed that all points of a horizontal plane normal to the crack propagation direction remain in the same plane after deformation. A further development of the model, which is presented here, became possible due to the method of potentials. This solution approaches the more general case, where there is no assumption that initially horizontal planes in the overlay must remain horizontal after deformation. Mechanically, this is a more realistic description of the problem, especially for cases where the crack tip is close to a boundary; i.e., immediately after crack initiation and when the crack has propagated nearly to the top surface. The general solution of two governing equations was sought in the form of potentials. Mode I stress intensity factors (SIF) were derived from superposition of the linear elastic solutions of two separate problems having different domains. The first problem considers the uncracked domain with the same prescribed horizontal displacements at the bottom as the original problem. The second problem considers the cracked domain, where horizontal displacements at the bottom boundary are prescribed to be zero. The sum of the solutions of these two problems in the linear elastic domain gives the desired Mode I solution at the vicinity of the crack tip. By applying Schapery's theory of crack propagation in viscoelastic materials, this model can be used to determine the energy release rate (ERR) in asphalt overlay subject to Mode I cracking caused by repeated temperature-induced loads. The model was used to compute Mode I SIFs at the crack tip for a series of incremental crack lengths, using assumed properties. Computed SIF values showed good agreement with SIF values computed by a finite element model (ABAQUS).

Anisotropic bounding surface model for clay under monotonic and cyclic loading conditions

Yang Yu; Zhejiang University; China
Zhongxuan Yang; Zhejiang University; China

Fabric anisotropy plays an essential role in the soil response, such as dilatancy and stiffness characteristics due to different loading direction under monotonic loading and pore-pressure development dependent on the interplay between fabric and loading direction under cyclic loading. The favorably used rotational hardening generally aims to capture the influence of anisotropic stress condition while failing to account for the inherent (fabric) anisotropy effect. In this study, an anisotropic bounding surface model that incorporates rotational hardening and fabric evolution is formulated to simulate the behavior of clay, while ensuring a zero-rotational angle and the highly anisotropic fabric at critical state. In addition, the model employs an anisotropic elasticity to consider the influence of the initial fabric at a low stress level, replicating the inclined undrained stress path and stiffness variation associated with bedding-plane orientation. The predictive capacity of the model can be demonstrated by simulating several monotonic tests on clay over a wide range of overconsolidation and anisotropic consolidation stress ratios, and cyclic tests under undrained and drained conditions covering varying stress and strain amplitudes.

Anomaly detection for CO2 capture and sequestration monitoring

Jose Hernandez Mejia; The University of Texas at Austin; United States
Matthias Imhof; ExxonMobil; United States
Michael Pyrcz; The University of Texas at Austin; United States

Carbon Capture and Sequestration (CCS) is the process of capturing CO2 that otherwise would be released into the atmosphere, and injecting it into geological formations for safe, secure, and permanent storage. It is important to monitor the CO2 plume development and to detect anomalies early to ensure reliable CCS for large-scale CCS projects. Anomalies can occur due to sudden or unforeseen changes in the subsurface or operational conditions. We propose a deep-learning Convolutional LSTM-Autoencoder neural network trained with high-fidelity reservoir simulations from injector and monitor bottomhole pressure (BHP) spatiotemporal responses for multiple subsurface scenarios. Anomalies are identified with the decoder reconstruction error and the probability distributions of the low dimensional representation of the latent space of the autoencoder. Once an anomalous pressure response is detected in a monitoring well, a physics-constrained spatial voronoi decomposition and dynamic time warping are implemented to identify the spatiotemporal source of the anomaly.

Application of Fe-SMA Bars as Self-Centering Elements in Bridge Piers to Improved Seismic Resilience

Masood Vahedi; University of Nevada Reno; United States
Hamed Ebrahimian; University of Nevada Reno; United States
M. Saiid Saiidi; University of Nevada Reno; United States

The utilization of advanced materials and new technologies, such as shape memory alloys (SMAs), is gaining attention to minimize earthquake damage and residual deformation in bridge piers. Such damage and deformation can lead to costly and time-consuming repairs and replacements of bridge structures, which can negatively impact the overall recovery and resilience of transportation infrastructure after an earthquake. This study aimed to investigate the feasibility of using unbonded iron-based shape memory alloy (Fe-SMA) bars as self-centering elements in accelerated bridge construction (ABC) piers, with the aim of reducing residual lateral displacement after earthquakes. Through shake table testing of a one-third scale bridge column specimen subjected to near-fault ground motions, and numerical nonlinear modeling using the OpenSees software, the analytical simulations and experimental measurements, including residual drifts, accelerations, forces, and hysteresis responses, were compared. Also, the results of the experimental test of the Fe-SMA column specimen were compared to a conventional cast-in-place reinforced concrete (RC) column without self-centering elements. The findings indicate that the use of Fe-SMA bars as self-centering elements in ABC piers has the potential to significantly reduce residual seismic deformation, ultimately improving the overall seismic resilience of transportation infrastructure.

Application of GNN for edge ranking in Transportation systems

Debasish Jana; University of California Los Angeles; United States
Sven Malama; University of California Los Angeles; United States
Sriram Narasimhan; University of California Los Angeles; United States
Ertugrul Taciroglu; University of California Los Angeles; United States

Infrastructure network systems, like transportation, power, and water distribution, can be represented via bidirectional and/or directed graphs. One of the most crucial problems in these cases is identifying the importance of edges in the graph and their influence on the graph structure. If any of those `important' edges are affected, the whole network's efficiency will be affected to a great extent. One conservative approach to finding such important edges is `edge betweenness centrality' -- an edge ranking measure to determine the influential edges of the graph based on connectivity and information spread. For instance, a connecting street between multiple communities is considered one of the most important streets in a transportation network -- any damage on that street due to any natural/artificial calamities (earthquake, flood, blast) could be detrimental to the whole system. Therefore, identifying such important edges and continuous monitoring is necessary during the urban infrastructure planning and operating stages. The exact computation of `edge betweenness centrality' using the conventional approach is highly computationally expensive and restrictive, especially for large directed graphs. Any modification in the graph parameters, such as the change in edge weight, node and edge deletion/addition, would require the calculation of the `edge betweenness centrality' from scratch. In a real transportation street network, the node/edge addition would represent a new road or road junction addition to the transportation network. Similarly, node/edge deletion would represent a road segment/road junction that is nonfunctional due to some natural/man-made event. This study proposes an approximate method to estimate the edge betweenness centrality for directed graphs using a deep learning-based approach. We adopt a Graph Neural Network (GNN) based model to address this problem, which is found to be computationally efficient compared to the conventional method. We demonstrate the performance of the GNN-based edge ranking framework on a series of synthetic graphs and real-world transportation datasets. The proposed methodology shows excellent potential in urban infrastructure improvement, such as budget allocation for various engineering networks.

Application of Hydro-Real-Time Hybrid Simulation to Examine the Response of Offshore Wind Turbines

Akiri Seki; Stanford University; United States
Jonah Gadasi; Oregon State University; United States
Cameron Irmas; Oregon State University; United States
Bret Bosma; Oregon State University; United States
Shangyan Zou; Michigan Technological University; United States
Michael Devin; Sandia National Laboratories; United States
Barbara Simpson; Stanford University; United States
Bryson Robertson; Oregon State University; United States
Bryony DuPont; Oregon State University; United States
Ted Brekken; Oregon State University; United States
Andreas Schellenberg; Maffei Structural Engineering; United States
Pedro Lomonaco; Oregon State University; United States

Due to the worldwide energy transition, offshore wind turbines (OWTs) are being built along the west and east coasts of the US where large wind resources are located. The design of the OWTs must consider coupled aero-hydro fluid-structure interaction as they are in the marine environment. However, data of realistic fluid-structure interaction response is very limited due to: [i] limitations in conventional experimental techniques that necessitate geometrically scaled structures along with similitude of the forces and time for the waves and wind, and [ii] computationally expensive cost and uncertain accuracy of results in handling combined computational fluid and structural models. The experimental approach may not accurately represent the full-scale prototype response, and the numerical approach requires validation with experimental data. Real-time hybrid simulation (RTHS) is a numerical-physical simulation method that can alleviate the aforementioned constraints by dividing a system into multiple portions, consisting of both physical and numerical sub-assemblies. The physical and numerical sub-assemblies interact, in real time, through sensors and actuators. The response of the coupled hybrid sub-assemblies represents the response of a complete system. Thus, the RTHS mitigates many of the similitude constraints imposed in conventional fluid-structure interacting experiments by applying the similitude laws separately in the numerical and physical sub-assemblies. This study coupled physical waves and a partial structure with offline/online-numerical wind and a structural model to explore the application of hydro-RTHS for characterizing both monopile and floating OWTs. The application to the floating OWT is ongoing. However, this study demonstrates the capability of the hydro-RTHS architecture to produce realistic response of the monopile OWT that cannot feasibly be obtained using conventional experimental approaches.

Application of Incremental Dynamic Analysis to Performance-Based Wind Design

Baichuan Deng; University at Buffalo; United States
Teng Wu; University at Buffalo; United States

The incremental dynamic analysis (IDA) is a method to provide thorough structural performance under a suite of load histories. It has been widely applied to performance-based earthquake engineering. The structural wind design method is also moving towards a performance-based wind design (PBWD) methodology and the recently published Prestandard for PBWD suggests IDA as an approach to examine the conditional failure probability of a structure under wind hazard. Several challenges may exist to apply the IDA to PBWD, e.g., the generation and selection of wind load history, the directionality consideration of the wind load history, the scaling of wind tunnel test data and their integration into high-fidelity numerical modeling of structures, and the computation efficiency of nonlinear structural analysis subjected to hour-long wind load histories. A comprehensive discussion of recent advances on the above-mentioned challenges is presented in this study. Then, a detailed case study is developed to provide some recommendations for wind IDA.

Applied Development of Environmental Declarations for Rotary-Kiln Manufactured Expanded Aggregates

Fariborz Tehrani; California State University, Fresno; United States

The paradigm shift in engineering toward the sustainable development of resilient infrastructure has highlighted the application of lifecycle analyses in engineering manufacturing, design, and construction. Environmental characteristics such as energy, emissions, water, and waste have been key parameters to measure the performance of sustainable and resilient systems. Sustainability rating systems and objective resilience approaches aim to assess these performance measures objectively. Product declarations, like environmental product declarations, are vital in programming and managing sustainable development efforts. This presentation highlights the development of environmental product declarations for various applications of rotary-kiln-manufactured expanded aggregates. The development involves significant applications in retaining structures, internally cured concrete pavements, masonry walls, and concrete floors. Analyses rely on industry data and cover all phases of products, from mining raw materials for production to recovering decommissioned components for reuse. Results indicate challenges and opportunities in applying lightweight aggregates and benefit engineering professionals in developing customized lifecycle analyses of projects using available declarations.

Arbitrary-Order Sensitivity Analysis in the Wave Propagation Behavior of Architected Materials Using HYPAD-FEM

Juan David Navarro; The University of Texas at San Antonio; United States
Juan Camilo Velasquez; The University of Texas at San Antonio; United States
Arturo Montoya; The University of Texas at San Antonio; United States
Harry Millwater; The University of Texas at San Antonio; United States
David Restrepo; The University of Texas at San Antonio; United States

Architected Materials (AMs) exhibit unusual dynamic behavior and control of mechanical waves. These interesting properties are assessed by solving the generalized eigenfrequency problem following Bloch's theorem. Hence, calculating the eigenvalues and eigenvectors sensitivities with respect to the parameters defining the AM (e.g., geometry, topology, and materials forming a repeating unit cell) is essential to engineer AMs that fulfill application-specific requirements. Current methodologies for sensitivity analysis in AMs are primarily limited to first-order, computationally inefficient, and subject to computation errors. To address these gaps, we introduce a new methodology that enhances traditional FEM formulations with the HYPercomplex-based Automatic Differentiation (HYPAD) method. HYPAD-FEM allows computing highly accurate estimates of arbitrary-order shape, material property, or loading sensitivities with respect to any input parameter in the model without the step size issues associated with traditional methods like finite differencing. In this talk, we will present the application of HYPAD-FEM for analyzing AMs. Specifically, we will present the methodology in the analysis of the 1-D diatomic lattice and a 2D square lattice, where we compute up to third-order sensitivities. And we will demonstrate the application of this methodology in maximizing the ban-gaps size for latticed AMs.

Architected materials with effective water intake, storage, and release properties inspired by the feathers of namaqua sandgrouse (Pterocles namaqua)

Jochen Mueller; Johns Hopkins University; United States
Lorna Gibson; Massachusetts Institute of Technology; United States

Desert sandgrouse, such as the Namaqua Sandgrouse, nest up to 30 km away from watering holes. Adult male desert sandgrouse have specially adapted feathers on their bellies that hold water, even during flight, allowing the birds to transport water back to the chicks at the nest. The structure of the belly feathers and aspects of the mechanism by which they hold water was first described by Cade and Maclean (1967). Here, we use scanning electron microscopy, micro-computed tomography, and videography to characterize the geometry of different components of the belly feathers and to show how differences in their bending stiffnesses contribute to the water-holding mechanism. The results of this study are used to model computationally water uptake by the feather and inspire architected materials with rapid intake and release, and efficient storage properties that may inspire the next generation of sports equipment, medical devices, and more.

Are Configurational Forces Real Forces

Roberto Ballarini; University of Houston; United States
Gianni Royer-Carfagni; University of Parma; Italy

In the Treatise on Natural Philosophy of 1879, Thomson and Tait suggest that any attempt to supersede Newton's description of the laws of motion cannot but end in utter failure. A force is something that tends to alter a "body's" natural state of rest, or uniform motion along a straight line, with respect to an inertial observer. The structure of space as given to us in intuition is geometry; it is the possibility of visualizing forces with lines, and their geometrical composition, that facilitates the practical solution of most problems of mechanics. There are cases, however, for which the geometric visualization of such forces is not straightforward. A classical example is that of configurational forces, pioneered by Eshelby to describe the potential movement of defects within the solid state. From the variation of the free energy consequent to the movement of the defect, say an inclusion, an associated force can be inferred due to the natural tendency of the system to achieve lower potential states. However, as admitted by Eshelby himself, such a force is in some sense "fictitious": its existence is demonstrated starting from a consistent continuum theory of mechanics, but the same theory predicts that the resultant of the traction acting along the boundary of the inclusion is null. We show in paradigmatic examples amenable of generalization that a configurational force can be viewed as the resultant of the contact forces acting on the perturbed shape of an object of substance equivalent to the defect, and evaluated in the limit of the shape being restored to the primitive configuration. The expressions for the configurational forces on cracks and dislocations are in agreement with those determined using classical variational arguments. It is hoped that this somewhat novel approach, which has been applied by Bigoni and coworkers to illustrate configurational forces in structural components, may open a new prospective in the use of configurational forces by permitting their physical and intuitive visualization.

Artificial Intelligence-based wildfire community risk assessment considering physical and social impacts

Abdur Rasheed; New Mexico State University; United States
Do-Eun Choe; New Mexico State University; United States

Wildfire, also called forest fire, is a natural disaster that causes significant destruction to human communities and ecosystems, leading to physical and social damage. The frequency and severity of wildfires have been significantly increased in recent years as a consequence of climate change, making it crucial to predict the behavior, threat, and risk of wildfires. This research proposes an artificial intelligence-based framework to predict wildfire hazard risk considering both physical and social damages. To this end, we utilized a historical climate database concerning temperature, humidity, topology, vegetation, and local wind conditions, as well as sociology data such as the cultural, demographical, and social statistics (as a set of causal data) and propose the wildfire hazard assessment measures that reflect both physical and social damage. To define the fundamental impacts of wildfire damage on humans, the physical damage, such as the frequency and severity of the fire, as well as the related social damage, such as the loss of solace from the landscape and the long-term social consequence, are also considered. The developed framework is specifically evaluated in the state of New Mexico where the social and psychological damages in the minority community have rarely been studied. Deep learning-based algorithms such as Convolutional/Recurrent Neural Networks are trained and tested on the database comprising of satellite images of wildfire-affected areas. The climate data obtained from National Oceanic and Atmospheric Administration (NOAA) is used for the prediction using simple machine learning algorithms including Support Vector Machine and boosted/bagged decision trees. The outcome of this study may provide valuable insights into proper wildfire risk management and mitigation strategies for local authorities and communities. Furthermore, the proposed method which combines the risk of physical and psychological damages can be applied to and refined for other regions.

Artificial language and machine learning-integrated approach for understanding and designing concrete with consideration of physiochemical properties

Soroush Mahjoubi; Stevens Institute of Technology; United States
Rojyar Barhemat; Stevens Institute of Technology; United States
Weina Meng; Stevens Institute of Technology; United States
Yi Bao; Stevens Institute of Technology; United States

This presentation introduces a machine learning-based approach for understanding and designing concrete that takes into account not only the mixture design variables but also the intrinsic physicochemical properties of the ingredients such as particle size distribution and chemical composition of binders and aggregates. The approach utilizes an artificial language to represent concrete mixtures and their ingredient information, a feature extraction method based on character-level N-grams, and an automatic deep learning model configuration. The method was applied to predict the compressive strength of complex concrete mixtures and the results showed high accuracy and generalizability. This research offers valuable insights into the underlying reactions involved in complex concrete mixtures and provides a basis for the design of sustainable and cost-effective concrete.

ASCE Student Steel Bridge Optimized Design and Modeling

Brayden Shaver; University of Tennessee at Chattanooga; United States
Paul Pike; University of Tennessee at Chattanooga; United States
Kyle Branning; University of Tennessee at Chattanooga; United States
Ignatius Fomunung; University of Tennessee at Chattanooga; United States
Joseph Owino; University of Tennessee at Chattanooga; United States
Weidong Wu; University of Tennessee at Chattanooga; United States

The University of Tennessee at Chattanooga (UTC) is going to host mid-south student conference in Spring 2023. This work presents how ASCE UTC Student Chapter designed and modelled the ASCE student steel bridge for the competition that addresses many existing design and modeling issues. In the past, steel bridges were designed by referring to those in the previous competitions, following expert's opinions, or trial and error. Additionally, applying loads through placing steel angles on decking makes it challenging to analyze and model the bridge. To overcome these obstacles, the UTC ASCE steel bridge team used an optimized design approach to automatically select the most economical, adequate bridge member sections. Grid analysis using stiffness method approach, together with elementary mechanics, were employed to transfer the weight of steel angles to concentrated forces applied at joints of the steel truss bridge. The steel bridge team performed preliminary experiments to measure the actual deflections that agree well with the computational modeling results.

Asphalt Chip Seal: An Alternative to Sealcoating

Steven Hoard; ESCSI Institute; United States

No matter the initial quality of asphalt pavement, it will need preventative maintenance over its service life to continue to provide safe, viable and beautiful roads. Additionally, pavement preservation can help maximize road budgets. Paving experts estimate that, depending on road conditions, every two dollars spent on pavement preservation can save four to 18 dollars on future costs.

Sealing cured asphalt can help the pavement resist oxidation from the sun, revitalize its surface and provide a protective layer against water, oil and salt. As such, sealing is a worthwhile investment for asphalt roads that are still structurally viable but are showing signs of age. When it comes to sealing, contractors generally have two options: sealcoating or using an asphalt chip seal.

While sealcoating seems to be an initially less expensive option, it cannot repair cracks and other forms of distress because it is a surface treatment that only mitigates water and other chemical penetration. It has no structural strength of its own and will need to be reapplied every other year or so. On the other hand, asphalt chip seal not only provides similar protection, but it also can reconstruct more distressed pavements (including those with minor alligator cracking). It can also last up to five times longer than sealcoating.

The following will take a deeper look into how chip seal made with lightweight aggregates can be an economical means of preventative maintenance as well as provide an overview into the best practices of using this material.

Benefits of Lightweight Aggregate Asphalt Chip Seal Chip seal made with lightweight aggregate such as expanded shale, clay or slate (ESCS) can provide a cost-effective surface treatment that both repairs roads and improves their safety and durability. Because ESCS has a network of unconnected voids, it provides an increased surface area to bond to the emulsion. As such, it can withstand high-speed traffic and normal wear-and-tear that pavements undergo—resulting in a surface treatment that can last up to 10 years.

The voids also increase the retention rate of aggregates, which can lead to a significant reduction of application and maintenance costs. For example, in 2017, the Carbon County Road Department reports that the increased retention rate of lightweight aggregate, as well as reduced fuel costs due to the material's lower density, resulted in over $300,000 in savings annually.

In addition, these voids lower the aggregate density, meaning should a patch of pavement be kicked up the force it would inflict on windshields and headlights is much lower than conventional aggregates. In fact, after switching to lightweight aggregate asphalt chip seal to repair I-84, representatives from the Utah Department of Transportation (UDOT) stated they have not had a single claim or complaint about damage. They continue, "This is unheard of for a chip seal."

The voids also help asphalt chip seal resist polishing for long-term skid resistance. This contributes to safer roads in both wet and dry conditions. And despite the long-term skid resistance, the aggregate creates a more uniform road surface, ideal for vehicles and bicycles alike. Using lightweight aggregate chip seal can be an efficient means of preventative maintenance if project managers observe the following steps as a best practice guide.

Step 1: Survey Site and Have a Pre-Construction Meeting Before starting a chip seal project, it is important to survey the site to ensure it is in good enough condition for preventative maintenance. While chip sealing can repair some damage, it is not recommended for unsealed cracks greater than a quarter of an inch, rutting deeper than 1 inch and medium- to high-severity alligator cracking. If a site has these damages, sealing and repair will need to take place prior to the placement of asphalt chip seal.

In addition to surveying the site, it is recommended to have a pre-construction meeting, so all parties have clear and defined expectations. This includes detailing any pre-application maintenance that needs to occur, confirming timelines, determining application rates and whether a site needs a single or double layer. Taking these steps before starting a project increases both the effectiveness of asphalt chip seal and the overall satisfaction with the finished project.

Step 2: Prepare the Site The next step is to prepare the site for chip sealing. For highly distressed sections of pavement, contractors should have crews seal any large cracks, fill ruts and repair other damages roughly three to six months prior to the application of asphalt chip seal. This timeline allows these repairs to cure fully, creating a suitable foundation for the asphalt chip to adhere to.

On the day the chip seal is to be placed, the road should be thoroughly cleaned. This includes washing off mud and sweeping away any dirt and debris from the pavement surface. If washing is required, the road should be allowed to dry completely. This step helps the emulsion stick directly to the old surface—reducing the risk of misapplication.

It should also be noted that ambient temperature should sit between 55 degrees and 90 degrees Fahrenheit (F), and the pavement temperature should be 70 degrees F and rising. Maintaining these temperatures on the day the chip seal is placed will help the material perform to its maximum capabilities.

Step 3: Place Chip Seal Once the preparations have taken place, contractors can place the chip seal. First, contractors should dial in the proper shot rate of emulsion based on site conditions—generally between 0.33 and 0.38 for type A, or ⅜ inch, chip sand 0.42 and 0.48 for type C, or ½ inch, chips. It should be noted that the rate should be increased for new asphalt or roads with more distress. For these projects, the spreader should stay very close to the distributor truck. For high traffic streets or ones with less distress, the shot rate can be decreased slightly.After applying the emulsion, the spreader should distribute chips in a uniform, single layer. Doing so helps ensure the chips will not grind against each other crushing and breaking. It is also important that the chips are not spread too thin; this will allow oil to bleed through the spaces between the ESCS aggregate. Then rubber tire rollers should follow the spreader to embed the chips firmly into the emulsion, so the chips will not peel off the road. It is best practice to perform at least three passes with the rubber tire rollers.

During these processes, contractors will need to pay attention to all equipment to sustain the quality of chip seal placement throughout the project. This includes maintaining the proper spray bar height and watching for plugged nozzles. Staying vigilant on these aspects of the job will keep the emulsion uniform and smooth, which will not only help the chip seal bond to the pavement better but will also ensure the most cost-efficient use of materials.

Step 4: Sweep After the chips have been placed and rolled, contractors should lightly broom or sweep the loose chips from the tip of the chip seal. Waiting longer, especially if the chips have been placed too heavily, will result in crushing.

For highways and non-curbed streets, the brooms can sweep the aggregates off the side. ESCS lightweight aggregates are chemically inert and free draining, so they will not cause harm to neighboring ecosystems. For guttered streets and residential areas, the brooms should be able to vacuum or pick up the chips into a box rather than side casting them into the gutter.

Extending the Life of Roads and Highways Following these steps can help contractors utilize asphalt chip seal as a preventative maintenance material. When the chip seal is made with lightweight aggregates like ESCS, it can provide a smooth and long-lasting surface to highway and municipal roads—extending the service life of most asphalts by 5 – 10 years, depending on traffic and environmental conditions. As such, asphalt chip seal presents a cost-effective alternative to sealcoating for pavements that are still structurally sound but are showing signs of aging.

Assessing Vulnerability of Historic Midwestern U.S. Timber Barns under Severe Windstorms

Moriah Hughes; Princeton University; United States
Branko Glisic; Princeton University; United States

Historic timber barns in the US Midwest are facing an uncertain future due to a combination of factors. The 2018 NCA report identified the infrastructural resilience of rural communities to natural disasters and climate change as lower than suburban and city areas. Barns in particular are a vulnerable rural community asset due to both their age, with weakening due to weathering and deterioration, and their vernacular design (rarely designed to codes). And despite their wide recognition as icons of American architecture, these buildings have been the subject of limited scientific research regarding their structural characterization, performance, or preservation. This is a symptom of the gap identified by researchers between the solutions of science and technology for rural or agricultural communities and the underlying principles of those communities and their historic development and survival. This is especially tragic as rural agricultural communities, and particularly barns, have long embodied sustainable development and a large capacity for resilience by the use of techniques such as incremental development and adaptive reuse. This work aims to develop the technical background for enabling effective risk management of these buildings by addressing the population vulnerability to the primary natural hazard affecting it: severe windstorms. It also aims to bridge the existing gap between science and technology approaches to rural agricultural community management by demonstrating how accepted principles of built cultural heritage preservation, including a scientifically rigorous approach to vulnerability and interventions, can be applied for a more responsible and sensitive management of this and other built cultural heritage assets in rural U.S. communities. The presentation will address current results of the project, including initial in-situ investigations, building population distinctives, and challenges faced.

REFERENCES

[1] NCA, 2018. "Fourth national climate assessment, Chapter 21: Midwest." https://nca2018.globalchange.gov/chapter/21/ Accessed 4 April 2022.

[2] Glenna, L. and Ransom, E.P. 2016. Agricultural Science and Technology: Tensions and Contradictions. International Handbook of Rural Studies, ed. Mark Shucksmith and David L. Brown. 240-249. New York: Routledge.

[3] Cruz, H., Yeomans, D., Tsakanika, E., Macchioni, N., Jorissen, A., Touza, M., Mannucci, M., & Lourenço, P. B. (2015). Guidelines for on-site assessment of historic timber structures. International Journal of Architectural Heritage, 9(3), 277–289. https://doi.org/10.1080/15583058.2013.774070

[4] Shabani, A., Kioumarsi, M., Plevris, V., & Stamatopoulos, H. (2020). Structural Vulnerability Assessment of Heritage Timber Buildings: A Methodological Proposal. Forests, 11(8). https://doi.org/10.3390/f11080881

[5] Pandolfi, F. (2022). Performance-based wind risk assessment: computational tools for a building-component oriented vulnerability approach [Ph.D. thesis, University of Naples]. Retrieved from http://www.dist.unina.it/dottorati-di-ricerca/archivio-tesi-di-dottorato

[6] Shortridge, J. (1999, Spring). Kansas Barns in Time and Place. Kansas History, 22 (1), 2-25.

Assessment of ship impact force on offshore structures with varying collision scenarios

Hyunjoong Kim; Liberty University; United States

Ship collision with offshore structures is an extreme event that rarely occurs during a structure's lifetime but may impact significantly. Most design documents consider ship collision from a risk perspective because of the rareness of the events. In recent designs, the frequency of ship collisions is calculated more rigorously than suggested in the design documents to overcome the conservativeness of design assumptions. Site-specific ship navigation data is often used if they are available. However, the consequence of ship collision is usually estimated using conservatively estimated design formulas. Such design formulas can give an upper bound impact force since a head-on collision with the whole frontal part of a ship in contact with the structure is assumed. However, using the formula may lead to an overestimated risk because the majority of collision scenarios do not associate such a head-on collision. This study investigates the variation of ship impact force considering various collision scenarios. A 3D finite element model of a tanker vessel is used for dynamic impact analysis. The modeling efforts have been concentrated on the frontal parts and the stiffeners. The rest of the ship is considered a lumped mass. The mass and size of the vessel are fixed to single values. The varying parameters include the impact angle, the impact velocity, and the vertical impact location. The last parameter, which accounts for the variability of ship drafts and the sea level, is realized by adjusting the portion of the ship frontal part involved in the collision. The simulation results show that the maximum impact force occurs with the head-on collision and the whole frontal part being crushed. The corresponding impact force turns out to be comparable to the design impact force estimated following Eurocode. The impact force decreases with a bigger impact angle and the smaller crushed part. Such a variation in the impact force is represented by envelope curves that have the impact angle, the impact velocity, and the vertical impact location as input arguments. The results of this study can provide a basis for reducing the ship impact force for the risk-based design of offshore structures against ship collision.

Assessment of the combined effects of climate change and structural aging on the hurricane-induced losses for typical US wooden single-family homes

Michele Barbato; University of California, Davis; United States

The US Gulf and Atlantic coasts are frequently affected by hurricanes, which produce significant economic and life losses every year. The effects of climate change and structural aging are expected to further exacerbate the hurricane risk in this region. Light-frame wooden single-family homes are particularly vulnerable to hurricane wind and windborne debris actions. This paper uses an extended version of the performance-based hurricane engineering (BPHE) framework to assess the combined effects of nonstationary hazard due to climate change, and of nonstationary vulnerability due to structural aging. A multi-layer Monte Carlo simulation approach is proposed for probabilistic damage, loss, and cost-benefit analysis. Uncertainties in the structural aging process and in the prediction of hurricane wind speed distributions under changing climate conditions are considered. This study compares the effects of different nonstationarity assumptions, i.e., climate change only, structural aging only, and combined climate change and structural aging. The proposed methodology is demonstrated through the hurricane loss analysis of a wooden single-family house located in Pinellas Park, FL. It is shown that, for this application example, both climate change effects and structural aging effects are significant when considered independently. The combined effects of climate change and structural aging can almost double the expected total losses during a 50-year service design life when compared to the case with no climate change and no structural aging.

Assessment of Wind Hazard Mitigation on a Tall Building equipped with Performance Control Devices using 3D Real-Time Aeroelastic Hybrid Simulation

Liang Cao; Lehigh University; United States
Haitham Ibrahim; Florida International University; United States
Thomas Marullo; Lehigh University; United States
James Erwin; Florida International University; United States
James Ricles; Lehigh University; United States
Amal Elawady; Florida International University; United States
Arindam Chowdhury; Florida International University; United States

Wind-induced vibrations, particularly in tall buildings, can produce considerable nonstructural damage and excessive acceleration. Such vibrations can be mitigated through the incorporation of performance control devices such as passive and semi-active damping devices. The effectiveness of these vibration mitigation systems against wind hazards needs to be accurately evaluated by considering possible aeroelastic effects. Numerical simulations of structural behavior under aerodynamic wind forces are challenged by the proper representation of such forces. Physical testing of scaled building models in wind tunnels also has limitations in evaluating wind-induced response due to many challenges such as scaling errors and inaccurate modeling of complex structural properties (e.g., mass, stiffness, damping) and nonlinearities (e.g., geometric, material).

The authors have recently proposed a novel 3D Real-Time Aeroelastic Hybrid Simulation (3D-RTAHS) method that can provide an accurate assessment of critical wind-induced dynamic response. The presentation will discuss the results of a study using the proposed 3D-RTAHS to investigate wind hazard mitigation of a forty-story building installed with various performance control devices. First, the details of the building are presented. The building consists of steel-braced frames that are augmented by outrigger systems about the minor axis of the floor plan. Second, the 3D-RTAHS method is introduced. The analytical substructure in the 3D-RTAHS contains the numerical model of the building, while a physical 1:150 scaled aeroelastic building and performance control devices form the experimental substructure. The experimental aeroelastic building model is used to measure real-time multi-directional aeroelastic pressures through distributed pressure taps on the model's surface. Third, various retrofitting strategies for wind-induced vibration are described. Performance control devices are placed in the outriggers to control floor accelerations and inter-story drift about the minor axis of the building. A tuned mass damper is placed at the roof about the major axis of the building. Lastly, the 3D-RTAHS results are presented. The building's accelerations and inter-story drift from controlled and uncontrolled cases are compared, where these cases correspond to the structure with and without the performance control devices, respectively. The results show that the performance control device produces significant wind vibration reduction of both maximum lateral floor accelerations and inter-story drift.

Augmented sample-based approach for multi-fidelity uncertainty quantification

Leila Naderi; Department of Civil and Environmental Engineering, Colorado State University; United States
Gaofeng Jia; Department of Civil and Environmental Engineering, Colorado State University; United States

Monte Carlo Simulation (MCS) is widely used for uncertainty quantification and propagation. However, MCS requires a large number of simulations, and in the case that the model has a high cost (e.g., high-fidelity model), direct application of MCS to evaluate stochastic integrals using high-fidelity model becomes computationally infeasible. To address such computational challenges, multi-fidelity approaches have been proposed which rely on a combination of results from cheap low-fidelity models with results from expensive high-fidelity models to establish an unbiased estimator of the statistics of the high-fidelity model. However, existing approaches usually assume some type of error or correlation structure between different model fidelities. In this work, a new formulation is proposed for multi-fidelity uncertainty quantification (MFUQ). The proposed approach relies on the reformulation of MFUQ to an augmented uncertainty quantification problem by artificially treating the model fidelity as a discrete random variable and augmenting it with other random variables/inputs. Further, a joint auxiliary distribution is defined in the augmented space of random inputs and model fidelity. Then stochastic sampling is used to generate samples from this joint distribution. Then the marginal distribution for the model fidelity can be estimated based on the corresponding marginal samples, which is then used to estimate the stochastic integral for the model with the highest fidelity. The proposed approach does not rely on correlation between different model fidelities. The optimal distribution for the number of runs of different model fidelities is established through a constrained optimization with a small number of initial runs of different model fidelities. The proposed method requires only a small number of runs of the high-fidelity model and a larger number of runs of lower fidelity models, which results in a smaller computational cost compared to MCS using large number of high-fidelity runs. The variance reduction and computational savings offered by the proposed approach are investigated using a benchmark problem.

Automated Design and Discovery of Mechanical Metamaterials

Qianyun Zhang; New Mexico State University; United States
Kaveh Barri; Johns Hopkins University; United States
Wenyun Lu; University of Pittsburgh; United States
Jianzhe Luo; University of Pittsburgh; United States
Amir Alavi; University of Pittsburgh; United States

One of the main challenges ahead of the mechanical metamaterial science is identifying the structures with desired performance in a wide design space of potentially infinitely many configurations of representative volume elements. Here, we present a new approach for design and discovery of mechanical metamaterials using the principles of natural evolution. We show the process of evolving thousands of 3D deigns for mechanical metamaterials with maximum bulk modulus as the design objective. The proposed evolutionary computational method can start the design process using merely a piece of matter which is a representative unit cell with a simple shape. Thus, it serves as an unsupervised machine learning approach that does not need a database for its training, yet it can explore a design space beyond its seeding points. The outcome of this evolutionary design and discovery process is a suite of mechanical metamaterials with hitherto unknown structures. We perform theoretical and experimental studies to further study the mechanical performance of the discovered 3D configurations. Finally, we present a vision toward direct evolution of structural representation at multi-scale by passing more complex seeding points to the evolutionary process.

Automated image localization to support rapid building reconnaissance in a large-scale area

Xiaoyu Liu; Purdue University; United States
Shirley Dyke; Purdue University; United States
Ali Lenjani; Stanford University; United States
Ilias Bilionis; Purdue University; United States
Xin Zhang; Purdue University; United States
Jongseong Choi; The State University of New York, SUNY, Korea; South Korea

Collecting massive amounts of image data is a common way to record the post-event condition of buildings, to be used by engineers and researchers to learn from that event. Key information needed to interpret the image data collected during these reconnaissance missions is the location within the building where each image was taken. However, image localization is difficult in an indoor environment, as GPS is not generally available because of weak or broken signals. To support rapid, seamless data collection during a reconnaissance mission, we develop and validate a fully automated technique to provide robust indoor localization while requiring no prior information about the condition or spatial layout of an indoor environment. The technique is meant for large-scale data collection across multiple floors within multiple buildings. A systematic method is designed to separate the reconnaissance data into individual buildings and individual floors. Then, for data within each floor, an optimization problem is formulated to automatically overlay the path onto the structural drawings providing robust results, and subsequently, yielding the image locations. The end-to-end technique only requires the data collector to wear an additional inexpensive motion camera, thus, it does not add time or effort to the current rapid reconnaissance protocol. As no prior information about the condition or spatial layout of the indoor environment is needed, this technique can be adapted to a large variety of building environments and does not require any type of preparation in the post-event settings. This technique is validated using data collected from several real buildings

Automated Multi-Damage Detection on Historic Buildings in Post-Disaster Areas Using Image Segmentation

Joe Kallas; The Pennsylvania State University; United States
Rebecca Napolitano; The Pennsylvania State University; United States

Existing historic buildings suffer from the negative impact of natural and man-made disasters, threatening both their integrity and durability. Digital technologies can be a great tool for accelerating the disaster recovery process. In previous work, the author worked on the massive digitization of damaged historic buildings in Beirut following the accidental blast of August 4th 2020, and helped in accelerating the implementation of emergency interventions. With the aim of accelerating furthermore the post-disaster inspection of historic buildings, the present research explores the use of computer vision and machine learning to automatically detect damages on collected images of damaged buildings from the Beirut Explosion. While most of the previous studies explored extensively the automatic detection of cracks on concrete and pavements, this paper suggests a multi-damage and multi-class segmentation of images, by detecting not only different types of damages but different levels of the same damage types as well. The outputs of this research showed successful results in detecting damages on untrained images of damaged buildings from Beirut explosion. Moreover, random images of damaged buildings were collected from google and tested on the trained model and showed successful results as well.

Automated planning for the construction of laterally resistant masonry walls using irregular stones

Qianqing Wang; École Polytechnique Fédérale de Lausanne EPFL, Earthquake Engineering and Structural Dynamics EESD; Switzerland

Bryan German Pantoja Rosero; École Polytechnique Fédérale de Lausanne EPFL, Earthquake Engineering and Structural Dynamics EESD; Switzerland

Ketson Roberto Maximiano dos Santos; Stochastic Analysis and Signal Processing Lab, Department of Civil, Environmental, and Geo-Engineering (CEGE), University of Minnesota Twin Cities; United States

Katrin Beyer; École Polytechnique Fédérale de Lausanne EPFL, Earthquake Engineering and Structural Dynamics EESD; Switzerland

The construction industry's carbon footprint may be reduced by switching to the usage of natural stones as building materials. Construction of dry-joint stone masonry structures is difficult because stones can have irregular shapes and nonuniform sizes. Moreover, it typically requires skilled masons, who are in a massive shortage nowadays. Using stone stacking robots provides an efficient solution to build such structures. Therefore, the development of efficient algorithms is essential for designing the layout of stone masonry while ensuring that the structural and architectonic standards are met to allow robots to finish the physical construction successfully. The lateral resistance of masonry walls is rarely taken into consideration by existing layout planning algorithms. In this regard, we propose an image-based solution for automating the stacking of raw stones in the construction of 2D load-resistant stone masonry walls. Image processing techniques are employed to speed up the process of choosing and placing stones as well as to produce a computation model for the evaluation of the lateral strength of walls based on limit analysis. The computation simulation models are based on a variational rigid-block modeling method, using mathematical programming to obtain the load multiplier of the wall directly. The structural performance of walls constructed with the algorithm is compared to that of walls constructed using existing algorithms and by expert masons, and competitive typology measures are established to facilitate this comparison. It is demonstrated that the obtained solutions are comparable with the ones obtained by skilled masons. Moreover, the developed algorithm is capable of design walls of different sizes using different stone data sets efficiently. With respect to the computational performance, the algorithm can design a 32-stone wall in just 10 seconds, having the potential to be used in real-time applications with robots for the construction of masonry walls.

Automatic Segmentation and Measurement of Surface Concrete Spalling for Structural Members

Luis Espinola-Diaz; UTEC; Peru
Smith Huamani-Rojas; UTEC; Peru
Luis Alberto Bedriñana; UTEC; Peru

Reinforced concrete (RC) bridges are a critical part of road infrastructure; however in Peru and in many other countries, bridge condition assessment is limited, in terms of frequency of inspection and maintenance. In view of this, for instance, the Peruvian Ministry of Transport and Communications has proposed guidelines indicating the minimum frequency of inspections and damage classification for existing bridges. Nevertheless, it is a costly and time-consuming task since the guideline is based on visual, on-site inspections of bridges. Moreover, the guideline requires the exposure of inspectors to dangerous and unnecessary inspection contexts. Therefore, there is a need for more efficient approaches for the damage assessment of existing RC bridges. The objective of this research is to develop an automatic, photo-based, damage detection tool using Deep Learning (DL) techniques to measure concrete cover spalling. The proposed method utilizes convolutional neural networks (CNNs) for image segmentation to separate the spalled and non-spalled regions in the images of concrete surfaces. Some common architectures, such as U-Net and Mask R-CNN, are evaluated. In addition to the segmentation, the proposed system is able to extract damage parameters such as spalling diameter and depth, for a complete, fast and accurate acquisition of information. The proposed system shown promising results of approximately 95% accuracy for image segmentation. After the extraction of damage parameters, the system is also able to classify the damage level according to current guidelines for bridge inspection.

Autonomous Crack Sealing Robot for Infrastructure Maintenance using Reinforcement Learning

Joshua Genova; University of Houston; United States
Subin Varghese; University of Houston; United States
Vedhus Hoskere; University of Houston; United States

Surface cracks in buildings, if left untreated, can be detrimental to the structure itself and its surroundings. In addition, maintenance of cracks can potentially be located in areas that are inaccessible and dangerous to humans. Treating surface cracks before they become destructive can help save the structure, cost of future repair, and prevent injuries. There have been several works in crack detection, but there has been limited research in the maintenance of cracks especially with reinforcement learning (RL). RL can help address unpredictable observations in highly stochastic environments such as bridges, buildings, and roads to name a few. The focus of this paper is to present a deep reinforcement learning (DRL) approach to automate sealing surface cracks using a 6 degree-of-freedom robotic arm. With an overhead camera positioned on top of the robot, the agent will be able to identify the position of the crack in the x-y plane and the trajectory needed to fill the crack. Another camera will be positioned as a side view, allowing the robot to identify the height difference between the robot's end-effector and area of interest. The robot is simulated with our own custom environment and tested with multiple RL algorithms for comparison. The policy will then be evaluated on a myCobot 280 Pi by Elephant Robotics. However, sim-to-real applications still pose as a great challenge today. We use CycleGAN to bridge the sim-to-real gap well as domain randomization for varying environment attributes like camera pose to increase the robustness of the RL algorithm. Using DRL to automate robot trajectory to seal surface cracks can help prevent disastrous cracks from transpiring and ultimately maintain the integrity of structures.

Autonomous Defect Detection in Bolted Connections of Highway Ancillary Structures Using Deep Learning

Faezeh Jafari; University of North Dakota, Grand Forks, ND 58202, USA; United States
Sattar Dorafshan; University of North Dakota, Grand Forks, ND 58202, USA; United States

Bolted connections in ancillary structures are prone to bolt loosening and missing due to cyclic vibrations induced by natural environmental factors, such as wind, and passing of heavy vehicles and trucks. Not only physical inspections are difficult and time-consuming, inspectors may miss connection defects in hard-to-reach regions of an ancillary structure. Advanced object detection methods can be used to detect common bolted connected defects such as missing and loosened bolts and nuts autonomously; however, these methods have not been implemented for condition assessment of ancillary structures. Finding these defects in a realistic environment could be difficult due to complex dynamic background, such as cars, bikes, and pedestrians. This paper proposes defect detection models based on two advanced object detection algorithms using deep convolutional networks, Faster R-CNN and Mask -RCNN. A dataset of 400 images with bolted defects were generated in this study including defected and sound laboratory-made and in-service connections. Relevant background, bolt defects, and nut defects were superimposed on images of intact and in-service ancillary structures to mimic realistic condition and to increase the size of dataset. Data augmentation approaches were applied to increase the number of images with bolted defect to 1500. Mask R-CNN adds an object mask (Region of Interest) to the existing Faster RCNN (bounding box recognition). The dataset was annotated for Faster R-CNN and Mask -RCNN to create a trainset and test set, with 1350 images and 300 images, respectively. The models were trained and tuned on this dataset to detect comprised connections. Intersection over Union (IoU) was used to evaluate the performance of the trained models by comparing the estimated area in the model predictions and the ground truth for both algorithms. The efficiency of both algorithms in terms of true positive rate (TPR), true negative rate (TNR), IoU, and accuracy (ACC) has been compared and discussed. The TPR, TNR, IoU, and ACC were 98%, 94%, 95%, and 97% for Faster R-CNN, respectively. This value was 0.98, 0.97,0.98, and 98% for Mask-RCNN, respectively. Comparing Mask -RCNN with Faster R-CNN, the results indicate that Mask -RCNN is more accurate and has higher IOU than Faster R-CNN.

Autonomous delamination detection in reinforced concrete bridge decks using infrared thermography and an encoder-decoder-type DCNN model

Eberechi ICHI; University of North Dakota -; United States
Sattar Dorafshan; University of North Dakota; United States

Structural health monitoring and condition assessment of existing bridge structures is a growing challenge. Conventional human inspection, contact, and destructive methods are accompanied with drawbacks such as cost and labor-intensive, safety concerns, traffic closure during an inspection, undermining structural stability, and subjective outcomes. Noncontact sensing and monitoring using infrared thermography (IRT) is considered an alternative to traditional manned inspection. Sub-surface delamination in bridge decks can be autonomously and objectively detected using IRT data with developed artificial intelligence (AI) models. Deep convolutional neural networks (DCNNs) are superior to conventional image processing techniques. However, due to a lack of validated ground truth data for in-service bridges, DCCNs has not been successfully utilized for delamination detection for in-service bridge decks. In this study, an encoder-decoder semantic segmentation-based CNN architecture has been adopted. Its hyperparameters have been tuned to detect subsurface delamination effectively. A publicly available SDNET2021 dataset with pixel-wise annotation was used to train, validate, and test the models. Five models with different combinations of augmentation and weighted-pixel datasets were developed and benchmarked with the control model. The models were deployed on three levels of preprocessing datasets; raw, background annotated, and manually cleaned datasets, resulting in an overall of seventy-five models. Four-out-of-five bridges were adopted for training and validation, and the fifth bridge was for testing. Five k-folds were carried out to check the robustness of the model on the datasets. Results show minimum and maximum values for the performance metrics being evaluated; 0.447 to 0.773 for global accuracy, 0.494 to 0.697 for mean accuracy, 0.239 to 0.716 for precision, 0.243 to 0.558 for True positive rate (TPR), 0.529 to 0.899 for True negative rate (TNR), 0.282 to 0.550 for mean IOU, 0.261 to 0.427 for mean F1-score ranges, and 0.495 to 0.623 for mean F1-score. The DCNN model performed relatively better than the image-based semantic-segmentation technique, with an overall accuracy of 0.69.

Autonomous Pavement Surface Evaluation and Rating (PASER) Condition Assessment Using a Cost-effective RGB-D Data Acquisition System

Yu-Ting Huang; Purdue University; United States
Nikkhil Vijaya Sankar; Purdue University; United States
Mohammad Reza Jahanshahi; Purdue University; United States
Fangjia Shen; Purdue University; United States

The pavement conditions have deteriorated as time passes. It can cost a considerable amount of money for rehabilitation once the pavement conditions are below a certain level of deterioration. However, the service life of a pavement can be extended longer and with a small amount of money if it has periodical maintenance. To effectively increase the frequency of inspection, in this study, a crowdsourcing-based inspection system that can be mounted on multiple vehicles for autonomous road condition assessment is proposed. The proposed inspection system can evaluate the pavement condition based on the Pavement Surface and Evaluation Rating (PASER) system which is a rapid index on a scale of 1-10 with 1 being the worst condition, and 10 being the best condition. The proposed system is composed of two RGB-D sensors that can capture the 3D information of the complete lane width. In addition, a GPS sensor is used for frame registration to obtain spatial and temporal pavement conditions. Vehicles equipped with this data acquisition system are driven over the road through the cities twice per week, thus comprehensive RGB-D data of the road surface are collected timely and widely. To assign the PASER score according to the pavement conditions, a U-Net-based model is trained to detect cracks, another RGB-D fused network is trained for 3D defects detection such as potholes. With the pixel-level segmentation results, it can be used to quantify detected defects including the thickness of the cracks, damaged areas of alligator cracks, and depth of potholes for the severity level classification. Additionally, the proposed autonomous road inspection system can be used to monitor the evolutionary change of the defects such as cracks and potholes for the damage prognosis.

Auxetic confinement of steel-reinforced concrete members with architected truss lattices

Thomas Vitalis; Graduate Research Assistant, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA; United States

Andrew Gross; Assistant Professor, Department of Mechanical Engineering, University of South Carolina, Columbia, SC; United States

Georgios Tzortzinis; Postdoctoral Researcher, Dresden Center for Intelligent Materials (DCIM), Technische Universitat Dresden, Dresden; Germany

Brian Schagen; Master's Student, Faculty of Civil Engineering and Geosciences, TU Delft, Delft; Netherlands

Simos Gerasimidis; Assistant Professor, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA; United States

Auxetic truss lattice architected materials have been well-studied in the literature for their tunable geometric parameters that can achieve desirable and superior mechanical properties compared to conventional truss lattices. Advances in additive manufacturing methods have allowed the manufacturing of stainless steel auxetic lattice specimens for the experimental investigation of their mechanical behavior. This study discusses the results of axial compression tests of two separate additively manufactured auxetic truss lattice geometries targeting civil infrastructure applications. The selected geometries include a 3D re-entrant honeycomb (bowtie) geometry and a double pyramid geometry due to their favorable mechanical characteristics, manufacturability with laser powder bed fusion (DMLS), and concrete flowability around them. Specifically, experimental testing results of bare lattices and mortar-lattice composites utilizing various geometric parameters composites will be presented and compared for each geometry. Furthermore, computations on the influence of different geometric parameters and the effectiveness of composite confinement are presented for a periodic unit cell. Overall, superior energy absorption and excellent post-peak performance were observed for the auxetic truss lattice geometries, even at large strains exceeding 20%, illustrating the promising potential for the scale-up of these reinforced concrete truss configurations.

Axial stress measurement in continuous welded rails using impact-driven vibrations

Alireza Enshaeian; University of Pittsburgh; United States
Matthew Belding; University of Pittsburgh; United States
Piervincenzo Rizzo; University of Pittsburgh; United States

Continuous welded rails (CWR) are track segments connected by weld joints. With respect to mechanically-jointed rails, CWR provide a smoother ride to passengers, can be traveled at higher speeds, require less maintenance, and have a longer life cycle. However, CWR are prone to buckling during warm seasons when high temperatures induce large compressive axial force in the rails. To prevent buckling and therefore derailments, rail owners enforce slow orders or even shut the lines temporarily. The only way to avoid such inconvenience is by estimating the temperature of the rail at which the rail may buckle, and this is related to the rail neutral temperature (RNT), which is the temperature of the rail steel at which the average stress across the rail cross-section is zero. The estimation of the RNT is currently achieved by labor-intensive and sometimes invasive methods. In the study presented in this paper, an in-situ nondestructive evaluation technique was investigated to estimate axial stress and RNT. As part of the study, a general finite element model of CWR under varying boundary conditions and axial stresses was developed to predict the natural frequencies of rail vibrations. The model was then validated experimentally and updated by testing a real track in the field. During the experiment, an instrumented hammer was used to trigger vibrations which were recorded with an array of wireless accelerometers. The power spectral densities of the accelerations were extracted and compared with numerical predictions to estimate the RNT using machine learning algorithms. The estimates were then compared with measurements conducted by a third independent party that used strain gages, showing very good agreement. In this paper, a discussion about the challenges and the outcomes of the generated physics-based finite element model is carried out.

Bayesian deep learning for probabilistic virtual load monitoring of offshore wind farms

Nandar Hlaing; ANAST, Department of ArGEnCo, University of Liege; Belgium
Pablo G. Morato; ANAST, Department of ArGEnCo, University of Liege; Belgium
Francisco de Nolasco Santos; OWI-Lab, Vrije Universiteit Brussel; Belgium
Wout Weijtjens; OWI-Lab, Vrije Universiteit Brussel; Belgium
Philippe Rigo; ANAST, Department of ArGEnCo, University of Liege; Belgium
Christof Devriendt; OWI-Lab, Vrije Universiteit Brussel; Belgium

Monitoring solutions can effectively reduce the uncertainties associated with the estimation of deterioration mechanisms experienced by offshore wind structures [1], especially farther from shore, where structural components degrade faster, and inspections are more complex/ expensive. While a full load monitoring set-up installed on all turbines in a farm can be considered impractical due to economic constraints, 'fleet-leader'-based virtual monitoring methods can yield structural response predictions to non-fully instrumented wind turbines only based on always-available data, e.g., from a supervisory, control and data acquisition (SCADA) system and accelerometers. Pre-trained virtual sensing models deployed on non-fully instrumented turbines might, however, render inaccurate predictions if the received monitoring information substantially differs from the training dataset. While standard deep learning approaches are capable of finding complex relationships between high-dimensional input monitoring data and structural response metrics, they generally do not provide an indication of the uncertainty associated with the generated predictions.

Profiting from deep learning generalization capabilities and principled Bayesian inference methods, we propose here a Bayesian deep learning framework for farm-wide load monitoring of offshore wind structural assets. Specifically, the proposed virtual load monitoring model maps SCADA and accelerometer data to the associated stochastic structural response through a probabilistic Bayesian neural network (BNN) [2]. Based on data collected from a fully monitored turbine (i.e., fleet-leader), the probabilistic BNN is efficiently trained via variational inference methods. Following Bayesian principles, the estimated load uncertainty metric is further decomposed into its aleatoric component, associated with inherent physical phenomena variability, as well as the epistemic uncertainty that arise from the imperfectly trained model. To test the proposed virtual monitoring method, a probabilistic BNN is firstly trained based on data collected from an operating offshore wind turbine and it is then deployed to other turbines located in the same farm. The results reveal that Bayesian deep learning models intrinsically report higher model uncertainties when receiving out-of-training input data, and therefore, potential inaccurate predictions generated for non-fully monitored wind turbines can be systematically detected.

References:

[1] Hlaing, N., Morato, P. G., & Rigo, P. (2022). Probabilistic virtual load monitoring of offshore wind substructures: A supervised learning approach. In The Proceedings of the 32nd International Ocean and Polar Engineering Conference, ISOPE-2022, volume 4. pp. 3137–3144.

[2] Hlaing, N., Morato, P. G., de Nolasco Santos, F., Weijtjens, W., Devriendt, C., & Rigo, P. (2022). Farm-wide virtual load monitoring for offshore wind structures via Bayesian neural networks. arXiv preprint arXiv:2211.00642.

Bayesian fragility estimation for risk assessment of structures within the setting of generalized stratified sampling

Srinivasan Arunachalam; University of Michigan; United States
Seymour Spence; University of Michigan; United States

Fragility functions are critical components of risk assessment and life cycle cost analyses to help analyze system vulnerabilities under natural hazards. However, numerical fragility estimation is difficult when it is not straightforward to sample at desired intensity measures (IMs), particularly at large values, as is the case when explicit hazard modeling is involved. In addition, since the evaluation of the violation of performance objectives (or limit states) at a chosen IM entails expensive nonlinear analysis, there is a need for balancing the number of such analyses with accuracy. This work proposes a Bayesian approach to estimate fragilities with minimum computational cost while rigorously characterizing the uncertainty in the resulting fragilities with the posterior distribution of the fragility model parameters. The difficulty in drawing samples of the IMs when the IM itself is an output of a numerical model (i.e., hazard model), is tackled by the employment of subset simulation to generate samples over a wide range of intensity levels (or multiple strata), which is termed as generalized stratified sampling. This process also enables the determination of the hazard curve which when combined with the posterior samples of the fragility yields the structural risk defined with a probability distribution. Through a case study, we illustrate how by enforcing a structure on the fragility function (e.g., lognormal or logit), a limited number of analyses are required only to estimate the fragility parameter distributions, while also addressing the efficient identification of IM values at which to perform analyses, data quality associated with the chosen nonlinear modeling approach, and the seamless integration of prior information.

Bayesian Inversion for Soil-Structure System Identification

Abdelrahman Taha; University of Nevada, Reno; United States
Hamed Ebrahimian; University of Nevada, Reno; United States

This study presents an effort towards improving the state of practice of soil-structure interaction (SSI) modeling and analysis. The current state-of-practice SSI modeling guidelines are based on analytical and numerical approaches that involve multiple idealizations and simplifications about the soil-structure system behavior. There is, however, a lack of experimental studies that calibrate the existing analytical and numerical solutions. To this end, a system identification (SI) framework is proposed in this study for soil-structure systems based on a Bayesian finite element (FE) model updating technique. Using this framework, the superstructure model parameters along with the soil-foundation system parameters, i.e., the impedance function, are identified using the recorded response of the building to ground motions or forced-vibration excitations. The identified model parameters are then compared to the state-of-practice recommendations, and the potential sources of discrepancies are discussed. While a few applications of this new SI framework are presented in this study, it can be applied to other soil-structure systems subjected to different ground motions. Doing that, the estimation results can collectively be used for assessing and potentially improving the current state-of-practice SSI modeling specifications.

Bayesian Model Calibration Under Statistical and Model Errors Based on Polynomial Chaos Methodologies

Zhiheng Wang; University of Southern California; United States
Roger Ghanem; University of Southern California; United States

Engineering systems modeling is challenging and inevitably introduces errors. These errors can result from incomplete probabilistic modeling of uncertain parameters and loads (i.e., statistical error), and inaccurate physical modeling of the underlying mechanism which induces discrepancy from the reality (i.e., model error). In this presentation, we provide a procedure to assess the predictive accuracy of stochastic models subject to statistical and model errors. The approach is grounded in polynomial chaos formalism, and relies on formulating the polynomial chaos coefficients themselves as random variables in which the errors are embedded. The prior joint distribution of these coefficients is calibrated according to observations in a Bayesian paradigm. We demonstrate our approach on several problems of interest in science and engineering.

Bayesian Neural Networks with Physics-Aware Regularization For Travel Time Modeling from Imbalanced Data

Audrey Olivier; University of Southern California; United States
Sevin Mohammadi; Columbia University; United States
Andrew Smyth; Columbia University; United States
Matt Adams; New York City Fire Department; United States

The combined use of data and physics-driven modeling is an essential component of predictive engineering. Amongst other data-driven models, neural networks show great performance in learning complex functions from data, but they often lack predictive power away from training data. Poor generalization makes using deep neural networks challenging in settings where small amounts of data are available, or when the data is highly imbalanced. Deep neural networks are also challenging to integrate within a Bayesian framework necessary to quantify both the aleatory and epistemic uncertainties often prevalent in engineering applications with scarce data. In this work, we argue that methods of ensembling with regularization can be rooted in a Bayesian framework and allow to integrate prior information while quantifying epistemic uncertainties. In particular, we show that using function-space regularization – in opposition to traditional parameter-space regularization -- allows to appropriately integrate prior information about the function space of interest and enhance predictive power away from training data. We apply this learning framework to build a probabilistic ambulance travel time predictor, leveraging historical ambulance data provided by the New York City Fire Department. A road network analysis, coarse in both time and space, is leveraged to build the function-space prior. Combining this physics-driven prior with a non-Gaussian likelihood allows to appropriately quantify aleatory and epistemic uncertainties, which are both significant in this example, and to improve out-of-distribution performance of the predictor.

Biaxial testing and elastic characterization of a laminated membrane composite

Steven Palkovic; Simpson Gumpertz & Heger; United States
Andrew Sarawit; Simpson Gumpertz & Heger; United States
Mehdi Zarghamee; Simpson Gumpertz & Heger; United States

Laminated membrane composites are used for large-span tension and air-supported structures and consist of multiple layers of woven fabric joined with a polymer film. These composites exhibit nonlinear, viscoelastic, and anisotropic mechanical properties that vary with applied loads. This presentation will describe the development and implementation of a biaxial test frame and procedure for characterizing this complex material behavior for structural analysis and design. Pneumatic actuators are used for applying constant loads along two orthogonal axes that align with the warp and weft orientation of the fabric yarns. Digital Image Correlation (DIC) is used to evaluate the local strains in a central region of the cruciform specimen under load. This experimental setup is used to capture the stress-strain relationship of the membrane with varying proportions of applied load. Test results are analyzed to develop a plane stress orthogonal material model considering load-dependent secant moduli and Poisson's ratio that is implemented within the finite element analysis software Abaqus. The resulting material model is used for structural analysis of membrane structures to realistically predict the maximum demand in each fiber orientation under design loads.

Bio-inspired Horizontal Burrowing Robot by Breaking Symmetries in Granular Media

Yi Zhong; Arizona State University; United States
Julian Tao; Arizona State University; United States

Self-burrowing robots are a class of robot that can move underground. These robots can find applications in geotechnical site investigation, sensor deployment, save and rescue, and construction. Breaking the symmetry is believed as the key to burrowing in the granular medium. In this study, a bio-inspired, minimalistic horizontal burrowing robot was proposed, fabricated, and demonstrated its burrowing characteristics in glass beads. The robot mainly consists of a tip (flat, cone, or auger), and a pair of cylindrical parts. The robot can achieve extension-contraction with the utilization of a linear actuator and have options for tip rotation with an embedded gear motor. The robot with the flat tip was the control case, as it represented a nearly symmetric design and yielded negligible net movements. With a non-rotational cone tip, the robot was no longer symmetric in shape, and it moved forward slightly. With a rotational cone tip, the kinematics was also asymmetric, and the robot moved faster and farther. With a left-handed auger tip, the asymmetry in shape and kinematics was further enhanced and yielded the fastest burrowing rate. All the asymmetries contributed to the difference in resistance during the robot movement. A generic load-displacement-based model was proposed to quantify the effect of asymmetries and predict the movement of developed burrowing robots.

Bio-inspired silica coating for steel fibers

Jialai Wang; University of Alabama; United States

Concretes are most used construction materials. They can be considered as a three-phase material, the cement matrix, reinforcements and interfacial transition zones (ITZ) between the cement matrix and reinforcements. Various materials have been used as reinforcements for concretes, including coarse/fine aggregates and various fibers (steel, glass, carbon, polymers, natural fibers). The ITZ plays a critical role on the mechanical properties and durability of the concrete. This invention proposes a low-cost, eco-friendly, bio-inspired method to coat a thin layer of silica on the surface of steel fibers so that the bond strength between the fibers and the cement paste can be significantly improved, leading to higher strength and durability of the produced concrete.

Bound Preserving Numerical Methods for Infiltration in Porous Media

Arnob Barua; Louisiana State University; United States
CE Kees; Louisiana State University; United States

Simulating the infiltration process in variably saturated media by solving Richards' Equation (RE) remains a computationally challenging task. The degenerate parabolic nature of RE, along with the strongly nonlinear coefficients, makes it very difficult to obtain accurate solutions without using highly refined meshes. In the conventional Finite Element Method (FEM), the grid size must be fine enough to ensure convergence and limit non-physical oscillations, which is computationally expensive. This research aims to develop a second-order accurate FEM discretization with no non-physical oscillations for RE on unstructured meshes. For solving nonlinear systems, modified Picard Iteration and Newton's iteration are compared. The stabilization of the numerical solution is done by adopting mass lumping and approximating internodal hydraulic conductivity using different averaging methods like arithmetic, upstream, and geometric mean. Though it enables the solution to converge at the practical coarse grid size without any spurious oscillations, it causes extra diffusion which hampers the accuracy of the solution. An anti-diffusion term is added to the low-order solution by the Flux Corrected Transport (FCT) method. This will converge faster but maintain the monotone profile, regardless of the grid size. The result of the new discretized form is applied and validated using the multidimensional test problems mentioned in previous papers. The 2D and 3D infiltration problems are done using the PROTEUS package.

Bridge Deck Underside Condition Assessments with UAS Acoustic Sensor

Damien Garland; University of Vermont; United States
Tian Xia; University of Vermont; United States
Dryver Huston; University of Vermont; United States

Concrete bridge decks are high performance structural elements that should endure decades of harsh loading and environmental conditions. Even though the top side is the wearing surface that is subjected to thermal loads, deicing salts and a host of dynamic mechanical loads, the underside often degrades, forming delaminations and spalls. The danger of falling debris and degraded serviceability prompt enhanced condition assessments of deck undersides. This presentation will discuss the development and testing of an acoustic deck underside condition assessment tool. The technique is apply a mechanical impulse to concrete bridge decks, and then collect, analyze and interpret the acoustic response. In a sense, this is an automated hammer tap, or chain drag type assessment. Due to difficulties with accessing the underside of a bridge, a UAS-mounted system has been developed. System design, signal processing algorithms and results from performance tests will be presented.

Bridge health monitoring using WIM-data driven reliability assessment

Mi G. Chorzepa; Associate Professor, The University of Georgia; United States
Ananta Sinha; PhD student, The University of Georgia; United States

Weigh-In-Motion (WIM) data-driven monitoring of bridge structures can be effectively used to improve bridge reliability and extend service life. Bridge load rating is routinely performed to assess the maximum load carrying capacities which are compared against vehicular live loads to determine reliability. Yet, the live load data have been one of the most uncertain elements of bridge monitoring and are evaluated using permanent WIM sensors. Bridge WIM are not widely used in Georgia although it has been instrumented on a few bridges. Currently, there are approximately 30 active WIM-instrumented locations that are managed by the Georgia Department of Transportation. A growing number of permanently installed WIM sensors on roadways have enabled bridge reliability assessment. It associates WIM-instrumented routes with bridge locations in order to better characterize vehicle axle spacings and loads applied to approximately 5,000 National Highway System bridge structures. Condition ratings of bridges identified as having low reliability are closely inspected and monitored. Additionally, anticipated live load patterns are predicted using a Deep Learning approach. While resources are limited to conduct vibration-based condition assessment of bridges in Georgia, WIM data has enabled a valuable reliability analysis, identified bridges that require close monitoring either due to deteriorating conditions or a significant increase in live loads. The WIM data-driven approach was particularly critical for bridges that are anticipated to be affected by the Savannah port deepening and significant weight increases observed in the last few years. Case studies involving conditions of low reliability bridges identified through this project will be presented.

Bridge pier structural performance prediction framework driven by scour monitoring and extreme event forecasting

Neandro DeMello; University of Florida; United States
Jennifer A. Bridge; University of Florida; United States

Flood-induced scour is one of the leading causes of bridge failures in the United States, accounting for 53% of recorded failures between 1989 and 2000 . With many existing bridges considered “scour critical”, it is essential to closely monitor its development for effective mitigation. However, despite advances in scour hole measurement techniques, continuous monitoring of scour remains underused and little guidance is available to maintenance engineers to assess structural stability from scour depth measurements. This research has developed a proof-of-concept, model-free decision support framework to predict the stability conditions of bridge piers subject to scour and strong storm events. This framework is built on a vast library of bridge pier failure surfaces – curves that define failure limits for combinations of scour, wind, and hydrodynamic loading for a large range of structural configurations and site conditions. Failure surfaces are combined with scour hole measurements and probabilistic extreme event forecasting (e.g., hurricane wind speeds, and/or surge heights) to perform continuous, real-time pier stability projections. User input is limited to basic structural and site information, from which a corresponding failure surface is automatically selected, either directly or through interpolation between surfaces in the library. In addition to real-time decision support, the presented framework also serves as a scenario planning tool to enable maintenance engineers to investigate the impacts of extreme events prior to occurrence.

In this study, the creation of the failure surface library and framework focused on pile bent pier designs, due to their widespread use. A broad scope of parameters was modeled such that almost all possible configurations of pier bent bridge designs and site conditions in Florida were considered. To achieve this, sensitivity studies were performed to identify parameters for which simplifications and assumptions could be made to build the failure surface library. Case studies were performed to verify that reasonable representation of structural performance was maintained.

Bspline material point method for strongly coupled poroelastic materials

Ashkan Ali Madadi; The University of Texas at Austin; United States
David Garza; The University of Texas at Austin; United States
Berkin Dortdivanlioglu; The University of Texas at Austin; United States

In this work, we studied the strongly coupled diffusion in elastic solids to combine the effects of fluid pressure with solid deformation in soft materials. Exposed to external loadings, soft materials, e.g., biological tissues, hydrogels, and clays, may undergo extreme, nearly incompressible, self-contacting deformations, while mesh-based methods such as the finite element method (FEM) have deficiencies in i) mesh distortions in substantially large deformations, ii) accuracy issues originated from volumetric locking effects, and iii) high computational cost stemming from the contact search algorithms. As an alternative to FEM, the material point method (MPM) is a continuum-based meshless particle technique attracting considerable interest due to its robustness against extreme distortions, ability to capture contact at no additional cost, and ease of parallelization. The main objective of this paper is to add the effects of the diffusive water to the poromechanical behavior of soft solids at large deformation using the B-spline material point method. In the limit of incompressibility and near incompressibility, coupling the pore water pressure with solid deformation suffers from numerical instability due to the violation of the inf-sup condition, leading to spurious nodal pressure solutions. To stabilize the mixed poromechanics formulation, we used the two-scale relation of B-splines and developed a mixed MPM to obtain a stable, oscillation-free nodal pressure solution. We validate the stability and accuracy of the developed mixed MPM through several benchmark problems, including the compaction of a soft hydrogel sphere and the rigid strip footing on saturated soil. Additionally, we test the robustness of the proposed MPM by modeling the tensile behavior of soft porous membranes, where no slip contact condition is assumed, and the results are compared quantitatively to the experimental data. The proposed methodology provides a robust computational foundation to study extreme deformations coupled with the fluid pressure observed in practical soft matter applications.

Buckling of Short Beams Considering Warping with Application to Fiber-Reinforced Elastomeric Isolators

Eduardo Montalto; University of California, Berkeley; United States
Dimitrios Konstantinidis; University of California, Berkeley; United States

Fiber-reinforced elastomeric isolators (FREIs) have been proposed as a low-cost alternative to traditional steel-reinforced elastomeric isolators. The use of lightweight carbon-fiber reinforcement and elimination of the attachment plates reduce the material, manufacturing, and installation costs, while improving the isolation efficiency. Nevertheless, the fiber reinforcement flexibility in bending allows cross-sectional distortions (or warping) to occur. This is deemed to have a significant impact on the buckling capacity of these devices, which is a critical aspect of their design. However, existing formulations accounting for such an effect predict vastly different buckling loads and, hence, studies about FREIs continue to use formulations developed for steel-reinforced isolators where warping is precluded. This research presents a theory for the buckling of short shear-deformable beams, suitable for the analysis of FREIs, based on a consistent linearization of the fully nonlinear two-dimensional problem. The proposed nonlinear deformation field considers the warping amplitude as an independent kinematic field, while the material constitutive relation selected assumes linearity of the stresses normal and tangent to the deformed cross section with respect to their work-conjugate strains. An approximate closed-form solution for the critical load, suitable for practical implementation purposes, is provided for the resulting higher-order equation. Theoretical differences giving rise to distinct buckling theories for higher-order shear beams are discussed in terms of (1) the assumed deformation field, (2) variational consistency and (3) nonlinear material behavior. Subsequently, modifications required to apply the theory to three-dimensional elements are described. The isolator effective warping-related rigidities and cross-sectional properties required to apply the theory are derived accounting for rubber compressibility effects and, for planar bearings, extensibility of the reinforcement. The adequacy of the proposed and existing formulations is assessed by means of a finite element parametric study of the buckling of unbonded FREIs; planar and three-dimensional cases are evaluated. The theory presented herein and its approximate solution exhibit excellent agreement with the numerical results, and the approximate solution is deemed adequate for practical implementation.

CabanaPD: A meshfree GPU-enabled peridynamics code for exascale fracture simulations

Pablo Seleson; Oak Ridge National Laboratory; United States
Sam Reeve; Oak Ridge National Laboratory; United States

Peridynamics is a nonlocal reformulation of classical continuum mechanics suitable for material failure and damage simulation, which has been successfully demonstrated as an effective tool for the simulation of complex fracture phenomena in many applications. However, the nonlocal nature of peridynamics makes it highly computationally expensive, compared to classical continuum mechanics, which often hinders large-scale fracture simulations. In this talk, we will present ongoing efforts to develop CabanaPD, a meshfree GPU-enabled peridynamics code for large-scale fracture simulations. CabanaPD is built on top of two main libraries: Kokkos and Cabana, both developed throughout the Exascale Computing Project (ECP). CabanaPD is performance-portable and exascale-capable, and it is designed to run on U.S. Department of Energy's supercomputers, including the newly deployed Frontier, which is the first exascale machine and today's top supercomputer worldwide.

Cable-Actuated Prestressed Origami Tubes

Megan Ochalek; Stanford University; United States
Manan Arya; Stanford University; United States

A Miura tube is an open polyhedral surface with planar quadrilateral panels connected with straight momentless hinges. A Miura tube can be folded to be flat in two different configurations. It is a periodic structure, with a unit cell that can be tessellated in many arrangements in multiple different directions. Thus, Miura tubes have compelling design scalability and flexibility, and have applications in civil engineering, spacecraft structures, and morphing robots.

Previous approaches to actuating the folding motion of such tubes have employed magnets and pneumatic pressure. We explore actuating Miura tubes using a single tensioned cable that is routed through holes in the panels in a closed-loop path. A single spool is placed in the middle of the cable, such that shortening one side of the cable lengthens the other side by the same amount. Through careful choice of the routing path, the total cable length can be made to remain more-or-less constant as the spool is rotated. The spool is controlled by a servo-motor, which may be mounted to a flat panel at either end of a Miura tube. By rotating the spool in one direction, the Miura tube can be made to transition from one flat-folded configuration to another flat-folded configuration; rotating the spool in the other direction reverses the folding motion of the tube. Within a unit cell, the winding path of the cable satisfies periodic boundary conditions, and thus this concept is compatible with the tessellation of Miura tube units in one direction. Additionally, the cable may be tensioned using an idler pulley.

Without this tensioned cable, the folding of the Miura tube is a kinematic deformation mode with zero stiffness. A surprising effect of the presence of this pre-tensioned cable is that the folding mode of the Miura tube acquires finite stiffness. Finite stiffness is present at all intermediate states between the two flat-folded configurations.

We present design approaches, preliminary analyses of behavior, and experimental results from small-scale prototyping efforts. These efforts are directed towards developing modular flat-folding roving robots for space exploration. In this concept, many robots could be flat-packed into a small volume as secondary payloads abord a mothership, and then be deployed to enable multi-robot exploration of a planetary surface. The robot consists of zipper-coupled Miura tubes (made of textile-enhanced rigid-flex printed circuit board) with non-folding wheels for locomotion. In this concept, the spool for actuating the unfolding cables is located within the non-folding wheels. The proposed cable-based actuation scheme has been demonstrated to function with thick-origami implementations of Miura tubes.

Can you trust your AI crack detection model in the wild: benchmarks & enhancement strategies

Chen ZHANG; Hong Kong University of Science and Technology; Hong Kong
Jize ZHANG; Hong Kong University of Science and Technology; Hong Kong

AI-based semantic segmentation approaches have shown great potential in asphalt and concrete crack detection. Yet, despite their high accuracy in controlled conditions, it is crucial to understand their performance with respect to a wide range of environmental noises. In this talk, we will present an exhaustive benchmark study for the robustness of crack detection segmentation models on popular benchmark datasets. Moreover, we will provide insights, and remedies for improving the crack-detection AI model robustness. Together, this work will aid future effort toward AI techniques that robustly generalize to real-world conditions.

Carbon nanotube (CNT) reinforced cementitious composites using carboxymethyl cellulose (CMC) treatment for enhanced dispersion, mechanical, and piezoresistive properties

Dawei Zhang; North Dakota State University; United States
Ying Huang; North Dakota State University; United States
Wenjie Xia; North Dakota State University; United States
Leonard Chia; North Dakota State University; United States

Carbon nanotubes (CNTs) reinforced cementitious materials have a great potential of possessing enhanced mechanical and electrical properties. However, a homogeneous CNT dispersion in the cementitious composite is generally regarded as the prerequisite to fulfill such advanced properties. This study investigated the dispersion, mechanical and piezoelectric properties of CNT reinforced cementitious composites using carboxymethyl cellulose (CMC) treatment by comparing with three other existing mixing methods, including mechanical mixing, surface treatments using octenyl succinic anhydride (OSA) modified tapioca starch as a polymeric additive, and sodium dodecylbenzene sulfonate (NaDDBS) as a surfactant. The experimental results indicated that the CMC treatment was categorized as a noncovalent functionalization and showed effectiveness in improving CNT dispersion, compressive strength, modulus of elasticity, Poisson ratio, and piezoresistive sensitivity of CNT reinforced cementitious composites. In addition, this study also explored the influence of cementitious material ingredients on the piezoelectric properties of CNT reinforced cementitious composites, revealing that the piezoresistive sensitivity reduced progressively as the addition of sand and coarse aggregates.

Carbon sequestration in cementitious materials: Characterizing the hydration processes in early-stage carbonated concretes

Marcin Hajduczek; MIT; United States
Damian Stefaniuk; MIT; United States
James C. Weaver; MIT; United States
Franz-Josef Ulm; MIT; United States
Admir Masic; MIT; United States

Concrete, with its main component, Ordinary Portland cement (OPC), is the most widely used construction material in the world. Due to a combination of factors including its widespread use, the extreme temperatures required to stabilize clinker phases, and the carbon-positive process of limestone (CaCO3) calcination to produce CaO, OPC production currently accounts for ca. 8% of global CO2 emissions. Growing concerns over the material's environmental impact, as well as the American cement industry's goal of reaching carbon neutrality by 2050, have prompted numerous solutions in recent years to mitigate greenhouse gas emissions associated with concrete use. One promising solution is the sequestration of anthropogenic CO2 in concrete through early-stage out-of-equilibrium forced carbonation before the material cures. While concrete has long been known to undergo potentially mechanically compromising late-stage CO2 sequestration throughout its lifespan, comparatively little is known regarding the factors and mechanisms governing the early stages of cement hydration during forced carbonate mineralization in both the cementing minerals and their aggregates.

To better clarify the potential strategic benefits of these processes, an integrated correlative time-space resolved Raman spectroscopy and indentation approach was applied to investigate the underlying mechanisms and chemomechanics of cement carbonation. To mimic the conditions that exist following CO2 enrichment during early-stage forced carbonation, a model system consisting of bicarbonate-substituted cement formulations was analyzed over time scales ranging from the first few hours to the first several days of hydration. This system allowed for the tracking of phase transformations in carbonated samples, while correlation function analysis was used to investigate the temporal evolution and detailed spatial distribution of the different mineral phases formed. The results from these studies suggest the presence of a short time window in which the carbonation of cementitious materials doesn't compromise the material's structural integrity, while simultaneously allowing significant quantities of CO2 to be mineralized in the form of calcium carbonate nanoparticles.

Carbon-cement supercapacitors: A scalable bulk energy storage solution

Damian Stefaniuk; MIT; United States
Nicolas Chanut; MIT; United States
James C. Weaver; MIT; United States
Yang Shao-Horn; MIT; United States
Franz-Jozef Ulm; MIT; United States
Admir Masic; MIT; United States

Motivated by the need to develop alternative energy storage solutions that utilize globally abundant mineral precursors, here we propose a porous carbon-cement-based composite material system as a scalable solution to support our society's urgent need to transition from fossil fuels to renewable energies. By employing multi-scale correlative SEM-EDX-Raman spectroscopy, we can quantitatively determine the spatial relationships between the constituent phases and their maturation pathways during the early stages of cement hydration, when hydrophilic cement reacts with water in the presence of a hydrophobic carbon phase to create a uniquely textured electron-conducting carbon network, permeating an insulating porous cementitious matrix.

We show that by combining the high specific surface of disordered micro-porous carbon available for charge storage, with hydration porosity in the cement paste saturated by an electrolyte, it is possible to produce functional carbon-cement supercapacitors. More specifically, from scaling relations of the energy storage capacitance obtained by cyclic voltammetry at different scan rates, we identify a rate-independent volumetric capacitance of these composite supercapacitors as an intensive quantity. This discovery represents an opportunity for mass scaling of energy storage capacity from the single electrode to architectural length scales using readily available material precursors that can be locally sourced from virtually anywhere on the planet. The availability and scalability of porous carbon-cement supercapacitors thus opens a new horizon for the design of multifunctional structures that leverage high energy storage capacity, high rate charge/discharge capability, and structural strength for sustainable residential and industrial applications.

Cascade failure analysis of transmission tower systems

Saransh Dikshit; Iowa State University; United States
Alice Alipour; Iowa State University; United States

Transmission tower systems are susceptible to weather events like tornadoes, hurricanes, derechos, etc. The present study quantifies the resilience of a line of electric transmission towers to straight-line wind. Fragility curves are established for the towers which are used to evaluate the probability of an initial tower failure and the probability of further towers failing in a cascade when the towers next to previously failed towers are weakened by their unbalanced loading.

CFD analysis of materials surface roughness changes on heat transport in multi-layer walls

Arkadiusz Urzedowski; Lublin University of Technology; Poland
Joanna Styczen; Lublin University of Technology; Poland

This study explores the relationship between the surface roughness of construction materials and heat transport. In connection to energy transformation, many efforts are being taken to construction zero-energy buildings. Among many factors, the thermal resistance of the wall is the most important one to determine the performance of the insulating package. Heat transfer through multi-layer walls is a very complex process, however in the air gaps between materials, which are considered in article, the dominant phenomena are radiation and convection. CFD analyzes were performed on three-dimensional model, which surfaces imitated the real shape of the materials. This method required performing surface metrology of materials obtained from a three-dimensional scanner and developed in 3D metrology software. Considered multi-layer wall consists of 0.25 m concrete, 0.15 m thermal insulation, 0.06 m air gap and 0.012 m cover. Three temperature ranges inside and outside the building were analyzed in the calculations: 278.15 - 298.15K, 273.15 - 293.15K and 268.15 - 288.15K. In conclusion, the use of reverse engineering, three-dimensional metrology and CFD allowed to estimate the impact of changing the shape of the surface on the thermal insulation of external building partitions.

CFD-enabled surrogate modeling of self-excited forces for single-box deck bridges

Sumit Verma; Texas A&M University-Corpus Christi; United States
Miguel Cid Montoya; Texas A&M University-Corpus Christi; United States
Ashutosh Mishra; Texas A&M University-Corpus Christi; United States

Wind-induced responses are among the more demanding performance indicators that drive the design of medium- and long-span bridges. Their deck cross-section geometries are designed to pursue the most beneficial balance between cost-effectiveness, mechanical contribution, and aeroelastic performance. Depending on the bridge use, location, project specifications, local climate, and mechanical properties, among others, the aero-structural optimum deck configuration can range from streamlined geometries that prioritize the aeroelastic performance to bluff bodies with effective mechanical properties and acceptable aerodynamics. In this context, design frameworks must be formulated versatilely to be efficient and accurate in all circumstances. This study addresses this issue by developing an aero-structural design framework based on a Kriging emulator trained with CFD dynamic simulations. Scanlan´s flutter derivatives are calculated by carrying out forced vibration simulations using 2D URANS, the Menter´s k-ω SST turbulence model, and imposing a single degree of freedom pitching or heave motion. Verification and validation studies are conducted to ascertain the accuracy of the results using experimental data available in the literature. An aeroelastic surrogate model is built to provide the flutter derivatives for any deck shape candidate design at any reduced velocity and angle of attack. This surrogate model is developed to be integrated into aero-structural design frameworks for the shape optimization of bridge decks.

Charactering the basic creep behavior of 3D printed concrete with layered structures

Mohammadhossein (Mahan) Kosarimovahhed; FLORIDA STATE UNIVERSITY; United States
Qian Zhang; FLORIDA STATE UNIVERSITY; United States
Sungmoon Jung; FLORIDA STATE UNIVERSITY; United States

Concrete additive manufacturing, also known as 3D concrete printing (3DCP), has recently captured attention among researchers due to advantages over conventional concrete. However, there is a knowledge gap about the mechanical response, especially the creep behavior of the material. In this paper, the short-term basic creep behavior of 3DCP materials with different layer constructions and loading directions was experimentally investigated using a compressive macroscopic creep test and the results were compared with that of the cast in mold samples with the same mixture composition. This research provides valuable experimental data on the short-term creep compliance of 3DCP that are urgently needed and discusses the parameters that influence the basic creep behavior of 3DCP.

Characterization of the Damage Tolerance of Composite Overlays through Subspace Evaluation

Corey Arndt; University of Tennessee; United States
Stephanie TerMaath; University of Tennessee; United States

Composite overlays to repair or reinforce damaged metal structure offers many advantages over traditional repair methods. However, the resulting composite/metal system exhibits complex progressive damage propagation that is influenced by a high dimensional parameter space. To characterize damage, an approach encompassing experimental testing, finite element analysis, and subspace surrogate modeling is demonstrated to predict and evaluate the damage tolerance of an aluminum plate reinforced with a co-cured bonded eglass/epoxy composite overlay under four point bending. Reduced order surrogate models are formulated from high fidelity models for the total damage energy absorbed as well as the individual contributions of each damage mechanism to understand the effects of these subspaces throughout the full damage tolerance space. This problem is shown to be highly dependent on the structural and loading configuration, and the contributions of each damage mechanism vary throughout the full space. The disbond damage at the interface between the resin and metal proved the most difficult for reduced order surrogate modeling and a binary function was needed to engage this damage mechanism when applicable based on the values of the most influential parameters. As a whole this problem is difficult to characterize and breaking the problem into interacting subspaces leads to improved information on influential parameters and efficient reduced order surrogate modeling.

Characterizing the elasto-adhesive length of polymeric materials

A. Derya Bakiler; Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX, USA; United States

Berkin Dortdivanlioglu; Civil, Architectural and Environmental Engineering, The University of Texas at Austin, Austin, TX, USA; United States

Mechanical characterization of the adhesive behavior of soft materials, e.g. hydrogels and biological tissues, remain elusive at small length scales. At these length scales ranging from micrometers to millimeters, surface effects such as surface tension and adhesive forces become of comparable magnitudes to that of the bulk and significantly influence the overall behavior of the structure. Thus, understanding the adhesive properties and mechanisms of interfacial failure of polymeric materials is crucial to be able to fully harness their potential in emerging soft material applications. In this presentation, we quantify the separation mechanics of soft-hard and soft-soft interfaces endowed by low-dimensional energetics by developing an interface-enriched, isogeometric finite element framework. The numerical results will elucidate the "elasto-adhesive length" of materials, defined as the ratio of adhesion energy and the young's modulus. The elasto-adhesion length over changing bulk modulus, interface tension, and interface stiffness will be reported through phase diagrams. Furthermore, the results will give insight into the traction-separation laws that govern polymeric materials at small scales, which remain yet an open question. The findings here will pave the way for the design, manufacturing, and assembly of small-sized structures involving highly deformable materials.

Characterizing the geomechanical constraints of long-term CO2 injection and storage through fully coupled 3D fluid flow, geomechanics and hydraulic fracture simulations.

Ankush Singh; ResFrac Corporation; United States
Mark McClure; ResFrac Corporation; United States
Garrett Fowler; ResFrac Corporation; United States

Scaling up of CO2 storage to gigaton scale requires abundance of favorable and well characterized geological storage sites. To understand the true storage capacity of a prospective geological target site we need to answer the question: how much fluid can be injected economically while minimizing the subsurface risks such as caprock failure and induced seismicity? The answer to this question requires subsurface characterization and modeling to understand the pressure and temperature changes induced by the fluid injection in the geological layers. We investigate the subsurface changes from injection and long-term CO2 storage by using a fully coupled 3D hydraulic fracture, compositional fluid flow and geomechanics simulator. We capture the thermoelastic fracturing from long term CO2 injection. We also analyze the Coulomb stress changes and the potential for triggering slip on pre-existing fracture planes of varied orientations due to thermos-poro-elastic stress changes. The simulations show that CO2 injection is a complex multi-physics problem. The pressure and stress magnitudes near the injection site vary temporally and spatially. We illustrate the formation and growth and hydraulic fracture due to the stress changes. We discuss the implications of fracture growth in the context of both potential injectivity improvements and risk of cap rock failure. We also discuss the implications of the stress change on the risk of induced seismicity. The simulations highlight the need for a well characterized stress state in order to design a field-scale CO2 injection project. Finally, we introduce an integrated workflow to optimize field-wide CO2 injection designs while reducing the subsurface risks.

Chemo-mechanical homogenization applied to climate and energy geomechanics

Chloe Arson; Georgia Institute of Technology; United States

Landscapes encode the history of the climate. For example, saprolite, the intermediate material between rock and soil, plays a critical role in the evolution of topography, nutrient supply, landslide hazards, and the global carbon cycle. The subsurface also bears resources used for the production of energy and construction materials. It is thus important to assess the response of soils, rocks and other geomaterials to a varying climate and to increasing societal demands In this talk, we present analytical models to predict the propagation of microscopic cracks in porous media subjected to variable mechanical, hydraulic and chemical conditions. We first explain a micro-mechanical model of anisotropic damage induced by the weathering of biotite minerals. The bedrock is modeled as a matrix that contains an anisotropic distribution of microscopic cracks and biotite inclusions endowed with a weathering strain field, called eigenstrain. The mechanical properties of the bulk rock are calculated by means of two Mori-Tanaka homogenization steps. With this model, we conduct a series of finite element simulations in bedrock under gently rolling topography and a range of biotite orientations. In our simulations, crack growth and stress redistribution are far more sensitive to biotite weathering than to the topographic or regional stresses, which suggests that biotite weathering is capable of dominating the development of bedrock damage. We deploy cohesive zone (CZ) elements at the boundary of the finite elements and show that biotite weathering can affect the trajectory of metric fractures. To upscale the transport properties of the bedrock from the microscopic to the metric scale, we then extend the theory of homogenization to diffusion problems by using imperfect interfaces. We develop a self-consistent model for halite that explains why rock made up of larger crystals exhibit lower creep deformation, while specimens with smaller grains have a lower diffusivity. Simulations show that grain boundary healing accelerates specimen compaction, while precipitation in the pores controls the evolution of effective diffusivity. These results are impactful for geological storage design, but it remains challenging to formally link the microstructure changes induced by chemical reactions and pore deformation to macroscopic physical and mechanical properties, because the key microstructural features that govern macroscopic fluid flow differ from those that dominate elastic, plastic and brittle behaviors. We thus conclude this talk by discussing Artificial Intelligence strategies to extract microstructure features from various image data.

Classical density functional theory for nanoconfined inhomogeneous water-Co2 mixture on mineral surfaces.

Ali Morshedifard; University of California, Irvine; United States
Mohammad Javad Abdolhosseini Qomi; University of California, Irvine; United States

The looming climate crisis necessitates an accelerated development of carbon capture and storage technology. A feasible solution is in situ injection of CO2 into underground basalt formations as done in Carbfix and Wallula projects. While carbonation mechanisms in water-rich cases are well understood, the research on the Co2-rich case is still in its infancy. Using grand canonical Monte Carlo (GCMC) simulations our group recently showed that the water nanolayer formed on the mineral surfaces, significantly alters the bulk reaction pathways. Moreover, the thickness of the nanofilm was shown to have a critical role in the carbonation reactions in the nanofilm. However, GCMC calculations take days to run and are difficult to converge. In this study, we use a physically-based equation of state named statistical associating fluid theory of Variable Range (SAFT-VR) along with density functional theory (DFT) to model the complex Co2-water mixture behavior at the mineral surfaces. We focus on forsterite which is the most thermodynamically and kinetically suitable candidate for carbon sequestration in mafic lithologies. We develop parameters for forsterite interaction with the fluid mixture. Next, the theoretical water film thickness is computed based on fluid densities on the surface and is compared against both GCMC calculations and experimental results from attenuation and total reflection IR spectroscopy. Besides the capability of the model to capture the trends correctly, the theoretical results can be obtained in a matter of seconds which is drastically shorter compared to GCMC. We hope that the developed model can facilitate further research into carbon sequestration of other minerals by providing an accurate alternative to expensive experiments or molecular calculations.

CO2 mineralization of silicate minerals and the potential inhibiting effect of amorphous silica-rich surface layers

Kumaran Coopamootoo; Princeton University; United States
Claire E. White; Princeton University; United States

The production of Portland cement clinker occurs by the decomposition of calcite ($CaCO_3$) in limestone, and this leads to 5-8% of anthropogenic CO_2 emissions. CO_2 mineralization of cement-based silicate constituents, including non-Portland cement clinker phases such as wollastonite ($CaSiO_3$), can be thought of as the reverse of this reaction and a technique that, if well-understood and tailored, could achieve significant CO_2 uptake to help counterbalance emissions from limestone decomposition. Mineralization occurs through the extraction of calcium cations from silicates dissolving in an aqueous environment and subsequent $CaCO_3$ precipitation. However, as cations are extracted, a structural rearrangement occurs at the surface of partially reacted silicate grains forming amorphous silica-rich surface layers (ASSLs). The ASSLs can inhibit further cation extraction and ultimately, the efficiency of mineralization. Very little is known about the conditions necessary to form ASSLs, its characteristics, or properties. In this work, we investigate the formation, resultant structure and properties of ASSLs when synthesized crystalline γ-belite (γ-C2S) dissolves. γ-C2S is hydraulically inactive and is therefore a candidate for CO_2 mineralization, which is similar to that of $CaSiO_3$ and naturally abundant $(Mg,Fe)_2SiO_4$ (olivine). Through a robust experimental scheme, we aim to map out the relationship between solution composition, temperature and pressure during the dissolution of γ-C2S, and the atomic structure, layer thickness and pore structure of the ASSLs formed. These findings will help us determine which dissolution conditions can best mitigate the formation of ASSLs during CO_2 mineralization of γ-C2S and other important silicate minerals.

Coarse graining planar kirigami, Part 1: Continuum PDE description

Paul Plucinsky; University of Southern California; United States
Ian Tobasco; University of Illinois Chicago; United States

Shape-morphing finds widespread utility, from the deployment of small stents and large solar sails to actuation and propulsion in soft robotics. Kirigami — patterns of cuts in a sheet — a versatile platform for shape-morphing, inspiring the design of such structures and devices. However, it remains a challenge to predict their response to a broad range of loads and stimuli. This talk explores general continuum modeling principles for kirigami.

In this talk, we describe a coarse graining procedure to determine all the slightly stressed modes of deformation of a class of periodic and planar kirigami. The procedure gives a system of nonlinear partial differential equations (PDE) expressing geometric compatibility of angle functions related to the motion of individual slits. Leveraging known solutions of the PDE, we present excellent agreement between simulations and experiments across kirigami designs, and highlight how the PDE type determines the character of the response.

This is Part 1 of a two part talk in collaboration with Ian Tobasco at UIC. For Part 2, see "Coarse graining planar kirigami, Part 2: A mechanism gradient theory".

Coarse graining planar kirigami, Part 2: A Mechanism Gradient Theory

Ian Tobasco; University of Illinois Chicago; United States
Paul Plucinsky; University of Southern California; United States

Kirigami sheets involve a lattice of cuts that exhibit strange morphing properties depending on the choice of the cuts. The first part of this talk showed how to view kirigami as a continuum, by deriving a partial differential equation (PDE) for its effective deformations. The question we address here is how to select a given PDE solution from the many possible solutions given boundary displacements or loads. We do so by coarse-graining the interpanel forces of a soft kirigami deformation to extract a strain-gradient like (actually a mechanism-gradient) term. The key idea is to spread the panel strains of fitting the kirigami about a given PDE solution in an optimal way. The full coarse-grained description of kirigami then includes both a term for enforcing the PDE through a bulk stress, and a term for regularizing the solution according to its mechanism gradients. We demonstrate the theory by applying it to predict the motion and force--displacement curves in examples.

This is Part 1 of a two part talk in collaboration with Paul Plucinsky at USC. For Part 2 see ``Coarse graining planar kirigami, Part 1: Continuum PDE description".

Coarse-Graining of Thermomechanical Behaviors of Functional Polymer via Energy Renormalization

Zhaofan Li; North Dakota State University; United States
Wenjian Nie; North Dakota State University; United States
Dawei Zhang; North Dakota State University; United States
Wenjie Xia; North Dakota State University; United States

Functional polymers, especially recently emerged conjugated polymers, possessing the characterization of relatively rigid conjugation backbone and peripheral flexible side chain have attracted considerable attention toward the application of organic electronic and optoelectronic devices. The computational prediction of the thermomechanical behavior of functional polymers to serve the needs of materials design and prediction of their performance is a grand challenge due to the prohibitive computational times of all-atomistic (AA) molecular dynamic (MD) simulations. Coarse-grained (CG) modeling is an essential strategy for making progress on this problem. In this work, focusing on one widespread explored functional polymer, we develop a temperature-transferable CG model based upon the energy-renormalization (ER) approach that allows for modeling of polymer dynamics over a wide temperature range and accessing greater spatiotemporal scales. The results show that the CG model faithfully and accurately capturing the short- and long-time scale dynamics, i.e., Debye-Waller factor and segmental relaxation time. Systematically exploration of the mechanical properties, such as tensile and shear, reveals that the cohesive interaction exhibits a great impact on the mechanical response. Our work highlights the necessity and feasibility of ER when modeling a functional polymer that possesses branched architecture, and sheds new light on the rational design of the temperature-transferable CG model of other functional polymer materials for thermomechanical and conformational prediction.

Combination of Statistical Linearization and Harmonic Balance for non-stationary random vibration analyses.

Beatrice Pomaro; Department of Civil, Environmental and Architectural Engineering, University of Padova, Via F. Marzolo 9, 35131 Padova; Italy

Pol D. Spanos; L. B. Ryon Chair in Engineering, Rice University, 6100 Main Street, Houston, TX 77005-1827; United States

Non-stationary nonlinear random vibrations involving polynomial kind of stiffness and damping nonlinearities of dynamic systems are investigated. Attention is focused on assessing the performance of two linearization schemes [1] for estimating the system response statistics. The first one relates to traditional Statistical Linearization, in which effective stiffness and effective damping are determined as functions of the response statistics. The second one introduces a prior first step of Harmonic Balancing in deriving response-amplitude dependent equivalent stiffness and damping. Then, the expected values of these parameters are considered, in proceeding to formulate a Statistical Linearization solution approach. In this context the expected values of the equivalent stiffness and damping, which depend on the statistics of the amplitude, are determined as functions of the variance of the system response itself. The solution procedure is completed by integrating in time the Lyapunov equation associated with the derived equivalent linear system. It is pointed out that the Harmonic Balancing is associated with the assumption of lightly damped nonlinear systems. This limitation, however, must be juxtaposed versus the option of using the pre-Harmonic Balancing for applying Statistical Linearization on hysteretic systems [2, 3] or systems with fractional derivatives [4]. This can be done without resorting to traditional representations, such as the classical Bouc-Wen model, which involve augmentation of the dimension of the requisite equivalent linear system. The two approaches are compared for a variety of nonlinear systems; a series of germane Monte Carlo studies are used to elucidate salient features of the two approximations.

[1] Roberts J.B., Spanos P.D., Random vibration and statistic linearization. Dover Publications Inc., Mineola, New York, 1999.

[2] Wen Y.K., Method for random vibration of hysteretic systems, Journal of the Engineering Mechanics Division, 102(2), 1976, 249-263.

[3] Naess A., Moe V., Stationary and non-stationary random vibration of oscillators with bilinear hysteresis, International Journal of Non-Linear Mechanics, 31(5), 1996, 553-562.

[4] Spanos P.D., Zhang W., Nonstationary stochastic response determination of nonlinear oscillators endowed with fractional derivatives, International Journal of Non-Linear Mechanics, 146, 2022, 104170.

Commercial and Sustainable Hydrogels for Internal Curing and Shrinkage Control in Concrete

Asif Jalal; North Dakota State University; United States
Ravi Kiran; Arizona State University; United States

Continuous water supply in the concrete matrix promotes cement hydration to gain full strength and maintain humidity levels to avoid autogenous and drying shrinkages. However, limited external water penetration and insufficient capillary water availability at a low water-to-cement ratio (w/c<0.36) concrete mix can lead to early age cracks, and lack of available moisture may lead to drying shrinkage and an increase in un-hydrated cement particles. Hydrogels made from super absorbent polymers (SAPs) and biobased materials can serve as a source of internal water when used as additives. However, the hydrogel's water donation potential and internal curing mechanisms are not entirely established in the literature. The current study aims to devise a new way to observe the water holding and releasing process in hydrogels made from SAPs and biobased materials and their contribution towards cement hydration and shrinkage control. Capsules filled with swollen hydrogel were inserted in a low w/c (0.3) mortar cube, and its internal curing was observed periodically until 56 days. As soon as the capsule dissolves, the hydrogel is observed to release water into the surrounding regions. The spread of the water region is governed by capillary and gravitation forces, and the water mobility depends on stored water content and the re-absorption ability of hydrogel when the humidity gradient gets reversed. Current research uses the measurement of water spread area as a proxy for the internal curing potential of a hydrogel. The effectiveness of the proposed technique was assessed on five commercially available SAPs (with different particle sizes and chemical compositions) and newly synthesized cornstarch-based hydrogel. The contribution of hydrogel-absorbed water towards cement hydration was investigated by conducting X-ray diffraction (XRD) on the capsule region and scanning electron microscope (SEM) analysis at different distances from the hydrogel capsule. Finally, autogenous shrinkage and drying shrinkage of two selected commercially used SAPs (by 0.2%wt) and cornstarch-based hydrogel (by 1%, 2%, and 3% wt. solution) were evaluated. Characterization studies indicate that hydrogel water absorption and desorption are governed by humidity levels in the vicinity that fluctuate with time. Therefore, it is in a cyclic fashion until the hydration process is near complete. Excess amounts of calcium silicate hydrates were observed around the capsule region, validating the positive influence of desorption water on the hydration process. The hydrogel's potential to maintain humidity levels assist in the remediation of early and later-stage shrinkages. The cornstarch-based hydrogel is observed to perform on par with hydrogels made from SAPs for internal curing and mitigation of shrinkage. This not only confirms the compatibility of the corn-starch hydrogel with cementitious-based material but serves as a sustainable and eco-friendly alternative to commercial SAPs for internal curing purposes.

Comparison of full-scale measurements and large-eddy simulations of wind pressures on a high-rise building.

Jack Hochschild; Stanford University; United States
Catherine Gorle; Stanford University; United States

The estimation of peak wind pressures on tall buildings is of fundamental importance for cladding design. Previously, we have demonstrated that large-eddy simulations (LESs) can accurately predict peak wind pressure measured in reduced-scale wind tunnel experiments of high-rise buildings. In the current study, we aim to compare full-scale pressure measurements with LES results to assess the uncertainty and variability that arises on a real building. Specifically, we will present a comparison of full-scale measurements on the Space Needle in Seattle to results from LESs. For the full-scale measurements, a sensor was selected that can make meaningful Cp measurements at windspeeds as low as 10 m/s and a custom sensing mote was designed to support long-term deployment on tall buildings. For the LESs, the model is generated with the opensource City4CFD tool, and the simulations are performed with the CharLES LES solver. The comparison focuses on the turbulence in the pressure signal, since the determination of the mean pressures from the full-scale measurements is complicated by sensor offset calibration and reference pressure uncertainty. The results from an initial deployment of 4 motes mounted on the building's sloped roof reveal a similar trend in the measured and LES rms and minimum peak pressure coefficients around the perimeter of the building, but the LES results generally reveal more turbulence in the pressure signal, with higher rms values and more negative minimum peak values. In ongoing work, we are identifying the main reason for this discrepancy, considering amongst others uncertainty in the inflow mean wind profile and turbulence statistics and uncertainty due to the omission of geometrical details in the model.

Comparison of LES and wind tunnel tests of wind loads on a low-rise building in an urban area.

Themistoklis Vargiemezis; Stanford University; United States
Catherine Gorlé; Stanford University; United States

Wind-resistant design of low-rise buildings and their components plays an important role to reduce losses, fatalities, and business discontinuities due to extreme wind events. Design wind loads on low-rise buildings are usually determined following building codes and standards. Their pressure coefficient estimates are generally based on wind tunnel (WT) tests of isolated buildings in open terrain. This is an important weakness for wind resilient design because they do not account for local interference effects due to the presence of surrounding buildings.

With the continuous increase of computational power and efficiency, computational fluid dynamics (CFD) offers an opportunity to study these complex urban flows and improve the representation of interference effects when estimating wind loads on low-rise buildings. The high-fidelity large-eddy simulations (LES) solve for the instantaneous fields allowing direct estimation of turbulent statistics, but the accuracy and reliability for wind loading predictions remain a concern, and further validation is required.

The objective of the present study is to validate LES predictions of wind loads on a low-rise building in the presence of interference effects. This is achieved by performing wind tunnel tests and LESs of two configurations: 1) the isolated building and 2) the building in its urban environment. First, we ensure that the LES set-up correctly reproduces the surface layer turbulence generated in the WT. Subsequently, we compare the pressure coefficients of the LES with the WT predictions. LESs with two different incoming surface layers are considered to quantify the effects of turbulence from the upstream wind field. The results show that when we explicitly consider the roughness elements in the LES, the predictions of mean and root-mean-square (rms) pressure coefficients are significantly improved. Ongoing work is considering simulations for different wind directions and will compare the existing data with measurements from a different WT. The latter will help in considering the repeatability of the experiments.

Comparison of stiffness reduction factors for rotary-straightened and hot-rolled W-shape members

Hyeyoung Koh; University of Wisconsin-Madison; United States
Barry Rosson; Florida Atlantic University; United States
Hannah Blum; University of Wisconsin-Madison; United States

As residual stresses in steel members significantly affect structural behavior, especially members prone to inelastic buckling, an appropriate residual stress pattern for steel members is crucial. Rotary straightened wide-flange steel members have a different residual stress pattern compared to conventional hot-rolled members. Previous research has indicated that the current stiffness reduction model provided in Chapter C of the North American Specification for Structural Steel Buildings, AISC 360, does not accurately account for the stiffness reduction of rotary-straightened W-shape columns and beam-columns. This study presents a parametric study of the current and existing stiffness reduction models on rotary-straightened and conventional hot-rolled steel W-shapes to examine the effect of different residual stress patterns adopted by AISC 360 and Eurocode 3 on member limit load capacity. Four stiffness reduction models were investigated, which include the current AISC 360 model, two models incorporating the Eurocode residual stress pattern, and a model incorporating a residual stress pattern of rotary-straightened members. Beam finite element models were created and second-order inelastic analyses were performed. Columns and beam-columns were analyzed with a range of different cross-sectional geometries that includes various aspect ratios, flange-to-web area ratios, and flange and web width-to-thickness ratios. The members were analyzed with uniaxial bending about the major and minor axes combined with several axial utilization ratios. Discussions on the effects of the assumed residual stress pattern on the stability limit state are provided along with comparisons of the stiffness reduction values for conventional hot-rolled steel members and rotary-straightened members. The results of this study provide further understanding of the stiffness reduction model's influence on the stability analysis of rotary straightened hot-rolled steel members.

Composition-structure-reactivity relationship for aluminosilicate glasses in alkaline environment

Kai Gong; Rice University; United States
Claire White; Princeton University; United States
Elsa Olivetti; Massachusetts Institute of Technology; United States

Establishing the composition-structure-property relationships for aluminosilicate glasses is important to many natural and engineering processes, including alkali-activated materials and blended cements. In this talk, we will present a collection of recent studies to uncover the atomic fingerprints that control the reactivity of aluminosilicate glasses in alkaline environments. We first showed that reasonable atomic structural representations can be generated using molecular dynamics (MD) simulations. Based on the obtained structural representations, we developed a number of novel structural descriptors (e.g., average metal-oxygen dissociation energy (AMODE)) that allow us to capture the relative reactivity of a wide range of aluminosilicate glasses (with compositions covering those of fly ash, slag and volcanic ash). Finally, based on the MD-generated structural descriptors, we further developed several compositional parameters (e.g., modified AMODE) that exhibit similar predictive ability as the MD-generated structural descriptor (e.g., AMODE) yet can be directly calculated from the chemical compositions of the glasses. These studies represent a critical step forward in establishing the important composition-structure-property relationships for complex aluminosilicate glasses.

Compress Au Nanoparticle towards 2-Dimensional Extreme: A Molecular Dynamics Study

Tanuj Gupta; Clemson University; United States
Michael Cai Wang; University of South Florida; United States
Huijuan Zhao; Clemson University; United States

In ancient craft, mechanical beating can thin bulk gold into gossamer leaves. With modern technology, it is unclear about the thinnest limit of gold, which is one of the most ductile materials Meanwhile, it has been shown that the compressive yield stress of gold nanoparticles is significantly higher than their bulk counterparts. A dislocation starvation theory has been proposed that dislocation growth below a certain length scale is obstructed because of the free surface. Further plastic deformation requires new dislocations to nucleate under sufficiently large stress. Therefore, it is interesting to investigate the mechanical behavior of gold nanoparticles under quasi-static compression and shock impact. In this study, we will adopt the classical molecular dynamics simulation to investigate the deformation mechanisms of gold nanoparticle, with a focus on understanding the role of free surface, particle size and orientation. We will also study the role of loading rate to the mechanical behavior of gold nanoparticles under compression, considering both quasi-static loading conditions and high-speed impact loading conditions. The numerical simulation results will be compared with the experimental observations.

Computation Infrastructure for Modeling Discontinuities within Materials: DEIP, BEAVER and MOOSE

Timothy Truster; University of Tennessee - Knoxville; United States
Sunday Aduloju; Oak Ridge National Laboratory; United States
Amirfarzad Behnam; University of Tennessee - Knoxville; United States

This presentation provides an overview of several open-source codes developed within our group for modeling of interfaces within materials. The popularity of discontinuous formulations for computational solid mechanics has steadily increased for physical applications such as fracture mechanics. A common approach for numerically realizing these methods is using the so-called zero-thickness interface finite elements. Unfortunately, standard commercial finite element codes do not contain mesh generation features for zero-thickness elements. Also, the modeling and simulation of complex engineering materials using the representative volume elements (RVE) has become quite extensive, for which periodic finite element meshes are important. However, few mesh generators today will produce such interface elements along the boundary of the periodic RVE, which are needed for modeling behavior such as sliding along grain boundaries in polycrystalline metals. To tackle these challenges, our group has been continually enhancing the Discontinuous Element Insertion Program (DEIP), a MATLAB code for inserting interface elements into two and three-dimensional meshes of all standard element types. Its algorithm is topologically based and requires only nodal coordinates and element connectivity as input. API are provided for meshes from Abaqus, Gmsh, and Cubit formats. Additionally, for modeling the physics of these interfaces, our group has recently developed an application for the MOOSE object-oriented finite element framework, called BEAVER. This application includes realizations of the Variational Multiscale Discontinuous Galerkin (VMDG) method, which provides closed-form expressions of the stability parameters needed for methods such as the interior penalty DG and Nitsche methods. Representative simulations from these codes are provided to highlight various applications.

Computation of Building Corner Peak Pressure Using CFD

Rathinam Selvam; University of Arkansas; United States

Computation of peak pressure on buildings will be very useful for safer design of buildings. Recent years, the University of Arkansas (UARK) has been validating the computed peak pressures on the Texas Tech University (TTU) building for the flow along the short side of the building. The computed peak pressures are in reasonable comparison with 1:6 scale wind tunnel (WT) measurements. As a next step, validating the CFD roof corner peak pressures are initiated. In the literature several papers reported standard deviation of the pressure but not the peak pressure. Only handful of works reported peak pressures. Due to extensive errors in generating turbulence either high spurious pressures are produced in the computational domain or energy loss at the building location is very high. So, the reliability of the reported works is questionable. Mansouri et al. (2022b) investigated 11 different inflow turbulence generators and from that they concluded that synthetic eddy method (SEM) may be one of the better methods of choice in reducing the spurious pressures. In this work SEM method is used as inflow turbulence generator. Mansouri et al. (2022a) reported that the largest grid spacing at the inflow controls the maximum frequency in the computational domain. Since corner vortex generation is a complex problem, high grid resolution is needed. On the other hand, using very high grid resolution (say H/128 or less) all over the computational domain will take large memory and many days of computational time even using parallel computing. Finding optimum grid spacings in the computational domain is one of the major research tasks. The grid spacing far away as well as close to the building has extensive impact on the building peak pressure. Hence, grid resolution of various sizes far and close to the building on turbulence transport and peak pressure are investigated. The research findings will be reported in the presentation. In addition, the computed peak pressures are compared with available WT measurements. Visualizations are used to show the development of the roof corner vortex and other details.

Computation of per atom strain in classical molecular dynamics simulations

Ranganathan Parthasarathy; Tennessee State University; United States
Andrew Mikhaeil; Tennessee State University; United States

The concept of local atomic-level stress is a powerful tool for describing several material phenomena and holds strong relevance for computational materials science. Its use extends beyond serving as a continuum interpreter of molecular simulations. For example, in metallic glasses, atomic-level stress has been recognized as a tool to characterize the structure, which is difficult to understand purely in terms of geometrical or topological descriptors. In other materials with no long-range order like Concentrated Solid Solution Alloys (CSAs), and amorphous polymers, the macro-scale mechanical properties typically have a direct correlation with their atomic structure due to the absence of grain boundaries and dislocations. Therefore, the atomic-level stress is a powerful tool in understanding diverse phenomena in disordered systems. The atomic-level stress is also very relevant in providing an understanding of the origin of mechanical failure at the atomic level in metals and metal alloys, as well as insight into the behavior of nanomaterials and biomolecules. However, for a complete continuum mechanical interpretation of classical atomistic simulations, it is necessary to compute the corresponding atomic level strains too. While there has expectedly been extensive research in defining and calculating atomic level stresses, research in defining and calculating atomic level strain is relatively scarce. The most used method to compute local atomic level strains in classical atomistic simulations is by comparison of relative average atomic positions between a current and a reference configuration. Atomic level stress is zero only in a perfect crystal, and is referenced, by definition, to the stress-free state of an atom in a perfect crystal. However, the reference configuration chosen for atomic level strain is user-dependent and generally not the perfect crystal. Therefore, it does not have a one-to-one energetic correspondence to the atomic level stress. Direct application of local elastic constants to the lattice mismatch strain not referenced to the perfect crystal does not account for either structural inhomogeneity or thermal effects and yields highly erroneous results. Furthermore, due to the impossibility of physically applying strain to particular atoms via local displacements, the calculation of local atomic-level strain has been observed to be a very difficult theoretical problem. In this work, we propose that the covariance of atomic positional fluctuations about equilibrium positions resulting from thermal vibration can be used to arrive at per-atom estimates for elastic components of both thermal strain as well as residual strain from structural inhomogeneity. For the example of a vacancy in an otherwise perfect crystal of fcc Aluminum, we demonstrate using molecular dynamics simulation that strain computed from lattice rearrangements with the reference configuration as the unrelaxed defective crystal results in strains too small in magnitude to cause the observed local residual stresses. We show that atomic positional covariance resulting from thermal vibrations can be used to estimate the elastic part of the total local atomic level strain.

Computational Evaluations of the Flexural Behavior of Steel-CLT Composite Floor Members

Megan Potuzak; Auburn University; United States
Kadir Sener; Auburn University; United States
David Roueche; Auburn University; United States

Recent building code revisions in the US have opened up new markets for mass-timber products, particularly for mid-to-tall-rise buildings. One potential market for substantial expansion is the use of timber panels in composite steel-timber floor systems, where these have a high potential to be economically, architecturally, and structurally feasible systems for mid-to-tall structures and expand the usage of timber panels for high-rise structures. In these novel flooring systems, cross-laminated timber (CLT) panels replace concrete slabs to provide floor elements that work compositely with steel framing and improve the structural performance compared to either material being used individually. This presentation will focus on a computational study conducted to evaluate and optimize the flexural performance of steel-timber composite floor members. The computational models were developed with three different complexity levels; i) 2D fiber-based section studies, ii) macro shell finite-element-method-based studies, and iii) detailed 3D-solid finite-element-method-based models. The detailed 3D finite element models accounted explicitly for each of the structural components and the various complexities of the flexural behavior. For the CLT portion, the models explicitly accounted for the individual plies, adhesive layers, mechanical fasteners, and the interaction (normal and tangential) between the contacting elements. The complex orthotropic behavior of wood is incorporated into the model, including the tension fracture and shear behavior, using smeared cracking approaches and fracture energy principles. The compression inelasticity of timber is modeled using a plasticity-based multi-directional continuum damage mechanics model. For the steel member and fastener elements, material inelasticity, including yielding, plasticity, ductile damage, and fracture are also modeled. The macro shell finite elements model the CLT components using composite layers through the thickness. Fully bonded behavior is assumed within the CLT component while accounting for the difference in behavior based on wood grain orientations. The screw connectors are modeled using nonlinear spring elements. Material inelasticity for the steel and CLT layers, including yielding, plasticity, tension cracking, damage, and fracture is modeled similarly to the detailed models. The study includes two parts; i) verifying the computational modeling approach against experiments, ii) conducting numerical parametric studies to optimize the material usage. The computational results are verified against several pushout and large-scale beam tests by making comparisons against the strength, stiffness, ductility, and slip performances. The numerical parametric study results will provide recommendations on achieving optimal composite action levels using mechanical fasteners suitable for this application.

Computational Modeling of Skid Resistance of Aircraft Tire on Wet Runway Pavement

Baiyu Jiang; Rutgers University; United States
Hao Wang; Rutgers University; United States

Many runway accidents are related to the loss of pavement friction during wet weather condition. Pavement grooves are required on runway to increase skid resistance and prevent hydroplaning of aircraft tire. However, pavement grooves deteriorate over time and weakens drainage capacity. This study aimed to develop an integrated approach to evaluate groove depth effect on water depths and skid resistance on runway pavement. Finite element modeling of tire-water-pavement interaction was developed to evaluate wet pavement friction coefficient of aircraft tire on grooved runway pavement. Spatial distribution of water film depth was obtained based on analytical modeling with different groove depths. The modeling results were compared and validated with field measurements. The results show that the depth of groove influences the friction coefficient largely. The thicker water film depth and the smaller friction coefficient are expected with the smaller groove depth. The effect of groove depth becomes more significant at the region close to the centerline of runway. The non-uniform distribution of water film depth would cause different skid resistance encountered by aircraft tires and increase safety risk of landing when aircraft wander happens. The developed simulation approach can be used to determine the threshold of groove depth for maintenance treatment considering rainfall condition, aircraft operation, and geometric design of runway.

Computational Modeling of Tensegrity Metamaterials

Julian Rimoli; University of California, Irvine; United States
Kevin Garanger; University of California, Irvine; United States
Julie Kraus; Georgia Institute of Technology; United States

The term tensegrity refers to a class of structures composed of slender members, in an arrangement such that tensile members belong to a continuous network, while compression members are either disconnected from each other or belong to isolated compression clusters. The concept of tensegrity has been recently incorporated into the design of nonlinear metamaterials. In the context of this work, we define metamaterials as structural arrangements built at a scale much smaller than that of the application they are intended to, thus exhibiting an effective behavior different than its constituents at that large scale. Tensegrity metamaterials were initially constructed as one-dimensional lattices, and it was only recently that a tensegrity structure was proposed that can tessellate R3[1]. This new development expanded the application space of tensegrity systems to more realistic three-dimensional ones, leading to the development of 3D tensegrity-based metamaterials [2]. While the mechanical response of these metamaterials can be modeled via traditional numerical approaches such as the finite element method (FEM), the richness of the behavior of its individual members (buckling, yielding, etc.) renders them very expensive in computational terms. In this talk, we will discuss different approaches for modeling the nonlinear behavior of tensegrity metamaterials, ranging from lumped-parameter systems [3-4] to machine learning-based homogenization [5-8]. Examples of application will show how they compare to FEM both in terms of precision and computational cost.

References

[1] Julian J. Rimoli, Raj Kumar Pal. Mechanical response of 3-dimensional tensegrity lattices, Composites Part B: Engineering, 115:20-42, 2017.

[2] Jens Bauer, Julie A. Kraus, Cameron Crook, Julian J. Rimoli, Lorenzo Valdevit. Tensegrity Metamaterials: Toward Failure-Resistant Engineering Systems through Delocalized Deformation, Advanced Materials, 33(10): 2005647, 2021.

[3] Julian J. Rimoli. On the impact tolerance of tensegrity-based planetary landers. In 57th AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, San Diego, CA, 2016.

[4] Julian J. Rimoli. A reduced-order model for the dynamic and post-buckling behavior of tensegrity structures. Mechanics of Materials, 116:146–57, 2018.

[5] German Capuano and Julian J. Rimoli. Smart finite elements: a novel machine learning application. Computer Methods in Applied Mechanics and Engineering, 345:363–381, 2019

[6] Hernan Logarzo, German Capuano, and Julian J. Rimoli. Smart constitutive laws: Inelastic homogenization through machine learning. Computer Methods in Applied Mechanics and Engineering, 373:113482, 2021.

[7] Aarohi Shah and Julian J Rimoli. Smart parts: Data-driven model order reduction for nonlinear mechanical assemblies. Finite Elements in Analysis and Design, 200:103682, 2022.

[8] Aarohi Shah and Julian J Rimoli. Data-driven approach for dynamic homogenization using meta learning. Computer Methods in Applied Mechanics and Engineering, 401:115672, 2022.

Computational Modelling of Flow-induced Fiber Orientation for Ultra-high-performance Concrete Flow

Tathagata Bhaduri; Rensselaer Polytechnic Institute; United States
Shady Gomma; Zagazig University; Egypt
Mohammed Alnaggar; Oak Ridge National Laboratory; United States

Ultra-high-performance Concrete (UHPC) shows significant post-cracking ductility thanks to the presence of smeared fiber reinforcement embedded in the matrix. However, the strain-hardening or strain-softening behavior, being an extrinsic property, is mostly guided by the fiber bridging efficiency along crack-opening directions. Hence, the procedure to align fibers along the principal tensile direction has a great influence in enhancing the mechanical properties of hardened fiber-reinforced UHPC. Besides, fiber constitutes the most expensive component in UHPC. In the macro-scale casting process, fiber orientation through a stable controlled flow regime is difficult to achieve. Recently, a novel nozzle flow-based casting method was developed to streamline the fresh UHPC mix with fiber in a preferential direction. This process allowed higher mix input at the inlet, followed by a tapered region to provide a gradual increase to flow velocity profile which induces higher torque and drag force on smeared fibers. Direct tension tests were conducted on notched prismatic samples cut from a slab cast with this process. Samples were cut both parallel and perpendicular to the flow direction from the center and edges of the slab. Results showed a significantly higher tensile capacity for specimens in the center along the casting direction compared to other samples with lesser scatter in experimental observations. In the current study, this process of orienting fiber was numerically simulated via computational fluid dynamics (CFD) informed stochastic fiber orientation model. The predicted fiber orientation was then used to inform a mesoscale numerical model known as lattice discrete particle model with fiber (LDPM-F) to simulate tensile failure of notched prismatic samples used in experiments. Very good agreement is observed for numerical simulations in mimicking the experimental failure behavior which also validates the applicability of the coupled computational framework.

Computational tool for community-level probabilistic building performance assessment under excavation-induced ground settlements.

Jinyan Zhao; University of California, Berkeley; United States
Matthew DeJong; Unniversity of California, Berkeley; United States

Urban excavations, such as tunneling and deep foundations, may introduce substantial ground movements. Such ground movements have caused significant damage to surface buildings and have become one of the man-made hazards during rapid global urbanization. Due to uncertain underground conditions, complex construction activities, and a large number of buildings subject to the hazard, the building performance assessment in urban excavation experiences significant uncertainty, and advanced computational methods and tools are needed for the resilience-/performance-based design of urban excavations.

In the presented research, a 3-dimensional (3D) soil-structure interaction model, which consists of an empirical ground movement model, a nonlinear soil-structure interface model, and a 3D finite element building model, is adopted in a community-level building performance assessment framework. The uncertainty of soil properties, surface building properties, and excavation-induced ground movements are considered with random field or random variable models. Due to the high dimensional uncertainty experienced by the excavation-soil-structure system, the dimension-independent Monte Carlo method is selected for the uncertainty propagation and quantification of surface building damage probabilities. Monte-Carlo methods require a large number of model evaluations, and to complete a community-level assessment in a practical duration, a computation tool is developed on the high-performance computer SAVIO at UC Berkeley. A case study of the community probabilistic assessment in an infrastructure tunnel excavation is presented to demonstrate the high-performance computation framework.

The research significance of the presented research is a modeling method of the spatial variable soil stiffness and excavation-induced ground movements on a community scale and a computation tool for the community-level simulation and probabilistic performance assessment. The presented research may also inspire discussions about an important yet less recognized type of hazard: land settlements.

Computational tsunami risk management

Cláudia Reis; Instituto Superior Técnico; Portugal
André R. Barbosa; Oregon State University; United States

Policies of tsunami risk mitigation are challenging to develop and implement due to the large amount of uncertainty associated with characterization of the tsunami hazard affecting the natural and built coastal environment. The generation of synthetic data to complement historical tsunami flow and velocity data is essential to understand the tsunami hazard and validation of the modeling of tsunami generation, propagation, and inundation phases. In addition, determining accurate force distributions for the design of critical infrastructure, often require an understanding of complex and highly non-linear fluid-structure interactions (FSI), which is only achievable using advanced computational fluid dynamics numerical modeling with large computational demands and generation and processing of large datasets. In this symposium, a multi-scale domain analysis approach is presented. The scales vary from many kilometers in the tsunami generation phase to a few meters in the structural analysis response phase. The discussion is centered on: (1) validation of the numerical schemes to model each scale considering uncertainty and reliability aspects associated with physical and modelling assumptions, and (2) needed computational resources in terms of simulation, storage and data processing required to assure a step-forward in tsunami engineering. Source uncertainties are presented to demonstrate the influence of source rupturing variability (e.g., fault rupture location and orientation, homogeneous or heterogeneous slip distribution) on the tsunami arrival time, inundation depth, flow velocity, and estimated forces for a coastal infrastructure. An example critical infrastructure system will be used as a case study to provide context to the results and findings.

Computationally Efficient Modeling of Microstructurally Short Cracks in Polycrystalline Materials

Damin Xia; Civil and Environmental Engineering, Vanderbilt University; United States
Caglar Oskay; Civil and Environmental Engineering, Vanderbilt University; United States

We present a reduced order modeling (ROM) approach to study the mechanical response of heterogeneous microstructures in the presence of embedded tortuous short cracks and elasto-visco-plastic deformations. The model reformulates the eigendeformation-based homogenization method (EHM) in which the local heterogeneous plastic deformations are approximated using the classical EHM ideas, whereas the crack separation fields are described in an efficient fashion through a small set of basis functions generated by proper orthogonal decomposition (POD). The reduced system of equations is evaluated by posing it as a constraint optimization problem. The constraints enforce unilateral contact conditions on the crack faces. To make the optimization process more feasible, an integrated form of the constraint is introduced, enabling the use of only one constraint regardless of the crack morphology. The proposed formulation has been implemented for polycrystalline materials, where the nonlinear deformation of the grains are described by crystal plasticity. The model predictions are verified against direct numerical simulations (DNS) by the crystal plasticity finite element method. The POD approach relies on the generation of snapshots to describe the reduced basis associated with the crack separation field. Two strategies are investigated to generate this basis: (1) the use of a priori knowledge on the mechanical loading; and (2) load direction sampling strategy in the absence of this information. The proposed ROM is evaluated under various loading conditions and different crack configurations. The model shows reasonable agreement with DNS results for the separation field, overall stress-strain, and local stress and strain predictions, and demonstrates a significant improvement in computational efficiency of up to two orders of magnitude

Concurrent Semi-Lagrangian Reproducing Kernel Formulation and Stability Analysis

Mohammed Atif; University of Illinois Chicago; United States
Sheng-Wei Chi; University of Illinois Chicago; United States

The semi-Lagrangian Reproduced Kernel Particle Method (RKPM) constructs the shape function based on the material points with a fixed-size kernel support and is formulated based on the updated Lagrangian formulation [1,2]. It circumvents the breakdown of deformation mapping in the conventional RKPM for severe deformation problems. However, the convective terms arising from the material time derivative of the semi-Lagrangian Reproducing Kernel (RK) complicate the numerical implementation and tremendously increase computational costs. This work introduces a new RK approximation scheme for the dynamic dependent variables, e.g., acceleration, velocity, and displacement, to offer a consistent way of formulating the variational equation of motion in the semi-Lagrangian framework. The proposed concurrent semi-Lagrangian RK approximation avoids the need to compute the convective term, thus simplifying the semi-discrete equation. Numerical benchmarks show the concurrent semi-Lagrangian RK increases the accuracy and efficiency under the high strain rate condition. Furthermore, to find the temporal stability of the concurrent semi-Lagrangian RK approximation in severe deformation problems, an eigenvalue analysis is performed on the semi-discrete equation of motion, and the relationship between temporal stability and deformation is studied [3]. Several manufactured problems in 1D and 2D are studied to validate the analytical estimate. The effectiveness of the proposed method is demonstrated using penetration simulations.

[1] Guan, P.C., et al., Semi-Lagrangian reproducing kernel formulation and application to modeling earth moving operations. Mechanics of Materials, 2009. 41(6): p. 670-683.

[2] Chi, S.-W., et al., A level set enhanced natural kernel contact algorithm for impact and penetration modeling. International Journal for Numerical Methods in Engineering, 2015. 102(3-4): p. 839-866.

[3] Belytschko, T., et al., A unified stability analysis of meshless particle methods. International Journal for Numerical Methods in Engineering, 2000. 48(9): p. 1359-1400.

Considering the non-linear behavior of materials in the design of lunar habitats

Arsalan Majlesi; University of Texas at San Antonio; United States
Amir Behjat; Purdue University; United States
Adnan Shahriar; University of Texas at San Antonio; United States
David Avila; University of Texas at San Antonio; United States
Arturo Montoya; University of Texas at San Antonio; United States
Shirley Dyke; Purdue University; United States
Julio Ramirez; Purdue University; United States

Designing habitats in lunar environments require analysts to identify materials that can resist several disturbances. These habitats are exposed to micrometeoroids that constantly impact the lunar surface with extreme velocities, moonquakes, and high-temperature fluctuations. The selection of appropriate materials for these designs requires considering the limited launch mass of NASA missions, the nonlinear behavior of materials under extreme loading, and cost, among other factors. Thus, conducting physics-informed trade studies can help the involved parties determine the best material options for designing these types of structures. Solidified regolith and a metallic alloy are two material alternatives that are being considered for space habitats. A trade study was conducted in this research work to compare the performance of monolithic domes made of regolith and a range of metallic alloys under the same applied load. The habitats were assumed to have a structural protective layer prohibiting ejecta impacts from fully penetrating the structure and having enough shielding against radiation. The displacements resulting from moonquakes and ejecta were approximated using a single degree of freedom (SDOF) model that was incorporated into a computational modeling framework that subjects the structure to random loading over a lifespan period while capturing the materials' degradation and nonlinear behavior. Mass transportation, length of functionality, and the state of the structure were the criteria used to compare the performance of the various modeled structures.

Constitutive Relationship Exploration in A fiber-reinforced Composite Material with Uncertainty

Zhengtao Yao; University of Southern California; United States
Roger Ghanem; University of Southern California; United States
Venkat Aitharaju; General Motors; United States
Jay Mahishi; General Motors; United States

Representative Volume Element (RVE) is a widely used conceptual and numerical device to explore the constitutive relationship of materials while soliciting information from their subscale. It describes the behavior at one material point of a physical device by homogenizing the local behavior over finer scales. By replicating the RVE throughout the analysis domain, a homogeneous mathematical model is typically synthesized. This simplification is used here in the presence of uncertainty, both in loading, in material properties of micro-constituents, and in modeling physical behavior, for a heterogeneous material. The mechanical behavior of this composite material for use as battery enclosure is explored in this work. Specifically, a hybrid composite is used in which glass and carbon fibers are embedded in epoxy resin.

The material properties of fiber tows and resin are modeled as random variables with independent beta distributions priors calibrated to experiments. The input strain tensor comes from a macro-scale three-point-bend test simulation. Models with and without cohesive elements at the fiber-epoxy interface are explored, for a deeper understanding of the physics of failure and an accurate prediction of the constitutive relationship. History of the six components of the stress tensor and strain energy density throughout the micro simulations are extracted as the dataset for learning. A novel energy layer is conducted for the prediction of xx, the direction of tows and tension, stress. PCA(Principle Components Analysis) is used to eliminate spurious discontinuities in the stress-strain curve when predicting stresses in directions transverse to the tows, yy and zz directions,. Failure for key timesteps is analyzed. A user-defined subroutine is developed in LS-Dyna and a mesoscale simulation for comparison is conducted to verify the accuracy of the subroutine.

Different failure modes, rip-off and longitudinal failure, are observed when certain strain patterns, specifically relevant to the direction and magnitude of the first principal strain, are applied. Precise predictions for the whole stress-strain curve in six components are achieved in non-cohesive model, using the novel machine learning methods along with newly found physics underlying it. The macro simulation with this AI-ML subroutine simulations is in high consistence with the mesoscale simulation and experiments.

With this machine learning method developed, principal stresses are found to be very important in influencing failure patterns of this composite material. The highly accurate surrogate model obtained for quickly getting the stress-strain curve of this complex material under uncertainties of material properties as well as complex boundary condition speeds up significantly high-fidelity macro scale simulations.

Continuum stress and strain analysis of the Discrete Element Method (DEM) as applied to shear loading of cuboidal grain assemblies

Yu-Hsuan Lee; University of Colorado Boulder; United States
Beichuan Yan; University of Colorado Boulder; United States
Zhou Lei; Los Alamos National Laboratory; United States
Richard Regueiro; University of Colorado Boulder; United States

LA-UR-23-20919 In this study, simulations of discrete elements within simple shear-like boundaries of a cuboidal assembly of grains are developed and conducted with the 3D discrete element method (DEM) software ParaEllip3d-CFD to explore the microscopic-to-macroscopic mechanical behavior of particles and particle-boundary interactions. The macroscopic continuum response, such as Cauchy stress and various finite strain measures, is upscaled from the particle scale response, within a classical nonlinear continuum mechanics framework. From the DEM results, local microscopic particle behavior is observed, such as particle motion, contact force direction and magnitude. With the Cauchy stress tensor analysis, both the whole spatial domain averaged stress and smaller sub-domain "local" stress are calculated. The averaged stress shows reasonable results for constant volume shearing case and constant vertical confining pressure case. The local stress reflects results corresponding to contact force concentration and principal stress direction, which explains how interparticle contact forces evolve during the shearing simulations in a continuum smeared manner. With the Delaunay tessellation between particle centroids formed at certain user-defined time intervals, the deformation gradient, and in turn various finite strain measures are calculated. The results match the shear boundary strain as a macroscopic comparison. Combining the local Cauchy stress and finite strain results, constitutive models can be further constructed and applied for large deformation and flow of granular materials response, which is not easily investigated experimentally without in-situ X-ray computed tomography (CT) and is difficult to extend to the higher velocity regimes of interest to the authors. References Beichuan Yan, Richard A. Regueiro, Influence of Particle Shape on Microstructure of Granular Materials under Gravity, ASCE Journal of Engineering Mechanics, 2021, 147(11): 04021102. Beichuan Yan, Richard A. Regueiro, Three-Dimensional Discrete Element Method Parallel Computation of Cauchy Stress Distribution over Granular Materials, International Journal for Numerical and Analytical Methods in Geomechanics, 2019, 43(5):974-1004. Beichuan Yan, Richard A. Regueiro, Definition and Symmetry of Averaged Stress Tensor in Granular Media and its 3D DEM Inspection Under Static and Dynamic Conditions, International Journal of Solids and Structures, 2019, 161:243-266. Beichuan Yan, ParaEllip3d-CFD. https://gitlab.com/micromorph/paraellip3d-cfd, 2020. Katalin Bagi, Stress and strain in granular assemblies. Mech. Mater., 22(3), 1996, 165-177. Boning Zhang, Richard A. Regueiro, On large deformation granular strain measures for generating stress–strain relations based upon three-dimensional discrete element simulations. International Journal of Solids and Structures, 66, 2015, 151-170 Bradford C. Barber, David P. Dobkin, Hannu Huhdanpaa, The Quickhull algorithm for convex hulls, ACM Trans. on Mathematical Software, 22(4), 469-483, http://www.qhull.org

Contributions of Internally-Cured Concrete to Sustainability and Resilience of Pavements

Daron Brown; Arcosa Lightweight; United States

Concrete pavements are the primary destinations for concrete and cement consumption in the United States. Hence, the construction, maintenance, repair, retrofit, and decommissioning of concrete pavements are vital to the sustainability and resilience of the transportation system. Enhancing the durability and extending the service life of concrete in highways and bridge decks contributes to reducing environmental, financial, and societal footprints. Further, preserving the physical and mechanical characteristics of concrete pavements is vital to the resilience of transportation systems in response to natural disasters, climate change, and increased traffic demands. Internal curing aims to promote the sustainability and resilience of transportation infrastructure through the mitigation of early-age cracking and warping of pavement surfaces. In addition, internally-cured concrete requires fewer joints, smaller concrete thickness, and less embedded steel reinforcement. Pre-wetted fine lightweight aggregates may also accelerate construction activities involving curing and expedite public access to constructed roads and bridges. This presentation explores engineering solutions to incorporate internal curing in concrete pavements focusing on sustainability and resilience.

Control Perfromance of Sloped Rolling-type Bearings with an Added Rotational Inerter

Shiang-Jung Wang; National Taiwan University of Science and Technology; Taiwan
Yi-An Lai; National Taiwan University of Science and Technology; Taiwan
Chung-Han Yu; National Center for Research on Earthquake Engineering; Taiwan
Yu-Wen Chang; National Center for Research on Earthquake Engineering; Taiwan
Ting-Yu Hsu; National Taiwan University of Science and Technology; Taiwan

This research numerically investigates the mechanical behavior of sloped rolling-type bearings equipped with an inerter. After deriving equations of motion, the mechanical behavior, under harmonic excitation, of a sloped rolling-type bearing with its inherent rotational mass (i.e., considering the inertial and restoring forces generated by the existing roller) and one with an added rotational inerter is numerically analyzed. It is demonstrated that the latter is mechanically different from the former, and, more importantly, the latter is more effective at controlling acceleration and displacement responses and practically more feasible. The acceleration control performance designed for sloped rolling-type bearings that ignore the inherent rotational mass can basically be retained when adding a rotational inerter if a suitable inertance-to-mass ratio can first be determined based on a specific acceleration target. Parametric and numerical analyses show that the peak acceleration responses of sloped rolling-type bearings with an added rotational inerter are less dependent on having a sufficiently large harmonic excitation period (i.e., on having the roller in motion within the sloped rolling range). In addition, the peak displacement responses under harmonic excitation can be effectively reduced compared with sloped rolling-type bearings that only consider the inherent rotational mass (i.e., without a rotational inerter). The same tendencies are seen when the sloped rolling-type bearings are subjected to ground motion records including far-field and pulse-like near-fault ones. Regardless of the ground motion, the sloped rolling-type bearings with an added rotational inerter show steady displacement reduction. Finally, a simple, practical, and acceleration-based procedure is proposed for designing sloped rolling-type bearings equipped with added rotational inerters based on observations from the parametric and numerical analyses.

Copula-based Quadratic Point Estimate Method under Incomplete Probability Information

Minhyeok Ko; The Pennsylvania State University; United States
Kostas Papakonstantinou; The Pennsylvania State University; United States

Numerous engineering problems often involve the evaluation of probabilistic moments of quantities of interest (QoI). Several computation techniques exist in the literature for such estimations, with sampling-based methods being the most generally applicable ones. However, typical sampling methods often require numerous model-calls in high-dimensional spaces to achieve sufficient accuracy. A different approach to this problem is sought through the development of dedicated probabilistic techniques resembling quadrature methods, such as the Point Estimate Method (PEM) and the Unscented Transformation (UT). PEM and UT-based methods rely on deterministic, weighted sampling points, established by matching a few input moments, sometimes doing so by employing optimization techniques for each considered problem. Several methods have been thus accordingly suggested, mainly having an either linear or exponential increase of the number of required samples with increasing dimensions, counterbalancing computational demands and estimation accuracy. Recently, the authors developed the Quadratic Point Estimate Method (QPEM) with 2n^2+1 sampling points, where n is the number of dimensions, providing analytical expressions for the sample locations and weights in the Gaussian space, without any optimization procedure requirements. QPEM can significantly improve the estimation accuracy of the output QoI moments, in relation to PEM and UT-based methods with linear sample size increase with dimensions, while at the same time having an affordable and competitive computational cost up to a considerable number of dimensions. The QPEM is further enhanced and generalized in this work by enabling copula integration into the framework, allowing effective approximation and modeling of the joint input probability density function (PDF) by estimating marginals and the random variables dependence structure. The copula-based QPEM involves three practical cases in this work, when: (a) the input PDF can be estimated from available data; (b) the input PDF is partially known, through marginals and covariance structures, and can be transformed to the Gaussian space; and (c) the input PDF is partially known but cannot be mapped to the Gaussian space. The validity and outstanding performance of copula-based QPEM are showcased against numerous other sampling methods, in various static and dynamic examples, also involving spatial stochastic fields and random excitations.

References

Ko, M., Papakonstantinou, K.G., 2023. Quadratic Point Estimate Method for probabilistic moments quantification. Under review.

Coupled Reservoir-Geomechanical Analysis and CO2 Leakage Modeling during CO2 Injection into the Hanifa Reservoir: A Study Focused on Climate Change Mitigation

Sikandar Khan; King Fahd University of Petroleum and Minerals; Saudi Arabia
Abdullatif Al-Shuhail; King Fahd University of Petroleum and Minerals; Saudi Arabia

The climate change caused by the excessive emission of CO2 has caused an increase in the global warming that has motivated the countries around the globe to set the global goal of net zero carbon dioxide emission. One way of mitigating climate change is to adopt low-carbon and energy-efficient technologies. Another way of reducing the climate change is to use the negative emission technologies in which carbon dioxide is stored in deep geological reservoirs for long time. In order to inject CO2 into the deep geological reservoirs, it is necessary to use high values of injection pressure. Injecting CO2 at high injection pressure will cause an increase in the reservoir's pressure. The faults that already exists in the reservoir and caprock are normally very sensitive to the pressure buildup and can be activated with excessive increase in the reservoir's pressure. The stored CO2 in the reservoir will leak to the overburden layers after the fault's activation in the reservoir and caprock. The CO2 leaked to the overburden layers will eventually contaminate the underground water sources and will finally leak to the earth's atmosphere. In this paper, the coupled reservoir-geomechanical analysis and CO2 leakage modeling have been performed during the injection of CO2 into the Hanifa reservoir. The location of the Hanifa reservoir is very feasible for CO2 injection because it is capped by the impermeable geological layers of Hith Anhydrite and Rus Anhydrite that will prevent the leakage of the stored CO2 into the Umm Er Radhuma potable water layer and to the earth's atmosphere. The structural deformation of the reservoir is modeled in this study that results in the vertical deformation of the ground surface. The coupled stability analysis is performed during CO2 injection; by taking into account both the variations in the reservoir's pore-pressure and stresses. The CO2 leakage modeling has been performed by considering a fault passing from the reservoir and caprock. Based on the stability analysis of the reservoir, safe CO2 injection parameters have been evaluated for the Hanifa reservoir that will prevent the leakage of the stored CO2 from the reservoir.

Coupling between ion irradiation-induced expansion and mechanical stress: An irradiation-induced flow phenomenon

Mohammed Alnaggar; Oak Ridge National Laboratory; United States
Yann Le Pape; Oak Ridge National Laboratory; United States

Concrete used as a biological shield for nuclear reactors is exposed to a variety of degradation mechanisms. Among the unique ones is irradiation damage. Typically, aggregate-bearing minerals especially siliceous minerals expand under neutron bombardment causing a so-called Radiation-Induced Volumetric Expansion (RIVE). In order to evaluate such effects, experiments need to be performed under heavy neutron irradiation within a reactor. These experiments are extremely challenging and thus very expensive due to coupling with heat and the different rate effects. In this presentation, a study is reported that evaluates the possibility of using ion irradiation as a cheaper method to understand neutron-induced irradiation damage. Experimental results indicate that ion RIVE is mostly an upward deformation as opposed to the typical volumetric deformation seen in neutron RIVE. Also, much less cracking was observed.

At ambient temperature, most rocks exhibit a brittle elastic behavior. At high temperature and pressure, rock-forming minerals exhibit crystalline plasticity and viscous-brittle transition. Previous experimental studies have hypothesized the possibility of ion irradiation--induced viscous or plastic flow but without rigorous testing, modeling or validation. The mechanism of irradiation-induced assisted viscous or plastic flow is not elucidated at this stage, so only hypotheses can be proposed. In this study, it can be hypothesized that the ion- or irradiation-ballistic effects weaken cleavage planes and promote slippages under high stresses. If that hypothesis were to be validated, then this effect would be predominant in ion irradiation experiments which cause large stresses. The presentation will show numerical simulations that try to test this hypothesis and will share the results and their comparison with experimental trends.

Crack-healing in reinforced concrete beams with engineered aggregates

Xiaoying Pan; University of Southern California; United States
Bora Gencturk; University of Southern California; United States
Hadi Aryan; University of Southern California; United States

Self-healing concretes using brittle macro-capsules require special mixing and placing techniques. Engineered aggregates (EAs), which have been developed by the authors in earlier studies, are hollow artificial aggregates that can be mixed directly into concrete without a need for special mixing or placing efforts. The EAs are randomly distributed in the concrete in the same way as natural aggregates. Self-healing in concrete with EAs occurs when the EAs crack with the concrete matrix and release the healing agent stored inside. In this research, the healing performance of reinforced concrete beams, with 130 mm × 203 mm × 1600 mm dimensions, made using polyurethane filled EAs was studied. The formation and propagation of cracks in three-point bending tests were monitored using digital image correlation (DIC). Displacement and strain maps on the surface of the beams were captured during all loading stages of initial cracking and re-loading after healing. The beams with polyurethane EAs showed smaller crack-opening (< 45%) in the initial stage of re-loading process compared to the reference beams with no EA or empty EAs (i.e., no healing agent). It was observed that the redistribution of stresses in the beam with polyurethane EAs caused development of more cracks. Ultrasonic pulse velocity (UPV) testing was also used to quantify the crack healing of the beams after initial cracking and 7 days of healing. The ultrasound diffusion coefficient showed a distinct healing of cracks in the beams with polyurethane EAs.

Crystal plasticity modeling for material strengthening effects of multilayered copper-graphene nanopillar compression

George Z. Voyiadjis; Louisiana State University; United States
Juyoung Jeong; Louisiana State University; United States

This work investigates plastic deformation mechanisms in metal-graphene nanocomposite to demonstrate the strengthening effect of materials through a crystal plasticity finite element (CPFE) model. Existing experimental research identified that the two-dimensional shape of graphene, which can effectively control dislocation motion, can significantly strengthen metals. Considering the nature of dislocation motions in hundreds of nanometer length scales, nanopillar compression tests were simulated by using the physics-based CP model that incorporated surface nucleation and single-arm source dislocation mechanisms. The crystal plasticity models have the configuration of a nanolayered composite with layers of copper grains and monolayer graphene sandwiched between them, with repeat layer spacings of 200 nm, 125 nm, and 70 nm, respectively. The present study quantified the pile-up of dislocations at the graphene layers, resulting in the ultra-high strength of copper polycrystals. Furthermore, a Hall-Petch-like correlation was established between yield strength and the number of embedded graphene layers. This was compared with published experimental results in the literature.

Data-driven breakage mechanics for granular media

Jacinto Ulloa; California Institute of Technology; United States
Anna Gorgogianni; California Institute of Technology; United States
Michael Ortiz; California Institute of Technology; United States
José E. Andrade; California Institute of Technology; United States

The modeling of crushable granular media remains a challenging problem in geomechanics, requiring the prediction of the mechanical state of a material whose microstructure is evolving through particle breakage. The breakage process causes irreversible changes in the grain-size distribution (GSD), notably affecting the macroscopic behavior of the granular packing. Nevertheless, despite its importance, the crushing of granular media was not studied deeply in continuum mechanics until the constitutive model of Einav [1], where a breakage internal variable was introduced to characterize the evolution of GSD. This well-established model has been extended to account for plasticity and other material behaviors via phenomenological functions and parameters.

The drawback of this approach, common to constitutive models in general, is the uncertainty and limited physical meaning of the material functions and parameters. Recently, Kirchdoerfer and Ortiz [2] proposed the framework of data-driven mechanics to overcome this limitation of constitutive modeling. In this framework, the basic equations of continuum mechanics are solved in conjunction with material behavior directly extracted from empirical data, which may be obtained from experiments or lower-scale simulations rather than from a constitutive model. As such, the method is exempt from phenomenological assumptions and allows us to employ and recycle material data.

In the present work, we develop a data-driven framework for breakage mechanics, representing a novel application of data-driven computing to materials with strongly evolving microstructures. We present numerical results relying on experimental data and lower-scale simulations using the level-set discrete element method [3]. These results and comparisons with Einav's constitutive model [1] suggest that the proposed framework can accurately predict the mechanical behavior and the evolution of GSD without employing constitutive functions and parameters, providing a promising alternative to continuum breakage mechanics.

[1] I. Einav. Breakage mechanics—Part II: Modelling granular materials. Journal of the Mechanics and Physics of Solids (2007b) 6:1298–1320.

[2] Kirchdoerfer, T. and Ortiz, M. (2016). Data-driven computational mechanics. Comp. Meth. Appl. Mech. Engng., 304, 81–101.

[3] J.M. Harmon, D. Arthur, and J.E. Andrade. Level set splitting in DEM for modeling breakage mechanics. Comp. Meth. Appl. Mech. Engng., 365:112961, 2020.

Data-driven design of low-carbon concrete mixture for additive construction

Chaofeng Wang; University of Florida; United States
Jianhao Gao; University of Florida; United States

The purpose of this study is to investigate a data-driven design approach for the development of low-carbon concrete mixtures suitable for additive construction methods. The authors used statistical analysis and machine learning algorithms to evaluate the impact of various ingredients on the carbon footprint and properties of the concrete. The results showed that it is possible to reduce the carbon emissions associated with concrete production by selecting appropriate mix proportions and raw materials. The findings of this study provide valuable insights for the design of environmentally friendly concrete mixtures for additive construction and demonstrate the potential of data-driven approaches for sustainable materials development.

Data-driven Modeling of Urban Wind Field Using Conditional Generative Adversarial Networks

yue dong; Colorado State University; United States
yanlin guo; Colorado State University; United States

Urban high-rise building envelopes may suffer severe damage induced by windborne debris during windstorms. Modeling the debris flight behavior in urban area accurately is critical for debris impact analysis. To analyze the debris flight behavior and evaluate the debris risk on urban buildings, the urban wind field that drives the debris flight must firstly be characterized. However, the traditional tools for simulating urban wind field, such as wind tunnel tests and Computational Fluid Dynamic (CFD), are usually expensive or time-consuming for complex urban environments and cannot offer an efficient prediction of the urban wind field for risk assessment, where fast simulation is critical for allowing a large number of Monte Carlo simulations. In this context, an efficient machine learning based prediction model of wind field around building clusters is proposed using conditional Generative Adversarial Networks (cGANs) in this study to facilitate the simulation of debris trajectory in urban environment. The input of the machine learning model is composed of the building cluster configuration and the inflow wind profile and the output is the 3D wind velocity field over building clusters. The training data for this prediction model is generated through CFD simulations with the Reynolds-averaged Navier–Stokes (RANS) model. The existing database of wind tunnel tests for high-rise buildings built by Tokyo Polytechnic University (TPU) is used for the validation of CFD simulations. Considering the issue of high dimensionality, a sensitivity analysis is conducted to inform efficient sampling in the input space to enhance the performance of the machine learning meanwhile to reduce the expenses in data generation. K-fold cross-validation is used to evaluate the performance of the machine learning model.

Data-driven non-homogeneous Markov deterioration models for bridges

Min Li; University of Michigan; United States
Gaofeng Jia; Colorado State University; United States

Reliable prediction of the condition deterioration of bridges is critical for effective bridge management (e.g., inspection, maintenance, and repair). Stochastic deterioration models (e.g., Markov models) established based on bridge inspection data are commonly used for bridge asset management. However, existing Markov deterioration models usually assume stationary transition probability, while the deterioration process is in general non-homogeneous and the deterioration rate could be different for each bridge, considering the differences in influencing factors such as age, current bridge condition, climate environment, and other external conditions. To address this, this work develops a data-driven non-homogeneous Markov deterioration model with time-variant transition probabilities. Gaussian process (GP) surrogate models are used to model the log-odds of the time-variant transition probabilities. The established GP model takes explanatory variables such as age, current bridge condition, and operation environmental factors as inputs, and predicts the log-odds as outputs. A Bayesian approach is developed to calibrate the stochastic deterioration model using bridge inspection data and the environmental information for different bridges. Because the inspection data is for the bridge condition, therefore there is no direct observation data on the log-odds (referred as latent outputs). To address this, observation data on the latent outputs are treated as unknown model parameters and are estimated together with the model parameters for the GP model. The established model allows more accurate prediction of bridge conditions since it considers the variability in the influencing factors for deterioration of different bridges. More importantly, the GP model also provides uncertainty on the prediction of the log-odds and hence the transition probabilities, which can be used to establish more robust estimates and support decision making under uncertainty. The proposed approach is applied to deterioration modeling for bridges in Colorado where deterioration models are established for different bridge components.

Data-driven projection pursuit adaptation in polynomial chaos expansion for high-dimensional problems

Xiaoshu Zeng; University of Southern California; United States
Roger Ghanem; University of Southern California; United States

Almost all modern structures in science and engineering are subjected to uncertainty, for example, random parameters and excitations. In the meantime, the development of computational science enables high-fidelity modeling of complex structures that copes with a high-dimensional parameter space. The task of uncertainty quantification (UQ) and pointwise predictions can be carried out through surrogate modeling. Polynomial chaos expansions (PCE) are mathematically rigorous in approximating the underlying physics and are well-suited for UQ and prediction. However, two significant challenges of PCE are that (i) it suffers from the curse of dimensionality, and (ii) the physical model must be evaluated on specific points when we use sparse quadrature rules to reduce the computational cost. In this work, we propose a data-driven projection pursuit adaptation (PPA) method in the framework of PCE to address these two challenges. With given data, the PPA method discovers the ``interesting'' projections adapted to the quantity of interest (QoI) and the PCE on these projections in an optimal way. The constructed approximation takes advantage of both projection pursuit regression and the PCE and has several significances. First, the embedded dimension reduction is based on given data with no additional model evaluations. Second, we tested several practical applications and showed that the PPA method could discover even a lower-dimensional representation than other methods, such as the classical and accelerated basis adaptation methods. Third, the method uses independent data and thus has less restriction on the data. Lastly, while most dimension reduction techniques are adapted to scaler QoI, the PPA method has multi-QoI capability where the same data set can be used to learn different models for various QoIs.

Database-enabled surrogate-assisted investigation on the interference effects of two adjacent buildings

Fei Ding; NHERI SimCenter, University of California, Berkeley; United States
Sang-ri Yi; NHERI SimCenter, University of California, Berkeley; United States
Alexandros Taflanidis; Department of Civil and Environmental Engineering and Earth Sciences, University of Notre Dame; United States
Ahsan Kareem; NatHaz Modeling Laboratory, University of Notre Dame; United States

The worldwide trend in urbanization is resulting in moving more people to densely populated urban centers. Those urban cities are extremely vulnerable to the impacts of dynamic wind, as the wind-induced interference effects result in the cluster of tall buildings undergoing complex interactions with their surrounding wind environment, which may pose undesirable load effects or even wind hazards on those buildings. Past studies have shown that the interference effects on two adjacent tall buildings could induce either shielding or amplification effects on the mean and peak pressure. The aerodynamically unfavorable building arrangements could lead to significant increase in the local peak pressure that could cause extensive damage to cladding and glass failure.

This study focuses on investigating the influence of the adjacent building arrangement and spacing, height ratio as well as incident wind directions on the surface pressure distributions of a tall buildings. In particular, the aerodynamic database developed by Tokyo Polytechnic University (TPU) is utilized to study the wind-induced interference effects. In view that the limited dataset provided by the wind tunnel experiments may not fully represent the various interfering wind environments, a high-dimensional surrogate model that is capable of predicting the mean and peak pressure coefficients in high-dimensional output space at random building arrangements is proposed, which is trained through the TPU database. To advance the understanding of the interference effects, sensitivity analysis coupled with the classification approach is applied to identifying the critical regions where the local peak pressures are significantly affected by the interfering factors.

Deep Learning models for subterranean navigation and soil characterization

Sanshrit Singhai; Georgia Institute of Technology; United States
Chloé Arson; Georgia Institute of Technology; United States

Self-excavating robots have gained interest in the geomechanics community because of the rich data set that they can collect in comparison to discrete vertical boreholes, and because of their potential use in areas with limited accessibility, e.g., mined fields or extra-terrestrial regoliths. It remains difficult to calculate the trajectory of such robots for optimal sampling under the constraint of obstacle avoidance. In this work, we present three deep-learning models that address three specific aspects of subterranean navigation for optimal soil characterization. The leading hypothesis is that more measures should be taken along the direction of depth if soil properties exhibit high spatial variability. Therefore, for a given navigation step, the increment of altitude of the robot ought to be large if the stress field has been uniform in the past few steps, and small if the stress field has exhibited large variations in the last few steps. We assume that the robot is slender and of circular cross-section, and that it takes equidistant steps along its trajectory. We develop three algorithms that, together, optimize the vertical position d/b of the robot at every step, where d is the depth of the robot and b is the diameter of the robot cross-section, which can be viewed as a cavity. The first model, called NN1, is an Artificial Neural Network that aims to predict the stress field around the cavity, hence bypassing the time-consuming Finite Element Method (FEM) simulations. NN1 takes five soil mechanical properties as input and generates stress contours as output. The model is trained and tested with stress contours obtained with the FEM. The second model, called NN2, is a Convolutional Neural Network that back-calculates the mechanical properties of the soil from stress contour maps. The third model, called NN3, is a Long Short Term Memory Recurrent Neural Network that predicts d/b at step n+1 from stress values sampled at certain points around the cavity at steps n, n-1, ... n-9. The problem is treated like a multivariate time series, where a time step corresponds to a robot marching step, and the dataset at each step is a list of stress components at different locations. The LSTM RNN first predicts the stress field at position n+1 from the input time series. A linear regression model is then used to calculate d/b at position n+1 from the minimum stress values predicted by NN3 at position n+1. The predicted stress field and ratio d/b at position n+1 are taken as input to NN2 to estimate the soil properties at position n+1, which are then taken as input to NN1 to generate stress contours. The stress fields estimated by NN3 and NN1 at position n+1 are then compared. A large difference between the two indicates a low predictability of the stress field from the knowledge of stress at the prior location, and thus suggests high spatial variability in soil properties, indicating that d/b at position n+1 should be closer to d/b at position n to capture a progressive change of soil properties, such as the interface between two geological layers. A reinforcement learning strategy is adopted to address this issue. Results show that the proposed method is more efficient than the FEM for well-constrained boundary value problems, and allows estimation of soil stress field along a trajectory automatically calculated for optimal sampling. The models work to optimize depth for planar trajectory in the (x-z) plane. Future work will be dedicated to 3D trajectories in terrains that contain rigid obstacles.

Deep learning-based bridge corrosion detection using UAV images

Zahra Ameli; University of Maine; United States
Eric Landis; University of Maine; United States

In the United States 40 percent of the bridges are built of steel (U.S. National Bridge Inventory (NBI)). Corrosion is a major factor in deterioration of these structures which can pose safety risks and significant economic loss if left untended. Each year the Federal Government and State departments of transportation (DOTs) spend billions of dollars on bridge rehabilitation and maintenance due to corrosion. To prevent or mitigate corrosion damage, regular inspection is essential. Inspections are often carried out manually, sometimes in hazardous conditions and in a process which could be very time consuming and costly. Unmanned Aerial Vehicles (UAVs), paired with Deep Learning (DL) algorithms have the potential to perform autonomous damage detection that can significantly decrease the inspection time, the need for human interpretation and lead to more objective inspections. There have been several studies in the area of DL-based corrosion detection. While most of the studies focus on the identification and localization of the corrosion, there is very limited study that precisely segment corrosion in irregular boundary shapes, to quantify corrosion areas and severity. Furthermore, there is very limited study that quantifies the severity of the corrosion by determining its condition state. A condition state is a determination of damage severity based on the guidance from American Association of State Highway Transportation Officials (AASHTO) and Bridge Inspectors Reference Manual (BIRM). The objective of this study is to implement a DL model for identifying and segmenting corrosion in steel bridge elements according to the AASHTO condition states (Good, Fair, Poor and Severe).

Deep Learning-based Integrated Probabilistic Cost Analysis for Future Decarbonized Hurricane-Prone Power Systems

Kamiar Khayambashi; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States
Andrés Clarens; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States
William Shobe; Batten School of Leadership and Public Policy, University of Virginia, Charlottesville, VA; United States
Negin Alemazkoor; Department of Engineering Systems and Environment, University of Virginia, Charlottesville, VA; United States

The emerging effects of climate change have emphasized the need for decarbonizing power systems, to lower greenhouse gas emissions and counter the negative impacts of global warming on the environment and society. However, various sources of uncertainty, including technological uncertainties and unpredictable consequences of climate change impede the transition to a carbon-free power system. To facilitate more informed decisions under uncertainty, we propose a framework for probabilities cost analysis of a future decarbonized power system. Our proposed approach provides an integrated chain of probabilistic models to evaluate the power system's expected total cost in light of changes in hurricane characteristics, population, electricity demand, and the cost of various technologies, including storage cost. A sensitivity analysis is then performed to investigate the main sources of uncertainties that drive the cost uncertainty of a decarbonized system. To carry out the probabilistic and sensitivity analysis in an efficient manner, we train a deep learning model as a surrogate for the computationally expensive simulations of the system. The proposed framework is showcased on Puerto Rico's power grid, a hurricane-prone isolated system. The results provide valuable insights for practitioners to plan for transitioning to a carbon-free power system under various sources of uncertainty.

Deep reinforcement learning strategies for structural control devices with variable inerter

Takehiko Asai; University of Tsukuba; Japan
Yuto Inaba; University of Tsukuba; Japan

Various kinds of devices employing inerter technologies have been proposed for the purposes of structural control and energy harvesting. Especially in recent years, considerable efforts have been made to develop variable inerter mechanisms to improve the performance further; however, to the authors' knowledge, practical algorithms to control the variable inerter mechanism in real time have not been proposed so far. In this research, deep reinforcement learning (RL) strategies are applied to the various kinds of variable inerter devices including tuned inertial mass electromagnetic transducer (TIMET), one of the inerter devices taking advantage of resonance effect proposed by the authors, to control the variable inerter mechanism in addition to the motor. The TIMET installed on a single-degree-of-freedom (SDOF) model is trained based on the deep RL algorithms, and numerical simulation studies on the SDOF model with the TIMET controlled by the trained agent are carried out. Then, the results show that the deep RL can be applicable for variable inerter devices in real time and has a great potential to improve the structural control performance of the variable inerter devices.

DEM Simulations of the Seismic Response of Tunnels in Deep Granular Deposit

Ahmed Khamiss; Southern Methodist University; United States
Usama El Shamy; Southern Methodist University; United States

The seismic response of tunnels constructed in a deposit of granular soil of depth greater than 20 m is examined in this paper. Three-dimensional discrete-element method (DEM) simulations were used to model the soil assembly and the tunnel lining. Soil particles were simulated as rigid spherical particles that are allowed to overlap at the contact points. The tunnel lining was modeled as a flexible system using a group of particles that were glued together using cementitious bonds to mimic the physical properties of an actual tunnel. Free-field boundaries were used at the model's lateral sides to prevent the propagating wave's reflections back to the domain and enforce the free-field motion. The DEM computational framework was validated using published centrifuge test results. DEM simulation results reveal good agreement with the experimental centrifuge test results when subjected to the same input motion. The results showed close agreement between both methods in terms of amplification factor, and induced shear stresses in the soil deposit. However, the numerical bending moment and settlement time histories exhibited higher residual values and amplitude during the dynamic phase of loading compared to the experimental results. Further simulations were carried out to investigate the seismic response of the system under different input motion characteristics. The dynamic earth pressure was monitored at certain points on the tunnel lining in addition to the settlement of the tunnel lining during seismic loading. It was found that the dynamic earth pressure and tunnel lining forces increased during seismic excitation and the final residual values were, in most cases, considerably larger than the initial static values. The results also showed that the maximum amplification factor, ground settlement and tunnel lining forces were experienced near the resonant frequency of the system. The maximum residual earth pressure after shaking was found to occur at a different frequency. The relative motion between the tunnel lining and surrounding soil showed higher significance in case of frequency of 2 Hz, and this was reflected on obtaining higher residual earth pressure at this frequency.

DEM-MBD Coupled Simulation of a Dual-auger Burrowing Robot in Dry Sand

Sarina Shahhosseini; ASU; United States
Mohan Parekh; ASU; United States
Junliang Tao; ASU; United States

This study demonstrates the application of a coupled discrete element method (DEM)– Multi-body Dynamics (MBD) framework in simulating the self-burrowing behavior of a dual-auger robot in dry sand. In geotechnical engineering, dry sand can usually be modeled using DEM based on laws of motion and contact mechanics. In robotics, a robot can be modeled using MBD, in which each component of the robot is modeled as interconnected rigid or flexible bodies whose motions also obey the laws of motion and are limited by kinematic constraints. The coupling of the two is realized using an open-source physics engine, Chrono. The self-burrowing robot consists of two horizontal augers that are connected to a common stabilizing stator using two motors. A typical co-simulation loop starts with the DEM module that solves the inter-particle and particle-structure forces and displacements; the particle-structure forces are then transferred to the MBD module to solve the robot's dynamics; the updated kinematics information is then transferred back to the DEM module. The design of the augers and the geometric parameters were studied to better understand geometry's effect on the robot's driving force. The values of the pitch ratio of the shaft and cone were changed to comprehend the effects of the augers on the self-burrowing thrusts and resistive forces.

Density-Driven Damage Model (D3M)of Concrete Structures

Yingbo Zhu; University of Pittsburgh; United States
Zachary Grasley; Texas A&M; United States
Alessandro Fascetti; University of Pittsburgh; United States

In this presentation, we will describe the mathematical derivation and numerical implementation of a novel regularized Density-Driven Damage Model (D3M) for simulating failure in concrete members. The novel idea behind the derivation of the approach is that damage is described as a function of the local change in material density. In this context, a three-phase mesoscopic representation of the material is used, where coarse aggregate, mortar, and the Interfacial Transition Zone (ITZ) are explicitly modeled to obtain a realistic representation of the material internal structure. We will present the mathematical derivation of the model, with emphasis devoted to the regularization of the computational approach. We will then proceed to demonstrate that the new regularized D3M shows little to no sensitivity to mesh size, while also predicting realistic compression-to-tension strength ratios and damage patterns at failure. Finally, we will show results from the model validation, by comparison with experimental results of 3-point bending tests on plain concrete beams of various sizes, also demonstrating that the regularized D3M is capable of predicting size effect in concrete members.

Design and 3D-Printing of Woven Textiles

Tian Chen; University of Houston; United States

Additive manufacturing processes such as 3D printing are uniquely suited towards fabricating topologically complex structures, for example, chain-mails, knits, weaves, or knots. The layer-by-layer deposition process enables the manufacturing of textiles with unique yarn geometries and topologies that are not feasible with traditional techniques. While 3D printed textiles have the potential to be a new class of meta-material, their mechanics have not been thoroughly studied. Here, we focus on biaxially woven textiles and discuss their fabrication, mechanics, and design. We develop an algorithm that generates parametric biaxial weaves. We map these design parameters to the weaves' mechanical properties through a two-stage Design-of-Experiments protocol. The samples are printed using a multi-material jetting process and tested under uniaxial tension until failure. The resulting stress-strain behavior is approximated by a bilinear model characterized by a transition strain and the post-transition stiffness modulus. The strain at which transition occurs is determined by the loading direction and the weaving pattern. The post-transition stiffness modulus is influenced by the loading direction, the yarn diameter, the weave pattern, and the yarn spacing in that order. Failure occurs through rupturing of the individual yarns, and not inter-layer delamination. Using these results, we demonstrate textile design with spatially varying stiffness and flexibility by tuning the interior angle at each quadrilateral formed by the intersecting yarns. Further, we use Chebychev net to cloth a substrate using patches of woven textile. The synergy between additive manufacturing and generative design may pave the way towards the fabrication of next generation functional textiles.

Design and component testing of pressurized sand-dampers: Effects of the design parameters

Konstantinos Kalfas; Southern Methodist University; United States
Nicos Makris; Southern Methodist University; United States

This study presents results from component testing on various configurations of a recently developed pressurized sand-damper in which a steel sphere is moving within a cylindrical tube filled with sand that is under pressure. The experimental campaign investigates the effects of the key design parameters of the damper, namely the effect of the clearance between the moving sphere and the cylindrical tube and the effect of the overall length of the damper to its force output. The recorded force-displacement loops when normalized to the strength of the pressurized sand-damper reveal remarkable order with stable behaviour and confirm decisively that the force output is rate-independent. The paper also presents recorded force-displacement loops where the sphere mounted on the piston-rod is replaced with a bolt where only the bolt-head and nut are protruding from the moving piston-rod. With this configuration, the pinching behaviour of the pressurized sand-damper at longer strokes is suppressed without generating large forces at longer strokes.

Design of Thick Origami for Reusable and Deployable Load Carrying Structures and Infrastructure

Yi Zhu; University of Michigan; United States
Evgueni Filipov; University of Michigan; United States

Deployable and reconfigurable structures inspired by origami can offer novel infrastructure-scale applications including reusable components, adaptive facades, and rapid to assemble buildings. However, existing origami-inspired structures have limited load-carrying capacity because they use thin sheets, non-uniform thickness topologies, and connections that remain unlocked and flexible. In this talk, we show a unified design, fabrication, and analysis method for thick origami systems to build deployable structures with load-carrying capabilities. First, we demonstrate that by designing super-imposed origami patterns and using appropriate locking hinges, it is possible to design modular thick origami structures with highly versatile configurations and functions. This design philosophy can produce deployable thick origami with uniform thickness and one-degree-of-freedom (1DOF) kinematics for constructing bridges, columns, beams, trusses, and many other load-carrying civil structures. Next, we show that these modular thick origami systems can be made using common digital fabrication techniques including laser and waterjet cutting. In addition, we established an analytical bar and hinge method to understand the kinematics, mechanics, self-weight, and external actuation of these thick origami structures. Finally, our work shows that the design of thick origami can be drastically different from that of thin origami. Instead of first designing the origami pattern and then adding thickness for engineering applications, directly designing for thick origami can offer advantageous properties like 1DOF kinematics, modularity, uniform thickness, and enhanced load-carrying capabilities. The proposed design and analysis framework in this work demonstrates a useful method to create deployable civil systems for rapid construction, building retrofitting, disaster mitigation, structural adaptability and more.

Design Targets to Achieve Community Resilience Metrics in a Changing Climate

Jiate Li; Colorado State University; United States
John van de Lindt; Colorado State University; United States

Scientists predicted that the future intensity and frequency of climate-induced hazards will continue to change as climate conditions change. This study focuses on the impact of hurricane intensity under various climate prediction scenarios on a virtual community located in Miami, FL. Research revealed that the mean of the annual maximum wind speed continues to increase because of global warming. By the end of the 21st century, the increase in wind speed would be significant, which leads to a higher likelihood of severe physical damage to residential buildings built to current standards, particularly with their long-term service lives. To investigate this, the retrofit of residential buildings for future loading, e.g., 2100, is investigated by applying concepts of climate-adaptive design at the individual building level to meet community resilience goals. These goals are specified as keeping the percent population outmigration below a community-selected threshold over the next 100 years. An archetypical (virtual) community is used for illustrative purposes, and hurricane fragility curves are used to assess the physical damage to structures. Building recovery time is simulated based on the resulting damage, which is then combined with household demographic characteristics to quantify population outmigration. Different levels of adaptive design for individual buildings are explored to achieve community-level climate resilience goals in a changing climate.

Development and Uncertainty Analysis of Probabilistic Vulnerability Model for Mid/High-Rise Buildings

Zhuoxuan Wei; Florida Institute of Technology; United States
Jean-Paul Pinelli; Florida Institute of Technology; United States
Kurtis Gurley; University of Florida; United States
Christian Bedwell; University of Florida; United States

Mid/high-rise commercial residential buildings (MHRB) are engineering buildings with more than 3 stories, which are becoming more prevalent in coastal areas due to increased population density. They typically suffer minor structural damage during hurricane events. However, recent hurricanes have shown their vulnerability to wind-driven rainwater penetration through the defects and breaches of the façade openings, which can result in substantial interior and contents damage, and subsequent time-related expenses. These damage and expenses can negatively impact the resilience of coastal communities. The authors developed a component-based probabilistic vulnerability model to produce realistic joint assessment of exterior, interior and contents damage of MHRB. The model combines estimates of opening defects and damage, with computations of water ingress, distribution, and propagation, and with a damage evaluation and costing algorithm. The presentation shall describe the modeling approach, including challenges and limitations. The presenters shall also discuss the uncertainty attached to some of the key interior damage model input variables (e.g. components water absorption capacities), its propagation and impact on the uncertainty of the vulnerability model outputs (e.g. mean values and uncertainty ranges). A better understanding and modeling of the damage mechanisms of MHRB should lead to a better understanding of the hurricane risk in coastal areas and a better assessment of mitigation measures.

Development of a custom metal DED 3D printer for real-time printing quality control

Subin Shin; Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology; South Korea

Sangjun Kim; Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology; South Korea

Hoon Sohn; Center for 3D Printing Nondestructive Testing, Department of Civil and Environmental Engineering, Korea Advanced Institute of Science and Technology; South Korea

In this study, a metal directed energy deposition (DED) 3D printer was developed with customized hardware and software platform, which can realize real-time modification of the printing laser power, powder feed rate, gas flow, and printing speed during the DED process. In-process monitoring devices, such as a coaxial infrared (IR) camera and a laser line scanner, have also been integrated into the custom metal DED 3D printer. By monitoring the melt pool using the integrated IR camera and laser line scanner, the custom printer is able to capture the melt pool morphology (e.g., melt pool length and width), and to optimize the printing process parameters and improve the quality of the printed products. Validation tests were performed on melt pool depth control by modifying the printing laser power, scanning speed, or powder feed rate based on the melt pool length and width monitored during the DED process. The test results demonstrate the potential for real-time control of the DED process, leading to improved efficiency and accuracy in the production of 3D printed objects.

Development of a damage-responsive self-healing system using bio-inspired polymeric fiber (BioFiber) for incorporation into infrastructure materials

Mohammad Houshmand Khaneghahi; Drexel University; United States
Divya Kamireddi; Drexel University; United States
Seyed Ali Rahmaninezhad; Drexel University; United States
Aidan Cotton; Drexel University; United States
Caroline L. Schauer; Drexel University; United States
Christopher M. Sales; Drexel University; United States
Ahmad Najafi; Drexel University; United States
Reeva Street; Drexel University; United States
Amirreza Sadighi; Drexel University; United States
Yaghoob (Amir) Farnam; Drexel University; United States

The damages induced to the concrete structures and infrastructures due to the crack formation and propagation impose hefty expenses on the governments and private sectors. Since self-healing techniques reveal potential advantages in the service-life extension and resilience of cracked/fractured materials, several researchers have shifted their focus from damage prevention methods to damage management strategies, such as self-healing, in concrete structures and infrastructures. We recently developed a bio-inspired polymeric fiber (hereafter called BioFiber) to deliver bacterial self-healing agents (bio-agents) into cementitious materials featuring damage-responsive healing activations. The bio-agents were used to establish microbially-induced calcium carbonate precipitation (MICP) in the concrete. The BioFibers manufacturing process involved loading endospores, i.e., dormant and non-reproductive form of bacteria, on the Polyvinyl alcohol (PVA) fibers protected by the sheath of a crosslinked biocompatible hydrogel. In this stage, the physical properties of hydrogel was tailored based on water up-take capacity and coating thickness. In order to incorporate the damage-responsiveness feature into the BioFiber, additional strain-responsive shell coating was added to the system. The main objectives of this study are to firstly investigate the material options for the outer shell coating using various lacquers and brittle polymers, and secondly evaluate the performance of the BioFiber's self-healing efficiency. To decide upon the shell materials, the following criteria were defined: (i) protecting endospores-laden hydrogel against penetration of concrete pore solution during the casting process, (ii) withstanding mechanical loading during concrete mixing, (iii) having low core-fiber to shell thickness, and (iv) damage-responsive rupture. For the shell materials, polystyrene (PS), polypropylene, polyethylene, epoxy resin, nitrocellulose, polylactic acid (PLA), polyvinylidene fluoride, and cyanoacrylate-based adhesive were experimented. The shell materials were shortlisted to the polymer blend of polystyrene and polylactic acid (1:1 mass) based on the results of impermeability, damage-responsivity, and concrete casting survivability. To minimize the shell coating thickness on the BioFibers, a parametric study was performed using a 6, 12, and 18 copolymer/solvent weight-to-volume (w/v) ratio. In the final stage, the self-healing performance of BioFibers was evaluated based on the quantity of precipitated calcium carbonate. Intact and fractured BioFibers were exposed to carbon/calcium/nitrogen sources to observe the bio-mineralization process. The amount of calcium carbonate was quantified using thermogravimetric analysis (TGA) which was conducted on the precipitated solid residue. The findings of this study revealed that the 4-layer coating of PS/PLA-12 w/v on the BioFiber can satisfy the shell criteria as well as produce significant amounts of calcium carbonate upon shell breakage.

Development of an integrated platform for probabilistic risk assessment using fault tree analysis

Nailah Afshan; North Carolina State University; United States
Saran Srikanth Bodda; North Carolina State University; United States
Abhinav Gupta; North Carolina State University; United States
Kevin Han; North Carolina State University; United States

Probabilistic risk assessment (PRA) is employed as a crucial tool for risk-informed decision-making under uncertainty and interdependencies within complex systems. This research aims to augment the risk evaluation of critical facilities in civil infrastructure systems subject to external hazards. The study primarily focuses on systems analysis, a key step in PRA, which utilizes fault and event tree analysis to propagate the fragility of structures, systems, and components (SSCs) for estimating the system-level risk. Several algorithms have been proposed for systems analysis over the last few decades such as binary decision diagrams (BDD), zero-suppressed BDD, method of obtaining cut sets (MOCUS), and more recently using compressed truth tables (CTTs). These algorithms have some limitations in solving the complete fault tree, but different algorithms have computationally superiority in solving different types of fault tree configurations such as a fault tree with no dependent events, one dependent event, and multiple dependent events. No attempts have been made to develop a unified framework that integrates all these algorithms. It is essential to have an easy-to-implement unified approach that would allow risk-informed decision-making under various scenarios using all these algorithms. This research attempts to develop such a framework. The proposed framework is modular in nature and has four basic components. The Initialization module takes the input file in Open-PSA model exchange format (opsa-mef) and processes it into valid analysis constructs. The second module is the optimization module which focuses on the modularization of the fault tree structure by applying different preprocessing techniques such as gate normalization, gate coalescing, module detection, etc. This module enables subsequent parallel processing of fault tree modules. The third module is the analysis module which receives output from the optimization module and runs one of the four analysis algorithms based on the type of fault tree structure. Finally, the reporting module presents the results such as critical accident sequences and importance measures.

Development of Johnson-Holmquist-Beissel Model in Discontinuous Deformation Analysis and its Application in Projectile Penetration

Chenghao Li; Sun Yat-sen University; China
Rui Li; Sun Yat-sen University; China
Junjie Chen; Sun Yat-sen University; China
Jianjun Ma; Sun Yat-sen University; China
Linchong Huang; Sun Yat-sen University; China

Mohr-Coulomb criteria, which has been employed in discontinuous deformation analysis (DDA), is insufficient for studying the dynamic responses of brittle materials. To better replicate the failure process upon projectile penetration, the parameters in Johnson-Holmquist-Beissel (JHB) constitutive model are redefined utilising DDA's calculation parameters. And JHB model is further implemented and validated in a self-developed DDA program. The result of the bonding unit test, which is used to validate the constitutive model's functionality in the programme, are highly congruent with those of the references. To demonstrate the model's applicability, the proposed JHB-DDA model is utilised to simulate and analyse projectile penetration under various scenarios. Typical factors such as residual velocities after different initial velocity penetrations, damage effects for different projectile nose coefficients (calibre-radius-head, CRHs), and target thickness, are investigated. The penetration results are in good agreement with the theoretical/numerical solutions in literature. The developed JHB-DDA model has considerable advantages over LS-DYNA in terms of explicit representation of material damage. Reasonable numerical results demonstrate that the developed JHB-DDA model can be utilised as an effective tool for predicting projectile penetration of brittle materials.

Development of Material Property Feasibility Constraints for a Multiscale Topology Optimization Framework Using Radial Basis Function Interpolations

Brent Bielefeldt; National Research Council; United States
Richard Beblo; Air Force Research Laboratory; United States
Eddie Meixner; University of Dayton; United States
Robert :Lowe; University of Dayton; United States

Considering structural design at both the macro- and mesoscale can result in novel and non-intuitive solutions, especially for applications in which there exist multiple performance criteria and/or constraints across multiple physical fields. In such an approach, it is crucial that the bounds of the design space at the mesoscale are well-defined such that the response of the structure at the macroscale remains feasible. Previous work has demonstrated the use of radial basis function (RBF) interpolations to generate N-dimensional constraint surfaces using optimal responses from a single Pareto frontier obtained via an initial optimization study that considers mesoscale structural topologies generated using a parametric L-system approach. However, it has been determined that the responses from a single Pareto frontier allow for the RBF constraints to extrapolate into areas that remain infeasible and are thus inadequate to fully define the bounds of the design space. This work will explore the extension of this approach to consider the \$2^N\$ Pareto frontiers that exist for a given problem and demonstrate that they result in more rigorous material property constraints. This method will then be applied to an academic example that considers both structural and thermal boundary conditions, and the effects of both the material property constraints and trade-offs between the two sets of boundary conditions will be detailed.

Digital twin for damage diagnosis in steel framed structures

GBANDI NIKABOU; Vanderbilt University; United States
JingWen Du; Vanderbilt University; United States
Pranav M. Karve; Vanderbilt University; United States
Sankaran Mahadevan; Vanderbilt University; United States

Large structural systems, under extreme natural hazard loadings, exhibit strongly nonlinear behavior that challenges commonly used diagnosis and modeling techniques. In such situations, the initial model may be inadequate for structural health monitoring. We present a digital twin approach that continuously updates the model with health monitoring data and includes uncertainty quantification in both sensor data and model prediction. A three-step modeling methodology is developed for diagnostic and prognostic analysis and uncertainty quantification. The first step consists of mapping the relationship between the locally measured wind speed at the building site and the wind speed measured at National Oceanic and Atmospheric Administration (NOAA) weather stations using a predictive model. This allows the prediction of the wind speed the structure will experience given weather forecasts at NOAA weather stations. The second step consists of building an FEA model of the door frame with wind pressure load as input and strain at specific points of the door as output. Principal components analysis (PCA) of synthetic data from an undamaged component (door) model is used to compute the Q-Statistic. Synthetic strain data for damaged components, with different damage configurations, is then projected onto the PCA baseline model for damage/anomaly detection. A model is then constructed to predict the damage index value given the wind speed (and other environmental variables) as input. This model is verified, calibrated, and validated using sensor data from the field, and the uncertainty in the surrogate model prediction is quantified. The validated model is then used for probabilistic prognosis to inform proactive decision-making ahead of critical events. The model is updated with new field data as it becomes available; due to the continuous updating, the model becomes a digital twin of the structure, achieving increasing accuracy over time. The proposed methodology is illustrated for a large steel frame and rolling door in an aircraft hangar.

Digital Twin of Foamed Concrete toward Design and Development of High Performance Building Envelope

S.H. Chu; Columbia University; United States
J.M. Zhang; Columbia University; United States
H.M. Yin; Columbia University; United States

Modern construction poses new requirements and constraints for material efficiency and multifunctionality. Lightweight concrete has been used in building envelope for the low raw material consumption and high thermal resistance. However, the labor cost and curing time are high in comparison with conventional sandwich construction. Modular construction is emerging to shift construction time and cost to material manufacturing for rapid construction and quality control. The key to success in modular construction lies in its material design towards concurrently high performance and lightweight. These two performance attributes are contradictory to each other. To break this dilemma, this study proposed a new form of lightweight ultra-high-performance concrete and made a parallel comparison to that traditional lightweight concrete. The stiffness, strength, thermal conductivity, and thermal expansion coefficient of the foamed concrete are characterized by the laboratory testing; in parallel using the microstructural parameters from the imaging process digital sample is reproduced as a digital twin, which is simulated for the thermomechanical behavior. The physical experiments can be well understood and a new design method of an ultra-lightweight concrete building panel is developed. Moreover, the relationship among the third-generation superplasticizer dosage, amount and type of lightweight inclusions, and water to cementitious ratio is clarified from the perspective of particle packing (for both solid and voids) and slurry film thickness. This research shall advance the further development of sustainable and resilient infrastructure.

Digital Twinning and Wind Load Estimation of Block Island Offshore Wind Turbines Using One Year of Data

Babak Moaveni; Tufts University; United States
Eric Hines; Tufts University; United States

In 2021, the authors have instrumented one of the offshore wind turbines (OWT) of the Block Island Wind Farm in Rhode Island, USA. The instrumentation include accelerometers, strain gauges, and inclinometers which are collecting data continuously since October 2021 at 50 Hz sampling rate. The paper shows physics-based as well as data-driven digital twinning of the instrumented OWT using vibration and SCADA measurements over a year of monitoring. The OWT is modeled in structural analysis software OpenSees and multi-physics wind-turbine simulation tool OpenFAST. An Augmented Kalman Filter (AKF) is used for estimation of equivalent wind load on the turbine during different operational and environmental conditions. Thrust and dynamic range of the estimated wind load are studies for different ranges of wind speed, rotor speed, and power. The average estimated thrust load is compared with the equivalent static thrust from measured moments as well as design loads. Finally, the fatigue life of the turbine at several hotspots on the substructure and tower are calculated and compared to those provided by the OWT designers.

Digital twins for inspections of reinforced concrete bridges

Asad ur Rahman; University of Houston; United States
Deepank Kumar Singh; University of Houston; United States
Subin Varghese; University of Houston; United States
Vedhus Hoskere; University of Houston; United States

The inspection of a bridges is a time consuming and expensive process and must be completed every two years in the united states. The AASHTO Manual for Bridge Evaluation describes seven types of formal inspections on publicly owned in-service bridges; initial/inventory, routine, in-depth, fracture-critical members, underwater, special, and damage. Existing procedures are unable to leverage previous inspection efforts adequately. Unmanned aerial systems (UASs) equipped with digital cameras in conjunction with structure-from-motion (SfM) photogrammetry software to produce 3D digital surface models of existing bridges and facilitate the inspection of bridge elements. However, the collection of hundreds of images result in large amounts of data that are difficult to manipulate. This research proposes deep learning-based processing techniques to extract actionable information and create efficient digital twin representations from such image-based models that can help bridge managers address the challenges of existing inspections without high demands of data storage and compute. The study will act as a step towards enabling the engineers and maintenance crews to comprehend the existing condition of the bridge.

Direct Numerical Simulation (DNS) of Binder-Grain Composite Materials Using Pure Discrete Element Method (DEM) Modeling

Beichuan Yan; University of Colorado Boulder; United States
Richard Regueiro; University of Colorado Boulder; United States

Direct Numerical Simulation (DNS) of binder-grain composite materials such as plastic bonded explosives (PBXs), clay and sand mixture, asphalt and gravel blend, etc, are challenging due to material complexity, spatial substance variety, grain shapes, interfacial uncertainty, and computational cost. A general and pure DEM modeling & simulation method has been developed to study the quasi-static and dynamic mechanical behavior of these materials, especially for the high pressure and high strain rate deformation, damage evolution and fracture. In this method, both the binder material (such as Kel-F and Estane polymer) and the filler grains (such as F50 quartz sand and IDOX powder) are simulated by adhesively bonded DEM particles at the length scale of microns, and the interface and interaction between different materials is also naturally modeled by adhesive DEM.

Firstly, different adhesive DEM models and breakage criteria are developed for the binder and filler materials, respectively. Secondly, a four-step numerical “manufacturing” process is programmed to generate binder and filler materials, and calibrate against laboratory experiments: isotropic compression, decompression, trimming and uniaxial compression. And thirdly, a relatively complicated procedure is employed to generate the binder-grain composite sample and perform quasi-static and dynamic impact on the sample, in which pseudo composite prills are packed via gravitational pouring, each then replaced by a “core + shell” (i.e., grain + binder) structure that is cut from the manufactured material blocks according to shape requirement, and pressed into a final sample via oedometer compression.

Discrete Element Method for Regolith-Tool Interaction Modeling of RASSOR Collection System

Daniel Gaines; Clemson University; United States
Qiushi Chen; Clemson University; United States
Laura Redmond; Clemson University; United States

In this work, a model is developed for evaluating the behavior of the NASA RASSOR drum system. The tool-regolith model is first calibrated comparing regolith laboratory testing with the results of a discrete element model of the same type and function. Sensitivity analysis is conducted to understand the effect of RASSOR Drum behavior on the lunar regolith collection, and is compared to laboratory results. The calibrated drum is then used to explore the effects of various control behaviors on the RASSOR drum and evaluated for the purposes of future RASSOR usage. This new regolith-tool interaction mode will provide necessary data and optimal operation parameters for the RASSOR drum as well as future lunar and Martian regolith sampling or collection instruments. In addition, this research will lay the groundwork for modeling more complex systems for planetary exploration missions.

Discrete element modeling and design optimization of bio-inspired drilling into the lunar regolith

Liang Zhang; University of Cincinnati; United States
Lei Wang; University of Cincinnati; United States
Quan Sun; University of the District of Columbia; United States
Jesus Badal; University of the District of Columbia; United States
Qiushi Chen; Clemson University; United States

In recent years, many nations have launched lunar exploration missions. Characterization of the lunar regolith is critical for the extraction and utilization of the in-situ resources to build a permanent base on the Moon. However, due to many challenges for drilling operations on the Moon, higher demands have been placed on the drilling tool design on the moon. Designing an optimal lunar drill and determining its controlling strategies become crucial to the research on the lunar regolith. This paper presents a discrete element modeling and multi-objective optimization design framework for the clam-inspired drill design into the lunar regolith. The parameters for the discrete element modeling are calibrated using the triaxial tests conducted on the lunar highlands simulants (LHS-1) using the Taguchi method. The burrowing process of the razor clam is used in the design of the drill into the lunar regolith and a discrete element modeling of clam-inspired drilling is then built. A new two-stage design optimization framework is proposed for the clam-inspired drill into the lunar regolith. In the first stage, the design parameters of the drill geometry (i.e., anchor height, anchor shape, and cone apex angle) are optimized and the design objectives are construction cost and total power consumption for the drilling. A multi-objective optimization is used to identify the most preferred geometry design for the drill. With the most optimal geometry adopted in the second step, the controlling strategies (i.e., downward velocity, rotation velocity, expansion velocity, and anchor-cone distance) are investigated in the design space and the drilling effectiveness and drilling efficiency are evaluated as the two design objectives. With the obtained optimal geometry design, the controlling strategies (i.e., downward velocity, rotation velocity, expansion velocity, and anchor-cone distance) are investigated in the second stage. The drilling effectiveness and drilling efficiency are evaluated as the two design objectives in the second stage, and the optimal controlling strategies are realized following a similar optimization procedure. The proposed discrete element modeling and design optimization framework provide an efficient solution for the design of a bio-inspired drill into the lunar regolith, which can also serve as a guide for the design of bio-inspired tools and technologies for other extraterrestrial bodies.

Discrete optimization of structures through a sequential decision process: benchmarking and validation

Maximilian Ororbia; The Pennsylvania State University; United States
Gordon Warn; The Pennsylvania State University; United States

Recently it was demonstrated that the discrete optimization of structures can be viewed as a sequential decision process, whereby a sparsely connected seed configuration is sequentially altered through discrete actions to synthesize an optimal solution given a specified design objective and constraints. In particular, this work models the discrete optimization of structures as a Markov decision process (MDP) and solves it using either reinforcement learning [1,2] or deep reinforcement learning (DRL) [2]. Within this framing, the MDP states correspond to specific structural designs represented as finite graph configurations and the actions correspond to specific design grammars that are applied to alter the finite graph, transitioning the design to a new state and graph configuration. Key to modeling discrete optimization as an MDP is the relation of the rewards to the change in the design's performance as the agent explores alternate configurations. Through this relation, the agent learns an optimal policy, that is, a sequence of necessary alteration actions, that maximizes its cumulative reward and it simultaneously synthesizes a high-performing design solution with respect to the design problem's objective and specified constraints. The discrete MDP model solved using reinforcement learning and DRL is applied to the discrete optimization of planar truss and frame structures. In this work, both the agent's learned optimal policy and the resulting synthesized design solution are validated against the policy determined by using a state-action value iteration dynamic programming algorithm, chosen for its strong convergence guarantees, and the global optimal design configuration identified from an exhaustive evaluation of all feasible design solutions, respectively. This work also discusses the development of deep neural network architectures to solve the discrete MDP model considering both topological and parametric actions and similarly validates the learned optimal policies and synthesized solutions for each network. Through several numerical examples, each with different state and action space cardinalities, it is observed that the agent effectively learns optimal policies leading to optimal solutions and outperforms other considered alternative methods with lower computational effort.

[1] Ororbia, M. E., & Warn, G. P. (2020). Structural design synthesis through a sequential decision process. Proceedings of the International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE Vol. 83983). American Society of Mechanical Engineers.

[2] Ororbia, M. E., & Warn, G. P. (2022). Design synthesis through a Markov decision process and reinforcement learning framework. Journal of Computing and Information Science in Engineering, 22(2).

[3] Ororbia, M. E., & Warn, G. P. (2023). Design synthesis of structural systems as a Markov decision process solved with deep reinforcement learning. Journal of Mechanical Design, 1-19.

Discrete particle simulation of granular pine residues in an FT4 powder rheometer

Zakia Tasnim; Clemson University; United States
Dr. Qiushi Chen; Clemson University; United States
Dr. Yidong Xia; Idaho National Laboratory; United States
Dr. Ahmed Hamed; Idaho National Laboratory; United States

Granular pine residue from forestry is a low-cost source of biomass feedstock for conversion into biofuels. Good flowability of the granular material is required, as poor flowability can lead to process upsets, such as jamming and clogging, during the comminution and handling operations. The FT4 powder rheometer has been used to characterize the dynamic shear strain rates of granular biomass materials. In this work, discrete element method (DEM) simulations of FT4 shear flow test containing granular pine residues with an average nominal size of 4 mm in FT4 are designed and conducted to elucidate relationships between the bulk shear-strain rate and particle material attributes such as shape, size distribution, and interparticle properties (i.e., friction and cohesion due to surface moisture). A DEM contact model developed to resolve the nonlinear, hysteretic strain-hardening behavior in bulk pine particles under stress consolidation is used versus the elastic contact model. Clumped spheres are used to approximate the pine particle shapes. The relevant experimental data are used for the DEM model calibration and simulation validation.

Discrete topology optimization of structures through deep reinforcement learning

Maximilian Ororbia; The Pennsylvania State University; United States
Gordon Warn; The Pennsylvania State University; United States

Topology optimization is a mathematical framework that in general seeks to determine the optimal layout of material in a design domain. If the design variables are continuous, then often sensitivities can be derived and used with gradient based optimization techniques. However, for certain applications the design variables are inherently discrete, for example the design of steel structures that are constructed of standardized steel sections. This work focuses on the latter, whereby the topology optimization of structures with discrete elements and discrete design variables is formulated as a sequential decision process solved using deep reinforcement learning (DRL), which has been shown to efficiently provide adept solutions to a variety of high-dimensional planning and learning problems. Hence, this work mathematically models the discrete topology optimization of planar structures, including trusses and frames, as a Markov decision process (MDP) that is solved using DRL. By modeling structural optimization as an MDP, the set of all feasible design solutions can be precisely represented and the MDP naturally, but not exclusively, accommodates discrete actions. In the context of the MDP, the states correspond to specific structural designs represented as finite graph configurations, the actions correspond to specific topological and parametric grammars that are applied to alter the structure which transitions the design to a new state and graph configuration, and the rewards are related to the improvement in the altered graph configuration's performance with respect to the design objective as well as the specified constraints. By solving the discrete MDP model using DRL, a deep neural network architecture is specifically developed to approximate the state-action value function, such that the network has far fewer parameters than the cardinality of the state space of feasible design solutions. This enables the framework to adeptly solve discrete topology optimization design problems with large state spaces. A benefit of the suggested method, in comparison to other discrete optimization methods, is that the MDP-DRL framework is grounded in mathematics and is not dependent on the specifics of the structural model. The framework is evaluated in the context of the topology optimization of planar trusses and frames with discrete elements and multiple discrete cross-sectional areas, and its utility is investigated through several numerical examples, each with different state space cardinalities. The objective of the design task is to determine both the layout of structural elements and the assignment of cross-sectional areas that minimize the displacement at a specified node for a given external force(s) determined using either linear or nonlinear finite element analysis, subject to stability and volume constraints. Through qualitative and quantitative comparison with other considered alternative methods, the framework is observed to adeptly learn optimal policies that synthesize optimal design solutions.

Discrete Wavelet Transform Based Earthquake Data Augmentation for Training Surrogate Models of Nonlinear Structures

Siddharth Parida; Department of Civil Engineering, Embry Riddle Aeronautical University; United States
Christina Bocirnea; Department of Civil Engineering, Embry Riddle Aeronautical University; United States
Supratik Bose; Forensic Engineering, Donan; United States
Georgios Apostolakis; University of Central Florida; United States

The computationally expensive estimation of engineering demand parameters (EDPs) via non-linear finite element (FE) models, while considering both earthquake and material parameter uncertainty, limits the use of the Performance Based Earthquake Engineering framework. Attempts have been made to substitute the FE models with surrogates, however, most of these models are function of material parameters only, which necessitates re-training for earthquakes not previously seen by the surrogate. In the current study, the authors propose a novel machine learning based surrogate modeling approach that considers both the uncertainties so that it can predict for unseen earthquakes. Generally, machine learning models consist of many parameters which need to be estimated from available data. However, due to limited availability of data in the field of earthquake engineering, often, it is difficult to develop stable models that can predict structural response by considering both uncertainties. To this end, the authors propose a discrete wavelet transform (DWT) enabled surrogate modeling framework for prediction of nonlinear structural response while accounting for the uncertainties. DWT is used in this study for earthquake data augmentation that enables generation of artificial ground motions and for time series feature extraction. The extracted features, along with the constitutive material parameters, are used to train a deep neural network (DNN). It is shown that DWT can efficiently augment existing small earthquake datasets while the DNN can capture the non-linear structural response with considerable accuracy. The framework is applied to develop a surrogate model for a non-linear three-story moment resisting frame. The nonlinearity is captured using Ibarra Krawinkler hysteretic behavior. The model is trained using a dataset created by augmenting the FEMA P695 far field ground motion dataset. The trained surrogate model is validated by predicting for the unseen Nepal 2015 earthquake while considering material uncertainty. It is shown that the proposed training method, using data augmentation, results in a robust surrogate model that can predict well for unseen earthquakes and material parameters.

Discrete, nonlinear, FE model for structural analysis of adobe piers at Huaca de la Luna

Cristiana Riccio; Politecnico di Milano; Italy
Anna Remus; University of Rochester; United States
Selman Tezcan; University of Rochester; United States
Luis C. Silva; Politecnico di Milano; Italy
Gabriele Milani; Politecnico di Milano; Italy
Renato Perucchio; University of Rochester; United States

The main stepped pyramid of the monumental religious complex Huaca de la Luna was built by the Moche civilization in stages between 100 and 650 C.E. Well-known for polychrome murals along the north façade and imposing presence in Trujillo, Perú's coastal desert, this monument has cultural, touristic, and academic value. However, it is at risk due to its proximity to seismic action along the Pacific Ring of Fire. The structure's foundation follows, to the east, the sloping granite of Cerro Blanco and to the west, the desert's sandy plain. Extant damage to the northwest corner and north façade has been investigated in previous works using 2- and 3D nonlinear FE analyses of a continuum model of the huaca. The present work introduces discontinuities that are present in the bricklaying pattern of the huaca by assembling a series of macroblocks to create a new geometry for the model. The macroblocks reflect piers of interdigitated adobe bricks that are constructed side by side. Macroblocks are introduced to the geometry starting at the west, where critical damage conditions develop according to continuum models. A sensitivity analysis of the structural response to the number macroblocks introduced and the friction between them is conducted. Using Abaqus/CAE Explicit, the 2D cross-section is analyzed in plane strain. Adobe and soft soil are modelled using the concrete damaged plasticity and Mohr-Coulomb formulations, respectively. Maximum lateral load capacity is determined by accelerating the structure's base and identifying a critical failure load, determined from the time-evolution of energies output from the simulation. Quantitative results indicate that macroblock architecture reduces the lateral capacity of the model; qualitative results indicate that the structural response is similar to both previous studies and extant damage.

Dispersive engineering of metasurfaces for directional and omnidirectional band gaps

Heedong Goh; The University of Texas at Austin; United States
Ke Ma; The University of Texas at Austin; United States
Loukas Kallivokas; The University of Texas at Austin; United States

We are concerned with the design of metasurfaces for controlling the propagation of elastic or acoustic waves. Of particular interest are wave steering and shielding applications. For shielding applications, we treat the metasurface design problem as an inverse medium problem: we seek to discover a metasurface's material composition to satisfy user-defined band gap(s) at prescribed frequency ranges. The band gap could be either directional, i.e., to be realized only at specific directions or angles of illumination, or omni-directional, i.e., to arrest wave propagation irrespective of the azimuthal incidence. In the elastic case, it is of added interest that an omni-wave band gap be realized, i.e., a gap at the same frequencies for both shear and compressional waves. For steering applications, we use the engineered metasurface as a liner along the steering path. We design the material composition of a metasurface's unit cell by casting a dispersion-constrained optimization problem over the cell's irreducible Brillouin zone. We define a Lagrangian comprising the band gap objective –cast as the vanishing of the group velocity at the gap frequencies– and the unit cell's side-imposed Floquet-Bloch eigenvalue problem. Next, we appeal to the Hellman-Feynman theorem to express the group velocity in terms of the Floquet-Bloch eigenvalues and eigenvectors, and convert the constrained optimization problem into an unconstrained problem amenable to a standard adjoint method. We demonstrate the metasurface's dispersive engineering with numerical experiments involving shielding and steering applications, in 2D and 3D, for both scalar and elastic waves.

DISPLACEMENT-BASED STRUCTURAL IDENTIFICATION USING DIFFERENTIABLE PHYSICS

Borna Rahnamay Farnod; The Pennsylvania State University; United States
Wesley Reinhart; The Pennsylvania State University; United States
Rebecca Napolitano; The Pennsylvania State University; United States

The current state of automated structural health monitoring primarily relies on vibrational data to update finite element models of structures. However, vibrational data often lacks the spatial resolution needed to locate inhomogeneities within the structure. In contrast, displacement-based methods provide detailed information about a structure's surface displacement and strain, which can serve as an alternative data source for updating finite element models. Recently, digital image correlation technology advances have made displacement-based data more cost-effective and accessible. However, the capability of displacement-based data to inform about a structure's interior spatially varying material properties is unclear due to the ill-posed nature of the inverse problem. In this study, we use a gradient-based optimization technique to determine the spatially varying elastic modulus of a structure by matching it to a target displacement field. The performance of this method is demonstrated by its ability to detect various types of inhomogeneities, its robustness to different initial conditions, and the effect of boundary conditions on the recovered solution. Additionally, we compare the use of surface data to traditional embedded sensor arrays in structures to determine the effectiveness of this approach. Our results demonstrate the capabilities and limitations of this framework in recovering inhomogeneous elastic modulus fields. Future developments with this technology may enable the construction of high-fidelity models of the interior material properties of assets for damage detection, localization, quantification, and prognosis.

Dissolution kinetics of silica fume in alkaline solutions

Yoonjung Han; Texas A&M University; United States
Jonathan Lapeyre; Texas A&M University; United States
Umme Zakira; Texas A&M University; United States
Mine G. Ucak-Astarlioglu; U.S. Army Engineer Research and Development Center; United States
Jedadiah F. Burroughs; U.S. Army Engineer Research and Development Center; United States
Jeffrey W. Bullard; Texas A&M University; United States

Silica fume has been used as a pozzolanic additive in concrete for several decades. Even so, the properties of silica fume that influence the extent and rates of its pozzolanic reactions in portland cement are not well understood. This is particularly important because the rates of pozzolanic reaction influence the rate of porosity reduction and strength gain at early and intermediate times. Therefore, this research aims to understand the dissolution kinetics of silica fume as a function of its composition, physical properties, and the alkalinity of the solvent. As a preliminary study, a batch reactor containing 0.0001M or 0.01M of potassium hydroxide solution was sampled at prescribed time intervals to characterize the rates of dissolution of a densified and an undensified silica fume material. The dependence of the dissolution rate on composition and solution pH will be described, and a rate equation will be developed to mathematically model dissolution rates as a function of these variables. The ultimate goal of this work is to use such a rate equation to extend cement hydration models to more accurately account for pozzolanic components in modern concrete mixtures, including ultrahigh-performance concrete with high replacement levels of silica fume and other pozzolans are commonly used. Toward that end, we will demonstrate the progress made so far by including silica fume reactions in the THAMES model of 3D cement hydration and microstructure development.

Distribution of Seismic Demand and Damage During the 2015 Gorkha Earthquake

Raymond Hilly; University at Buffalo; United States
Supratik Bose; University at Buffalo; United States
Andreas Stavridis; University at Buffalo; United States
Yingjie Hu; Univeristy at Buffalo; United States

Due to the lack of instruments in Nepal, there is a lack of data on the intensity of the seismic motion during the 2015 Gorkha earthquake around the country. This study addresses this gap and develops intensity maps for Kathmandu and 11 other municipalities in Nepal utilizing damage assessment reports submitted by local engineers, combined with finite element analyses. These maps are obtained using the post-earthquake assessment surveys by correlating damage grades to peak first-story drift. A recently proposed strut modelling framework is employed to assemble a nonlinear numerical model for the prototype buildings representing the typical buildings in Nepal. Incremental dynamic analyses are performed using the ground motions from the 2015 Gorkha earthquake, as well as commonly used far-field ground motions from the FEMA P695 suite. This allows transformation of the surveyed buildings into 34,000 locations of known intensity measures, such as, peak ground acceleration and spectral acceleration. The estimated intensity points are grouped into spatial bins and used to develop shake maps, using the empirical Bayesian kriging interpolation approach. As a result, shake maps for Kathmandu and 11 other municipalities in Nepal are obtained.

Dual state-parameter estimation of continuous structural systems using Adaptive Physics-informed parallel neural networks

Rui Zhang; The Pennsylvania State University; United States
Gordon P. Warn; The Pennsylvania State University; United States
Aleksandra Radlińska; The Pennsylvania State University; United States

In this research, an adaptive physics-informed parallel neural networks (APIPNNs) framework is developed and demonstrated for the dual state-parameter estimation of continuous structural systems based on limited and noisy sensor data. The APIPNNs framework integrates sensor data and knowledge of the physics of the system by embedding the sensor data, governing partial differential equations (PDEs), and boundary conditions into the loss function of the neural network (NN) architecture. Through minimizing the physics-informed loss function, the NNs parameters and unknown structural parameters can be estimated, and hence the full state of the system is then predicted by the trained APIPNNs. In the context of continuous structural systems, for general applicability, the supports, dimensions, and boundary conditions that produce discontinuities must be considered in the computational domain. To accomplish this, the computational domain is divided into multiple subdomains, and each subdomain is represented as an individual governing PDE adjoining adjacent subdomains by means of continuity conditions and solved synchronously by the APIPNNs. As such, each NN provides a unique representation in each subdomain while also satisfying additional constraints of continuity and differentiability at the interface between two subdomains. Moreover, the loss function of PIPNNs has multiple loss components with, in general, convergence at dissimilar rates during the training of the NNs. To overcome the discrepancy in the convergence rates of the different loss components, weighting terms are introduced, and their values are altered adaptively throughout the training of the NNs. The values of the weighting terms for each loss component are derived from the Neural Tangent Kernel (NTK) theory, which utilizes the eigenvalues of the NTK matrix of the NNs to calibrate the convergence rate.

The APIPNNs framework is demonstrated through application for the identification of three different continuous structural systems, including a stepped bar, a three-span continuous beam subject to a dynamic moving load, and a two-span plate. The goal of the applications is to estimate the unknown rigidity of the system as well as to predict the full state of the system based on the limited and noisy sensor data. The sensor data are simulated by superposing the reference acceleration responses calculated analytically by modal analysis with superimposed Gaussian noise. From the three applications on different continuous structural systems with various characteristics, it is observed that the APIPNNs framework can accurately estimate the structural state and unknown parameters. Furthermore, in the context of the inverse problem, the proposed APIPNNs framework was observed to be robust with respect to noise levels in the sensor data.

Dynamic response prediction of nonlinear MDOF systems by neural-network-augmented physics models

Jaehwan Jeon; Seoul National University; South Korea
Junho Song; Seoul National University; South Korea

Accurate prediction of the dynamic response of a structure is essential in various efforts to assure structural reliability. However, epistemic uncertainties in physics-based models and their parameters may lead to a significant gap between the prediction and the reality. It was recently proposed to narrow the gap by augmenting a physics-based model with a deep-learning model trained by actual data. These so-called neural-network-augmented physics (NNAP) models showed promising results but have not been applied to multi-degree-of-freedom (MDOF) structural systems. This study introduces modal truncation to the NNAP model for accurate prediction of the dynamic responses of nonlinear MDOF systems. In detail, the physics-based model is transformed to lower-dimension coordinates using a modal truncation method before augmenting a neural network describing phenomena with significant epistemic uncertainties. As a result, the information regarding the mode shapes and natural frequencies provides a reliable basis for the proposed hybrid modeling approach. The prediction performance of the proposed method is successfully verified through a numerical example of the Lysefjord bridge structure showing various nonlinear behaviors, including the interaction between the response and dynamic wind loads. The proposed approach is expected to provide an effective conduit for measurement data to accurate response prediction of real-world structures.

Dynamics and extreme response probability distributions of linear elastic structures subjected to harmonizable loads

Zifeng Huang; Institute for Risk and Reliability, Leibniz University Hannover; Germany
Michael Beer; Institute for Risk and Reliability, Leibniz University Hannover; Germany

Owing to the preservation of the physical interpretation of local power-frequency distribution at each time instant, evolutionary power spectral density (EPSD) has wide application in the characterization of non-stationary loads and the prediction of their induced structural responses. Though being popular, EPSD has one theoretical deficiency. Given a multi-variate non-stationary load with time-varying coherences, its correlation in the time domain is calculated by decomposing its EPSD matrix. When different decomposition methods, e.g., Cholesky decomposition or proper orthogonal decomposition, are used, the obtained correlation may be not unique.

In this presentation, the ambiguity of the correlation by EPSD is explained. Then, the non-stationary loads are modeled by harmonizable processes. The calculation of the dynamics and extreme response probability distributions of linear elastic structures by harmonizable loads are introduced. The second-order statistical moments of a zero-mean harmonizable load are characterized by its Loève spectrum. When a harmonizable load is applied to a linear elastic structure, the correlation and Loève spectrum of the structural response can be uniquely and conveniently calculated using the structural frequency response function and the load Loève spectrum. Assuming that the complete probabilistic information of the harmonizable load is characterized by several random physical parameters contained in the load Loève spectrum, and the conditional probability distribution of the load given the values of the physical parameters is Gaussian, the conditional probability distribution of the structural dynamics response and that of extreme responses, given the values of the load physical parameters, can be easily obtained with the response correlation. By multiplying the conditional probability distributions of the structural responses with the joint probability density function (PDF) of the load physical parameters, and integrating the product over the sample space of the load physical parameters, the dynamics and extreme response probability distributions of the structure can be obtained. The proposed framework for the calculation of the dynamics and extreme response probability distributions of linear elastic structures by harmonizable loads are verified using a numerical case.

Dynamics of bilayer topological Maxwell lattices and the quest for omnimodal polarization

Mohammad Charara; University of Minnesota; United States
James McInerney; University of Michigan; United States
Kai Sun; University of Michigan; United States
Xiaoming Mao; University of Michigan; United States
Stefano Gonella; University of Minnesota; United States

Maxwell lattices are characterized by a number of degrees of freedom matching the number of constraints in the bulk. Certain finite Maxwell lattices exhibit topological polarization, which manifests as the ability to localize zero modes and states of self-stress on opposite edges. This feature has been shown to persist in structural lattices whose realistic hinges can store bending energy, albeit diluted and shifted to finite frequencies. Specifically, structural lattices display asymmetric wave transport, whereby waves travel into the bulk when a lattice is probed from the rigid edge, but localize when excited from the floppy edge. Thus far, most studies have focused on in-plane elastodynamics, for which, under proper idealization assumptions, the polarization can be described by formal topological indices. In contrast, the out-of-plane effects of topological modes in plate-like lattices has been left largely unexplored. In this presentation, we explore the flexural implications of topological modes in Maxwell lattices, with emphasis on specially designed Maxwell bilayers. We demonstrate the availability of out-of-plane localization, resulting from coupling in-plane strains in the individual layers to out-of-plane curvature of the bilayer. We show that, in ideal bilayers, such polarization is also topologically protected, and study its faith in structural bilayers using finite element simulations and laser vibrometer-assisted experiments.

Effect of anisotropic consolidation on cyclic liquefaction of granular materials: insights from 3D-DEM modeling

Ming Yang; Northwestern University; United States
Mahdi Taiebat; University of British Columbia; Canada

The impact of anisotropic consolidation on the cyclic liquefaction resistance of granular materials is not fully understood due to limited laboratory experiments with inconsistent conclusions. In this study, anisotropic consolidation is quantified as the ratio of initial horizontal and vertical normal stresses. Our hypothesis is that the controversial results from laboratory tests are due to differences in inherent fabric caused by distinct sample preparation methods. Through 3D Discrete Element Method (DEM) constant-volume cyclic simple shear simulations, we systematically investigate the effect of anisotropic consolidation on cyclic liquefaction resistance of samples composed of polydisperse spherical particles. We adopt three different sample preparation protocols, mimicking lubrication and vibration, to construct the DEM samples under the same initial mean stress and density but with different inherent fabrics, quantified by coordination number and contact-normal fabric anisotropy. Results showed that anisotropic consolidation has a consistent effect on cyclic liquefaction resistance in loose and medium-dense samples, regardless of preparation protocol, but that does not apply to dense samples. We also assess the correlations of initial shear wave velocity, state parameters associated with both void ratio and coordination number, and fabric anisotropy of the samples at their pre-shearing states with their cyclic liquefaction resistance.

Effect of occupant position on ejection and injury mitigation during the rollover of cutaway buses

Mohamad Alagheband; Florida State University; United States
Sungmoon Jung; Florida State University; United States
MohammadReza Seyedi; Zoox.Inc; United States

Rollover of a vehicle is an uncommon event, but it is responsible for a disproportionately high number of fatalities and serious injuries compared to other types of accidents. As a result of a rollover, passengers are injured through three main mechanisms: intrusion (movement of the bus body into the passenger space), projection (movement of the passenger resulting in impact with the bus body), and ejection (partial or complete exit from the bus body). This research focuses on mitigating cutaway bus passenger injuries caused by projection and ejection (including partial) during rollovers. The cutaway bus tilt rollover test was performed according to ECE R66, numerically and experimentally. Anthropomorphic Test Devices (ATDs) Hybrid III 50th males were placed in four seats, two on the impact side and two on the far side. The effect of occupant position (far or near side) on injury mitigation due to ejection was investigated. The acceleration curves for the head and chest were used to produce two of the most used injury criteria: the head injury criterion (HIC) and the chest severity index (CSI). Also, ejection risk related to the unintentional opening of emergency exits during rollover was analyzed. Ejection risk due to the unintentional opening of emergency exits during rollover was also investigated. Results show occupant position plays a significant role in the unbelted passenger head acceleration. HIC values for far-side occupants correspond to fatal brain damage while those on the close side suffer severe brain damage

Effect of stamped dimples on the stiffness of plates under uniaxial compression

Isabel de Oliveira; Princeton University; United States
Jun Sato; University of Tokyo; Japan
Sigrid Adriaenssens; Princeton University; United States

Thin plates and shells present higher stiffness than their original flat configuration with added corrugation or stamping [1]. The sheet metal stamping process – manual or automated – influences the stiffness of a stamped thin plate. Manual stamping produces soft dimple curves resembling a soft sine wave, different from the sharp cross-sections produced by industrialized metal forming techniques. The ratio of the sine profile length (l) to depth (h) of a dimple is defined as l/h. In the present work, sheet metal with artistic dimples resembling jasmine flowers is studied under uniaxial compressive loading. If the stamp produces a soft cross-section profile curve with small l/h ratios, the plate buckling load may decrease as on plates with geometric imperfection. If that profile is accentuated presenting large l/h ratios, the buckling load increases. So how does the wavelength of the stamped cross-section (dimple) influence the stress distribution and buckling of the plate under uniaxial compression? Through a finite element model in Abaqus [2] using shell elements, we study the linear buckling behavior of a simply supported plate under uniaxial compression for five separate cases. The first case is a plate without dimples, and the other four cases have increasing ratios of l/h =[0.5, 1, 2, 3]. The dimple distribution on the plate and dimple size remain the same for all cases, as well as the sheet thickness and boundary conditions. The stress distribution and buckling loads are compared between each case, showing increased buckling capacity for plates with low l/h ratios. This study enables a structurally informed design of stamps for artistic dimple manufacturing, providing a quantitative analysis of stiffness improvement and a discussion of potential strategies to guide the placement of dimples on a plate for future work.

References

[1] Zahner, Bead Rolling, 2020. https://www.azahner.com/labs/beadroll/ (accessed May 06, 2021).

[2] Dassault Systemes Simulia Corp., “Abaqus/CAE.” Johnston, 2022.

Effects of encapsulated granular media on energy absorption under dynamic loading

Luis Baldelomar Pinto; University of Illinois Urbana-Champaign; United States
Kathryn Matlack; University of Illinois Urbana-Champaign; United States

Understanding the behavior of materials under high strain-rate dynamic loading is important to improving their performance for impact energy absorption and blast mitigation applications. Granular media has been investigated for impact mitigation due to their ability to slow down shock wave propagation through their frictional properties and plasticity. However, only limited studies have explored the influence of granular media filler on shell structures for improved impact and blast mitigation. Here, we explore the idea of combining regions of granular media embedded within encapsulated regions for improved impact mitigation. In this presentation, we computationally investigate the response of granular-filled shell structures under high strain rate loading, investigating parameters such as granular media volume fraction, friction between grains, and friction between the granular media and the containment structure. We accomplish this by modeling media using a combined finite element method and discrete element method (FEM-DEM) approach. By simulating compression of encapsulated granular media under different loading velocities, we elucidate the effects of granular media interactions on dynamic energy absorption.

Efficient Bayesian Posterior Sampling Aided by Kriging Surrogate Model

Aakash Bangalore Satish; University of California, Berkeley; United States
Sang-ri Yi; University of California, Berkeley; United States
Alexandros Taflanidis; University of Notre Dame; United States

Bayesian inference using computational models of engineering systems entails sampling from the posterior probability distribution of the model parameters. However, evaluating the model a large number of times to draw samples can be computationally prohibitive. To overcome this, a kriging-based approach is proposed to efficiently approximate the posterior probability density. The approach builds the approximation iteratively, assessing convergence at the end of each iteration using a weighted normalized root mean squared error. If convergence has not been achieved, new experiments are designed sequentially using a weighted integrated mean squared error criterion. The weights in the criterion are a function of the target density and the bias introduced by using the approximation. This choice of weights is made to improve the accuracy and precision of the approximation in important regions of the parameter space while also exploring the parameter space adequately. The approximation is refined using the data from the from the new batch of sequentially designed experiments until the termination criteria for convergence to the target density are met. The method is demonstrated in an example application of updating the probability distribution of parameters governing the nonlinear response of a steel frame.

Efficient Combination of Modal Data for Structural Parameter Estimation Using Artificial Neural Networks

Milad Mehrkash; University of New Hampshire; United States
Erin Bell; University of New Hampshire; United States

Thanks to the development of simulation software packages, complex structures can be modeled and analyzed to make predictions of their mechanical behaviors and assess their structural conditions. However, many uncertain parameters make the modeling process complicated and the developed models less reliable. Therefore, updating the finite element models by estimating their structural parameters is necessary. An artificial neural network as a data-driven and machine learning approach has shown great potential for parameter estimation. Particularly, when the modal data are used as the physical properties of the structures to be input to the networks, the structural parameters may be estimated with considerable efficiency and accuracy. However, the suitable combination of modal data, including natural frequencies and mode shapes, to be incorporated into the neural network input layer is still challenging. The appropriate modal combination should save computational time and effort while maintaining the required estimation accuracy. In this study, the problem of putting together the modal data in the network input in an efficient way for structural parameter estimation is addressed. Two common multi-layer feedforward neural networks, multi-layer perceptrons and radial basis functions are utilized to show how the incorporation of modal data in their inputs could affect the model updating results. Some analytical models developed in SAP2000® are updated through in-house API structural parameter estimation scripts. The model updating program employs the capabilities of the Deep Learning Toolbox of MATLAB® to estimate the structural parameters of models with simulated damage. The findings of this research give hints to the structural condition assessment researchers and practitioners to design more robust and efficient neural networks for structural parameter estimation and health monitoring projects.

Efficient reliability-based topology optimization via polynomial chaos expansion: A multi-fidelity, greedy-Kaczmarz approach

Alberto Torres; Johns Hopkins University; United States
James Guest; Johns Hopkins University; United States
James Warner; NASA Langley Research Center; United States
Mazdak Tootkaboni; Univeristy of Massachusetts Dartmouth; United States

An efficient, simulation-based approach for the propagation of uncertainties within a Reliability-based Topology Optimization (RBTO) framework is proposed. Designs obtained from deterministic topology optimization techniques exhibit non-redundant features and can be susceptible to variations present in material properties and uncertainties occurring in the manufacturing process or during end-use conditions. As topology optimization methods have advanced and interest from industry grown, the need for reliable and robust designs has elicited the development of algorithms capable of efficiently incorporating complex uncertainties into our existing frameworks. Traditional Monte Carlo simulations (MCS) become prohibitively expensive when considering sophisticated computational models, and this expense is further exacerbated by the iterative nature of topology optimization. Other works have introduced techniques that alleviate the computational burden of uncertainty-aware design, such as perturbation methods, spectral approaches, and approximations of the reliability. While these methods can drastically reduce the cost of uncertainty propagation, the savings often come at the cost of complex, challenging sensitivity calculations, reducing computational savings or affecting the stability of the optimization problem. By utilizing a simulation approach coupled with an efficient surrogate of the uncertain model, our proposed method can efficiently propagate uncertainties through the optimization problem without a substantial modification to the sensitivity calculations. The framework generates a Polynomial Chaos expansion (PCE) to serve as the surrogate model relating random inputs to corresponding uncertain outputs. Due to the nonintrusive nature of the PCE, sensitivities can be defined as a combination of gradients from the deterministic optimization problem. As the surrogate is dependent on the current underlying structure, it must be rebuilt as the optimizer improves the topology, appending a substantial computational cost. To efficiently produce new surrogates, we implement a multi-fidelity, greedy-Kaczmarz routine, leveraging the reduced cost of low-fidelity models to obtain an inexpensive, approximate PCE surrogate. The greedy-Kaczmarz algorithm is then used to identify a small set of highly influential samples that are propagated through the high-fidelity model and used to return the high-fidelity PCE surrogate intended for propagation of uncertainties within the TO framework. Results are provided for RBTO utilizing an inverse tangent reliability constraint. While the work is presented using a coarse mesh approximation as the low-fidelity model, the approach is applicable to all low-fidelity models capable of adequately approximating the system response under all uncertain inputs.

Efficient Wiener path integral most probable path determination based on extrapolation

Ilias Mavromatis; Columbia University; United States
Ioannis Kougioumtzoglou; Columbia University; United States

The recently developed Wiener path integral (WPI) technique for determining the stochastic response of diverse nonlinear dynamical systems relies on the concept of representing the system response joint transition probability density function (PDF) as a functional integral over the space of all possible paths satisfying the initial and final states of the response vector (e.g., Petromichelakis and Kougioumtzoglou 2020). Further, employing a functional integral series expansion, the contribution only of the first term is considered, ordinarily, pertaining to the path with the maximum probability of occurrence. This is referred to in the literature as the most probable path and corresponds to an extremum of the functional integrand. In this regard, the most probable path, which is used for determining approximately the system response joint transition PDF, is computed by solving a functional minimization problem that takes the form of a deterministic boundary value problem (BVP) (e.g., Petromichelakis et al. 2021). This BVP corresponds to a specific grid point of the response PDF effective domain. Note, however, that for a specific nonlinear system under consideration, the equations of the BVP are independent from the grid point. In fact, only the boundary conditions change with different grid points, whereas the equations of the BVP remain unaltered. Remarkably, the BVPs corresponding to two neighboring grid points not only share the same equations but, also, the boundary conditions differ only slightly. Thus, it is expected that the BVP solutions, i.e., the most probable paths, referring to the two grid points, are highly correlated.

In this paper, the above unique aspect of the technique is explored further and it is shown that solution of a BVP and estimation of the response PDF value at a specific grid point can be used for extrapolating and estimating efficiently the PDF values at neighboring points without the need for solving additional BVPs. Notably, the developed approach enhances significantly the computational efficiency of the WPI technique while exhibiting a satisfactory accuracy degree. Various nonlinear systems are considered in the numerical examples for demonstrating the reliability of the technique. Comparisons with pertinent Monte Carlo simulation data are included as well.

Petromichelakis I., Kougioumtzoglou I. A., 2020. Addressing the curse of dimensionality in stochastic dynamics: A Wiener path integral variational formulation with free boundaries, Proceedings of the Royal Society A, vol. 476: 20200385.

Petromichelakis I., Bosse R. M., Kougioumtzoglou I. A., Beck A. T., 2021. Wiener path integral most probable path determination: A computational algebraic geometry solution treatment, Mechanical Systems and Signal Processing, vol. 153, 107534: 1-24.

Elastic and Plastic Characteristics of Lithium–Graphite Intercalation Phase

Edris Akbari; Louisiana State University; United States
George Z. Voyiadjis; Louisiana State University; United States

Despite many attempts to find alternative anode materials, graphite is even now the prevalent anode for lithium-ion batteries due to its low cost, higher capacity, better cycle performance, and safety than Li metal (with avoiding dendrite formation). However, a number of concerns remans that must be addressed, such as the effect of lithium ion de/intercalation process and the polymeric binder content of binder the mechanical properties of anode. To this end, X-ray Photoelectron Spectroscopy (XPS) and XRD tests were used to identify and localize the binder and lithium ion in the graphite base. However, mechanical properties of anode were evaluated through nanoindentation at the room temperature. Nanoindentation test produced an elastic modulus of 3.5±0.6 GPa. Moreover, engineering stress–strain curve was converted from the load–depth curve of a deep spherical indentation test via using optimization method to measure the effective indentation strain and stress.

Embodied Carbon Optimization of Multi-Material Truss Structures Subjected to Manufacturability Constraints

Zane Schemmer; Massachusetts Institute of Technology; United States
Josephine Carstensen; Massachusetts Institute of Technology; United States

The construction industry is one of the largest contributors to annual carbon dioxide emissions. With the imminent consequences of climate change, it is important to find sustainable solutions for designing and constructing the built environment. One method is limiting the embodied carbon footprint of a structure during the design stage. The embodied carbon here refers to the up-front carbon needed to prepare and transport the construction materials and/or components based on local resource data. Currently, there is a lack of design methods that allow engineers to efficiently minimize an embodied carbon objective. Topology optimization lends itself nicely to this problem because it generates structural designs that minimize an objective while respecting constraints. These designs, however, can often be complex and difficult to fabricate. This makes their implementation into the industry less enticing. To make optimized design outputs less complicated, special constraints need to be considered.

To enable the design of new multi-material structural solutions associated with reduced carbon emissions, this work formulates a truss topology optimization design problem that directly minimizes this objective. Whereas reducing the structural weight is sufficient in achieving carbon savings for single-material design, previous work has shown that it may lead to suboptimal solutions when designing with multiple distinct materials. The new design framework uses the ground structure approach and specifically examines the optimization of timber-steel hybrid structures. To ease the constructability, the design problem is posed as a mixed-integer linear program that can limit joint complexity. Binary decision variables are used to create an explicit definition for the existence of a certain material within each truss member. Continuous variables within a user-specified range are used to determine the area of active truss members. This means that, if an element is selected to exist, it can be forced to take on a minimum area for fabrication purposes. Thus, the need for post-processing is reduced. Additionally, joint complexity in the design can be reduced by limiting the total number of elements protruding from a joint and/or from a connection with steep angles. The new algorithms are tested on several benchmark problems and solved using Gurobi.

Embodied carbon-based topology and sizing optimization of seismic retrofit for non-conforming RC structures

Fabio Di Trapani; Politechnico di Torino; Italy
Antonio P. Sberna; Politechnico di Torino; Italy
Josephine V. Carstensen; MIT; United States
Giuseppe C. Marano; Politechnico di Torino; Italy

Seismic retrofitting interventions for reinforced concrete structures are generally associated with noticeable costs, significant invasiveness, and relevant downtime. The environmental impact of such interventions is not generally considered a design parameter, although there is a pressing need for reducing CO2 emissions in the field of civil engineering [1,2]. Recent studies [3,4] proved that automated design of seismic retrofit can be effectively carried out using computational intelligence for a cost-based optimal design. However, minimum cost-based design does not necessarily entail low carbon emissions. In this frame of reference, this study proposes a genetic algorithm-based framework for the embodied carbon-based optimization of different typologies of retrofitting techniques. The framework provides automated design of seismic retrofit (topology and sizing) of reinforced concrete columns, to upgrade a RC structure to resist the current design code seismic demands. The Global Warming Potential (GWP) is used as an effective measure of the embodied carbon emissions associated with each reinforcement technique. The case study test of a typical non-seismically conforming reinforced concrete building structure is investigated. GWP optimization is carried out considering four different possible retrofitting techniques (steel jacketing, concrete jacketing, FRP jacketing, and steel bracing). The optimal results are finally compared in terms of environmental impact and associated economic costs. Results will show that the proposed framework could be used as an effective tool for a sustainable design of seismic retrofit of existing reinforced concrete frame structures.

References:

[1] Clemett N, Carols Gallo WW, O'Reilly, Gabbianelli G, Monteiro R. Optimal seismic retroftting of existing buildings considering environmental impact. Engineering Structures 2022, 250: 113391.

[2] Ching E, Carstensen JV. Truss topology optimization of timber–steel structures for reduced embodied carbon design. Engineering Structures 2022, 252: 113540.

[3] Di Trapani F, Sberna AP, Marano GC. A new genetic algorithm-based framework for optimized design of steel-jacketing retrofitting in shear-critical and ductility-critical RC frame structures. Engineering Structures 2021, 243:112684.

[4] Di Trapani F, Sberna AP, Marano GC. A genetic algorithm-based framework for seismic retrofitting cost and expected annual loss optimization of non-conforming reinforced concrete frame structures. Computers and Structures. 2022; 271:106855.

Emotion Recognition Using Footstep-Induced Floor Vibration Signals

Yuyan Wu; Stanford University; United States
Yiwen Dong; Stanford University; United States
Hae Young Noh; Stanford University; United States

Structural vibration signals induced by occupant footsteps contain a lot of useful human information, including occupancy, human activity, identity, and emotion and health status. Among these, emotion recognition to identify people's emotional status, such as happy and sad, is important in many smart building applications such as, enhancing a person's self-awareness, allowing emotion-adaptive human-computer interaction, and mental health monitoring. Previous studies reveal that people's gait patterns are a strong indicator of their emotions. To capture people's changing gait patterns affected by their emotions, existing approaches use cameras, wearable or portable devices. However, these devices come with corresponding drawbacks, such as being limited by visual obstructions and requiring users to carry devices causing discomfort to the users. To overcome these problems, we introduce a new emotion recognition approach using footstep-induced floor vibration signals. The main intuition of our approach is that, as the person's gait patterns change under various emotions, their footsteps induce distinct floor vibration patterns. A key challenge to achieve our goal is that the way emotions affect gait patterns is complex. To this end, we design and extract both emotion-sensitive gait-related features and signal-based features from the footstep-induced floor vibration signals. These features and their correlations to emotions are then characterized for feature selection. To evaluate our approach, we conduct a real-world walking experiment using a combination of light, videos, and music as emotion elicitation. Our approach achieves an accuracy of up to 94% in identifying happy and sad emotions.

Energy Dissipation Mechanisms in Cross-Grain Fracture of Spruce

Parinaz Belalpour Dastjerdi; University of Maine; United States
Eric Landis; University of Maine; United States

In a study of cross-grain fracture of structural timber, tests of small compact tension specimens were conducted using a waveform-based acoustic emission (AE) monitoring system. Tension tests consisted of a crack mouth opening displacement (CMOD) controlled loading for specimens of different end-grain orientation angles. In addition to AE and load-CMOD data, a digital microscope recorded crack propagation during the tests. Fracture results showed crack propagation along a path of least resistance that varied depending on end-grain orientation. AE waveforms were analyzed using a self-organizing map to identify dominant signal types, which could then be used to train an artificial neural network for AE event classification. The AE event classes were tied to specific micro damage mechanisms, including cell wall tearing, cell separation, and crack bridging. The energy associated with each of these mechanisms was then measured and tied to their role in overall specimen load-deformation behavior, crack growth, and fracture. Results showed that mechanisms were tied to end-grain orientation with cell wall tearing dominating crack growth along an earlywood path, while cell wall separation appeared stronger in the crack path extending in the radial direction. Tearing produced significantly higher energy release per event, but separation produced more low energy events. Crack bridging events were characterized by high activity in the later stages of fracture, but contained a low degree of energy release per AE event.

Engineering now! Are we ready?

Franz-Josef Ulm; MIT; United States

Never before have the challenges for engineers been greater and more burning that in the face of climate change, from the energy transition to the sustainable construction of a just society. Will it be possible? In this talk, I will discuss some approaches that all originate from the premise of preparing us engineers for these challenges and opportunities. With sustainability and resilience at heart, I will advocate that engineers and industries take up the new physical realities in a data-centric way and translate them into engineering solutions; from new multi-functional building materials such as concrete that can store energy, to smartphone enabled infrastructure sensors and molecularly inspired retrofitting of our urban neighborhoods for more resilience and social justice in the face of climate change. AS research continues to advance in all these areas, it will depend on all of us to break out of our silos (academic, disciplinary, cultural) and translate these emerging approaches into actual sustainable solutions for societies at large.

Enhance Structures' Resilience with Particle Physics: a Statistical Approach of Quasi-Static Brittle Fracture.

Ariel Attias; Massachusetts Institute of Technology; United States
Franz-Josef Ulm; Massachusetts Institute of Technology; United States

In the past 40 years, the frequency of climate disasters in the United States has significantly increased, with wind-related hazards being the most prominent in terms of material costs and human losses. As the world experiences intensifying urbanization, there is a pressing need for tools that can accurately assess the resilience of urban areas to these hazards. To address this challenge, we propose a hybrid approach that combines finite-element analysis and statistical physics to model the failure of common construction materials under wind loads. Our focus is on developing a robust and easily implementable fracture formalism that can be applied in industrial settings. This innovative method bridges the gap between traditional engineering analysis and statistical physics, providing a unified framework for modeling the behavior of brittle fracture.

Similarly to classical element-deletion methods, we characterize the fracture state at the element level with a binary occupation number. The global dynamics of these binary variables is formulated in an ensemble way, minimizing the semi-grand potential of the system. We prove that this formulation is a statistical generalization of the (convergent) eigen-erosion scheme that has been proposed by Pandolfi & Ortiz [1], making a formal handshake between the classical theory of fracture and statistical physics.

Our method effectively tackles challenges that are inherent to computational brittle fracture, including initiation, branching, and efficiency. It enables in-situ prediction of fracture propagation through the use of ensemble derivatives, without requiring prior knowledge of the challenging-to-estimate critical energy release rate. Importantly, we are able to capture size-effects, a crucial aspect for practical applications.

We demonstrate the practicality of our method through a real-life application of a wind-loaded structure. By predicting its progressive failure through damage curves inferred from statistical observables, we link our findings to a life-cycle analysis of the structure, highlighting the potential of our method in practical engineering applications.

[1] Pandolfi, A. & Ortiz, M. (2012), "An eigenerosion approach to brittle fracture", International Journal for Numerical Methods in Engineering, Vol. 92, 694-714

Enhanced Human Interfaces for Rebar Inspection using RGBD-equipped UAV – Field Application

Mahsa Sanei; University of New Mexico; United States
Ali Mohammad khorasani; University of New Mexico; United States
Fernando Moreu; University of New Mexico; United States

In recent years, the inspection of structures has incorporated the interface between the inspector and the data enabling better scenarios for humans in the field. For example, rebar inspection is a critical task that involves checking the reinforcement bars before pouring the concrete structures to ensure compliance with the as-built drawing. In the last decade, researchers have advanced Unmanned Aerial Vehicles (UAVs) and RGBD cameras for structure inspection in the construction industry. The use of RGBD-equipped UAVs for rebar inspection has several advantages over traditional methods, such as reduced inspection time, increased safety, and improved accuracy. This research develops a new low-cost RGBD-equipped UAVs methodology with automatic rebar spacing applications for field inspection. This new access to rebar spacing enables a new interface between the inspector and their job of collecting rebar spacing without contact, more accurately, and safely. The algorithm uses machine learning to process the 3D point cloud data collected by the RGBD cameras to segment the rebar point cloud data and automatically calculate the rebar spacing. The ultimate goal of this research is to implement an automated method to detect and quantify rebar defects while keeping the inspectors in the loop for making informed-decision. The field application demonstrates the feasibility of this method and provides a basis for future research and development in the use of UAVs for rebar inspection.

Enhanced Mechanical Properties of Marine sponges Inspired Tubular Metamaterials

Zhennan Zhang; University of Louisville; China
Yanyu Chen; University of Louisville; China

The process of trial-and-error over millions of years of evolution is an efficient method for discovering structural materials with unprecedented mechanical properties. The Euplectella aspergillum, also known as the marine sponge, has a cylindrical lattice-like skeleton composed of lightweight silica spicules, making it a prime example for providing enhanced strength and resilience. However, how the sponges skeletal lattice behaves under different loading conditions still requires further investigation. It is necessary to develop a comprehensive mechanical testing system for marine sponge-inspired tubular metamaterials to support their development for a wider range of applications. Here we use the skeletal anatomy of E. aspergillum as inspiration to design a group of 3D printed mechanically robust tubular metamaterials. To understand the mechanical benefits of the sponge's skeletal architecture under different loading conditions, we conducted a series of mechanical experiments including three-point bending, axial, and radial compression tests. Our experimental results suggest that bioinspired tubular metamaterials exhibit high flexibility and ability to resist bending. It has demonstrated that the stiffness of bioinspired design is ~2 greater than that of a conventional tubular design. Additionally, the strength of the sponge-inspired design is ~3 greater, and its toughness is ~4 times greater. These enhanced mechanical properties are attributed to the interconnected channels and struts that distribute stress evenly and allow for bending without breaking. This remarkable bending behavior makes it particularly suitable for applications that require a high degree of flexibility, such as in the human body where blood vessels and trachea need to bend and twist. Another unique point of sponge-inspired metamaterial is its ability to resist radial and axial loading. The interconnected channels and struts of the sponge-inspired design function as a reinforcement system, enabling it to withstand high pressure and prevent catastrophic collapse. Our experiments have shown that the sponge-inspired design exhibits ~1.3 times larger radial compression stiffness and ~2.2 times larger axial compression stiffness compared to unreinforced counterparts. These findings highlight the potential of sponge-inspired tubular structures for efficient and deformation-resistant designs under various loading conditions.

Enhanced Support Vector Machine for efficient reliability analysis of offshore wind turbines

Xukai Zhang; Texas A&M University; United States
Asim Khajwal; Texas A&M University; United States
Arash Noshadravan; Texas A&M University; United States

The main goal of this study is to present a novel and efficient surrogate-based reliability framework for improved risk-based maintenance optimization of offshore wind turbines (OWT). OWT have great potential to be one of the most reliable sources of renewable energy. From a structural perspective, an improved understanding and prediction of the life cycle performance of OWT are critical in informed decision-making for efficient design and maintenance management of these complex systems. A reliable predictive maintenance strategy that accounts for uncertainty for loading and lifetime performance will help to reduce the burden of costly expenditures by extending the maintenance intervals. The high-fidelity simulation when combined with uncertainty propagation required for reliability analysis is often time-intensive and computationally costly. Surrogate-based modeling can be an alternative solution for efficient reliability-based maintenance optimization of OWT. Inspired by this approach, the proposed study consists of two main contributions. First, a physics-based description of deterioration modeling and failure analysis is presented through the introduction of Fault Tree Analysis that simulates the limit state functions. The detailed physics-based simulation of the structural demand under aerohydrodynamic loading often requires the utilization of advanced high-fidelity simulation tools. This can be computationally demanding in reliability assessment, which also involves numerous simulations for uncertainty propagation, such as using Monte Carlo simulations. As such, the second contribution of the proposed research is to tackle this challenge by introducing an efficient surrogate-based reliability analysis. The proposed approach relies on the methods of imbalanced learning that account for the effect of the under-sampled failure domain to enhance the accuracy and efficiency of a surrogate model based on the support vector machine technique. The proposed framework provides an efficient risk-informed decision support tool for the lifecycle optimization of OWT under uncertainty and extreme load conditions.

Enhancing Community Resilience with Minimal Instrumentation and Performance-based Seismic Monitoring of Buildings

Milad Cheraghzade; University of Nebraska-Lincoln; United States
Milad Roohi; University of Nebraska-Lincoln; United States

The authors present the extension newly developed concept for performance-based seismic monitoring for resilience-informed decision-making for instrumented buildings. The paper presents a methodology to incorporate structural health monitoring (SHM) systems through minimal instrumentation and data fusion to quantify seismic resilience metrics, which can be subsequently incorporated into infrastructure and community resilience models. The methodology consists of four main steps 1) measurement and uncertainty quantification, 2) model-data fusion, 3) seismic resilience assessment, and 4) decision-making. The methodology possesses several advantages that make it appealing for resilience-informed decision-making for instrumented buildings, including i) the metric quantified can be used as input to loss and resilience estimation methodologies (e.g., FEMA P-58), ii) it requires minimal instrumentation to accurately quantify the seismic performance metrics of an instrumented building. The performance of the proposed methodology is illustrated using real-world measured data from a reinforced concrete building instrumented by the California Strong Ground Motion Program (CSMIP).

Enhancing the Blind-with-Buildings Interaction Using a Digital Controller with Augmented Auditory Feedback

Kaveh Malek; University of New Mexico; United States
Fernando Moreu; University of New Mexico; United States

In several real-world situation, the blinds need to pass through indoor trajectories in unfamiliar buildings. To enhance the blinds' interaction with buildings and to enable them to track a planned path with adequate degree of precision, this study develops a feedback closed-loop control system with a PD controller and implement it in Augmented Reality (AR) platform. The algorithm includes formulation of dynamic model of VIP walking. This dynamic is adjusted in real-time by observing the user position and walking velocity of previous sampling time using AR orientation capabilities. Initial phase involves the simulation of the control system on a computer using white noise to model the inherent error in human-computer interaction. This simulation includes the evaluation of stable parameters and verification of the system in terms of observability, controllability, and performance. Next, the method is deployed in an AR headset and is tested using several indoor experiments. Overall, the results of computer simulation and experimental analysis agree that if the stable parameters for the system are established, the method keeps the user around the aimed trajectory with a limited level of persistent random deviations.

Ensemble-based time series analysis considering lag information and feature importance to predict power outages during winter storms

Jangjae Lee; Texas A&M University, College Station; United States
Stephanie Paal; Texas A&M University, College Station; United States

Winter storm "Uri" descended upon the Southeast region of the U.S. in February 2021, causing tremendous damages estimated to be greater than $195 billion. During these extreme weather conditions, at least nine states from the southeastern regions experienced power outages, with rolling outages instituted in some regions to maintain electricity. The extremely high demand for electricity was the primary reason for widespread power outages, which lasted at least one day. To address this problem, a predictive model based on time series analysis for estimating power outages during a winter storm is developed in this work. Since power outages continuously change over time for each county in the affected region, the prioritization for supply of electricity is required to make effective mitigation actions. To develop the predictive model considering time series data for power outages, this paper extracted the features using the NASA API for weather information, the census dataset for geographical properties, as well as various resources related to the power outages. In this study, we developed an ensemble-based time series prediction framework comprised of three different machine learning models using lag information and feature importance. The developed model was evaluated using performance metrics such as mean absolute error (MAE), root mean squared error (RMSE), and the coefficient of determination. This study estimated outages for 234 of the 254 counties in Texas (the information for 20 counties is missing from this dataset). The developed ensemble model showed highly accurate performance on the majority of the counties across Texas (224/234 or 95.73% of the counties included in the dataset). Additionally, when compared to the single machine learning model, the ensemble model produced less negative results, demonstrating that it is a robust, accurate, and efficient way to predict the number of outages on a per county basis during an extreme winter storm.

Environmental Effects on Output-Only Vibration Parameters of Reinforced Concrete Systems

Maya Rao; Forell Elsessor; United States
Riley Brown; Thorton Tomas; United States
Karl Gaebler; Kimley Horn; United States
Carol Shield; University of Minnesota; United States
Lauren Linderman; University of Minnesota; United States

As sensors and data acquisition systems become less expensive, large-scale and long-term deployment of structural health monitoring systems becomes feasible; however, a key challenge remains in analyzing in-situ system response, which can be colored by environmental effects and system nonlinearities. For example, monitoring changes in the dynamic signature of a structure could be an effective tool within a monitoring system to conduct identify system changes, but environmental effects may mask the relative changes of the dynamic signature of the structure. An understanding of the relationship between the environmental effects and system response is required to efficiently and confidently use monitoring systems for identifying structural changes. The monitoring system on the I-35W St. Anthony Falls Bridge, which crosses the Mississippi River in Minneapolis, MN, provides a uniquely large data set to establish the relationship between environmental factors and natural frequency of the structure. A preliminary investigation into these relationships reveals that while the natural frequencies of some modes appear to decrease with an increase in temperature, others do not follow this pattern. Additionally, the large spread and non-linearity of data collected suggests a complex relationship between natural frequency and temperature. To verify the relationships established on the I-35W Bridge, a controlled, laboratory experiment was conducted to establish the effects of temperature and humidity on the natural frequencies of indeterminant structures, constructed of both steel and concrete. The concrete structure exhibited shifts in the natural frequency as a function of temperature that paralleled those observed on the I-35W post-tensioned box-girder structure. Additionally, increases in relative humidity corresponded to an increase in the natural frequency. While both temperature and relatively humidity impact the natural frequencies of the post-tensioned concrete beam, there was limited influence on mode shapes. The controlled setup allows for the impact of humidity and temperature to be separated and clarified with the ultimate goal of a systematic approach to remove environmental effects from identified vibration signatures.

Error quantification and guidance on the use of wind tunnel-informed stochastic wind load models for the applications of performance-based wind engineering

Thays Duarte; University of Florida; United States
Srinivasan Arunachalam; University of Michigan; United States
Arthriya Subgranon; University of Florida; United States
Seymour Spence; University of Michigan; United States

The emergence of performance-based wind engineering (PBWE) frameworks over the last decade has enabled the probabilistic performance assessment of building systems subject to stochastic wind loads. One crucial step in obtaining reliable wind-induced responses lies in the accurate simulation of multivariate wind load processes. Among several approaches, the proper orthogonal decomposition (POD)-based spectral representation approach has been widely used due to its efficiency. The calibration of POD-based models is generally performed using generalized empirical spectral functions, which are only available for a limited selection of building geometries and wind directions. To overcome this limitation, a data-driven stochastic wind load model has been proposed in which typical wind tunnel records are used to calibrate the model, ensuring that aerodynamic phenomena are captured for any specific building and wind direction. Despite the advantages, the errors associated with such a model still need to be investigated and quantified. To this end, extensive wind tunnel datasets have been collected on a rigid rectangular model for various wind directions and experimental settings. The datasets were divided into two groups: one was used to define the target spectra, and the remaining was used to assess wind tunnel record variability. Errors associated with a typical wind tunnel record, numerical model, and mode truncation are investigated. Results provide insight into the advantages and limitations of the data-driven wind model that can be translated into recommendations for the use of wind tunnel records in calibrating the stochastic wind model for PBWE applications.

Error quantification of wind tunnel-informed stochastic wind model based on the translation processes for simulation of non-Gaussian wind pressures on buildings

Thays Duarte; University of Florida; United States
Srinivasan Arunachalam; University of Michigan; United States
Arthriya Subgranon; University of Florida; United States
Seymour Spence; University of Michigan; United States

Simulation of multivariate stochastic wind processes is essential for assessing building system performance through probabilistic performance-based wind engineering (PBWE) frameworks. In particular, stochastic wind models based on the translation processes provide a powerful approach to simulate non-gaussian stationary wind processes that match exactly the target marginal distribution. The calibration of such a stochastic wind model with wind tunnel data has been recently proposed, but there is still a lack of guidance and information on potential errors that can be introduced when calibrating the translation process using typical wind tunnel records (e.g., 30 to 60 seconds). With the aim of quantifying errors associated with such a wind tunnel-informed stochastic model, an extensive experimental study was carried out on a rectangular rigid model considering multiple wind directions and settings. Errors associated with the wind tunnel variability, calibration process, numerical scheme, and mode truncation are investigated and quantified. These findings will help assemble recommendations on appropriate wind tunnel testing practices as well as guidelines for calibrating the data-driven stochastic wind model for PBWE applications.

Eshelby Tensor in Integral Nonlocal Elasticity: Theoretical Formulation and Numerical Validation

Wei Ding; Purdue University; United States
Fabio Semperlotti; Purdue University; United States

Eshelby's inclusion problem has long been one of the most well-known fundamental problems in the field of classical linear elasticity. The solution procedure and corresponding analytical result, widely known as the Eshelby tensor, have played a critical role in the modeling of micro-mechanical problems and have found important applications including, but not limited to, homogenization of both heterogeneous materials (such as composites and porous materials) and materials including defects (such as fracture mechanics and dislocations).

Although Eshelby's inclusion problem and related micro-mechanical applications have been extensively studied over several decades, there are still fundamental gaps between theory and physical processes. Recent theoretical and experimental studies have identified the existence of non-negligible nonlocal effects in many types of micro-mechanical systems. Classical local linear elasticity, which serves as the theoretical postulate of Eshelby's inclusion problem, cannot capture nonlocal effects and therefore limits the potential application of Eshelby's method to the more general class of nonlocal micro-mechanics.

In an effort to address the incompatibility between nonlocal effects and the traditional Eshelby's method, we extend Eshelby's work to integral nonlocal elasticity. In particular, this study includes 1) the analytical derivation of the nonlocal Eshelby tensor for 2D circular inclusions, and 2) its numerical approximation and validation. The static Green's function for infinite homogeneous nonlocal solids is derived based on the integral nonlocal constitutive relation and the Fourier transform approach. Following the thought experiment proposed initially by Eshelby, the nonlocal Eshelby tensor is then derived by leveraging the static Green's function. A constant eigenstress assumption is adopted in order to account for the perturbation of the eigenstrain field induced by the nonlocal effects. Numerical examples and nonlocal finite element simulations are performed to validate the analytical form of the nonlocal Eshelby tensor. To guarantee the overall convergence of the formulation, constitutive relations with mixed local-nonlocal kernels and fractional kernels are adopted. The nonlocal Eshelby tensor is shown to be space-dependent and to reduce to the classical local Eshelby tensor form when the limit case of a local constitutive relation is considered.

Evaluating and tailoring stiffness of lattices for various states

Yash Agrawal; Civil and Systems Engineering, Johns Hopkins University; United States
Gabriel Dreisbach; Civil and Systems Engineering, Johns Hopkins University; United States
James Guest; Civil and Systems Engineering, Johns Hopkins University; United States

Architected materials provide opportunities for designers to optimized or tailor the mechanical response of structures through design, while advances in manufacturing have provided an avenue to realizing such optimized designs. This talk examines the use of topology optimization for designing architected materials in various states, including geometrically complex, deformed, and stochastic states. We will present a novel super-element approach for capturing geometric details with computational efficiency, capturing changes in stiffness as a function of operational state, and facilitating property perturbations for robust performance. Although lattice-based architected materials will be the focus, the approach is extendable to other classes of architected materials.

Evaluating Regression and Generative Modeling Paradigms for Materials Design

Arindam Debnath; Pennsylvania State University; United States
Wesley Reinhart; Pennsylvania State University; United States

Advanced manufacturing processes including Additive Manufacturing (AM) have transformed the manufacturing landscape due to the newfound potential for freeform fabrication, enabling both geometrical and material freedom in design. This freedom naturally leads to elevated complexity in accessible design space that is challenging to probe by conventional design methods such as rational design or parametric search. As a result, machine learning is becoming an attractive tool for accelerating the design of these materials. While conventional materials design has utilized regression models to rapidly test hypothesized material compositions in a search for improved ones, more recent generative modeling approaches provide for the possibility of "inverse modeling."

We have recently developed deep-learning-based generative models to perform inverse modeling of materials with tailored properties. Generative modeling offers an attractive solution to materials design problems due to its ability to approximate the inverse function directly (i.e., properties to composition) without the need to search the design space. However, we have also faced challenges in training our models on small datasets which are typical in materials design. Here we compare the design of multi-material composites using these generative models (the "inverse design" paradigm) and surrogate regression models (the "forward design" paradigm). We discuss the lessons learned from our preliminary work and strategies we are developing to measure the effectiveness of each approach in designing composites for programmed mechanical response.

Evaluation of Feature Selection Methods for the Shear Failure Mode Prediction of Prestressed Concrete Beams

Luis Alberto Bedriñana; Universidad de Ingenieria y Tecnologia - UTEC; Peru
Jhon Tovar; Universidad de Ingenieria y Tecnologia - UTEC; Peru
Christian Malaga-Chuquitaype; Imperial College London; United Kingdom

Prestressed concrete (PC) beams are commonly used in bridges and buildings; however, their shear failure mode is difficult to predict during the design phase of a project. Although this shear failure mode is directly related to the shear capacity of PC beams, conventional shear models cannot directly predict the shear failure of such beams. Hence, it is important to explore new methods for the shear failure mode prediction of PC beams. Recently, Machine Learning (ML) techniques are being applied to such problems in Structural Engineering with remarkable accuracy and precision. However, there is not any clear consensus on the minimum number, type, and selection process of input features to develop an efficient ML model for the mechanics of PC beams. The selection of input features may affect the final performance of a data-driven model as some features can be redundant, noisy, or non-informative, so it is important to establish practical guidelines for the implementation of data-driven models in structural engineering. This paper evaluates the influence of different feature selection techniques on the performance of a ML classifier for the shear failure mode of PC beams. To this end, a comprehensive database, consisting of 668 experimental tests of PC beams was used in the analyses. Several Wrapped and Filter methods were applied to this dataset to select a relevant set of input features. The selected features with each of these methods were used to train 3 ensemble learners with an optimal set of input features. An additional model, trained with the full set of available features, was also used for comparison. Most of the evaluated feature selection methods showed that around 5 to 10 features are sufficient to maintain an adequate performance on the classifier; however, Filter methods showed better performance than Wrapped methods. From the performance comparison among the different models, it was noted that the Recursive Feature Elimination (RFE) method provided the most accurate ML classifier (F1_score = 0.821) with a set of 10 input features (around 60% of the total available features). Lastly, the interpretability of the final predictive model was evaluated. This work provides a reference for structural engineers to select, compare, and validate feature selection methods for classification problems in reinforced concrete mechanics.

Evaluation of kirigami-inspired façade concepts to improve building energy performance

Rodrigo Arauz; University of Pittsburgh; United States
Aminallah Pourasghar; University of Pittsburgh; United States
John Brigham; University of Pittsburgh; United States

There has been growing interest in development of design concepts for building façade systems that can adapt to their environmental conditions naturally or through a control mechanism to improve some measure of performance [1]. For the example of photovoltaics integrated within a façade, adaptively controlling the orientation of the façade with respect to the sun can increase the effectiveness of the photovoltaics. Another concept is to adaptively open or close portions of the façade to control light or air entering the building. Many methods have been proposed to achieve adaptivity, with one promising approach being the use of intrinsic structural mechanisms, such as kirigami-inspired designs. In particular, kirigami-engineered elasticity makes use of in-plane actuation to achieve out-of-plane deformation [2], which could potentially benefit solar tracking, ventilation, etc. Although promising, relatively few design options have been considered, limited design objectives have been quantified, and minimal work has been done to evaluate the potential impact on building performance.

The present research will establish and apply a numerical approach to evaluate the potential effect of kirigami-inspired façades on building performance. More specifically, a type of kirigami- engineered elasticity will be considered, and the performance will be quantified with respect to energy cost and energy gained from irradiance and ventilation functions. Additionally, structural performance will be quantified and applied as a constraint to ensure structural feasibility. The computational approach to evaluate building performance utilizes finite element analysis to predict the mechanical response of the façade component, which is combined with additional models to estimate irradiance and ventilation with respect to given environmental conditions. The performance evaluation is then integrated into an optimization algorithm to estimate the façade design that maximizes energy efficiency. In addition to presenting this computational approach, several building scenarios will be considered as test cases, including variations in size and building location. Different operational scenarios will also be considered, such as winter versus summer operation.

[1] Loonen, R. C. G. M. (2018). Approaches for computational performance optimization of innovative adaptive façade concepts. Eindhoven.: Eindhoven university of technology.

[2] Ahmad Rafsanjani and Katia Bertoldi. Buckling-induced kirigami. Physical Review Letters, 118(8):084301, 2017.

Evolution of Stress Tensor in terms of Multivariate Probability Distributions using Internal State Variable Theory

Abhinav Ramkumar; Purdue University; United States
Marcial Gonzalez; Purdue University; United States

This work presents a generalized Granular Micromechanics Approach (GMA) [1] that allows us to utilize the statistical description of the microstructure (i.e., distributions of contact forces, interparticle distances, and orientation) to parametrize the evolution of the stress tensor for a granular assembly. This work aims to systematically determine the appropriate parametrization of the distribution of microstructural state variables embedded in space and time. The goal of this work is to obtain injective mapping between multivariate distributions of material state variables and the evolution of the stress tensor using internal state variables (ISVs). Internal state variables allow us to capture the important information that leads to the evolution of the system, as is seen in path-dependent and dissipative materials . This analytical model can then be calibrated through experimental observations or particle-scale numerical predictions [2] of the internal state variables identified through this process. This technique can allow one to not only predict the macroscopic evolution of the system, but also inform manufacturing processes to enhance product performance in a wide range of engineering applications.

[1] A. Misra, P. Poorsolhjouy , Granular micromechanics model of anisotropic elasticity derived from gibbs potential, Acta Mech. 227 (5) (2016) 1393 .

[2] Marcial Gonzalez, Payam Poorsolhjouy, Alex Thomas, Jili Liu, and Kiran Balakrishnan. Statistical characterization of microstructure evolution during compaction of granular systems composed of spheres with hardening plastic behavior. Mechanics Research Communications, 92:131–136, 2018.

Experimental Evaluation of Post-Tensioning Losses in Mass Timber Wall Panels

Jacob Gesh; Oregon State University; United States
Esther Baas; MSS Engineering, Inc.; United States
Mariapaola Riggio; Oregon State University; Italy
Andre R. Barbosa; Oregon State University; Portugal
Lech Muszynski; Oregon State University; Poland
Gabriele Granello; Oregon State State University (Adjunct Faculty); Italy

Post-tensioned (PT) rocking wall systems have been shown to allow for the design of structural systems that can enhance the seismic resilience of buildings. While the first applications of the technology were on reinforced concrete walls, more recently PT rocking wall systems have also been implemented using mass timber panels like cross-laminated timber (CLT), laminated veneer lumber (LVL) and mass ply panels (MPP). Since the technology is relatively new, there is limited information about the system's long-term performance. Specifically, the amount of post-tensioning loss due to creep in timber cannot be accurately predicted yet. This leads to several challenges and costs from a design perspective, for example by allowing the anchorage of the system to be accessible for potential re-stressing. Therefore, the goal of this research is to quantify and model the variables that affect the post-tensioning losses accounting for in-plane strain components due to the effect of time and varying climate exposure on PT rocking walls consisting of CLT and MPP. To reach this goal, an experimental program was designed that consisted in two phases. Phase 1 included the testing of medium-scale, post-tensioned panels exposed to a constant environment and to a series of humidity cycles, respectively. Phase 2 included the testing of full-scale 8.5 m tall CLT and MPP post-tensioned walls that were monitored in a structural testing laboratory exposed to naturally varying indoor conditions for one year. The purpose for testing these full-scale walls was to calibrate and validate the model developed from the phase 1 tests.

Experimental investigation of nature-inspired nano-architected porous materials

Seo Young Ahn; The University of Utah; United States
Pania Newell; The University of Utah; United States

Porous materials are crucial for various fields such as materials science, biomechanics, petroleum engineering, civil engineering, and mechanical engineering. They are a class of materials with unique physical and chemical properties dictated by the size, shape, and distribution of the pores within them. In nature, porous materials contain uniquely optimized pore morphologies leading to exceptional properties. For instance, the porous structure of bones are optimized for mechanical strength, while also allowing it to store minerals and support the growth of blood vessels. Additionally, the porous structure in wood gives it insulating properties and mechanical strength, making it a useful building material. Inspired by nature and with the advancement in manufacturing we can now architect materials that mimic the pore morphology of natural porous structures. These architected structures will also enable us to investigate the relationship between macroscopic properties and the underlying pore morphology. Moreover, by architecting similar realistic porous structures, scientists and engineers can gain a better understanding of the relationships between structure and function, and design new materials with specific properties for specific applications. This study explores the micromechanical behavior of the realistic nano-architected porous materials. The structures are designed with porosities ranging from 35\% to 65\% using nature-inspired gyroid functions and are created via two-proton polymerization 3D printing on the Nanoscribe 3D printer. The in-situ mechanical test is performed using micropillar compression with Hysitron PI-89. The experimental results show a decrease in the extracted Young's modulus in comparison to the fully dense counterpart. This outcome falls within classical analytical models focusing on porosity in the macroscopic scale, indicating that the classical model applied to macroscales are also applicable to our nano-architected porous structures. These findings provide valuable insights into how realistic porous materials behave under mechanical loading and can inform the design of stronger, more durable, and more efficient materials and structures for various applications.

Experimental Investigation on Enhancing Tube Energy Absorption Capacity by Orifice Effect

Farhad Farzaneh; Florida State University; United States
Sungmoon Jung; Florida State University; United States

In recent years, lithium-ion batteries (LIBs) have gained popularity as a breakthrough energy storage technology due to numerous advantageous features. However, due to LIB sensitivity to heat and deflection, they need battery thermal management (BTM) and mechanical load protection. Now, a wide variety of BTMs are available. To be more specific, two primary approaches to thermal control of batteries have been developed. Active cooling of the battery pack by wind or liquid as a refrigerant, or passive cooling via phase change material (PCM). Phase change material (PCM)-based BTM is a unique passive thermal management technology that regulates temperature using PCM latent heat. PCM's phase transition perform effective temperature control on LIBs. PCMs can also be used to enhance energy absorption capacity. This study proposes that filling tubular energy absorbers is an effective way to increase their capacity to absorb energy. PCM-filled circular tubes were experimentally investigated. Caps with orifices on tube end surfaces were used to enclose PCM. As a revolutionary form of energy absorption, energy absorbers were filled with an incompressible and squeezable substance. Due to the dissipation of energy during material squeezing through orifices, it was expected that filled tubes would provide greater energy absorption performance than empty tube systems. Enhancing energy absorption has been experimentally proved. Performance of filled tubes subjected to crushing was analyzed by quasi-static lateral force. A hemi-cylindrical indenter was used to laterally compress the samples. The influence of geometrical characteristics of filled tubes under lateral pressure was predicted using systematic case design (SCD). Derivations of the specific energy absorption capacity (SE) of filled tubes as a function of geometrical factors such as wall thickness, tube diameter, and orifice size were made. Parametric study was used to analyze how various geometric parameters affect SE. We conclude by proposing an empirical formulation of energy absorption as a function of geometrical parameters for a PCM-filled capped-end tube, which can predict energy absorption with at least 95% accuracy.

Experimental investigation on the in-plane compressive behavior of curved steered fiber laminated panels

Avinkrishnan Ambika Vijayachandran; University of Michigan; United States
Shiyao Lin; University of Michigan; United States
Anthony Waas; University of Michigan; United States

Development of novel technologies for manufacturing composites, like Robotic Automated Fiber Placement (RAFP) and Automated Tape Laying (ATL) have helped in faster, cheaper, and precise production of laminated composite structures. In addition to these benefits, RAFP also helps the designer to optimally distribute the fiber paths in a structure so as to maximize critical structural performance indices like buckling loads. To that extend, a novel algorithm for representing the fiber paths using Bezier splines, in conjunction with the use of a “global manufacturing mesh" was introduced by the authors previously [1]. This method not only helped reduce the number of optimization variables, but also modeled the manufacturing parameters like course width and minimum radius of curvature explicitly. The effect of manufacturing signatures like gaps and overlaps were also captured [2]. A surrogate model based on Artificial Neural Networks (ANNs) was used along with a multi-objective genetic algorithm to obtain a “Pareto front" of solutions from which three feasible solutions were identified based on the criteria that the total gain in mass be less than 10%, the decrease in global stiffness capped at 10% and more than 25% increase in buckling load compared to a unidirectional laminate. In the proposed study, the manufacture, nondestructive inspection, and structural testing of these chosen optimal designs under in-plane compression are discussed. Once manufactured, a coordinate measuring machine (CMM) is used to compute the slight initial curvature. Optical microscopy is used to study the variation of ply thickness at the location of overlaps. Test fixtures are designed to accommodate the slightly curved panels following with the panels are tested under in-plane compression. 2D and 3D Digital Image Correlation (DIC) is used to record the in-plane and out-of-plane displacements which shall be used to obtain the transition loads for each of the panels tested. REFERENCES [1] Vijayachandran AA, Davidson P, Waas AM. Optimal fiber paths for robotically manufactured composite structural panels, International Journal of Non-Linear Mechanics, 2020. [2] Nguyen MH, Vijayachandran AA, Davidson P, Call D, Lee D, Waas AM. Effect of automated fiber placement (AFP) manufacturing signature on mechanical performance of composite structures, Composite Structures, 2019

Experimental Study of Roof Gravel Motion Initiation

Md Safwan Ahsanullah; Glenn Department of Civil Engineering, Clemson University; United States
Nigel Kaye; Glenn Department of Civil Engineering, Clemson University; United States

Wind loading and windborne debris tend to be a major source of threat to the built environment during extreme wind events, such as hurricanes and windstorms. Decades of research and post-storm investigations show that one of the most common forms of windborne debris is blown off roof gravel. This study experimentally investigates the removal of loosely laid roof aggregate from the built-up rooftop of low-rise buildings. A series of large-scale wind tunnel tests are carried out for this purpose in Wall of Wind-Experimental Facilities (WOW-EF), a large-scale hurricane testing facility at FIU. A square plan low-rise building, with dimensions L × W × H = 11' × 11' × 7.2', is exposed to open terrain boundary layer flow. The roof is covered in a 3" layer of roof aggregates and a total of 6 parapet configurations are tested ranging between h/H=0 to h/H=0.1. For this study, only the critically important oblique wind angles are considered between θ = 35° and θ = 45°. During the test, high-definition videos are recorded for each case from multiple perspectives to identify the various stages of gravel removal phenomena and their associated critical removal windspeeds, as defined by Kind (1975) [1]. For each case, all these critical windspeeds are recorded from the videos as well as the windspeed at which the roof area is exposed due to scouring. At this point, a salient object detection (SOD) neural network architecture, U2-net [2], is used to perform frame-by-frame image analyses and generate binary images showing scour holes on the roof surface. The areas of scour holes are plotted against time for various wind angles and parapet configurations to observe the development of the scour holes.

Ref:

[1] Kind, R.J., 1975. Further Wind Tunnel Test on Building Models to Measure Wind Speed at Which Gravel Is Blown off Rooftops. National Research Council Canada, Ottawa, Canada. LTR-LA-189.

[2] Qin X., Zhang Z., Huang C., Dehghan M., Zaiane O.R., Jagersand M., 2020. U2-Net: Going Deeper with Nested U-Structure for Salient Object Detection. Pattern Recognition, 106, Article 107404.

Experimental study of the effect of single fiber pullout behavior of recycled steel fiber on the performance of fiber reinforced concrete

Md. Mashfiqul Islam; Department of Civil & Environmental Engineering, FAMU-FSU College of Engineering, Florida State University, FL, USA; United States

Qian Zhang; Department of Civil & Environmental Engineering, FAMU-FSU College of Engineering, Florida State University, FL, USA; United States

The mechanical and durability properties of concrete are often improved with steel fibers. However, virgin manufactured steel fibers are very costly and have a very high carbon footprint, so more sustainable and economic steel fiber sources are urgently needed. Recycled steel fibers (RSF) recovered from used tires represents a promising sustainable source for steel fibers in the concrete industry. In comparison to virgin fibers, RSF exhibits distinct fiber pullout characteristics due to their irregular shape and surface characteristics. Furthermore, RSFs exhibit much greater geometric and physical variability compared to virgin fibers, which may affect the performance and durability of fiber reinforced concrete (FRC) structures. These represent the major challenges to the broader adoption of RSF, especially in high-quality constructions. In this paper, the single fiber pullout behavior from a concrete matrix is experimentally evaluated for irregular shaped RSFs derived from used tires. To quantitatively characterize the variability of the RSF properties and bond behavior with cementitious matrix, a statistical analysis is also performed. Based on the test result, an analytical model is proposed for modeling the pullout behavior of RSF. A mesoscale fiber reinforced concrete model was then employed to determine the influence of RSF on the mechanical properties of the resultant FRC materials and their variability. Various factors that affect the resultant FRC material performance are discussed. The result of the study provides insights into the design of FRC materials with RSF.

Experimental study on the effect of complex heterogeneous terrain on wind pressure in low-rise building

Lee Sak An; Florida State University; United States
Sungmoon Jung; Florida State University; United States

Even though the heterogeneous terrain can cause large uncertainties of wind characteristics, a study for quantification of the effects is still insufficient. This study performed extensive wind tunnel testing using Terraformer, the fully-automated terrain simulator. The simulated terrain information was obtained from 60 real sites in the US. The wind pressure coefficient currently used in the design standard and the wind loads that can be caused by real heterogeneous terrain were compared. In addition, the variability of wind pressure that can occur according to the degree of terrain heterogeneity within the same exposure category was investigated.

Experimental Testing of T-FLC Yielding Element with Non-Degrading Hysteretic Profile to Limit Floor Accelerations in SMF-Spine Systems

Jessica Duke; Lehigh University; United States
Richard Sause; Lehigh University; United States
James Ricles; Lehigh University; United States
Larry Fahnestock; University of Illinois Urbana-Champagne; United States
Barbara Simpson; Stanford University; United States
Bryam Astudillo; Stanford University; United States
Zhuoqi Tao; University of Illinois Urbana-Champagne; United States

A novel yielding-element, the T-FLC, was developed in conjunction with full-scale experimental tests. The element has non-degrading hysteretic behavior over a multitude of cycles and large demands for a given target deformation and fixture geometry. In December 2020, full-scale testing was performed on a 4-story SMF with an elastic, pinned-base supplemental LFRS (known as a spine) to evaluate the effect of adding force-limiting connectors (FLC) between the SMF and spine at every floor. The goal of introducing FLC between the SMF and spine was to reduce floor accelerations while maintaining a consistent drift profile. A novel FLC design was created to handle the particular forces and deformation demands required of this experimental test. Analytical models of the test setup provided the required FLC design strength for sample ground motions. A T-shape element (T-FLC) made of high-performance steel was selected as the yielding component for the FLC. The design length of the T-FLC was selected based on geometric constraints of the test setup; the design area of the T-FLC was sized to meet a relatively small deformation target of one inch at ultimate load; the design area was also tapered to control the location of yielding along the element length. Through quasi-static experimental testing, it was found that this T-shape yielding element (T-FLC) design provides non-degrading hysteretic behavior over a multitude of cycles and for deformation demands larger than three times the target deformation. Hybrid simulations utilizing real-time results from physical T-FLC specimen testing showed improvements in global structural behavior of the SMF and spine test structure when compared to analytical model results of the SMF and spine alone. Experimental test results from the December 2020 tests also validated the design of this T-FLC device – adding FLC between the SMF and spine lowered floor accelerations with little effect on the story-drift profile. The results of these experimental tests indicate that this type of T-FLC element may prove beneficial for other passive structural control applications where post-yield deformations need to be constrained for given fixture geometries.

Experimental Validation of Real-Time Hybrid Substructuring for a Seismically Excited Building using an Inertial Shaker Transfer System

David Vanasse; University of Connecticut; United States
Sergio Lobo-Aguilar; University of Costa Rica; Costa Rica
Richard Christenson; University of Connecticut; United States

Real-Time Hybrid Substructuring (RTHS) is proposed as a cyber-physical method, combining both experimental and numerical testing, to capture the system-level dynamic interaction between numerical and physical substructures. With RTHS, a structural dynamic system can be partitioned into separate experimental and numerical components or substructures. In a typical RTHS configuration, a transfer system is used to impart numerically determined displacements onto the physical substructure and force sensors are used to measure the resulting restoring forces, which are feed back into the numerical model to determine the displacement response at the next integration time step. As an advancement in a research method to assess seismic performance, this research will experimentally demonstrate the use of an inertial shaker as the transfer system to provide the required force applied to the physical component. A 2-story seismically excited building model is considered, where the first story of the building is physically tested and the top story is numerically modeled. The first story is subjected to a ground acceleration as it sits upon a bench-scale shake table and the calculated story shear of the top floor is imparted to the top of the first story through the use of an inertial shaker. In turn, the absolute acceleration of the top of the first story is measured with an accelerometer and used as input to a numerical model of the top story of the building structure. This system will capture the dynamic interaction between the two stories and provide realistic system-level seismic response of the building system. As RTHS continues to become more feasible due to advances in numerical computing power, digital signal processing, and high-speed actuation, innovation in the general framework and coupling of the substructures should be further explored. This research intends to promote that dialog in the substructuring community.

Experimental Validation real-time, weighted control algorithm on civil infrastructure

Courtney Peckens; Hope College; United States
Clara Voskuil; Hope College; United States
Dylan Clem; Hope College; United States

Civil infrastructure is subject to damage from large external loads, such as earthquake and winds. One method of mitigating such effects is to introduce active control techniques which require a seamless integration of information across sensors, controllers, and actuators. To promote information flow, wireless sensor networks have been used as a low-cost alternative to traditional wired sensing and actuation systems. While such networks enable a richer exchange of information between sensors and actuators and enable improved localized control capabilities, they also introduce their own additional challenges such as latency in the communication channel and computational inundation at individual control nodes. This study seeks to alleviate these challenges by employing real-time, front-end signal processing at the sensing node that results in a decomposition of information according to its spectral content. This information is then passed to a control node which can implement a simplistic sum of weighted inputs to calculate a control force that is then communicated to an actuator. This process eliminates complex computations at the control node and promotes real-time control within the system. This proposed control algorithm is experimentally validated on a small-scale, four-story structure subject to base excitation. Results from this control scenario are compared to a more traditional control algorithm, the Linear Quadratic Regulator.

Exploiting Buckling and Contact: Exploring a New Approach for Tackling Shape and Topology Optimization With Challenging Solid Mechanics Behavior

Ryan Alberdi; Sandia National Laboratories; United States
Craig Hamel; Sandia National Laboratories; United States
Kevin Long; Sandia National Laboratories; United States
Aabhas Singh; Sandia National Laboratories; United States
Adam Cook; Sandia National Laboratories; United States

In the last decade, a rich set of mechanical responses has been demonstrated by treating nonlinear solid mechanics phenomena such as buckling and contact as behaviors to be exploited rather than avoided. However, systematically exploiting such highly nonlinear mechanical phenomena has been a challenge precisely because these nonlinearities provide such an array of responses. Shape and topology optimization provide systematic design approaches but are overwhelmingly focused on linear physics, and problems with bifurcations and contact remain a challenge. This is mainly due to the fragility that most current approaches introduce when mapping a design parameterization to a computational domain for forward problem solution with nonlinear physics. Hence, our main focus is on obtaining robustness with both the forward problem solution and inverse problem parameterization. To do this, we utilize a unique library for solving nonlinear solid mechanics problems that poses them in an energy minimization form and uses a trust region algorithm to handle saddle points and differentiate between stable and unstable equilibria. Enabling the use of this library for optimization-based design are CAD-based shape and level-set-based topology parameterizations which smoothly map to a conforming mesh at each optimization iteration. We explore how this approach can be used to tailor geometry to harness buckling and contact for driving novel and useful responses.

Exploring Interaction Methods for Human Machine Collaboration in Bridge Inspection via Augmented Reality

Alan Smith; Virginia Tech; United States
Eric Bianchi; MITRE Corp; United States
Kyle Tanous; Virginia Tech; United States
Joseph Gabbard; Virginia Tech; United States
Rodrigo Sarlo; Virginia Tech; United States

Currently bridge inspection tasks are completed using simple pen/paper workflows, which require the user to manually input the resulting data into multiple disconnected systems after each inspection. Recent research initiatives have shown the potential of image processing and machine learning to assist in bridge inspection tasks, however even the most advanced automated techniques struggle with context and edge cases, particularly when they operate independently of input from human inspectors. We propose that meaningful collaboration between inspectors and computer vision algorithms can improve overall performance. Augmented reality interfaces have shown recent success with allowing users to interact naturalistically with their environment, however, existing image processing techniques operate on the image space, and are not compatible with interactions based on the physical environment. In this study, machine learning and image processing techniques are incorporated into an augmented reality bridge inspection workflow. This is based on an offline server/client pipeline capable of functioning in GPS and internet denied environments. Challenges such as parity between the image space where the algorithms function and the physical environment that the user acts upon are explored in detail. Finally, four potential interaction methods are explored consisting of human only, machine only, human modifying machine output, and machine modifying human output. A user study is conducted to determine accuracy, time on task, cognitive demand, and usability of each of the four interaction methods.

Exploring the Thermomechanical and Interfacial Behaviors of Nano-Clay Using Molecular Modeling

Sarah Ghazanfari; North Dakota State University; United States
Wenjie Xia; North Dakota State University; United States

The most commonly found swelling sodium montmorillonite (Na-MMT) clay mineral has different applications such as nuclear waste storage at elevated temperatures/pressures and biotechnology. In the first part of present study, employing all-atomistic (AA) molecular dynamics (MD) simulations, the current study explores the tensile behavior of the Na-MMT clay minerals at a raised temperature ranging from 500 K to 1700 K and pressures ranging from 200 atm to 100,000 atm. Moreover, we calculate the mean-square displacement (MSD) of all atoms except hydrogen and Na counter ions where the results denote pressure enhancement increases the molecular stiffness by suppressing atoms' mobility and a similar pattern is observed when temperature decreases. In the end, the dynamical heterogeneity of the Na-MMT model is quantified where the local molecular stiffness distribution of the simulation box reveals the natural heterogeneous behavior of the system which agrees with other experimental studies. In the second part, we use density functional theory (DFT) to examine the relationship between the two simple alanine amino acids and MMT clay mineral. Five model systems were investigated in order to gain a better knowledge of peptide bond formation/break catalyzed by inorganic substrate. To trace the system's total energy as a function of the reaction coordinate, the transition state (TS) search approach is ultimately used for each of the model systems. The results of this work pave the way for the specifically tailored design of clay-based materials in the realms of biotechnology, nuclear waste storage, and shale gas extraction.

Extension of the novel Line Element-less Method for plates shaped with re-entrant angles

Antonina Pirrotta; Dipartimento di Ingegneria, Università degli Studi di Palermo; Italy
Carsten Proppe; Karlsruhe Institute of Technology (KIT); Germany

Several engineering problems, comprising civil, aeronautical, chemical and mechanical engineering applications [1], often require estimating the response of elastic thin plates of arbitrary or complex shape. Clearly, plate deflection strongly depends on both the geometrical shape and given boundary conditions, and thus approximate numerical methods are usually employed for their analysis. In this context, Finite Element Method (FEM), Boundary Element Method (BEM) and Rayleigh-Ritz approaches are among the most widely used. Very recently, an innovative meshfree method, the so-called Line Element-less Method (LEM), has been proposed to determine the response of plates under uniformly distributed edge moments [2]. Note that, this method is based on the evaluation of line integrals only. Therefore, it does not require any discretization neither in the domain nor in the boundary, and then it appears to be quite convenient when studying plates of complex shapes or boundary conditions. However, using the previous formulation, it was not possible to handle plates in bending, shaped with re-entrant angles; then this contribution aims to extend the aforementioned LEM to this latter case. Analyses are carried out for several plate shapes, showing the elegance and simplicity of the proposed procedure, which allows the computational cost to be kept at minimum. Further, comparisons of LEM based deflection functions vis-à-vis pertinent Finite Element method will assess the accuracy and reliability of the considered approach.

References

[1] Szilard, S., "Theories and applications of plate analysis: Classical, numerical and engineering methods", Wiley, Hoboken (2004).

[2] Pirrotta, A., Bucher, C., "Innovative straight formulation of plate in bending", Computer and Structures, 180, 117-124 (2017).

Fabric characteristics of jammed and unjammed granular materials

Yida Zhang; University of Colorado Boulder; United States
Yuxuan Wen; University of Colorado Boulder; United States

The Jamming phase diagram (JPD) maps the phase states of granular materials to its intensive properties such as shear stress and density (or packing fraction). We investigate how the fabric structure of granular materials is related to its different phases in JPD via three-dimensional discrete element simulations. Quasi-static simple shear tests ensuring uniform shear strain field are conducted on bi-disperse spherical frictional particles. Specimens with different initial solid fractions are sheared until reaching steady state at a large shear strain (200%). The jamming threshold in terms of coordination numbers of different contact networks are determined. A unique jamming threshold of non-rattler fraction is identified, which is consistent with findings from previous photoelastic experiments (Bi et al., 2011). The evolution of fabric anisotropy of the contact network during shearing is examined. By plotting the fabric data in the coordination number Z vs. fabric anisotropy F plane (i.e., the "fabric path"), a unique critical fabric surface (CFS) is observed for all specimens regardless of their initial phase states, consistent with our previous observations (Wen and Zhang, 2022). We further propose a mapping between the classical JPD and the fabric F-Z space to identify the fabric signals that correspond to the jamming phase transition of granular materials. The proposed CFS complements the usual JPD by revealing the microstructural correspondence of the different phase states of granular packings, offering a new perspective to interpret the phase transitions of granular materials subjected to compaction, shearing, and other complex loading histories.

REFERENCES:

Bi, D., Zhang, J., Chakraborty, B., Behringer, R.P., 2011. Jamming by shear. Nature 480, 355-358. Wen, Y., Zhang, Y., 2022. Evidence of a Unique Critical Fabric Surface for Granular Soils. Géotechnique, published online.

Falling Weight Deflectometer tests on multi-layered pavements: design and evaluation of innovative experiments

Rodrigo Díaz Flores; TU Wien; Austria
Valentin Donev; TU Wien; Austria
Mehdi Aminbaghai; TU Wien; Austria
Lukas Eberhardsteiner; TU Wien; Austria
Luis H. Zelaya-Lainez; TU Wien; Austria
Raphael Höller; TU Wien; Austria
Christian Hellmich; TU Wien; Austria
Ronald Blab; TU Wien; Austria
Martin Buchta; Nievelt Labor GmbH; Austria
Bernhard L.A. Pichler; TU Wien; Austria

Falling Weight Deflectometer (FWD) tests are performed worldwide to gain insight into the structural health of pavement structures. The dynamic load induces a damped vibration of the hit pavement structure. Displacement sensors called geophones measure the maximum deflections at specific distances from the falling weight along the driving direction. Herein, two challenges are tackled in the context of engineering mechanics approaches: (i) As regards concrete slabs of rigid pavements, the described standard FWD test cannot detect potential asymmetries of the structural behavior. (ii) Performing nominally identical FWD tests on the same multi-layered pavement structure, but at different dates, usually yields different surface deflections. As for (i), deflections are measured in eight different directions during central FWD tests, see https://doi.org/hcnx. Newly built slabs are found to behave in a virtually double symmetric fashion, while old slabs, which had been in service for many years, show significant asymmetries. With the aim to combine the advantages of the standard FWD approach (= rapid in situ characterization) and of the approach involving multi-directional measurements of deflections (= expressiveness regarding the assessment of asymmetric structural behavior), a T-shaped arrangement of geophones is finally introduced. As for (ii), a concrete-over-asphalt composite pavement is equipped with temperature sensors, asphalt strain gauges, and accelerometers. FWD tests performed in summer, winter, and transitional periods lead to different surface deflections. Concrete and asphalt are characterized in the laboratory. The stiffness of the cement-stabilized granular layer is determined in situ. Sledgehammer strokes produce elastic longitudinal waves. Signals of the buried accelerometers allow for quantification of the time of flight of the waves through the layer of interest. Its stiffness is quantified using the theory of elastic wave propagation through isotropic media. A multilayered elastostatic model is used to back-calculate, from deflections measured during FWD tests, the stiffness of the subgrade. It is found to be the larger, the smaller its temperature. The model is used to develop an asphalt-related temperature correction for the measured surface deflections. The seasonal variation of the corrected deflections refers to the seasonal variation of the stiffness of the subgrade. This is shown by computing, from corrected deflections, k-values of the dense-liquid model and correlating them with the seasonally varying modulus of elasticity of the subgrade. Finally, an engineering approach for correction of surface deflections is developed, which requires only measured deflections as input.

Fiber Orientation and Topology Optimization of Tow-Steered Composite Laminates with Manufacturability Control

CHUAN LUO; Johns Hopkins University; United States
James Guest; Johns Hopkins University; United States

Automated fiber placement technologies, such as tow steering, allow manufacturing of composites with curvilinear fiber paths, offering the potential for improved structural performance over conventional laminates using stacked plies having constant orientation. Various design methods have been developed to optimize fiber orientation and topology that capture and fully leverage the promising properties of tow-steered laminated composites to satisfy stiffness and strength demands relevant to engineering applications. Although automated fiber placement technologies offer more design freedom than classical laminates with fixed orientation, manufacturing constraints must be considered to ensure optimized designs can be readily manufactured. Therefore, in the present work, we consider various forms of constraints on fiber orientation paths, including changes in curvature, to improve the manufacturability of optimized solutions. Considered design objectives include (i) maximizing stiffness and (ii) maximizing strength by minimizing the maximum failure in the composite laminates, which is evaluated by the maximum stress failure criteria based on a three-dimensional state of stress, where both in-plane and interlaminar stress components are considered. Numerical results show that the optimized designs can effectively reduce the maximum failure index by optimizing the layout of fiber orientations in each layer of composite laminates, resulting in more efficient stress distributions within the structure. Furthermore, the proposed method is capable of achieving efficient tow-steered composite structures with good control over a series of manufacturing requirements related to improving fiber continuity and gaps, and controlling fiber curvature.

Field implementation of indirect strain sensing using acceleration response of bridges

Soheila Eshkevari; Lehigh University; United States
Soheil Eshkevari; Massachusetts Institute of Technology; United States
Debarshi Sen; Southern Illinois University Carbondale; United States
Iman Dabbaghchian; Lehigh University; United States
Shamim Pakzad; Lehigh University; United States

Bridge fatigue assessment is crucial for maintaining the American road infrastructure. This typically entails continuously measuring strain response of a bridge subjected to daily traffic loading. However, deploying and maintaining strain sensors significantly increases cost and effort compared to acceleration sensors. In this work, we propose a neural network architecture that performs indirect sensing, measuring strain from acceleration response. The proposed network consists of convolutional neural networks (CNN) and transformers, to account for nonlinear interdependencies, uncertainties and noise associated with field data, and effectively convert accelerations to strain by capturing both the pseudo-static and dynamic features of the strain response. As a case study, we demonstrate the efficacy of the proposed network using field data collected from the Gene Hartzell Memorial Bridge in Easton, PA. This novel framework allows high accuracy strain estimation from acceleration as well as rainflow cycle counting diagram that is employed for bridge condition assessment and subsequently life-cycle assessment.

Finite Element Analysis for Predicting greenhouse gas emissions in riparian and hyporheic zones

Chengwu Jiang; Georgia Institute of Technology; United States
Martial Taillefert; Georgia Institute of Technology; United States
Chloe Arson; Georgia Institute of Technology; United States

Biogeochemical processes in riparian and hyporheic sediments regulate the exchange of greenhouse gases (GHGs) with surface waters and are responsible for a large fraction of global GHG emissions. Methane (CH4) and carbon dioxide (CO2) generated within riparian soils and streambed sediments are eventually transported to streams by gas exchanges. Biogeochemical transformations (i.e., methanogenesis and methanotrophy) influence the emission of CH4 and the production cycles of dissolved inorganic carbon (DIC). In addition, GHG nitrous oxide (N2O) is produced by partial denitrification or nitrification in wetland sediments. At the scale of a riverbed, GHG emissions from sediments are influenced by complex soil heterogeneities and hydrological variations (variations in precipitation, temperature, stream discharge, porosity, and tortuosity), and are thus difficult to predict. Therefore, it is crucial to simulate GHG emissions at the terrestrial-aquatic interfaces (TAIs) by adopting reactive transport models (RTMs) that eliminate spatial and temporal heterogeneities.

In this work, we present models of chemical reactive flow in water-saturated and partially saturated soil to simulate the processes that lead to GHG emissions with the Finite Element Method (FEM). First, we study the transient changes in ferrous iron (Fe2+) concentration in a 1D streambed upon oxidoreduction, diffusion, and conduction. Next, we use a RTM to predict GHG emission through a vertical column of sediments as a function of initial and boundary conditions, as well as soil porosity, diffusivity, and permeability. We interpret the results in relation to the hydraulic forcings and locations along the bank slope that these 1D cases represent. Lastly, we simulate water level changes in 2D, in a riverbed cross section. The 2D FEM model is benchmarked against series of 1D models to understand the effect of lateral flow and transport in GHG emissions from riparian and hyporheic sediments. Parametric studies are conducted to understand the dominating factors in the 2D RTM. This research will contribute to a larger effort to map GHG hot spots from riparian and hyporheic sediments.

Finite element model of fault zone of northeast Japan subduction zone for intermediate depth earthquake initiation.

Ashay Panse; University of Illinois at Chicago; United States
Craig Foster; University of Illinois at Chicago; United States
Shen Wei Chi; University of Illinois at Chicago; United States
Fnu Sindhusuta; University of Illinois at Chicago; United States

The intermediate depth earthquakes account for about 90% of all deep earthquake and cause significant damage and casualties. The mechanisms involved in causing these earthquakes are complex and are currently not well understood. In this research, we are building a finite element model of the Northeast Japan subduction zone. In our model, which is about 800 km deep, we examine the potential mechanisms driven by phase transformation at high temperature and pressures. We take into account the fracture propagation, temperature changes and mineral phase transformation to check for fault slip initiation and propagation. The effect of ductile and brittle behavior of the material will be examined as the fault propagates in an extended finite element model in Abaqus. Some of the popular hypotheses for the causes of intermediate depth earthquakes will be tested and compared to earthquake recurrence patterns at those depths.

Finite element model updating of non-proportional non-viscous damping systems using complex eigenvalues and eigenvectors

Yu Otsuki; Georgia Institute of Technology; United States
Yang Wang; Georgia Institute of Technology; United States

This study proposes a finite element (FE) model updating method for exponential non-viscous damping systems using complex eigenvalues and eigenvectors. The exponential non-viscous damping provides complex eigenvalues/vectors for elastic modes and real-valued eigenvalues/vectors for non-viscous modes. This study first reveals the difficulties in accurately identifying real-valued eigenvalues/vectors for non-viscous modes using a commonly used system identification method. Next, we propose the optimization formulation to minimize the difference between the simulated and experimental complex eigenvalues/vectors for elastic modes. The method applies large structures that can contain multiple substructures with different damping properties. For brevity, we assume that damping properties are uniform over each substructure. In addition, mass proportional viscous damping and stiffness proportional non-viscous damping are adopted for each substructure, which results in overall damping being non-proportional. To improve computational efficiency, the analytical gradient of the proposed optimization formulation is derived and implemented. For validation, the model updating of a full-scale steel pedestrian bridge is performed. The method is first validated in simulation and further validated by experimental data using only a limited number of measured DOFs and modes.

Finite Element Model Updating through Global Optimization ofFinite Element Model Updating using Primal-Relaxed Dual Global Optimization Algorithm Smooth Nonconvex Problems

Trent Schreiber; Georgia Institute of Technology; United States
Yu Otsuki; Georgia Institute of Technology; United States
Yang Wang; Georgia Institute of Technology; United States

Finite element (FE) modeling has become a powerful tool in predicting the response of various engineering structures. However, predictions from the numerical model often differ from in-situ experimental measurements due to numerous approximations and inaccuracies in the model. The in-situ experimental data obtained from the as-built structure can be used to update selected model parameters, such as stiffness-related values, to obtain a more accurate FE model that truly reflects the behavior of the as-built structure. This research investigates FE model updating using the eigenvector difference approach, which is based on vibration modal property differences. The eigenvector difference approach is a nonconvex optimization problem, for which generic solvers cannot guarantee global optimality. However, the problem can be reformulated so that the solution can benefit from its biconvexity. Using a primal-relaxed dual decomposition approach, the global optimum can be found for biconvex problems. The formulation of the model updating algorithm and several examples that demonstrate its functionality are presented in this paper.

Finite Strain Robust Topology Optimization Considering Multiple Uncertainties

Nan Feng; University of Notre Dame; United States
Shiyao Sun; University of Notre Dame; United States
Guodong Zhang; Southeast University; China
Kapil Khandelwal; University of Notre Dame; United States

A topology optimization framework incorporating multiple uncertain sources is presented to design robust structures at finite deformations. The overall goal is to design structures that are insensitive to uncertainties in the operating environment related to loading, material, and geometric/manufacturing processes. In particular, uncertainties are modeled by either random vectors or random fields which in turn are discretized by Karhunen–Loève expansions. A second-order stochastic perturbation method is proposed to quantify uncertainties in the objective function, i.e., end compliance, and consistent analytical adjoint sensitivities are derived for the gradient-based optimization algorithm. In addition, an adaptive linear energy interpolation scheme is leveraged to address the mesh distortion issue in low-density regions under large deformations. The proposed optimization framework is applied to several test cases and the effects of different uncertain sources on the optimized designs are systematically studied. The robust designs are demonstrated to be less sensitive under variations of uncertain sources as compared to their deterministic counterparts. Moreover, it is found that the incorporation of uncertainties in optimization formulation helps to achieve stable designs whereas a deterministic design might be unstable.

First-passage stochastic incremental dynamics methodology for nonlinear structural systems with fractional derivative elements

Peihua Ni; Institute for Risk and Reliability, Leibniz Universität Hannover; Germany
Ioannis Mitseas; School of Civil Engineering, University of Leeds; United Kingdom
Vasileios Fragkoulis; Institute for Risk and Reliability, Leibniz Universität Hannover; Germany
Michael Beer; Institute for Risk and Reliability, Leibniz Universität Hannover; Germany

A novel first-passage probability stochastic incremental dynamics analysis (SIDA) methodology for nonlinear structural systems with fractional derivative elements subject to a fully non-stationary seismic excitation vector consistently designated with contemporary aseismic codes provisions (e.g. Eurocode 8) is developed. Specifically, the vector of the imposed seismic excitations is characterized by evolutionary power spectra compatible in a stochastic sense with aseismic codes elastic response acceleration spectra of specified modal damping ratio and scaled ground acceleration [1]. Rendering to a combination of the concepts of stochastic averaging and statistical linearization, the approximative non-stationary response displacement joint probability density function (PDF) is efficiently derived in a straightforward manner retaining the particularly coveted attributes of computational efficacy and comprehensiveness [2,3]. Subsequently, the coupling with the survival probability model [4] allows for the efficient determination of the first-passage PDF for a scalable intensity measure for each and every of the considered limit-state rules. The selected engineering demand parameter of the first-passage time constitutes an excellent response related variable with twofold meaning; it performs structural behaviour monitoring considering intensity and timing information whereas it is inherently coupled with limit-state requirements [5]. Further, the associated low computational cost, the ability to address a wide range of complex nonlinear/hysteretic structural behaviours, and the aseismic code-compliant property enhance the potential for applications in the fields of structural and earthquake engineering. A nonlinear system model endowed with fractional derivative terms serves as the numerical example for demonstrating the reliability of the proposed methodology. The accuracy of the proposed method is assessed in a Monte-Carlo-based context conducting nonlinear response time-history analysis involving a large ensemble of Eurocode 8 spectrum compatible accelerograms.

[1] Cacciola P., 2010. A stochastic approach for generating spectrum compatible fully nonstationary earthquakes, Computers & Structures 88, 889–901.

[2] Fragkoulis V. C., Kougioumtzoglou I. A., Pantelous A. A., Beer M., 2019. Non-stationary response statistics of nonlinear oscillators with fractional derivative elements under evolutionary stochastic excitation, Nonlinear Dynamics 97, 2291–2303.

[3] Kougioumtzoglou I. A., Ni P., Mitseas I. P., Fragkoulis V. C., Beer M., 2022. An approximate stochastic dynamics approach for design spectrum based response analysis of nonlinear structural systems with fractional derivative elements, International Journal of Non-Linear Mechanics 146, 104178, doi: 10.1016/j.ijnonlinmec.2022.104178

[4] Solomos, G.P. and Spanos, P.D., 1983. Structural reliability under evolutionary seismic excitation. International Journal of Soil Dynamics and Earthquake Engineering, 2(2), pp.110-114.

[5] Mitseas I. P., Beer M., 2021. First-excursion stochastic incremental dynamics methodology for hysteretic structural systems subject to seismic excitation, Computers and Structures, vol. 242, doi: 10.1016/j.compstruc.2020.106359.

Fisher Information based Optimal Sensor Locations for Structural Identification: Non-Stationary Inputs and Non-Classically Damped Systems

Dhiraj Ghosh; Indian Institute of Technology Kanpur; India
Suparno Mukhopadhyay; Indian Institute of Technology Kanpur; India

In vibration-based structural identification, the determination of optimal sensor locations has been predominantly attempted for problems with known or stationary inputs, and for classically damped systems. However, in many cases, the input excitation may not be measured and may be nonstationary. Similarly, many systems, such as primary-secondary systems, may not be classically damped. In this study, we consider two such cases. The optimal sensor locations, for identifying different parameters (modal as well as stiffness) are obtained by maximizing the associated Fisher information, such that the optimally located sensors contain the maximum information about the parameters of interest. First, we consider the case of unmeasured non-stationary base excitation, modelled as a uniformly (amplitude) modulated random process. Under such motions, it is shown that the sum of eigenvalues of the output power spectrum, considered as measurement parameter, follows an exponential distribution. The Fisher information is then shown to comprise of the sum of these eigenvalues, along with the sensitivities of the output power spectrum to the parameters of interest. Next, we consider primary-secondary systems, which can be non-classically damped, and formulate the approach in the state-space framework to deal with the mode shapes being inherently complex. The methodology is illustrated through numerical simulations as well as experimental data from shake table tests. The effect of unobserved modes is also studied. It is shown that, while stiffness depending on unobservable modes are not identified or have high estimation uncertainty, the optimal sensor set-ups for identifying a stiffness and for identifying the modes most sensitive to that stiffness are not necessarily the same. Finally, the importance of optimal sensor locations in damage detection is highlighted through the shake table tests. It is shown that the estimation uncertainties in structural parameters and damage severities are least for optimally located sensors.

Fluctuation-based fracture and healing of materials and structures in the semi-grand canonical ensemble

Nima Rahbar; Worcester Polytechninc Institute; United States

Fracture mechanics is defined by Griffith as the irreversible change of energy between two equilibrium states at constant loading. Monte Carlo sampling can be used to compute the energy change introduced by fracture, the energy release rate and its critical value, the fracture energy, and healing from fluctuations. This summarized the idea of fluctuation-based fracture mechanics in the semi-grand canonical ensemble (SGCMC) developed earlier by Prof. Franz Ulm. Herein, we review recent developments of SGCMC and show an application for modeling healing in structural materials.

FluidFlower concept for visualizing and studying CO2 storage: From lab experiments to quantitative imaging

Jakub W. Both; University of Bergen; Norway
Martin A. Fernø; University of Bergen; Norway
Jan M. Nordbotten; University of Bergen; Norway

Geological CO2 storage couples several multi-physics and multi-scale phenomena, which have been difficult to capture simultaneously in a single lab-scale experiment. The recently established, in-house developed, so-called FluidFlower concept allows for such. The recurring theme is the possibility to construct a porous medium from unconsolidated sands and conduct repeatable fluid displacement experiments in the lab. The availbility of up-to-room-scale rigs provide the opportunity to design fairly complex, geologically inspired formations incorporating several facies and fault-like structures. Furthermore, the rigs are equipped with a glass front panel allowing for visually and accurately tracking fluid displacement, when using pH-sensitive dyes and high-resolution photography.

With the FluidFlower concept at hand, a model validation study has been performed involving several numerical modeling groups. Repeated room-scale CO2 storage experiments haven been conducted, designed to capture several key phenomena of geological CO2 storage as dissolution and convective mixing. The visible CO2, both in dissolved and mobile state, is measured based on optical images taken of the FluidFlower rig. To allow for a meaningful comparison with numerical simulations, the in-house developed, open-source tool DarSIA (Darcy-scale Image Analysis toolbox) has been utilized. It allows for automated upscaling of fine-scale images, and thereby for the data conversion of the photographs to Darcy-scale saturation and concentration maps. Furthermore, it allows to accurately track the development of fingers, structural geometrical displacements (of sand grains), as well as compute differences of seemingly similar configurations using proper metrics, all aiding the quantitative analysis. Efficient run times allow for real-time integration within digital twin concepts and history matching technology.

In this talk, the entire FluidFlower chain will be presented and its opportunities for quantitative analysis of fluid displacement experiments under room conditions will be demonstrated.

Folding Polygonal Kirigami Tubes

Martin Walker; University of Surrey; United Kingdom

Kirigami is a form of origami which includes cuts and enables the creation of complex morphing 3D shapes from 2D sheets. Engineers have been inspired to adopt the techniques of kirigami to develop a wide range of novel designs ranging from deployable structures to medical devices and stretchable electronics. In its most common form kirigami designs are created by imposing a pattern of cuts in a flat sheet. Three-dimensional movement is generated by deforming the sheet (in many cases by introducing in-plane tension).

Taking a kirigami sheet and deforming it isometrically, by wrapping into a cylinder for example, can introduce new mechanical behaviour. Recent research has shown that the curvature induced by wrapping changes the mechanical behaviour in comparison to the original flat sheet. In this study we investigate the effect of folding a flat kirigami into a polygonal cross-section tube. Assuming predictable, regular, kinematic behaviour is desired we show that the folding process introduces an additional design constraint: kinematic compatibility along the fold lines (polygon edges). We show how changes to the fold design affect global mechanical behaviour and compare to the flat and tubular cases.

Forces between Calcium-Silicate-Hydrate Surfaces: A Density Functional Approach

Thomas Petersen; University of Southern California; United States

Calcium-silicate-hydrate (C-S-H) is the primary binding phase in cement paste. Over the past two decades, research has refined our understanding of the material's molecular composition and the physics that govern the cohesion between its layers and surfaces. C-S-H precipitates as semi-crystalline calcium-silica sheets that are separated by interlayer water. In contact with the pore solution, the surface silanol groups ionize to develop a surface charge that reaches about 3e^-/nm2. The cohesion between opposing C-S-H surfaces results from the subsequent structured and correlated arrangement of Ca2+-ions and water molecules near these charged interfaces. Most attempts to model these correlation forces have resorted to molecular dynamics simulations, which are computationally intensive and cannot simulate long-term dynamics. In this talk, I introduce a density functional theory that retains much molecular scale information while drastically reducing the system's degrees of freedom. Rather than tracking positions of ions and molecules, their equilibrium density distributions are estimated by minimizing a grand potential. The potential's excess free energy incorporates correlations arising from steric, electrostatic, and associative interactions and guides the restructuring and layering of ions and molecules near charged surfaces such as C-S-H.

Formulation of a nonlocal gradient enhanced numerical model for geomaterials guided by controllability criteria

Dawei Xue; Northwestern University; United States
Xilin Lu; Tongji University; China
Giuseppe Buscarnera; Northwestern University; United States

Nonlocal plasticity models have been extensively used to suppress mesh-sensitivity in numerical analyses involving strain localization. Both integral and gradient formulations usually introduce nonlocality through the internal variables controlling material softening. In order to gain full regularization effects in such class of material models, an over-nonlocal formulation is often used. In this contribution, we show that in the presence plastic nonnormality full regularization may not be achieved, thus implying that mesh-independence is not guaranteed for every choice of the nonlocal regularization parameters. To overcome this problem, we link mathematically the loss of regularization to the uniqueness and/or existence of the incremental plastic response by making reference to the concept of controllability for plastic solids. For this purpose, we make reference to the strain kinematics within a deformation band, so as to inspect the conditions at which regularization is lost in the presence of non-associated plastic flow. By doing so, we find a lower limit of admissibility for the parameters controlling the effectiveness of the gradient regularization. This lower limit is heavily affected by the degree of plastic nonnormality. In addition, we show in analytical form that the thickness of the deformation band is related to both the controllability modulus and the gradient regularization constants, which suggests that the thickness of the process zone may change in response to the prevailing plastic flow characteristics and evolve during active plastic deformation. To better illustrate the relevance of these results, we conduct a number of strain localization simulations for a constitutive law calibrated to match the deformation response of high porosity rocks. Our numerical results confirm that effective regularization can be attained only if the over-nonlocal weighting coefficient is higher than the abovementioned lower limit.

Fourier-enhanced multiple-input neural operators for accurate and efficient surrogate modeling for geological carbon sequestration

Zhongyi Jiang; Department of Chemical and Biomolecular Engineering, University of Pennsylvania; United States
Min Zhu; Department of Chemical and Biomolecular Engineering, University of Pennsylvania; United States
Lu Lu; Department of Chemical and Biomolecular Engineering, University of Pennsylvania; United States
Dongzhuo Li; ExxonMobil Technology & Engineering Company; United States
Yanhua Yuan; ExxonMobil Technology & Engineering Company; United States
Qiuzi Li; ExxonMobil Technology & Engineering Company; United States
Kun Wang; ExxonMobil Technology & Engineering Company; United States

It is critical to speed up reservoir simulations for geological carbon sequestration projects. For example, the optimization and decision-making tasks under subsurface uncertainty requires large numbers of forward simulations under various subsurface scenarios. For these tasks, conventional reservoir simulators could be inefficient due to their high computational cost, whereas (physics-informed) data-driven surrogate modeling has the potential to enable fast prediction once trained on reasonable amount of data from full-physics simulations. Surrogate modeling based on neural networks directly learns solutions of PDEs. Several numerical experiments suggest that neural operators, such as Fourier neural operator (FNO) and deep operator network (DeepONet), can speed up reservoir simulation significantly and have even demonstrated the potential for real-time prediction. However, existing neural networks usually limit the inputs to a single domain of the same high dimension (e.g., a 2D field). This approach is not only inflexible in handling inputs of different dimensions and characteristics, but also requires unnessarily high computational resources (e.g., GPU memory), which hinders their applications to complex and large-scale systems. In this work, we develop Fourier-enhanced multiple-input neural operators to address this scaling-up challenge. On one hand, the proposed neural operator consists of multiple branch nets that offer flexibility for inputs. It can handle field and scalar inputs separately, so that the network parameters and GPU memory are significantly reduced. On the other hand, the proposed operator leverages fast Fourier transform (FFT) to attain high accuracy. Compared with 3D FNO, the time axis is handled using the trunk network, which offers further reduction in GPU memory. Our technique also enables query of simulation outputs at arbitrary time slices, a unique feature with potential profound practical value. We benchmarked MIONet performance against other neural operators. We found that in particular, MIONet can achieve the state-of-the-art accuracy in predicting subsurface CO2 saturation and pressure profiles while it requires significantly fewer computing resources and smaller training sets. Furthermore, we discuss possible future directions for further improving the accuracy and robustness of MIONet for large-scale numerical simulations in geological carbon sequestration.

Fracture and damage mechanics on sea ice floes using LS-ICE DEM

Rigoberto Moncada Lopez; California Institute of Technology; United States
Jacinto Ulloa; California Institute of Technology; United States
Mukund Gupta; California Institute of Technology; United States
Andrew Thompson; California Institute of Technology; United States
Jose Andrade; California Institute of Technology; United States

The decay of sea ice from densely packed to open water regimes comprises a combination of melt and breakage events. Factors like floe size distribution, geometry and external forcing make this phenomenon complex to simulate. Representation of floe breakage or fracture is especially challenging as it is extremely sensitive to floe conditions, e.g., floe size distribution, geometry and thickness. As floes become thinner and weaker, they tend to reach a breakage failure threshold after staying intact for most of their lifespans. Despite these complex mechanisms, fracture modeling on individual floes has often used idealized parametrizations. Here, a more in-depth description of the mechanical conditions of floe breakage events is proposed through the implementation of an arbitrary shape DEM model, LS-ICE, to physically characterize floe fracture. This model uses level sets to represent irregular geometries and thickness variations. Since floe fracture tends to result from accumulated damage, an elasto-damage model is also used. To obtain damage, stresses from floe contact and collisions, surface waves, and fluid drag are utilized. As a result, LS-ICE was able to reproduce floe fracture like that of satellite observations in the Arctic ocean, combining DEM and continuum damage mechanics. In the future, this method could enhance large scale sea ice simulations, which are essential for climate prediction, design of marine infrastructure and polar navigation.

Fracture mode investigation in the Brazilian splitting test using a micromechanics-based variational phase-field model

Mina Sarem; KU Leuven; Belgium
Nuhamin Eshetu Deresse; KU Leuven; Belgium
Jaincto Ulloa; California Institute of Technology; United States
Els Verstrynge; KU Leuven; Belgium
Stijn François; KU Leuven; Belgium

This presentation focuses on the simulation of the Brazilian splitting test on mortar samples under monotonic loading using a variational phase-field model based on micromechanics. The model aims to connect macroscale field variables with physical dissipative mechanism at the microcrack level by linking plasticity with the sliding of closed microcracks and damage with the growth of open microcracks [1]. The study addresses the potential complications of stress concentrations near the applied loads by employing a viscoplasticity regularization within the variational framework. The parameters of the model are calibrated using experimental results from a Brazilian splitting test conducted using Digital Image Correlation (DIC) measurements [2]. The response of a volume element under a homogeneous strain field is presented to examine the effect of the viscosity parameter, and the fracture mode of the Brazilian splitting test is studied to gain a better understanding of different failure modes. The calibrated parameters are then used to assess the validity of the model and its prediction capabilities by applying them to another sample with the same material but different size and boundary conditions. Results show that the numerical failure prediction is consistent with the experiment, confirming the validity and reliability of the simulation model. REFERENCES [1] J. Ulloa, J. Wambacq, R. Alessi, E. Samaniego, G. Degrande, and S. Fran¸cois, A micromechanics-based variational phase-field model for fracture in geomaterials with brittle-tensile and compressive-ductile behavior. J. Mech. Phys. Solids, Vol. 159, pp. 104684, 2022. [2] N.E. Deresse, C. Van Steen, M. Sarem, S. Francois, and E. Verstrynge. Acoustic Emission analysis of fracture and size effect in cementitious mortars. Applied Sciences- Basel, 12(7):3489, 2022.

Fragile topology and corner modes in elastic self-dual kagome metamaterials

Pegah Azizi; University of Minnesota; United States
Siddhartha Sarkar; University of Michigan, Ann Arbor; United States
Kai Sun; University of Michigan, Ann Arbor; United States
Stefano Gonella; University of Minnesota; United States

Fragile topological states of matter lack certain protection attributes typically associated with topology and therefore exhibit relatively weak manifestations, whose strength is often dictated by the symmetry of the system and its boundaries. As a result, these states are typically elusive and not widely observed across a broad class of systems with different symmetries in phononics. Moreover, they are typically confined to special symmetry classes and, in general, rarely studied in the context of phononic media. In this work, we theoretically predict the emergence of fragile topological bands in the spectrum of a twisted kagome lattice in the so-called self-dual configuration, under the key assumption that the hinges are elastic finite-thickness ligaments that can store bending energy. The interplay between the edge modes appearing in the bandgaps bounding the fragile topological states is also responsible for the emergence of localized non-trivial corner modes at selected corners of a finite domain, which qualifies the lattice as a second-order topological insulator. We corroborate our findings through a series of experiments conducted on a physical prototype via 3D Scanning Laser Doppler Vibrometry.

Fragility assessment of bottom plate and shell of above ground storage tanks during flood events using finite element analysis

Md Manik Mia; Louisiana State University, Baton Rouge; United States
Sabarethinam Kameshwar; Louisiana State University, Baton Rouge; United States

The purpose of this study is to investigate the flood performance of bottom plate and shell in above ground storage tanks (ASTs) by developing fragility models. Specifically, material failure in the bottom plate and tank shell of ASTs was investigated. Due to economic and strategic reasons, these ASTs are often located in coastal regions which are susceptible to hurricanes. Consequently, above ground storage tanks have suffered significant damage during past hurricanes resulting in spills of hazardous chemicals into surrounding environment. Although, seismic and wind failure of ASTs were studied extensively, the literature is currently lacking the performance of ASTs during flood events. Besides, the design guidelines are deficient with regards to flood related failure of ASTs. The shell buckling of ASTs during hurricanes has been investigated by previous researchers, however, material failure of shell due to flood load is unknown. In addition, relative likelihood of material failure of bottom plate and tank shell has not been studied yet. To address these gaps, this study investigates material yielding and rupture failure of bottom plate and tank shell. Using Latin Hypercube Sampling (LHS), design parameters such as tank diameter, relative density and height of stored contents, yield strength, surge height and bottom plate thickness were sampled uniformly. In this study, finite element software LS – Dyna was used to investigate the response of above ground storage tanks during flood events. For each design parameter combinations, maximum stresses in bottom plate and tank shell were determined from finite element analysis and were compared against two different failure thresholds corresponding to material yielding and rupture. Step wise logistic regression was used in order to develop fragility models and applied to four case study tanks. The results revealed that bottom plate is more vulnerable in terms of material yielding and rupture and would fail first before tank shell during flood events.

Framework for Near-real-time Seismic Damage Detection of Structural Systems using Structural-mode-based Graph Neural Network

Minkyu Kim; Seoul National University; South Korea
Junho Song; Seoul National University; South Korea

Prompt identification of structural damage is essential for effective post-disaster responses. With the rapid development of sensing technology and data science, vibration-based methods have been mainly used for structural damage identification. However, most of these methods do not consider the spatial correlation between sensors, which is one of the essential damage-sensitive features. This paper proposes a near-real-time damage identification method based on a graph neural network (GNN) using the structural response data recorded during an earthquake event. The proposed method features a structural-mode-based weighted adjacency matrix to enable the GNN model to learn the spatial correlation and structural characteristics. The GNN model has an autoencoder architecture, one of the self-supervised deep neural networks that can detect anomalies in the input data by extracting important latent features. The proposed method consists of the following three main parts: (1) an 'encoder' that learns latent variables of input data considering the spatial correlation; (2) a 'graph structure decoder' representing structural characteristics of the graph by reconstructing the adjacency matrix; and (3) an 'feature decoder' that learns vibrational characteristics by reconstructing the response data. The GNN model is trained to reconstruct structural responses and the structural-mode-based adjacency matrix of the target structure in a healthy state. The seismic damage is then identified by the structural damage index calculated based on the reconstruction errors of input data, which can capture changes in spatio-temporal characteristics. As numerical investigations, the proposed method is applied to two- and three-dimensional steel frame structures. Structural analyses are performed using ground motions from the PEER-NGA strong motion database to create the train, validation, and test datasets. The proposed method is verified with the near-real-time simulation using the test dataset. The example demonstrates that the proposed GNN-based method performs accurate seismic damage identification in near-real-time. The proposed method is expected to help reduce the time required for the post-disaster decision-making process by providing near-real-time damage identification. The proposed framework will contribute to the future development of an effective post-disaster operational and maintenance strategy.

From Geo to Bio and back – Learning from Multiphysics processes in porous media to explore the evolution of branched biological networks

Nariman Mahabadi; University of Akron; United States
Benjamin Blonder; University of California, Berkeley; United States

Over billions of years of natural selection, nature has evolved complex and apt topologies to solve all sorts of problems. A conspicuous class of such topologies is the ramified heterogeneous structures in numerous biological systems such as the root and axis system of plants, leaf venation networks, and the cardiovascular system of animals and humans. The evolution and function of such branched structures is not only critical for their survival and fitness but also has fascinated and inspired engineers to tackle pressing grand challenges including climate change, extreme events, geohazards and energy recovery. This presentation discusses how our group is exploring the rules of life by adopting the fundamentals of Multiphysics coupled processes in porous media and geo-materials. As an example, we show the predictive capability of our computational framework to study the function, adaptation, and resilience of multifunctional leaf venation networks. A clear understanding of the evolution of these complex networks informs new and better tools and paradigms for geo-engineering applications including landfill leachate collection and multifunctional foundation systems.

From partial and limited structural health data to optimal management of engineering systems

Pablo G. Morato; University of Liege; Belgium
Charalampos P. Andriotis; Delft University of Technology; Netherlands
Konstantinos G. Papakonstantinou; The Pennsylvania State University; United States

Engineering systems are exposed to deterioration mechanisms and mechanical stressors throughout their service life, which lead to operational performance decline and increased failure risks. While the damage conditions can be quantified through engineering models, the resulting predictions normally contain significant uncertainties that hinder efficient decision-making. Benefiting from information collected through monitoring and/or inspections, such uncertainties can be effectively reduced. However, sensor installations and inspection visits are associated with significant and recurrent costs, as well as their own uncertainties, demanding, therefore, rigorous planning. This planning, aiming to determine the essential information content over the entire life of the system, cannot provide utmost benefits and be generally accomplished without jointly considering future maintenance and operational scenarios.

Addressing the aforementioned issues, we propose here an algorithmic framework for decision-making under uncertainty and imperfect structural health information, capable of maximizing the value of information in monitored engineering systems. Bayesian belief updates shape in real-time our probabilistic perception about the system states, through observations coming from sensors and inspectors, while maintenance actions alter the actual structural condition [1]. To deal with the complexity of solving this joint data collection and maintenance planning problem, with exponentially increasing dimensionality based on the state, action and observation set cardinalities, we rely on an actor-critic Deep Reinforcement Learning (DRL) approach. The actor prescribes optimal actions, including when, where, how, and what data to collect, whereas the critic is a life-cycle cost surrogate model predicting the long-term effects of these choices. Both the actor and critic are parametrized by deep networks, trained using an advantage function that steers policy gradients towards jointly maximizing the value of information and maintenance.

To demonstrate the effectiveness of the proposed approach, we apply the methodology to the case study of a wind farm management, in which the structural elements are subject to fatigue and the installed sensors degrade over time. Along with non-destructive inspections, information about the system is also obtained through suggested installation of strain gauges. The expected total costs of the identified DRL policies are compared with conventional strategies, offering considerable reduction of risks and maintenance costs, and verifying the successful applicability of the developed methodology in maximizing the information value of diverse monitoring and inspection data in large-scale structural system settings.

[1] Morato, P.G., Andriotis, C.P., Papakonstantinou, K.G. & Rigo, P. 2022. Inference and dynamic decision-making for deteriorating systems with probabilistic dependencies through Bayesian networks and deep reinforcement learning. arxiv 2209.01092.

FROM SMALL SCALE FRACTURE TESTS TO OPEN METROLOGY

Christos Athanasiou; Georgia Tech; United States

From Da Vinci to Galileo to modern experimentalists a variety of characterization methods have been introduced to investigate the fracture of materials. Although significant advancements took place over the years, determining the fracture properties of materials at small length scales is still extremely challenging mostly due to the need for advanced and expensive proprietary experimental equipment as well as sophisticated finite element methods. In this talk, we will introduce two breakthrough testing methods that bypass the above-mentioned challenges and allow for high-throughput, reproducible fracture testing at small scales. The first method involves light for contactless mechanical testing of multiple test specimens while avoiding defects introduced during specimen manipulation. The second method integrates experiments with data-driven approaches, enabling rapid deployment and reliable testing of materials with non-trivial shapes, thus overcoming the limitations of currently employed empirical solutions and finite element simulations. These methods enable open metrology approaches for multiscale testing, significantly expanding access to multiscale fracture tests with faster/better/cheaper tools. Such approaches and their potential in a range of critical applications - from environmental remediation to sustainable energy storage and space exploration – will be discussed.

Gait Speed Estimations Using the Change of Amplitude of Vibration Signals

Jean Michel Franco Lozada; University of South Carolina; United States
Yohanna MejiaCruz; University of South Carolina; United States
Juan M. Caicedo; University of South Carolina; United States
Zhaoshuo Jiang; San Francisco State University; United States

Structural vibrations have been widely used to gather information about structural systems to determine their dynamic characteristics and to evaluate their performance under dynamic loads. For example, engineers might monitor the vibrations of a bridge in response to heavy traffic to assess its stability and detect any potential problems.

The use of structural vibrations, however, has gained attention in recent research as a means to gain insights into the structure's occupants rather than the structure itself. This new approach has many potential applications that go from healthcare to security. In healthcare, for example, detecting and predicting falls and estimating gait parameters that can help identify underlying medical conditions.

This presentation discusses a new model that uses floor vibrations to estimate clinical markers such as walking speed. The model is designed to mimic the expected acceleration of a moving person and estimate the marker by performing a piecewise fitting from multiple acceleration signals. The estimations of the proposed model are compared to measurements taken from wireless body-mounted sensors commonly used to measure walking speed in clinical settings. Results from multiple trials of a person walking in a hallway instrumented with accelerometers will be discussed during the presentation.

Gaze informed path optimization of building inspection for automated damage diagnostics

Muhammad Rakeh Saleem; The Pennsylvania State University; United States
Rebecca Napolitano; The Pennsylvania State University; United States

The use of unmanned aerial vehicles (UAVs) for building inspection tasks requires users to understand flight patterns and their interaction with the environment, to detect potential damage for structure assessment and documentation, and to capture expert knowledge and train drones for informed decision making. While most UAV inspections are based on either pre-programmed flight paths or remote-controlled UAVs, each mode has its downside. To achieve autonomous inspections, a comprehensive end-to-end framework is proposed, incorporating both expert knowledge and decision-making. This work seeks to develop a methodology for efficient building inspection using eye tracking and optimized path planning for damage detection. To this end, experiments will be performed, and data will be collected for feature extraction and data fusion combining gaze data and the inspector's knowledge. This eye tracking information, correlating structural inspection with attention guidance, will be used for robot trajectory and path planning to see how they move efficiently between different structural components to identify and localize different damage. This method will facilitate information sharing and decision-making, minimizing disaster reconnaissance missions' overall time and cost.

General, unsupervised structural health monitoring based on generative adversarial networks

Mohammad Hesam Soleimani-Babakamali; Virginia Tech; United States
Ismini Lourentzou; Virginia Tech; United States
Korosh Nasrollahzadeh; K. N. Toosi University of Technology; United States
Rodrigo Sarlo; Virginia Tech; United States

This study proposes an unsupervised, online structural health monitoring framework general enough to be applied to a wide variety of structures and sensor configurations. The methodology leverages Generative Adversarial Networks (GAN) which train on data in real-time. Both the GAN's generator and discriminator networks are used. The discriminator network is the novelty detector, increasing its output when new sensor data deviates from that previously seen. The generator augments the initial data in order to tune the detection threshold for the discriminator output. The models are trained with the Fast Fourier Transform of structural accelerations as input, avoiding the need for any structure-specific feature extraction. Dense, Convolutional (CNN), and Long Short-term memory (LSTM) units are evaluated as discriminators under different GAN training loss patterns, i.e. the differences between discriminator and generator training losses. The framework is evaluated on two benchmark datasets. With only 100 seconds of training data, it achieved 95% novelty detection accuracy, distinguishing between different damage classes and identifying their resurgence under varying sensor configurations. Finally, the majority-vote-ensemble of discriminator-generator pairs at different training epochs is introduced to reduce false alarms, improve novelty detection accuracy and stability.

Geometric mechanics of random kirigami

Lauren Niu; Harvard University; United States
Gaurav Chaudhary; Harvard University; United States
Qing Han; University of Notre Dame; United States
Marta Lewicka; University of Pittsburgh; United States
Lakshminarayanan Mahadevan; Harvard University; United States

The presence of cuts in a thin planar sheet can dramatically alter its mechanical and geometrical response to loading, as the cuts allow the sheet to deform strongly in the third dimension. We use numerical experiments to characterize the geometric mechanics of kirigamized sheets as a function of the number, size and orientation of cuts. We show that the geometry of mechanically loaded sheets can be approximated as a composition of simple developable units: flats, cylinders, cones and compressed Elasticae. This geometric construction yields simple scaling laws for the mechanical response of the sheet in both the weak and strongly deformed limit. In the ultimately stretched limit, this further leads to a theorem on the nature and form of geodesics in an arbitrary kirigami pattern, consistent with observations and simulations. By varying the shape and size of the geodesic in a kirigamized sheet, we show that we can control the deployment trajectory of the sheet, and thence its functional properties as a robotic gripper or a soft light window. Overall our study of random kirigami sets the stage for controlling the shape and shielding the stresses in thin sheets using cuts.

Global Motions of a Floating Platform with Tuned Liquid Damper in Waves

Wen-Huai Tsao; Department of Civil and Environmental Engineering, Louisiana State University; United States
Ying-Chuan Chen; KBR; United States
Christopher Kees; Department of Civil and Environmental Engineering, Louisiana State University; United States
Lance Manuel; Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin; United States

A tuned liquid damper (TLD) can serve as an ecologically friendly and effective dynamic vibration absorber for offshore structures. The out-of-phase sloshing forces cancel the external excitations and then the kinetic energy of the structure can be dissipated through the fluid viscosity. The authors placed the porous media in a TLD to enhance its damping capacity. The optimal design for the roll mitigation of a freely floating platform was verified through the potential flow and Navier-Stokes flow models in our previous study [1]. This device is improved by adding a spring-dashpot subsystem underneath the TLD to further reduce the heave motion. The sway reduction of a moored structure will be also investigated. Different TLD systems are compared. Their interactions with the floating structure are analyzed. The hydrodynamic simulations are completed through a CFD-FEM toolkit Proteus. Proteus solves the multiphase Navier-Stokes equations and handles the free surface via the hybrid volume of fluid (VOF) - level set (LS) methods. The wave-structure interaction is solved by coupling Proteus and the multibody simulation engine Chrono. Both toolkits are open source and available in the public domain. The numerical evaluation shows that a properly designed TLD with porous media can effectively reduce the structural response in terms of vibration amplitude around resonance. Future application in floating wind turbines is presented.

Graph Neural Networks for Efficient Assessment of Transportation Network Response to Disasters

Tong Liu; University of Illinois at Urbana-Champaign; United States
Hadi Meidani; University of Illinois at Urbana-Champaign; United States

The already highly complex process of managing transportation networks greatly increases in an emergency. To prepare for and manage an emergency, it is critical to have addressed all four planning concerns: mitigation, preparedness, response, and recovery. This includes understanding the current infrastructure state, prioritizing an investment plan for improving resiliency, predicting future states in context of likely emergency scenarios, designing risk mitigation plans and establishing a communication capability for implementing risk mitigation plans. This effort must address risks associated with not only the network assets but also the emergent traffic dynamics that would likely ensue in context of the scenarios. To enable an efficient and accurate computational decision support, we propose a fast approach based on graph neural networks (GNN) to compute network response, in particular network connectivity and shortest distance measures, considering given different target nodes. We will show that the developed GNN is generalizable to various extreme events and even can be trained on one network, and be tested on another network. Networks from Bay Area, Manhattan and Florida are used and their responses to earthquakes and floods are studied.

Handling High-dimensional Data through Basis Reduction via Interactive Decomposition: Application to Smart Meter Big Data

Esmaeil Rezaei; University of Massachusetts Dartmouth; United States
Mohammad Pourghasemi Saghand; University of Massachusetts Dartmouth; United States
Yanlai Chen; University of Massachusetts Dartmouth; United States
Arghavan Louhghalam; University of Massachusetts Dartmouth; United States
Mazdak Tootkaboni; University of Massachusetts Dartmouth; United States

Available techniques for data dimension reduction rely heavily on computationally intensive matrix factorizations, such as Singular Value Decomposition (SVD) and as such quickly become intractable when dealing with massive datasets. In this work we present a new strategy that offers remarkable efficiency and an error indicator certifying the accuracy by which the properties of the original data are preserved. The proposed strategy draws upon the reduced basis decomposition and recent advancements in the Reduced Basis Methods (RBMs) which have garnered a lot of attention in recent years as efficient dimension reduction tools for solving parametrized partial differential equations. We propose to speed up the construction of the reduced basis by adopting the concept of "Reduced Residual" that enables measuring the error efficiently on a subset of dimensions proportional to the intrinsic dimension of the given data set and apply the proposed strategy to smart meter big data that is being used, increasingly, for accurate forecasting of electricity demand which is vital to developing resilient management strategies for energy systems.

Harnessing Carbon Sequestration to Manufacture Coral-Inspired Extremely Tough Materials

Haoxiang Deng; University of Southern California; United States
Yuyan Gao; University of Southern California; United States
Haixu Du; University of Southern California; United States
Ketian Li; University of Southern California; United States
Yanchu Zhang; University of Southern California; United States
Kyunghoon Lee; University of Southern California; United States
Qiming Wang; University of Southern California; United States

Concrete as traditional construction material accounts for at least 9 percent of all the world's CO2 emissions. However, in the marine world, stony corals fabricate calcium carbonate skeletons via biomineralization by consuming CO2 and carbonate ions in seawater, which inspires us a carbon-negative next-generation manufacturing method of construction materials. In this presentation, a novel electrochemical process is harnessed to mimic corals' biochemical processes to manufacture skeletons and their gorgeous hierarchical structures designed by species evolution. This presentation first manifests the hierarchical structures inside stony corals and the mechanism of the novel coral-inspired electrochemical manufacturing process compared with the biomineralization procedure of corals. Then, it shows the performance of the coral-inspired carbon-negative material. Later, we applied such electrochemical manufacturing to mimic the microstructures of the septum of corals. Besides, the structures with coral-inspired microstructures are compared with state-of-the-art counterparts to show their advanced mechanical properties. Finally, the scaling-up method will be demonstrated.

Harnessing microorganisms to manufacture engineered living materials with environmentally friendly, low-cost, mechanically strong, and fire-resistant performance

Yuyan Gao; Department of Civil and Environmental Engineering, University of Southern California; United States
Audie Lee; Department of Civil and Environmental Engineering, University of Southern California; United States
Qiming Wang; Department of Civil and Environmental Engineering, University of Southern California; United States

Seeking environmentally friendly, low-cost, scalable approach for strong and safe building material is a long-term goal of human beings. Recently, prefabricated houses have become popular because of their low price, flexible design, and fast building time. However, traditional materials used during construction like wood and cement are not eco-friendly materials. Biomineralization of calcium phosphate (CaCO3) from nature is an environmentally friendly, energy-saving, low-cost, and scalable fabrication approach. Here we present a predesigned, bacteria-assisted biomineralization of CaCO3 to build the structure from soft Polyurethane (PU) sponges. We use the liquid PU precursors to build the shape of the sponge by casting mold and then the porous sponge is immersed into the bacteria-assisted CaCO3 growth medium. The CaCO3 will gradually fill the porous sponge and the material becomes mechanically strong. Mechanical performance, thermal transfer performance, and fire-resistant performance are tested, and it shows the overall excellent performance of the biomineralized structure. A phase-field modeling of the CaCO3 growth process also verifies the enhanced mechanical properties. This approach has the potential as a new fabrication method for eco-friendly engineered living materials and can be widely used in the construction industry.

Healable Magneto-elastic Networks from Self-assembly with Tunable Network Patterns and Mechanical Properties

Xinyan Yang; Northwestern University; United States
Junqing Leng; Northwestern University; United States
Cheng Sun; Northwestern University; United States
Sinan Keten; Northwestern University; United States

Magneto-active soft materials show significant potential in the applications of soft robotics, control systems, and waveguides due to their programmable shapes, adaptive stiffness, and tunable strength, arising from magnetic-elastic coupling. Magneto-elastic networks coming from this composite design have been fabricated by 3D printing and laser cutting techniques as a monolithic body. These architected network materials offer great energy dissipation capacity per weight under impact but the damage incurred is permanent. To overcome this, a novel magneto-elastic network that can be self-assembled from elastic elements decorated with permanent magnets under random vibrations is proposed in this work. The magneto-elastic unit configuration is shown to dictate the assembled network topology. The design criteria for those units to form mechanically robust networks are derived based on computer simulations, energetic analyses, and experimental validation. Once subjected to large conformational changes or fracturing into pieces in extreme environments, these magneto-elastic lattices can self-heal to their original functional structure by first resetting to the ground state and then reassembling. The self-assembly and self-healing properties enable them to be fabricated and repaired on-the-fly. This work combines concepts from magnetic handshake materials and thermalized granular systems with elastic network designs to understand the self-assembly, elasticity, and failure mechanisms of elastic bar elements with sticky magnetic ends. The presented work will broaden the engineering applications of magneto-elastic soft materials in the field of fatigue-free reusable protective materials and actuators.

Heat and mass transfer analysis for nanofluid flows in a channel

Gabriella Bognar; University of Miskolc; Hungary

Numerical study of laminar flow in a micro-sized backward-facing step channel for water-based nanofluids containing Al2O3 and TiO2 nanoparticles is presented and the impact of the temperature differences between the inlet and the downward wall temperatures is investigated. We introduce a temperature-dependent separation flow model. The velocity increases with increasing concentration of nanoparticles. However, when comparing Al2O3 and TiO2 nanofluids, Al2O3 has a velocity and shear stress higher than TiO2 for 0.04 volume fraction. Increasing the volume fraction of nanofluid led to an increase in the rate of heat transfer from the wall to the fluid, as the thermal properties improved as the volume ratio increased. The performance efficiency index (PEI) decreases as the volume fraction of the particle increases after a certain amount of nanoparticles. The simulation results of the nanofluid separation flow in the recirculation and reattachment shows that the velocity increases as the temperature difference increases, the size of the primary and secondary recirculation regions behind the step is significantly influenced with the temperature difference, a larger temperature difference means a larger recirculation zone.

Heterogenous Sensor Placement Under Uncertainty Considering Sensor Failure

Amin Jabini; University of Southern California; United States
Erik Johnson; University of Southern California; United States

This study presents a sensor placement optimization method using deep reinforcement learning (RL) that considers sensor failure and system parameter uncertainty. The sensor placement problem is a well-established combinatorial optimization problem, characterized by inherent uncertainties in parameters affecting system response sensor measurements. These uncertainties render deterministic solutions insufficient and necessitate a computationally tractable approach for accounting for them. The proposed method incorporates a Markov Decision Process (MDP) as a stochastic environment, and a sensor placement agent trained using DRL. The agent's objective is to maximize the effectiveness of sensor placement within a system by selecting sensor types and locations. The agent's sequential decision-making is guided by a reward function that is specifically designed based on the observability Gramian, calculated using sampled parameter values from a priori distributions, and the probability of failure of each sensor type, accounting for sensor quality. In each episode, the agent repeats the sensor placement process until a certain number of sensors, determined by the budget, is reached. The agent updates its policy model through experience data collected from interacting with the environment until an optimal policy is achieved. The proposed approach is validated through simulation of a case study involving heterogeneous sensors in a shear building model. The methodology can be applied in real-world scenarios to address uncertainties in sensor placement optimization.

Hidden environmental footprint of roadway network: when mechanistic models meet data analytics

Mazdak Tootkaboni; UMass Dartmouth; United States
Meshkat Botshekan; MIT; United States
Franz Ulm; MIT; United States
Arghavan Louhghalam; UMass Dartmouth; United States

We propose a framework where we move beyond empirical measures of sustainability and introduce a truly mechanistic view of road-condition induced energy dissipation and excess fuel consumption. Random vibration theory, vehicle dynamics, Bayesian inverse analysis, asymptotic methods and crowdsourced telematics data are brought together to monitor road surface conditions and provide a physics-consistent examination of sustainability performance and environmental footprint of transportation infrastructure.

Hierarchical Bayesian Approach for Electromechanical Properties Updating in Piezoelectric Energy Harvesters

Rafael Ruiz; University of Michigan-Dearborn; United States
Alejandro Poblete; Universidad de Chile; Chile
Gaofeng Jia; Colorado State University; United States

In the last decade, the use of piezoelectric materials for energy harvesting applications has presented a significant increase. The piezoelectric energy harvesters (PEHs), typically consist of a cantilevered beam composed of piezoelectric layers. Energy harvesting is accomplished by locating the devices in vibratory environments, which causes the oscillatory deformation of the beam. In this way, the piezoelectric layers generate an electric charge when deformed. Multiple and diverse models have been developed to describe and predict PEH's electromechanical behavior. Despite the high development of models, mismatches with experimental observations are detected in practical applications, mainly caused by uncertainties introduced in the manufacturing process. The Bayesian inference framework, grounded on the probability theory, is a powerful tool for dealing with uncertainties in engineering systems modeling. It provides methods for model parameter identification utilizing the classical Bayes theorem, in which prior information on the parameters and experimental data are employed. Thus, model parameters are identified as probability density functions, conditioned on experimental data. This process leads to a posterior understanding of the parameters, ultimately allowing a robust predictive analysis. Two schemes of the Bayesian inference framework for parameter identification are explored in this work. The first one corresponds to the classical scheme, while the second corresponds to a hierarchical approach. For multiple experiments, though, adopting a classical scheme may lead to a wrong account of parameter uncertainties. It has been observed that under different kinds of uncertainties, the classical scheme critically underestimates them. This is not attributable to the Bayesian methodology itself but to an improper formulation of the probabilistic model. In this sense, a new hierarchical approach is proposed. The hierarchical Bayesian model is an extension of classical Bayesian modeling, where an extra level of parameters, called hyperparameters, introduces the hierarchy: they are used to parametrize prior distributions, adding a new information dependency in the model formulation. The results demonstrate the hierarchical Bayesian scheme's capability to properly identify model parameter uncertainties across multiple harvesters, leading to reasonable robust predictions and allowing the characterization of uncertainties coming from the manufacturing process.

High Fidelity Modeling of Fracture Under Extreme Hydrodynamic Events: A Coupled SPH-Phase-Field FSI Approach

Mohammad Naqib Rahimi; Stony Brook University; United States
Georgios Moutsanidis; Stony Brook University; United States

Coastal structures and regions are continuously exposed to coastal floods, tsunamis, and storms. The effects of these extreme hydrodynamic events on structures have been increasing due to the rapid climate change, and their impact on coastal communities can be devastating, ranging from costly and severe property damage to human losses. Computational modeling of such events through physics-based simulations, and the ability to predict their effect on coastal structures, is an important tool in increasing climate resilience of coastal communities. However, in the development of such models special care should be taken in order to handle certain challenges such as free-surface flows, large structural deformations, and material separation. This work focuses on the development of a particle-based non-local approach for modeling structural fracture and fragmentation in fluid-structure interaction (FSI) scenarios of extreme hydrodynamic events. We employ the Smoothed Particle Hydrodynamics approach for the discretization of both fluid and structural domains. The framework is supplemented with a hyperbolic phase field model of brittle fracture that allows for the realistic modeling of crack nucleation, propagation and branching. Furthermore, a novel FSI coupling algorithm that increases the accuracy of the approach is presented. The proposed approach is verified and validated, and a few challenging problems are presented demonstrating its capabilities.

High-dimensional symbolic regression via neural feature polynomials for interpretable machine learning plasticity

Bahador Bahmani; Columbia University; United States
Hyoung Suk Suh; Columbia University; United States
WaiChing Sun; Columbia University; United States

This paper introduces a new approach that combines the strengths of the expressivity of deep neural networks and the interpretability and portability of the mathematical expression determined by symbolic regressions to formulate plasticity models that can precisely capture the plastic behaviors of solids. By introducing neural network architectures that generate feature space and aggregate those data in a polynomial form, we enable the yield function to be determined analytically. By comparing with the benchmark state-of-the-art algorithms, the proposed method is capable of delivering more robust and accurate predictions, while the divide-and-conquer approach significantly improves the computational efficiency, especially for high-dimensional models aimed to capture material behaviors that lack material symmetry, exhibit size-dependent effect or complex hardening/softening mechanisms. By leveraging the portability of symbolic regression, the resultant models can be easily deployed to third-party software such as UMAT in ABAQUS. Extensions of the proposed approach for inverse problems and materials design in feature space will also be discussed.

High-fidelity Seismic-induced Failure Mode Prediction for RC Bridge Columns Using Generative Adversarial Networks

Ting-Yan Wu; Department of Civil Engineering, National Taiwan University; Taiwan
Rih-Teng Wu; Department of Civil Engineering, National Taiwan University; Taiwan
Ping-Hsiung Wang; Department of Civil Engineering, National Taipei University of Technology; Taiwan
Tzu-Kang Lin; Department of Civil Engineering, National Yang Ming Chiao Tung University; Taiwan
Kuo-Chun Chang; Department of Civil Engineering, National Taiwan University; Taiwan

Surface damage of reinforced concrete (RC) bridge columns are essential indicator to evaluate the performance level of the bridges. To assess the potential failure modes subjected to earthquakes, laboratory experiments or in-situ tests are often conducted to understand the damage status under different loading scenarios. However, such experimental works are quite expensive, time-consuming and labor-intensive. In this study, a novel framework based on conditional generative adversarial network (cGAN) is proposed to forecast the failure mode of RC bridge columns in a high-fidelity manner. By integrating the information of the column design parameters as well as the user-desirable performance level, i.e., Damage Index (DI) of the column, the proposed framework is able to predict the surface damage patterns of RC bridge columns with merely 110 training images collected from experimental cyclic loading test conducted at National Center for Research on Earthquake Engineering (NCREE) in Taiwan. Two network architectures and three label encoding strategies are explored to investigate the performance in forecasting the damage patterns. Compared to the vanilla cGAN, the proposed network incorporates classifiers and regressors into the discriminator, and the corresponding Frechet Inception Distance (FID) score is enhanced by 38% when generating the synthetic patterns. By embedding DI as a numerical label, the network is able to predict the unseen damage patterns using damage indices not available in the training dataset. Promising results have demonstrated that the proposed approach is capable of synthesizing decent failure patterns under user-defined performance levels and column design parameters, and therefore providing a platform for bridge engineers to evaluate the potential failure modes during seismic design and retrofit.

Hindcasting Residential Building Damage and Predicting Recovery for the Mayfield, Kentucky December 2021 Tornado

Wanting (Lisa) Wang; Department of Civil and Environmental Engineering, Colorado State University; United States
John W. van de Lindt; Department of Civil and Environmental Engineering, Colorado State University; United States
P. Shane Crawford; Federal Emergency Management Agency; United States
Blythe Johnston; Department of Civil and Environmental Engineering, Colorado State University; United States
Guirong Yan; Department of Civil, Architectural and Environmental Engineering, Missouri University of Science and Technology; United States

From December 10 to December 11, 2021, a deadly tornado outbreak struck across several states in the United States, including Arkansas, Illinois, Kentucky, and Tennessee. The tornado outbreak resulted in at least U.S. $3.9 billion in damage, more than 90 fatalities, and hundreds of injuries. Mayfield, Kentucky, a small city was hit by a long-track tornado rated as an Enhanced Fujita 4 (EF4) scale, and was one of the communities most heavily damaged during the tornado outbreak. The NIST-funded Center for Risk-Based Community Resilience Planning, headquartered at Colorado State University in Fort Collins, Colorado, developed a multi-disciplinary computational environment, called the Interdependent Networked Community Resilience Modeling Environment (IN-CORE). This open-source computational environment is designed to integrate physical infrastructure with socio-economic systems and perform community resilience assessments affected by various natural hazards. Following the tornado event, an analysis was performed for the City of Mayfield to provide information on improved residential building codes. Specifically, the IN-CORE modeling environment was used to (approximately) hindcast the community-level building damage and forecast the community-level building recovery in Mayfield for residential buildings using the idealized EF4 tornado scenario. In addition, considering the uncertain intensity and frequency of tornado events, a series of EF0-EF5 scenarios were simulated based on the actual tornado centerline to capture how a different building code or mitigation strategy would have enhanced community resilience at different levels. In this presentation, the accuracy of this hindcast will be examined, the methodology discussed, and the prediction for Mayfield's residential recovery will be provided.

Holistic inverse design of origami using interpretable machine learning

Yi Zhu; University of Michigan; United States
Evgueni Filipov; University of Michigan; United States

Origami principles provide novel methods to build engineering systems for applications in soft robotics, programmable metamaterials, reconfigurable structures, and more. Despite the many advancements and emerging applications of origami in engineering, designing origami structures remains a challenging task. This talk presents an origami inverse design approach, where an origami feature-performance database is first populated then analyzed using interpretable machine learning. We show that the decision tree-random forest machine learning method is particularly suitable for fitting origami databases to enable a holistic inverse design for these complex systems. More specifically, we developed a method to identify representative tree branches from a trained random forest to provide informative inverse design rules. This method can handle categorical features for comparing and selecting better origami patterns and can solve multi-objective problems for designing functional origami with multi-physical behaviors. Furthermore, our methodology can be integrated with existing algorithms to simultaneously achieve shape fitting and design for non-geometrical performance. The proposed framework enables holistic inverse design, considering both shape and function, to create origami structures that achieve superior performance for various engineering applications.

Homogeneous lattice modes of Miura-ori tessellations with voids

Anandaroop Lahiri; Indian Institute of Technology madras; India
Phanisri Pradeep Pratapa; Indian Institute of Technology Madras; India

Elastic modes of origami lattices are of scientific value in the context of metamaterial applications. Miura-ori is a well-studied origami pattern, especially in engineering. A deeper understanding of spatially homogeneous deformations can be useful to homogenisation-based material characterisation. Miura-ori with rigid parallelogram panels deforms exclusively through crease-folding with a single degree of freedom (DOF). Substituting parallelograms with rigid triangular panels introduces two additional DOFs per vertex. Despite the additional DOFs resulting from triangulation, research has shown that the two-dimensional (2D) lattice of rigid triangulated Miura-ori (RTM) exhibits only three homogeneous modes. We propose a formulation where the DOFs are represented in terms of folding-angles, which we henceforth refer to as the folding-angle-framework (FAF). Within this framework, a compatibility-matrix approach can be used to model the kinematics of rigid-panel origami such as RTM tessellations. We study a special class of 2D lattices with interconnected RTM strips, which results in an origami tessellation with voids. Unlike the 2D RTM lattice without voids, we find that for the origami lattices with voids, the compatibility constraints based on the crease folding-angles alone are insufficient to capture the admissible deformation modes. Additional loop-closure constraints, based on Denavit-Hartenberg analysis of spatial linkages, must be imposed on creases around each enclosed void. Homogeneous deformations can be classified based on relative displacements between corresponding nodes of adjacent unit-cells. One set of modes is characterized by zero relative-displacements of nodes despite non-zero crease folding-angle perturbations within each unit-cell. The remaining modes are characterized by non-zero relative displacements between corresponding nodes of adjacent unit-cells, resulting in accumulated deformations across the lattice. We observe that such deformations are exclusive to the space of Bloch-wave modes within the folding-angle framework and are not straightforwardly obtained using a bar-and-hinge framework of modelling origami lattices. The novel 2D lattices, irrespective of the size and aspect ratio of enclosed voids, exhibit exactly six such exclusive FAF modes which can be further characterized using intuitively defined relations between crease-perturbations.

Homogenization model for layered media: the coupling effect of bedding direction and mineral fabric

Tingting Xu; Johns Hopkins University; United States
Chloé Arson; Georgia Institute of Technology; United States

We present a new homogenization model to study the elastoplastic damage behavior of layered media. We focus on the coupling effect of the mineral fabric direction and the bedding layer direction. The macroscopic constitutive law is derived by performing a two-step homogenization.

We consider a heterogeneous layered medium exhibiting a periodic structure. Intrinsic anisotropy comes from the direction of the bedding, the texture of minerals, and the presence of microfractures. Mineral texture is characterized by the shapes and orientations of the mineral inclusions in each individual layer of the bedding. Considering different types of mineral and ellipsoidal voids, the self-consistent homogenization is employed to obtain the stiffness of the equivalent homogenized layer. Microfracture propagation is modeled as interfacial debonding between mineral inclusions and the Homogenized Equivalent Medium (HEM). A numerical integration is adopted to calculate the Eshelby's tensor of the ellipsoidal inclusions embedded in the anisotropic HEM.

Secondly, based on the homogenized properties of the layer, we consider a laminated composite with imperfect inter-layer interfaces that can exhibit normal and shear displacement jumps. The weak cohesion of the bedding planes is characterized by a nonlinear cohesive law, which depends on the interface cohesive strength, hardening modulus, and softening modulus. An analytical derivation of the effective properties is proposed for general layered media based on the Asymptotic Homogenization Method (AHM).

Lastly, the two-step homogenization procedure is applied to additively manufactured gypsum. We perform a set of numerical simulations to examine the influence of the relative orientation between mineral fabric, layering, and stress direction. The model can capture intrinsic and stress-induced anisotropy.

Horizontal flow bioreactor for mimicking the migration of late-stage prostate cancer cells to bone

Sharad Jaswandkar; North Dakota State University; United States
Haneesh Jasuja; North Dakota State University; United States
Kalpana Katti; North Dakota State University; United States
Dinesh Katti; North Dakota State University; United States

Prostate cancer bone metastasis is the leading cause of cancer-related mortality in men in the United States. The main consequence of cancer bone metastasis is the underlying severe damage to skeletal tissue. Unfortunately, due to the inadequate understanding of the mechanism of interstitial fluid flow on prostate cancer cell growth and migration, the treatment of advanced-stage prostate cancer has been mainly ineffective. As a result, drug treatment options are limited, resulting in low survival rates among individuals. In the present work, we have designed a unique bioreactor system to precisely recapitulate the effect of interstitial fluid flow on the migration of late-stage prostate cancer. First, we established the influence of a high flow rate on cell growth. PC3-type prostate cancer cells experienced decreased DNA content from increased flow rate. Furthermore, we revealed that PC3 cells underwent apoptosis when a high flow rate was introduced. Lastly, gene expression and western blot experiments showed that PC3 cells undergo apoptosis via activation of TGF-β1. The migration rate of prostate cancer cells in the presence and absence of bone was evaluated to understand further the role of interstitial fluid flow on prostate cancer tumor formation at the bone site. We observed that CXCR4 levels did not change in the presence of interstitial flow. However, it was determined that bone upregulated CXCR4 levels, leading to increased MMP-9 levels. Additionally, both αVβ3 integrins and MMP-9 levels were upregulated under fluid-flow conditions, contributing to an increased migration rate. In the present study, we evaluated the effect of fluid flow conditions on prostate cancer cell growth. We also investigated the effect of physiological fluid velocity on the migration rate of PC3 cells. Our findings suggest that interstitial flow-induced shear stress may be a critical factor in regulating the migration of prostate cancer cells. It is well known that fluid-flow shear stress determines cell behavior in regulating tumor biology. Therefore, findings from the present work can aid in controlling tumor progression and developing new inhibitors or therapies. In addition, the novel bioreactor we developed could be utilized to understand the future growth and migration of different cancer types at tissue-engineered secondary sites.

How can graph neural networks help in the analysis and design of structures

*Kai Guo; Institute of High Performance Computing, A*STAR; Singapore*

Recent advances in graph neural networks (GNNs) have demonstrated improved performance on node-level or graph-level, supervised or semi-supervised, classification or regression tasks, and these GNNs models are applicable to the design problems of many structures that can be represented by graphs. Here, we will present a semi-supervised approach based on GNNs to design truss-like structures by knowing the mechanical responses of only a small number of nodes, along with the connectivity and mechanical properties of the structures, instead of explicitly knowing the boundary and loading conditions. We will also show a GNN model that can fast predict the natural frequencies of proteins from primary amino acid sequences and contact or distance maps, leading to an end-to-end protein frequency prediction tool with an existing contact/distance map prediction model combined

How Does Chemical Makeup of Recycling Agents and Antioxidants Affect the Long-Term Performance of Recycled Asphalt Binder Blends?

Hamzeh Haghshenas; Asphalt Binder and Mixture Lab Manager, SES group & Associates LLC, Turner-Fairbank Highway Research Center, Federal Highway Administration (FHWA); United States

David Mensching; Asphalt Materials Research Program Manager, Turner-Fairbank Highway Research Center, Federal Highway Administration (FHWA); United States

Michael Elwardany; Assistant Professor, Civil & Environmental Engineering, FAMU-FSU College of Engineering, Florida State University; United States

Panos Apostolidis; Research associate, Civil Engineering and Geosciences, Delft University of Technology; Netherlands

The chemical characteristics of asphalt binders dictate their rheological performance. The aim of this study is to investigate the effect of chemical makeup of Recycling Agents (RAs) and antioxidants on the long-term performance of recycled asphalt binder blends. To this end, three different RAs; an aromatic extract oil, a naphthenic oil, and a vegetable oil; were selected, and their chemical properties were characterized by employing saturate, aromatic, resin, and asphaltene analysis, Fourier-transform infrared spectroscopy, and elemental analysis. Then a control recycled blend was made from 35% virgin asphalt binder and 65% laboratory-prepared recycled asphalt binder and was modified by the RAs. The RA-modified blends and the control recycled blend were investigated under each of four different conditions: no aging, standard aging, extended aging, and severe aging to examine their long-term performance. A Bending Beam Rheometer (BBR) and a Dynamic Shear Rheometer (DSR) were used to determine the resistance of binders to cracking at low- and mid-range temperatures, respectively. The results indicated that the binders modified with vegetable oil that contains carbonyl, hydroxyl, and sulfonyl groups did not comply with the low-temperature cracking criterion (m-value) after the extended aging condition. Binders with naphthenic oil, which has a high saturates content, showed the poorest long-term performance based on DSR and BBR test results. In contrast, the cracking performance of the binders with aromatic oil was superior at both low- and mid-range temperatures, even after the extended aging condition. Finally, to improve the long-term performance of binders with naphthenic and vegetable oils, their synergy with an antioxidant (i.e., zinc diethyldithiocarbamate: ZnDEC) was examined. The results showed that the efficacy of these RAs was improved with the addition of ZnDEC; however, the efficacy of the ZnDEC varied depending on the RA used which require further investigation.

How fracture properties of sediments influences bioturbation: A discrete numerical approach

Xuejing Wang; University of Massachusetts Dartmouth; United States
Sanjay Arwade; University of Massachusetts Amherst; United States
Kelly Dorgan; University of South Alabama; United States
Arghavan Louhghalam; University of Massachusetts Dartmouth; United States

Bioturbation is an essential process by which ecosystem engineers, such as worms and other macrofaunal invertebrates, modify their habitats by mixing sediment grains and other particles. Researchers discovered that the abundance and activity of bioturbators are critical factors to bioturbation rates after conducting extensive investigations on a variety of species-related contribution factors, including type of communities, functional roles, activities, and size of species; however, how the mechanical properties of sediments contribute to bioturbation and thus impact the bioturbator has not been well explored. Recent computational model-based studies of bioturbations in sediments with varying fracture toughness have postulated that fracture toughness and its variability can be important determinants of sediment crack propagation and branching. However, existing studies have used numerical tools that cannot model fracture propagation, thus is not able to examine branching and scattering of microcracks in sediments with high levels of heterogeneities. Here we utilize a discrete modeling approach to examine the impact of mechanical characteristics of heterogenous sediments on the characteristics of bioturbation. To this end, we examine sediments with variable fracture toughness, while assuming constant elastic modulus for the entire domain. We generate random fields according to Weibull distribution of different mean values and Coefficients of Variations (CoV) for the fracture toughness. The samples, subject to burrowing pressure, are analyzed via the hybrid energy-based lattice element method (LEM), which is shown to effectively model fracture and crack propagation in heterogeneous materials [1]. The results of our analysis suggest that increasing the CoV of fracture toughness leads to more scattered microcracks over the entire domain, with its impact being more significant for domains with lower toughness. We also observe that the spatial gradient of sediment fracture toughness plays a significant role in branching of cracks at the burrower's tip. Finally, we examine how the way infauna loads the sediment can impact the formation of microcracks, crack branching, and crack steering.

[1] Wang, X., Botshekan, M., Ulm, F.-J., Tootkaboni, M., & Louhghalam, A. (2021). A hybrid potential of mean force approach for simulation of fracture in heterogeneous media. Computer Methods in Applied Mechanics and Engineering, 386, 114084. doi:10.1016/j.cma.2021.114084

How well do we really know the b-value? New estimates of earthquake magnitude for the Delaware Basin and the effect of magnitude uncertainty on induced seismic hazard estimates.

Sydney Gable; University of Michigan; United States
Yihe Huang; University of Michigan; United States
David Shelly; United States Geological Survey; United States

The Delaware Basin, a subset of the greater Permian Basin located in western Texas and southeastern New Mexico, is currently a hotbed of induced seismic activity where the frequency of relatively large magnitude events (M > 4) has been increasing over the last ~5 years including a magnitude 5.4 event in November of 2022. Since large, induced events are quite infrequent, our understanding of seismic hazard, recurrence intervals, and magnitude exceedance for these earthquakes is heavily dependent on a thorough understanding of the magnitude frequency distribution (MFD) and source parameters of numerous small events in the same region. However, magnitude estimates for small earthquakes are often inconsistently measured or simply not available for certain magnitude types. This project aims to both produce updated estimates of earthquake magnitudes for the Delaware Basin region, paying particular attention to how scaling relationships may change for small and large earthquakes, and to understand the effects of magnitude uncertainty on estimates of MFD and seismic hazard for induced earthquakes. We re-estimate magnitude for events in the Delaware Basin using a relative magnitude method calibrated with coda-envelope-based moment magnitudes developed for the Permian Basin. We also investigate the temporal and spatial variations in MFD and b-value using these updated magnitudes. Previously, we have found that for recent events in western Texas, the use of new relative coda magnitudes yields a decrease in b-value during the 1.5 years between January 2021 and June 2022 signaling a greater proportion of large events in the region than what would have been calculated using originally cataloged magnitudes. We extend this analysis to include events prior to 2021 and events located in southeast New Mexico to facilitate a better understanding of induced seismic hazard in this region.

Human-disaster interfaces enabled by Low-cost Efficient Wireless Intelligent Sensors (LEWIS)

Fernando Moreu; University of New Mexico; United States
Ali Khorasani; University of New Mexico; United States
Kaveh Malek; University of New Mexico; United States

This presentation summarizes the work developing low-cost sensors to monitor post wildfire flooding events with sonar and rain sensors. The authors worked with the Pueblo of Ohkay Owingeh in the co-design of sensors to inform the threshold values after fires to better prioritize decisions in the field. The platform is named Low-cost Efficient Wireless Intelligent Sensor (LEWIS) and the system was optimized to collect information in remote locations enabled with off-the grid energy with solar and battery power. The sensor networks were connected with a hot-spot that is showing the data in a server for users. Examples of alarm systems as well as interactions with owners to inform on the optimization of the messages is discussed. The future deployment in remote locations as well as data processing for error correction on rain data is discussed, as well as its validation.

Hybrid Origami Patterns

Kevin T. Liu; Department of Civil and Environmental Engineering, Princeton University; United States
Glaucio H. Paulino; Department of Civil and Environmental Engineering, Princeton University; United States

Origami provides a method to transform a flat surface into complex three dimensional geometry, which has applications in deployable structures, material science, robotics, and more. The Miura-Ori and the Eggbox are two basic planar origami patterns consisting of tessellated congruent quadrilaterals that have been used frequently in origami engineering. Both patterns have been studied closely, and derivative origami patterns have been developed based on them. Here we study the hybrid structure formed by combining unit cells of the Miura-Ori and Eggbox patterns. We find the compatibility constraints required to form the hybrid structure and derive properties of its kinematics such as Poisson ratio and locked states. We then compare the Miura-Eggbox Hybrid with the Morph pattern, another generalization of the Miura-Ori and Eggbox patterns. Such hybrid patterns have tunable properties, which can impact engineering applications.

HYBRID RANS-LES SIMULATION OF TURBULENT HEAT TRANSFER IN A BACKWARD-FACING STEP FLOW

Olalekan Olubunmi Shobayo; School of Engineering, Liberty University, VA; United States
Dibbon Keith Walters; Mechanical Engineering, University of Arkansas; United States
Samuel Ruegsegger; School of Engineering, Liberty University, VA; United States

ABSTRACT Computational fluid dynamics (CFD) results for turbulent flow and heat transfer in a backward-facing step (BFS) are presented. This study investigates an inflow of fully developed turbulent fluid for BFS case involving significant heat transfer, complex physics including turbulent separation, reattachment, of boundary layer (BL) in the presence of a strong adverse pressure gradient. Several previous studies have established that conventional turbulence modeling methods, such as the Reynolds averaged Navier–Stokes (RANS) approach, have proved to be generally inadequate in predicting the effects of turbulent separating and reattaching flows with heat transfer. The objective of this study is to evaluate turbulent heat flux predictions in streamwise and wall-normal directions using three different classes of modeling approach: Reynolds-averaged Navier-Stokes (RANS), large-eddy simulation (LES), and hybrid RANS-LES. Uniform heat flux is applied to upstream viscous wall to evaluate models' heat flux predictions and the effects of increasing wall heat flux in separated BL. Results are interrogated at a Reynolds number of 5540 (based on the step height and upstream centerline velocity) and a Mach number of 0.006. Specific models considered are k-w SST RANS model, monotonically integrated LES (MILES), improved delayed detached eddy simulation (IDDES), and dynamic hybrid RANS-LES (DHRL). The DHRL model includes both the standard and modified formulation that has been previously documented in the literature.

Hybrid Simulation with Combined Displacement and Force Based Experimental Control Points

Claudio Sepulveda; UC San Diego; United States
Gilberto Mosqueda; UC San Diego; United States
Chia-Ming Uang; UC San Diego; United States
Chung-Che Chou; NCREE; Taiwan
Kung-Juin Wang; NCREE; Taiwan

Hybrid simulation solves the dynamic response of a combined numerical and experimental model most commonly using displacement-based numerical time-integration schemes. In this approach, the experimental substructure is treated as an element of the numerical model with boundary conditions imposed through an actuation system commanded at every time-step. While displacement-controlled actuators can accurately impose deformations at most boundary degrees of freedom (DOF), controlling stiff DOF such as the axial DOF in columns can be challenging. Force-controlled actuators are a suitable option for stiff DOF though they require a custom implementation to generate the force command and return the measured displacement as feedback. Past implementations of force-controlled actuators in hybrid tests have ignored the displacement feedback and thus neglecting displacement compatibility at the boundary between the numerical and experimental substructures. In order to examine the seismic response of steel moment frame structures where column shortening can be significant, a new framework is proposed using mixed displacement and force control mode for hybrid simulation. The method is applied within the OpenSees structural analysis platform and uses a displacement-to-force control points applied through concepts of linear control theory to reduce errors. The framework is first assessed through virtual hybrid simulation and then applied in an actual hybrid simulation with a full-scale steel moment frame subassembly. Due to its high stiffness, the column axial degree of freedom was driven in force-control, while the lateral DOF were in displacement-control. The column had significant axial shortening due to local buckling, which was measured and used to impose an equivalent force on the numerical model to satisfy displacement compatibility between the corresponding numerical and experimental DOF at the boundary.

Identification of Fractional Dynamical Systems using Recursive Nonlinear Stochastic Filtering Methods

Kalil Erazo; Rice University; United States
Alberto Di Matteo; University of Palermo; Italy

System identification (SI) is the inverse problem of using measurements of the response of a system to infer the parameters that define its mathematical models. The objective is to optimize the predicting capability of a model by minimizing (in some sense) modeling uncertainty and modeling errors. In structural mechanics, applications of system identification include structural condition/damage assessment and prediction, improvement of design methods, and structural control. Efforts in SI have traditionally focused on its implementation in linear and nonlinear systems. In this study we discuss the application of a class of time-domain recursive system identification methods in the context of structural systems comprising fractional derivative elements. In contrast to classical linear systems, where stiffness and damping are independent structural characteristics, fractional-order elements influence both stiffness and damping simultaneously, which allows to model the response and behavior of a broader class of dynamical systems.

In this work we study the effectiveness of recursive nonlinear filtering parameter estimation methods in the identification of structural fractional systems. We study the advantages and limitations of four methods: the extended, unscented, and ensemble Kalman filters, and the particle filter. The analyses are performed under different conditions including various measurement noise levels, known and uncertain inputs (input-output and output-only implementations), different types of inputs (earthquake ground motions, stationary white and colored noises), and different types of measurements.

Image-based 3D Modeling as a Damage Tool Prioritization in Post-Disaster Areas

Joe Kallas; Penn State; United States
Rebecca Napolitano; Penn State; United States

On August 4th, 2020, a colossal blast at the port of the Lebanese capital, one of the largest in history not caused by a nuclear reaction, changed Beirut's historic neighborhoods within seconds from a busy, vibrant and living cultural hub into an urban fabric of shattered buildings, collapsed masonry walls and scratched pitched roofs. With not enough preparedness for such a calamitous event, the affected local community faced significant challenges as they attempted to recover from the damage done. Once a heritage site is lost, damaged or destroyed, the recovery and rehabilitation process is slow, if (at all) possible. In the wake of such events, there has been a growing interest to digitize historic sites and buildings to preserve them (digitally) against unforeseen threats such as natural or man-made disasters. However, little work has been done to explore the role of 3D documentation for post-blast inspection of masonry historic buildings. The objective of this work is to expose an efficient workflow for accelerating the assessment process of damaged historic buildings by the application of digital technology in post-disaster areas, through the case study on the Beirut Blast. The originality of this work resides in the fact that this was the first time ever that Beirut and its historic buildings were massively digitized. This paper outlines how and why 3D image-based modeling was implemented, emphasizing on the timely benefits for disaster recovery and improvement of decision making in a similar emergency case. The results of the documentation produced a fast yet accurate 3D models of the affected historic buildings in Beirut, despite the challenging structural properties of the post-blast built environment. Post-processing of the data provided cultural heritage experts and engineers with valuable documents for structural deficiencies, damages and accessibility, which facilitated the remote assessment of the buildings and accelerated the implementation of emergency interventions.

Impact Detection and Localization Using Deep Learning and Information Fusion

Yuguang Fu; Nanyang Technological University; Singapore
Zixing Wang; Purdue University; United States
Amin Maghareh; Verus Research; United States
Shirley Dyke; Purdue University; United States
Mohammad Jahanshahi; Purdue University; United States

Due to their unpredictable nature, many impact events (e.g., overheight vehicles striking on bridges) go unnoticed or get reported many hours later. However, they can induce structural failures or hidden damage that accelerates the structure's long-term degradation. Therefore, prompt impact detection and localization strategies are essential for early warning of impact events and rapid maintenance of structures. Most existing impact detection strategies are developed for aircraft composites panels utilizing high rate synchronized measurement from densely deployed sensors. Limited efforts have been made for infrastructure or human habitats which generally requires large-scale but low-rate measurement. In particular, due to harsh environment, structural impact localization must be robust to limited number of sensors and multi-source errors (e.g., measurement errors). In this study, an effective impact detection and localization strategy is proposed using limited number of vibration measurements, especially in harsh environment (e.g., in deep space). It has two main steps. In the first step, wavelet denoising and event filtering are performed to detect the occurrence of impacts of all suspicious events. In the second step, convolutional neural networks are trained for each sensor node and are fused using Bayesian theory to improve the accuracy of impact localization. The proposed strategy is illustrated using 1D structure, and further validated in 3D geodesic dome structure numerically. The results demonstrate that it can detect and localize impact events accurately and robustly on structures.

Impact of Tall Building Cluster Layout on Urban Wind Field and Debris Flight Trajectory

Shaopeng Li; University of Florida; United States
Yue Dong; Colorado State University; United States
Kimia Yousefi Anarak; Colorado State University; United States
Yanlin Guo; Colorado State University; United States
Kurtis Gurley; University of Florida; United States
John van de Lindt; Colorado State University; United States
Ryan Catarelli; University of Florida; United States

Windborne debris during hurricanes can significantly damage building envelopes. Of particular concern is the windborne debris risk for tall buildings with glass façade/cladding systems in urban areas, where a cluster of tall buildings in the city center (e.g., central business district) could result in complex wind fields and intricate debris flight behaviors. To effectively mitigate the windborne debris risk for tall buildings in cities, it is critical to have a clear understanding of debris flight characteristics in a complex urban wind fields under various building layouts. In this NSF supported study, computational fluid dynamics (CFD) simulations are used to obtain the urban wind fields under different spatial layouts of tall buildings. With the obtained wind fields from CFD simulations, three-dimensional physics-based models are utilized to simulate the flight trajectories of windborne debris, where the effect of turbulence is also investigated. Computational simulations will ultimately be validated and informed by physical wind tunnel experiments of both the wind field and debris flight trajectory. To generalize the findings of the study results to a wide array of cityscapes, it is necessary to consider a variety of multi-building cluster layouts. This EMI presentation will focus on the parameterization scheme to select representative generic multi-building cluster layouts necessary to computationally and experimentally investigate building vulnerability to debris damage. Specifically, three parameters are used to capture the variation in building center distance, offset ratio and the rotation angle of side buildings. Sensitivity analysis is systematically conducted to investigate the impact of building cluster layouts on the windborne debris risk of urban tall buildings.

Impacts of moisture content on the flowability of milled biomass

Yimin Lu; Georgia Institute of Technology; United States
Wencheng Jin; Idaho National Laboratory; United States
Jordan Klinger; Idaho National Laboratory; United States
Hariswaran Sitaraman; National Renewable Energy Laboratory; United States
Sheng Dai; Georgia Institute of Technology; United States

Biomass is one of the most promising resources for producing sustainable aviation fuels thus reducing the use of fossil fuels and enabling decarbonization. However, handling variable biomass feedstock is a challenging task. Milled biomass particles can often jam in various industrial equipment, jeopardizing the safety and cost of upstream operations in a biorefinery. Unlike conventional granular materials like sand, biomass particles often have a high aspect ratio, irregular shape, and pores inside particles. These inner pores complicate the granular flow behavior with varying moisture content. When water exists in intra- and inter-particle pores with sizes ranging from nanometers to micrometers, intricate processes like hydrogen bonding, capillary effects, liquid bridge, and lubrication occur. This study evaluates the impacts of moisture content on the flowability of loblolly pine chips during hopper discharge. The fiber saturation point determined by differential scanning calorimetry analysis was approximately 30%. Then, dynamic compaction, consolidation, and angle of repose tests were performed to obtain meso-scale mechanical properties of tested samples under various moisture contents. These tests were directly used to obtain the material parameters in a continuum-mechanics model developed to numerically evaluate the macro-scale flow behavior in wedge-shaped hoppers. The results suggest that the effective discharge rate decreases significantly with increasing moisture content up to the fiber saturation point, beyond which moisture content has no apparent impact on the flow discharge of pine chips. This study promotes the scientific understanding of biomass flowability affected by moisture content and sheds light on the trouble-free handling of milled woody particles with high moisture.

Implementation of a fabric driven mobilized friction angle to improve estimated K0 in Norsand

Mason Ghafghazi; University of Toronto; Canada
Wyatt Handspiker; University of Toronto; Canada

Norsand is a simple, yet elegant constitutive model for granular soils with wide acceptance in geotechnical engineering and especially in the tailings industry. Norsand is based on the original CamClay model, while being capable of capturing behaviour of granular soils by decoupling hardening from the critical state and adopting a mobilized friction ratio and the state parameter. Norsand's appeal comes from its simplicity and the fact that practically all its parameters have physical meanings, and can be obtained directly and objectively from drained triaxial compression tests.

Comparisons to measurements suggest that Norsand significantly overestimates the coefficient of lateral earth pressure at rest (K0) due to its yield surface shape and adoption of normality. A simple concept of fabric viewed as a tendency of the material for failure on a preferential plane was implemented in Norsand. Fabric acts on the model by pulling the mobilized friction ratio (angle) towards the preferential plane as the material evolves towards the critical state. It was shown that this simple, physically meaningful, and easy to calibrate modification can improve the K0 values estimated by the model in both loose and dense states.

Improving Accuracy and Computational Efficiency of Optimal Design of Experiment via Greedy Backward Approach

Mehdi Taghizadeh; Department of Engineering Systems and Environment, University of Virginia; United States
Dongbin Xiu; Department of Mathematics, The Ohio State University; United States
Negin Alemazkoor; Department of Engineering Systems and Environment, University of Virginia; United States

Non-intrusive least-square-based polynomial chaos expansion (PCE) techniques have attracted increasing attention among researchers for simple yet efficient surrogate constructions. Different sampling approaches, including optimal design of experiments (DoEs), have been developed to facilitate the least-square-based PCE construction by reducing the number of required training samples. DoEs mainly include a random selection of the initial sample point and searching a pool of (coherence-optimal) candidate samples to iteratively select the next points based on some optimality criteria. Here, we propose a different way from the common practice to select sample points based on DoEs' optimality criteria, namely backward greedy. The proposed approach starts from a pool of coherence-optimal samples and iteratively removes the most uninfluential sample candidate among a small and randomly selected subset of the pool, instead of the whole pool. Several numerical examples are provided to demonstrate the promise of the proposed approach in improving the accuracy, robustness, and computational efficiency of DoEs. Specifically, it is observed that the proposed backward greedy approach not only improves the computational time for selecting the optimal design but also results in higher PCE accuracy. Most importantly, the proposed approach ends the debate on which optimality criteria must be used for DoEs as different criteria yield similar accuracy, when they are used in a backward procedure to select the design points.

In-Situ Measurements of Stresses and Kinematics in Triaxial Tests

Ryan Hurley; Johns Hopkins University; United States
Ghassan Shahin; EPFL; Switzerland
Ye Tian; Johns Hopkins University; United States
Oyvind Torgersrud; Oyvind.Torgersrud@ngi.no; Norway
Eleni Stavropoulou; EPFL; Switzerland
Edward Ando; EPFL; Switzerland
Andrew King; Soleil Synchrotron; France

Triaxial tests have been a staple of soil and rock mechanics studies for decades, furnishing the macroscopic stiffness and strength used in engineering predictions and computational models. Researchers have increasingly acknowledged that these tests are not elemental, but in fact boundary value problems accompanied by complex grain-scale behaviors including localization and breakage. Here, we present data which reveals not only the macroscopic stiffness and strength but also the microscopic grain-scale behaviors occurring during triaxial compression of sands at confining pressures ranging from 10 to 45 MPa. The data was obtained from a series of triaxial tests performed at synchrotron facilities with in-situ x-ray computed tomography (XRCT) and 3D x-ray diffraction (3DXRD) on samples containing between 1500 and 42000 grains. We report grain-resolved stresses, kinematics, and breakage, and shed new light on critical assumptions made in soil mechanics and granular physics, such as the nature of kinematics and principal stress rotations in and out of shear bands.

In-Vitro Assessment of Lumbar Spinal Fusion in Human Cadaver Models Using Self-powered Sensors

Amir Alavi; University of Pittsburgh; United States
Kaveh Barri; Johns Hopkins University; United States
Jianzhe Luo; University of Pittsburgh; United States

More than 400,000 lumbar spinal fusion surgeries are performed each year in the United States. Many of these cases will experience post-operative complications. A key factor to determine the success of spinal fusion is quantitative assessment of its mechanical stability. Here, we study the performance of a novel self-powered and wireless implant for in-vitro monitoring of posterior lumbar spinal fusion in human cadaver models. The implant is composed of two major components: (1) a piezoelectric transducer attached to the spinal fusion rods, and (2) a Fowler-Nordheim (FN) sensor-data-logger with ultra-low power requirements (~100 femtowatt). The electric signal generated by the piezoelectric transducer due to the strains induced on the spinal rods can modulate the FN sensor-data-logger synchronized dynamic state. Variations in the mechanical stability of the fused segments during the healing process change the piezoelectric electric signal and accordingly the dynamic state of the data-logger. We verify this process through a series of simulated fusion states in cadaver models. We discuss how the generated time-evolution curves can be used for continuous monitoring of the healing process

Incorporating a Finite Element-Based Structural model within a System of Systems Modeling Framework to Analyze Smart Habitats in Deep Space Environments.

Adnan Shahriar; The University of Texas at San Antonio; United States
Arsalan Majlesi; The University of Texas at San Antonio; United States
David Avila; david.avila@my.utsa.edu; United States
Arturo Montoya; The University of Texas at San Antonio; United States

The design and evaluation of safety controls for Smart Habitats (SmartHabs) can be achieved within a system of systems modeling framework that captures the technical complexities and interconnected processes that are required for their safe operation under extreme environmental conditions in deep space. External disturbances, such as meteoroid impact, can damage the structure of the habitat and trigger cascading faults and failures in interconnected systems (e.g., interior environment) that put the crew at risk. Hence, to model the propagation of failure among systems, it is essential to integrate a structural model with damageable features with non-structural systems of the SmartHab. The Finite Element Method (FEM) provides the flexibility of analyzing structures with varying geometries and material properties under multiple loadings. However, the computational time and accuracy of this simulation technique depend on the number of degrees of freedom of the model and the complexity of the analysis technique. Thus, the structural FEM-based model must overcome computational limitations to interact with non-structural systems of the SmartHab and capture cascading events in real time. In this paper, we illustrate the development of a structural mechanical model that can be integrated within a system of systems modeling framework for SmartHabs. The metrics to evaluate the effectiveness of the developed models are introduced and discussed to facilitate the future integration of FEM models within complex systems.

INDENTATION SIZE EFFECT IN CARBONITRIDED AISI 1045 STEEL

TABIRI KWAYIE ASUMADU; Worcester Polytechnic Institute; United States
Dr. Kwadwo MENSAH-DARKWA; KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY; Ghana
Dr. Emmanuel Gikunoo; KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY; Ghana
Dr. Desmond Klenam; Worcester Polytechnic Institute; United States
Mobin Vandadi; Worcester Polytechnic Institute; United States
Prof. Samuel Kwofie; KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY; Ghana
Prof. Nima Rahbar; Worcester Polytechnic Institute; United States
Prof. Winston Wole Soboyejo; Worcester Polytechnic Institute; United States

Surface engineering is essential for materials that are used for contact, thermal and corrosive applications. Through benchmarks achieved in surface engineering, the mechanisms responsible for materials' mechanical and tribological properties are well established and exploited over the years. One phenomenon that has gained attention in recent decades is indentation size effect (ISE). Mechanistic and phenomenological theories have been developed to explain the observed size dependence of strength behaviour. The dislocation microstructure evolution, deformation mechanisms and the contribution of length scale parameters responsible for this effect is not fully understood. This paper explores the effects of surface carbo-nitriding on material length scale and dislocation microstructural parameters of 1045 steel. The material was carbo-nitrided at 500oC and 900oC, prior to, metallographic characterization and micro/nano-indentation. The statistically stored and geometrically necessary dislocation densities increased with increasing carbo-nitriding temperature. A bi-linear relationship was also established from the plot of hardness squared versus the indentation depth. Three regimes of dislocation behaviour (dislocations source–limited/starvation, discrete dislocations, and continuum dislocations) were observed in this study. The observed trends are also explained using dislocation densities that were estimated using dislocation theories. The implications of the results are also discussed for the carbonitrided steels.

Inducing Bone Regeneration in Critical Bone Defects using "LegoBlocks" and Bone Morphogenic Proteins

kalpana katti; North Dakota State University; United States
Krishna Kundu; North Dakota State University; United States
Dinesh Katti; North Dakota State University; United States

Large bone defects that cannot heal without interventional therapies are termed as 'critical bone defects'. Current clinical therapies for treatment of these defects have many limitations such as lack of available tissue, risk of infections, donor site morbidity, and most importantly the difficulty of transplant integration. Tissue engineered scaffolds as such as unable to fill large defects due to lack of uniform tissue growth and necrosis in central part of the scaffold. In order to address these issues we developed a unique 'legoblock' inspired interlocking polymer clay nanocomposite scaffold block system. The interlocking block assembly maintains the mechanical integrity of the scaffold. Further we utilize bone morphogenic proteins 2 and 7 (BMP-2 and BMP-7) on these interlocking blocks. Coculture of osteoblast cells (hFOB) and mesenchymal stem cells (MSCs) is used to seed the interlocking blocks. We evaluate long-term effect of BMPs on bone regeneration for a period of 9 weeks. The BMP-2 and BMP-7 are relealed to a 100% by day 16. At 9 weeks, nanoindentation experiments on BMP-2/BMP-7 soaked scaffolds indicate a 120% increase in the elastic modulus, attributed to enhanced ECM formation. Significantly mproved cell proliferation, viability, and differentiation of the cells is also observed on the BMPs soaked scaffolds. We also observe a significant increase in the bone-related proteins, osteogenesis-related proteins, and Wnt-factors-related proteins with BMPs soaked scaffolds. Thus BMPs played a crucial role in initial osteogenesis and ECM formation. In addition, Alizarin Red S staining and scanning electron microscopy images show a significant increase in the mineralized bone nodule formation with BMPs coated samples compared with uncoated samples suggesting BMPs played a decisive role in bone regeneration. Thus, BMPs play a crucial role in osteogenesis at the initial stages and continue to impact bone growth past the time period of total release. This study demonstrates the use of interlocking scaffold system as a bone grafts for critical size bone defects. Induction of osteogenesis using the nanoclay materials as well as enhanced osteogenesis is enabled in the unique scaffold block interlocked system.

Industrialized and Robotic Construction Advances in Terrestrial Construction and Opportunities in Space Construction

Naveen Kumar Muthumanickam; National Renewable Energy Lab; United States

Advancements such as industrialized prefabrication and robotically controlled additive deposition are becoming promising technologies to support rapid construction of buildings at volume and scale. However, apart from the structural shell of the building, optimal integration of other systems – mechanical, electrical, plumbing, thermal, power generation, storage and distribution, is key to enabling functional buildings. Leveraging such methods to integrate various systems in the buildings requires the building design to be optimized for constructability constraints imposed by the industrialized and robotically controlled production setups. The Industrialized Construction Innovation (ICI) team at the National Renewable Energy Laboratory (NREL) has been focusing on research and development of such industrialzied and robotic construction technologies and processes that can lead to production of buildings which are resilient to extreme climatic conditions at reduced cost and time. There is a potential synergy between such advancements in terrestrial construction, which can be leveraged for the benefit of space (orbital and extra-terrestrial) construction. Similarly, advances in space construction can lend itself to accelerated adoption of robotic construction methods in terrestrial construction. This presentation will give an overview of selective research efforts of the ICI team at NREL, along with brief snippets of potential collaborations with agencies like NASA.

Inelastic Buckling of Hybrid FRP-Metal Long Tubes under External Pressure

Hayder Rasheed; Kansas State University; United States

Since FRP tubes offer lightweight and corrosion-resistant characteristics compared to steel, it is beneficial to introduce them both in fabricating the synergistic hybrid FRP-metal pipeline. A relatively recent tube composition made of laminated FRP shell lined with a metal pipe is introduced. The inner metal pipe acts as a structural component and a permanent mandrel for the placement and curing of the filament wound outer laminated FRP shell. In this study, an imperfect hybrid laminated FRP-metal long cylindrical shell is analyzed under external pressure. This solution is supplemented with localized plasticity induced at the four lumped springs positioned at the points of maximum moments in the ovalized cross section. By varying the FRP to metal content of the pipe, elastic or inelastic buckling is admitted. Comparisons are made and conclusions are drawn.

Inerters: Mapping the Multiple Mechanisms for Magnifying Mass

Jonathan Shell; University of Tennessee; United States
Nicholas Wierschem; University of Tennessee; United States

Inerters are two node mechanical elements that can provide mass effects in dynamic systems as a result of their restoring force, which is proportional to the relative acceleration between the element's nodes. Due to the mechanics of these devices, the mass effects they provide can be significantly larger than the physical masses that they comprise, making them ideal for applications where size and weight are design concerns. Inerters have been studied in systems to suppress dynamic responses in civil, marine, aerospace, automotive, and industrial applications. While many mechanisms that have been used to realize inerters work by converting the translational motion of a structure into the rotation of a flywheel, there are a range of other ways to realize an inerter. This presentation reviews several of the mechanisms used in literature and the authors' own work to realize inerters, including circulating fluids, ball screws, rack and pinion gears, timing belts, and lever mechanisms. A brief discussion is also provided concerning the use of pin-ended connections to address misalignments that would otherwise be detrimental to the effectiveness of inerter mechanisms. This overview of the current state of rotational inerter technologies is provided to demonstrate the versatility and robustness of options available for the design of inerters in dynamic systems. With the large number of ways to realize inerters, they can be realistically considered for passive control of dynamic systems across a wide range of engineering disciplines and at many scales of operation.

Influence of Carbon Nanofibers and Multiwalled Carbon Nanotubes on the Elastic and Creep Properties of Metakaolin - Based Geopolymers

Ange-Therese Akono; Northwestern University; United States
Yunzhi Xu; Northwestern University; United States
Haklae Lee; Northwestern University; United States
Nathanial Buettner; Northwestern University; United States

We investigate the influence of nanomaterials on the mechanical characteristics of metakaolin-based geopolymers reinforced with multiwalled carbon nanotubes MWCNT) and highly graphitic high-cost tubular carbon nanofibers (CNF). The synthesis occurs in a three-step process that involves (i) pre-dispersion of nanofillers in deionized water using an ultrasonic horn, (iii) synthesis of the potassium silicate solution, and casting of the nanocomposite using centrifugal mixing and vacuum degassing. The total energy dispensed during the pre-dispersion process is quadratically proportional to the mass fraction of nanofillers. The viscoelastic response is measured using creep nanoindentation tests At the microscopic scale, MWCNTs result in an increase in both the elastic modulus and the contact creep stiffness. The positive correlation can be attributed to an increase in polymerization given the large surface area of MWCNTs, 50 m2/g, and to the filling of mesopores by MWCNTs. In contrast, for CNFs, no clear correlation is observed between the CNF mass fraction and the elastic modulus and creep compliance. This finding suggests that a quadratic scaling of the CNF dispersion energy is not adequate in this instance to optimize the mechanical characteristics; this finding further highlights the influence of the CNF dispersion energy on the mechanical properties of CNF-geopolymer nanocomposites.

Influence of carbonation on alkali-silica reaction

Dayou Luo; Univeristy of Massachusetts, Lowell; United States
Jianqiang Wei; Univeristy of Massachusetts, Lowell; United States

Alkali-silica reaction (ASR) has become a major degradation mechanism causing severe expansion, cracking, and shortened service life in concrete structures, and thereby both economic and environmental issues. Although carbonation is also considered an inevitable challenge threatening concrete durability, a well-controlled early-age carbonation treatment is found favorable to accelerate the strength gain and improve both the short- and long-term performance of concrete. In this study, the efficiency of carbonation in suppressing ASR is investigated by conditioning the mortar specimens containing highly-reactive chert-based aggregates under different CO2 concentrations. The results indicate that the carbonation under 20% CO2 suppressed the 30-day ASR-induced volume expansion to 0.06% with no detectable cracks and the highest strength gain, which is 61.0% higher than that of the control group, revealing the robust and promising role of carbonation in ASR mitigation. A subsequently implemented carbonation can still result in an immediate decrease in volume expansion in the specimens after a 7-day ASR attack. To uncover the underlying mechanisms, the CO2 uptake and carbonation profile of the specimens were determined by thermogravimetric analysis (TGA) and energy dispersive X-ray spectroscopy (EDS), respectively. It is unveiled that the CO2 uptake induced a significant conversion of calcium hydroxide into calcium carbonation, and the decreases in crystallization and Ca/Si ratio of ASR gels from 0.13 to 0.45 during carbonation might also play critical roles in triggering the desired ASR mitigation.

Influence of Gypsum on Tricalcium Silicate in Blended System: in situ X-ray Total Scattering Study

Hyeonseok Jee; University of Illinois Urbana-Champaign; United States
Chirayu Kothari; University of Illinois Urbana-Champaign; United States
Nishant Garg; University of Illinois Urbana-Champaign; United States

Despite several advantages of ordinary Portland cement (OPC)-based concrete, which has been the main construction material, the need for more sustainable construction materials has increased due to the high carbon footprint of OPC. As one of the promising alternatives, limestone calcined clay cement (LC3) has received academic attention. Since the LC3 system has higher aluminate contents than OPC, the LC3 system needs higher gypsum contents than the conventional OPC. Although gypsum mainly reacts with aluminate phases and controls their hydration, gypsum also affects the hydration behavior of calcium silicate phases such as tricalcium silicate (C3S). Thus, it is important to understand the effect of gypsum on calcium silicate phases in blended systems, which has not been clearly understood. In this study, the hydration behavior and nano-structural development of tricalcium silicate in blended systems were investigated. Three different systems were assessed to evaluate the effect of gypsum in blended systems: (i) synthetic C3S, (ii) synthetic C3S with metakaolin, and (iii) synthetic C3S with metakaolin and limestone. The reaction kinetics of the systems were examined via isothermal calorimetry. In addition, the time-dependent nano-structural development of the samples was scrutinized via in-situ X-ray total scattering with atomic pair distribution function analysis.

Influence of Loading Rate and Crystal Structure on Constitutive Anisotropy of Silica Cubes

Ibraheem Gharaibeh; University of Tennessee, Knoxville; United States
Daniel Casem; U.S. Army Research Laboratory; United States
Wadi Imseeh; Caterpillar Inc., Peoria, IL; United States
Khalid Alshibli; University of Tennessee, Knoxville; United States
Peter Kenesei; Advanced Photon Source, Argonne National Laboratory, IL; United States
Hemant Sharma; Advanced Photon Source, Argonne National Laboratory, IL; United States

The effects of crystal structure and loading rate on the constitutive behavior of silica sands has not garnered as much attention in the literature despite extensive research on granular materials. The main constituent of silica sand particles is α quartz crystal, which has a hexagonal lattice and a trigonal crystal structure. The effects of quartz crystal structure and loading rate on the constitutive behavior of synthetic silica cubes were investigated using 3D X-ray diffraction (3DXRD), synchrotron micro-computed tomography (SMT), and 3D finite element (FE) analysis. Since the silica cubes have a simple known geometry (1 mm3), testing them has eliminated the predominant influence of complex particle morphology in natural silica sands; and thus helped manifest the underlying effect of quartz crystal structure. The cubes were loaded in different directions with respect to the crystal local planes at quasi-static and high strain (Kolsky bar) loading conditions. Experiments and 3D FE analysis showed how changes in the crystal local orientation of the silica cubes with respect to the loading direction produced different stress-strain responses. The 3D FE analysis was validated using the experiments to accurately predict the behavior of silica material. Accordingly, it was concluded that the crystal structure of quartz fundamentally causes a directional anisotropy in the constitutive behavior of silica particles based on both experimental measurements and 3D FE analysis. The presentation also discusses the influence of loading rate on strength of silica cubes.

Influence of Micro- and Crystalline-Scale Properties on the Fracture of Silica Sand Particles Using 3D Finite Element Analysis

Wadi Imseeh; Caterpillar Inc; United States
Mohammad Safi; University of Tennessee; United States
Khalid Alshibli; University of Tennessee; United States

Particle fracture significantly influences the constitutive behavior of sands and impacts many geotechnical engineering applications such as dynamic compaction, hydraulic fracturing, pile driving, and stability of dams. When sand is loaded in confined1D compression, particles rearrange and ultimately fracture causing the yielding response in the uniaxial stress-strain curve. There are limited studies that investigated the fracture behavior of sand at particle-scale using 3D imaging. In this paper, in-situ synchrotron micro-computed tomography (SMT) was used to acquire multiple images of a sand specimen while loading it in confined 1D compression. The paper then investigates the fracture characteristics of silica sand particles using the rich experimental data and 3D finite element (FE) simulations. The 3D FE simulations were generated using digital image processing of the in-situ SMT scans, unique 3D meshing algorithms of individual sand particles, and coding development in ABAQUS FE software for a material point user-subroutine that models the fracture of quartz mineral. The in-situ SMT images were processed to produce 3D FE meshes that accurately resemble the complex morphology of the natural sand particles. The paper discusses different fracture modes of sand particles that were mainly determined by particle morphology and quartz constitutive behavior. For instance, sand particles within the specimen were found to fracture at higher stress-levels when they established more contacts with their neighboring particles and exhibit mostly spherical shapes rather than elongated.

Informed post-earthquake building inspection planning using adaptive batch-mode active learning

Amirhossein Cheraghi; University of Florida; United States
Ge Ou; University of Florida; United States
Yinhu Wang; University of Utah; United States
Nikola Markovic; University of Utah; United States

Having a prompt and accurate estimation of infrastructural damage across the region immediately after earthquake is of vital importance for emergency response and resource allocation. Previous research validated that the post-seismic survey with sparse observation can be used to infer the regional infrastructural damage through machine learning models. The inspection cost of the post-seismic reconnaissance is composed of the costs associated with the number of required inspections and cost due to traveling between sequential inspections. Therefore, maximizing the effectiveness of the survey inspection under a time constraint requires the consideration of both the machine learning dynamics and routing optimization. To solve this problem, the authors proposed a learning-routing framework for early post-seismic reconnaissance planning that enables the trade-off between learning and routing objectives. In the framework, an adaptive batch active learning is developed based on a Gaussian process regression model. Based on mutual-information criterion, the active learning acquisition function recommends a batch of candidate buildings to be inspected on a daily basis, and the buildings are selected adaptively from the batch considering an optimal route schedule. In addition, we developed a novel convergence criterion independent of the uninspected data which quantifies the convergence of the active learning process and guides the termination of the inspection. Comparing with the baseline method, the results showed the proposed method trains a reliable GPR model with 25 percent fewer inspections and less time and resource, yet the same level of accuracy is maintained.

Insight into the stability and load carrying capacity estimations of double curved shells

Adrian Gliszczyński; Lodz University of Technology; Poland

Most of the considerations on the pre- and postbuckling behavior of double-curved (DC) structures are theoretical, while in practical applications the DC parts of rocket tips are usually reinforced such that the structure is damaged by exceeding the strength rather than by stability. These elements can be optimized and thus have a lower weight and similar load capacity, but it is necessary to build an appropriate result database. The problem of testing the stability of DC structures is also emphasized by the fact that there is no information in the literature on the resistance of such structures to initial imperfections. In particular, it is a question of a systematic comparison of research. Moreover, in the literature no studies constituting a benchmark of various methods related to identical geometries of DC structures have been found. It is reported that in this paper, double curved concave and convex DC structures were analyzed and maps of real geometric imperfections measured for validated conical and cylindrical (MSI) structures were adopted as imperfection disturbance. Moreover, imperfections based on buckling modes from the linear bucking mode-shaped imperfection (LBMI) and those resulting from the application of perturbation load (Single Perturbation Load Approach - SPLI) were considered.

Insights on Hyperparameter Importance in Crack Segmentation DCNNs

Carlos Canchila; University of Alabama; United States
Shanglian Zhou; University of Hawaii at Manoa; United States
Wei Song; University of Alabama; United States

In recent years, deep convolutional neural networks (DCNNs) have gained popularity for image-based crack segmentation due to their outstanding performance, self-adaptability, and reduced subjectivity. Despite the many advantages offered by DCNNs, their development is a complex and time-consuming task that requires expertise to select hyperparameters for implementation or adaptation. A Bayesian optimization technique can be applied to determine an optimal set of hyperparameters for crack segmentation DCNNs. However, the optimization of all hyperparameters is very time-consuming. Understanding the influence of individual hyperparameters can provide more efficient DCNN design and optimization. Unfortunately, Bayesian optimization cannot evaluate the influence of individual hyperparameters and their interactions on DCNN performance. In this study, a sensitivity analysis is conducted for crack segmentation DCNNs using real-world 3D roadway range images. The results show it can successfully evaluate the relative importance of the hyperparameters on segmentation accuracy and offer insights on future DCNN design and optimization process.

Integrating image and LiDAR data for measuring road and roadside objects on hillside streets

Sven Malama; University of California Los Angeles; United States
Debasish Jana; University of California Los Angeles; United States
Sriram Narasimhan; University of California Los Angeles; United States
Ertugrul Taciroglu; University of California Los Angeles; United States

Automatic road and roadside object condition assessment is an essential task in the field of road infrastructure management. It not only helps in predicting future maintenance needs, planning budget allocation, and ensuring the safety of road users, but also assists in the estimation of flood and landslide hazards. The literature primarily addresses the determination of road width and road surface condition, which poses an incomplete picture of a more complex and holistic assessment. Additionally, road inspectors conduct manual evaluations, which are time-consuming, prone to error, and do not offer real-time information. This research offers a deep learning-based solution for autonomous road and roadside object condition assessment. The proposed method leverages the advantages of both image and LiDAR data by using an image segmentation network to extract semantic road feature information on a series of images and subsequently projecting the semantic labels into the point cloud. Imposing geometrical constraints and polynomial surface fits supports the detection and removal of outliers and enhances the reliable interpretation of point cloud data in difficult terrain conditions predominantly found in hillside areas. The segmented point cloud, containing real scale information, assists in determining the road condition-related attributes such as street width, curb heights, sidewalk widths, and slope angles adjacent to the roadway. This framework is validated on real-world data collected using a geo-tagged multi-sensor mobile mapping platform in the Los Angeles hillside areas. It demonstrates high potential in fully automatic road and roadside object dimension estimation for street improvement purposes. The technique also has the advantage of being scalable and easily integrated into road infrastructure management systems.

Interactive buckling in thin-walled steel angle columns leading to a more consistent structural design methodology

Behnam Behzadi-Sofiani; Imperial College London; United Kingdom
Leroy Gardner; Imperial College London; United Kingdom
Ahmer Wadee; Imperial College London; United Kingdom

Thin-walled steel angle section components are versatile structural members that are used extensively in construction. They are particularly common within electrical transmission pylons and other lattice tower structures owing to their practical connectivity. However, since their geometric centroid and shear centre are not coincident, they have always posed technical challenges for structural designers particularly when subject to compression owing to the natural interaction between flexure and torsion particularly after instability is triggered. Indeed, it is well established that the present provisions for designing thin-walled angle section members subject to buckling within European design code for steel structures have significant issues that can lead to overly conservative strength predictions. In the present work, novel mechanical insights in terms of interactions between buckling modes are presented and discussed; these naturally clarify some of the aforementioned issues and lead to more rational design recommendations that are shown to improve the consistency of ultimate strength predictions when compared to the current design methodologies used in industrial practice.

Inverse Determination of Shrinkage and Fracture Properties of Engineered Buffer Materials for Geological Repositories of Nuclear Waste Using an Integrated DIC-FEM Approach

Mohammad Rahmani; Texas A&M University; United States
Abdullah Azzam; Texas A&M University; United States
Julia Grasley; Texas A&M University; United States
Yong-Rak Kim; Texas A&M University; United States
Jongwan Eun; University of Nebraska-Lincoln; United States
Seunghee Kim; University of Nebraska-Lincoln; United States

This study presents an inverse method to determine the shrinkage and fracture properties of desiccating bentonite clay that is often used in engineered barrier systems (EBS) at geological repositories where canisters filled with radioactive nuclear wastes are stored in tunnels surrounded by natural rocks. Due to the high temperature around the canister and the subsequent evaporation of water, bentonite will likely shrink. Considering the arrangement of bentonite in a confined condition, the shrinkage process is also mechanically restrained, leading to desiccation cracking. This desiccation cracking increases the risk of opening pathways for the radioactive matter to disperse and the subsequent contamination of soil. Therefore, it is imperative to accurately understand and predict the desiccation behavior of the engineered buffer material. In this study, restrained ring tests were designed and conducted to observe the shrinkage and desiccation cracking behavior captured by a digital image correlation (DIC) system. A finite element model (FEM) with cohesive zone elements was used to simulate shrinkage behavior and desiccation cracking of bentonite clay. The shrinkage and fracture properties of bentonite were inversely identified through an optimization process where material parameters in FEM were iteratively calibrated, so the displacement field obtained by the FEM agreed well with the full-field displacement captured by DIC. The integrated experimental-computational method in this study can determine damage-induced material characteristics subjected to complex multi-physical conditions of EBS.

Investigating Changes to Seabed Properties Due to Biogenic Processes in the York River Estuary, Chesapeake Bay

Chesna Cox; The University of South Alabama / The Dauphin Island Sea Lab; United States
Kelly Dorgan; The Dauphin Island Sea Lab; United States
Nina Stark; Virginia Tech; United States
Grace Massey; Virginia Institute of Marine Science; United States
Carl Friedrichs; Virginia Institute of Marine Science; United States
Adrian Rodriguez-Marek; Virginia Tech; United States
Eric Hunstein; Virginia Tech; United States
Md Rejwanur Rahman; Virginia Tech; United States

Animals that live in marine sediments are known to modify the physical characteristics of their habitats. Infauna can increase sediment strength by increasing cohesion through mucus secretion and compacting sediment during burrowing and tube building. Alternatively, infauna can weaken sediment by disrupting cohesive bonds and excavating burrows. Infaunal impacts depend on the behaviors of the dominant species and likely vary with depth in sediment. How these changes translate to larger-scale geotechnical site characterization are not well understood. Linking infaunal behavior to sediment physical properties can improve understanding of object-seabed interactions, e.g., unexploded ordinance detection and management. This study aims to characterize impacts of infauna on sediment strength by sampling different sediment communities inhabiting sediments with similar grain sizes. Data processing is ongoing, but preliminary observations of infauna from three sites sampled along the York River Estuary show different dominant taxa among sites. Burrowing bivalves that possibly weaken sediment are abundant in the upper estuary, and tube-dwelling organisms that possibly strengthen sediment are abundant in the lower estuary. The results of this study will improve interpretation of geotechnical data in areas with abundant infauna, as well as improve our knowledge of how infauna interact with their environments and affect engineering properties of seabed sediments.

Investigating large language models' understanding of mechanics

Mohd Zaki; Indian Institute of Technology Delhi; India
N. M. Anoop Krishnan; Indian Institute of Technology Delhi; India

Scientific theories and facts are available in the form of books, research papers, and websites. The advancement of computing power enabled the researchers to train language models which can understand the scientific text and explain it in the form of natural language when prompted. These models have more than ~100 billion parameters and are trained on programming codes in addition to text data. This training paradigm imparts these models the capability to solve mathematical equations, write computer programs, analyse a given text and answer the associated questions. Recently, these models became available for public use and hence can be equally used by students and teachers. In this work, we analyse the capability of two generative large language models ChatGPT and GPT-3 in solving and understanding undergraduate and graduate-level mechanics-based questions. Specifically, we take questions which require reasoning, numerical solving, and writing programming codes for their solution. This analysis will help the teachers to engage with students in an intriguing manner and design course materials to enable an in-depth understanding of mechanics.

Investigating the Accuracy of Wind Tunnel Simulations for Wind Profiles over Heterogeneous Terrain: A Comparison Study with Field Measurements

Sejin Kim; University of Michigan; United States
Nasrollah Alinejad; FAMU-FSU College of Engineering; United States
Sungmoon Jung; FAMU-FSU College of Engineering; United States
Pedro Fernández-Cábán; FAMU-FSU College of Engineering; United States

This study investigated the applicability and accuracy of wind tunnel test for simulating wind profiles over heterogeneous terrain. A fully automated terrain simulator of the University of Florida, so called Terraformer, was used to mimic the upstream terrain configuration as accurate as possible, trying to realize realistic terrain effect on wind flow. Nine actual field sites were selected, and their aerial images were analyzed to determine the distribution of roughness element height of Terraformer. Mean wind speed, turbulence intensity, skewness, and kurtosis along the vertical height, as well as wind spectra, were measured in the wind tunnel. Through a comparative study between the wind tunnel and field measurement data, pros and cons of the applied wind tunnel technique regarding replicating wind characteristics of field data were discussed. In addition, suggestions are made for future wind tunnel experiments using Terraformer.

Investigation of Damage and Crack Propagation in Quasi-Brittle Materials via Peridynamics

Semsi Rakici; Georgia Institute of Technology; United States
Bora Pulatsu; Carleton University; Canada
Ece Erdogmus; Georgia Institute of Technology; United States

Quasi-brittle materials such as concrete and masonry are widely used in civil engineering applications. However, the low tensile strength and fracture toughness of these materials make them vulnerable to cracking, which can cause serious safety problems. Therefore, it is crucial to use a reliable numerical tool to capture the quasi-brittle material behavior and damage mechanism. This study uses a bilinear bond-based peridynamic model to investigate the damage and crack propagation in quasi-brittle materials. First, mode-I and mixed-mode fracture simulations for a concrete beam are used to validate the numerical method. The same model is then used to simulate the collapse mechanism of masonry arches and to estimate their load-carrying capacity under vertical static loading. While modeling the masonry arc structure, a macro modeling approach is followed to reduce the computational cost and the number of numerical parameters used in simulations. In addition, a convergence study and sensitivity analysis of material properties is performed. The results show that the peridynamic models successfully capture the crack propagation and structural behavior of quasi-brittle materials with a limited number of input parameters.

Investigation of densification effect and anti-scour potential using mangrove-inspired pile group

Xiwei Li; Arizona State University; United States
Leon van Paassen; Arizona State University; United States
Junliang Tao; Arizona State University; United States

Mangrove's tangled root system forms a denser barrier that helps to protect the coastline from erosion, such unique features inspire a measure to mitigate local scour around monopile foundations. This study proposes a bio-inspired solution in which a ring of skirt pile group inspired by the mangrove root system is hypothesized to reduce the flow velocity and densify sediment around the centered monopile. Flume experiments were carried out to investigate the relative densification effect and corresponding scour mitigation effect under various pile installation sequences. The 2D DEM simulation was conducted to simulate the pile installation process and study the sediment dynamic behavior at a particle-scale level. Cavity expansion theory was incorporated to consider the soil plug effect during skirt pile installation. The experiment and modeling results show that the installation of skirt piles exhibits geotechnical benefits for scour mitigation.

Investigation of heterogeneous strain data fusion for output-only system identification

Tahsin Afroz Hoque Nishat; University of Arizona; United States
Hongki Jo; University of Arizona; United States
Jian Li; University of Kansas; United States
Simon Laflamme; Iowa State University; United States
Austin Downey; University of South Carolina; United States
Caroline Bennette; University of Kansas; United States
William Collins; University of Kansas; United States
Sdiq Taher; University of Kansas; United States
Han Liu; Iowa State University; United States

Thin-film based large-area skin sensors have various advantages in measuring large deformation and covering complex geometries of structural surfaces. Soft elastomeric capacitor (SEC) is one of these types of strain sensors which measures the summation of the orthogonal strains (i.e., x and y directional strain) in terms of their capacitance change. Various methods have been developed to convert such capacitance changes into readable digital or analog signals. However, intrinsically higher noise levels coming from such capacitive strain sensors themselves and bidirectional sensing characteristics can lead to inaccurate measurement irrespective of the data conversion methods. This study aims to improve the quality of SEC measurement by using limited number of conventional resistive strain gauges (RSG) in combination with the capacitive strain sensors (i.e. SECs) with particular focus on output-only system identification applications. A principle of heterogeneous strain data fusion is proposed. The performance of proposed strain data fusion is experimentally validated via series of lab-scale shear building tests on a shake table.

Investigation of Hurricane Wind Effects on Solitary Wave Energy Dissipation in a Storm Surge

Hunter Boswell; Missouri University of Science and Technology; United States
Grace Yan; Missouri University of Science and Technology; United States
Wouter Mostert; University of Oxford; United Kingdom

Despite being an essential characteristic of storm surge development, the effects of wind on breaking waves are currently not well understood. In this study we will explore the effect of hurricane winds on solitary wave breaking in a storm surge environment. Direct numerical simulations are used to solve the Navier-Stokes equations in two phases to simulate the wave breaking. In this study, solitary waves shoal and break in a simplified storm surge type bathymetry, featuring a gradual transition in depth. The beach slope and storm surge depth of this bathymetry as well as the initial wave amplitude are varied under a constant highwind speed, representative of hurricane-like conditions, and the wave breaking energy dissipation results will be compared with prior studies in which no wind was present. The results will also be compared with the theoretical predictions of a shallow water inertial model, previously shown to have good data collapse for solitary waves breaking in this type of bathymetry without wind.

Investigation of Scaling-Up Cement Paste Rheological Measurement to Fresh State Behavior of Concrete

Raul Marrero Rosa; Northwestern University; United States
Ayesha Ahmed; Northwestern University; United States
Elmer Irizarry; Northwestern University; United States
Liza Dill; Northwestern University; United States
Nasser Nduhi; Northwestern University; United States
David Corr; CTL Group, Northwestern University; United States
Gianluca Cusatis; Northwestern University; United States

Fresh rheological properties are essential for the buildability, extrudability, and pumpability in the additive manufacturing of concrete. The dense colloidal particle suspension interaction within the cement paste slurry system is the origin of flow within the concrete composite. Chemical admixtures and supplementary cementitious materials (SCMs) are the usual approaches to change the rheological behavior of the cementitious paste. An experimental campaign of (1) mini-slump test, (2) tack test, (3) small amplitude oscillatory shear, (4) ram extrusion pressure, (5) sliding pipe rheometer, (6) compression, and (7) fracture test is performed on the modified cement paste to understand the effect of the addition in the fresh properties and hardening of cement paste. Water-to-cement ratio, chemical admixtures, and SCMs change the cement slurries' fresh properties, and a correlation between the different fresh state tests (1 - 5) is used to describe the flow behavior of the different systems. In addition, the hardened properties evolution is obtained by compression and fracture tests. The cement paste fresh behavior is used to predict fresh concrete behavior and to inform computational models as a pathway to decrease the number of trials in the design space within the additive manufacturing process of concrete, including coarse aggregates and fiber reinforcement.

Investigation of the Effect of Dynamic Axial Force on the Lateral Response of RC Columns Using Real-Time Hybrid Simulation

Yunbyeong Chae; Seoul National University; South Korea
Jamin Park; Seoul National University; South Korea
Minseok Park; Myongji University; South Korea
Chul-Young Kim; Myongji University; South Korea

Real-time dynamic testing for column members subjected to both lateral and axial forces has been seldom conducted due to the difficulty of real-time axial force control for axially stiff members. Thus, the experimental data showing the effect of time-varying axial force due to the vertical ground motion is quite rare, although most of column structures are subjected to both time-varying horizontal and vertical loads at the same time during earthquake. Recent advance in real-time force control enables this type of test to be conducted. In this study, real-time hybrid simulation (RTHS) for a two-span bridge subjected to both horizontal and vertical ground motions is introduced. A reinforced concrete (RC) pier in the middle of the bridge is experimentally tested in the lab, while the remaining parts are numerically modeled. The time varying axial force of the RC pier due to vertical ground motion was applied by using the displacement-based adaptive time series (D-ATS) force control method along with the use of a flexible loading beam (FLB). The RTHS was repeated by varying the intensity of vertical ground accelerations and the weight of the bridge superstructure. It was found that the gravity load (static axial force) on the RC pier can significantly affect on its lateral behavior. However, the time varying axial force (dynamic axial force) due to the given vertical ground motion did not change the lateral response substantially. More details of test results will be presented and discussed.

Investigation of the Impact of Dynamic Fuel Moisture on Fire and Plume Behavior

Ritambhara Dubey; Florida State University; United States
Neda Yaghoobian; Florida State University; United States

Fuel moisture content is a crucial factor governing fire and plume behavior and thus, guides prescribed fire planning and wildfire management tactics. The fuel moisture content variation depends on the local meteorological variables, soil conditions, and fuel properties. Fire alters the local turbulent wind, temperature, radiation, and relative humidity and consequently the fuel moisture content. The fact that these conditions experience significant variation during fire introduces an element of variability in the fuel moisture that is not understood. In the current study, we seek to investigate the effect of spatiotemporally varying fuel moisture on fire behavior and near-field plume dynamics through computational modeling. By employing an elaborate dynamic fuel moisture model coupled with large-eddy simulation, this study compares the fire behavior and plume dynamics of a heading fire over flat terrain for cases with dynamic and constant fuel moisture content.

Investigation of the Reactivity in Epoxy-Modified Asphalt (EMA) as an Alternative Paving Material for Durable Open-Graded Friction Course (OGFC)

Michael Elwardany; FAMU-FSU College of Engineering, Florida State University; United States
Adrian Andriescu; SES Group & Associates, LLC; United States
Hamzeh Haghshenas; SES Group & Associates, LLC; United States
Panos Apostolidis; Delft University of Technology; Netherlands
Raj Dongré; Dongré Laboratory Services; United States
David Mensching; Federal Highway Adminstration; United States
Jack Youtcheff; Federal Highway Adminstration; United States

There is an interest among several highway agencies around the world to utilize Open-Graded Friction Course (OGFC) as a surface paving layer for various safety and environmental benefits. The oxidative aging in surface layers contributes to the loss of adhesion between binder and larger aggregate particles which in turn leads to raveling which is considered the predominant failure mechanism in OGFC. The Epoxy-Modified Asphalt (EMA) technology is an alternative paving material that may provide a solution to enhance the durability of OGFC. Although the use of Epoxy-Modified Open-Graded Friction Courses (EMOGFC) in New Zealand and the Netherlands has shown promising and superior performance and resistance to raveling, one of the major challenges for the wide implementation of EMOGFC is the lack of comprehensive understanding of the reactivity between epoxy components and the reactive compounds in base binders. This study aims to investigate how the chemistry of the base binders controls the reactivity, effectiveness, and performance of reactive polymer-modified asphalts. To this end, four different base binder sources were carefully selected to represent different chemistry and potential reactivity with epoxy modifiers. Binders were modified with various dosages of epoxy package ranging from 0 to 25% by weight and tested using Bending Beam Rheometer, Dynamic Shear Rheometer's concentric cylinders geometry, Asphalt Binder Quality Test, and Fourier-Transform Infrared Spectroscopy. Results highlighted the limitation of some standard test methods and proposed specification limits when evaluating EMA. The proposed framework showed effectiveness in quantifying reactivity in EMA and in selecting optimal epoxy dosages. Additionally, the study provided a proof of concept for how the blend's reactivity can be optimized by changing the relative concentration of Part B (fatty acids and asphalt flux) in the epoxy package. This study is part of a larger effort to advance the knowledge and state of practice of EMOGFC technology for successful implementation in the USA.

Investigation of Vegetation Shielding Effects on Structural Vulnerability

Aikaterini (Katerina) P. Kyprioti; University of Oklahoma; United States
Joaquin P. Morris Barra; Universidad Católica del Norte; Chile
Chris Irwin; University of Notre Dame; United States
Alexandros A. Taflanidis; University of Notre Dame; United States
Andrew B. Kennedy; University of Notre Dame; United States

Structures across coastlines are susceptible to overland flow due to storm or tsunami waves with such events causing, in many cases, severe damages either at a component level (local failures) or worse at a global level threatening the system's integrity. Shielding of nearshore structures by natural or anthropogenic obstacles has been proven beneficial in such settings, reducing the direct impact of an approaching wave to the structure. In this presentation, an investigation of the dissipation effects offered by vegetation located in front of the structure is performed utilizing hydrodynamic numerical simulations of wave run-up events. A variety of vegetation geometries is examined under different intensity waves, generating a numerical database where different quantities of interest are available such as the applied structural load (either measured as a pressure profile or as a resultant force), the moment flux, the velocities and free surface elevations in a variety of locations within the simulation domain. Based on this database multiple surrogate models (mathematical approximation of the input-to-output relationship) can be trained to offer predictions for different quantities of interest, with the focus here being on the facilitation of efficient structural vulnerability assessments with minimal computational cost, since the multiple calls of the hydrodynamic model in such a setting would be computationally very expensive, if not impossible. Gaussian Processes are used here to offer a direct quantification of the prediction uncertainty that will be leveraged in the examined cases studies, involving the vulnerability assessment of the out-of-plane failure for an infill masonry wall and the derivation of global fragility curves for a reinforced concrete frame. Interesting trends will be revealed with respect to the vegetation geometry and the interactions generated with the shielded structures.

Investigation on the performance of a rolling pendulum isolation system subject to 3D seismic excitations

Esteban Villalobos Vega; University of Oklahoma; United States
Erika Vanderheiden; University of Oklahoma; United States
P. Scott Harvey; University of Oklahoma; United States

Rolling pendulum isolation systems are a popular means of protecting sensitive equipment within buildings, but the performance of these systems subject to tri-directional seismic excitations has not been studied to date. This paper presents an investigation on the seismic response of a rolling pendulum isolation system considering realistic 3D loading. Floor motions are simulated for various locations within two archetypal buildings—a special moment resisting frame (SMRF) and a buckling restrained braced frame (BRBF)—subject to risk-targeted tri-directional ground motions. Both geometric and material nonlinearities within the building models are included, as well as out-of-plain flexibility of the floor slabs. Nonlinear time history analyses performed in SAP2000 are used to realize floor motions at various locations within the building, and the simulated floor motions are imposed on an experimental isolation system using a 3D shake table at the Donald G. Fears Structural Engineering Laboratory at the University of Oklahoma. The isolation system under consideration utilizes the Ball-N-Cone design augmented with a high-damping coating. Tests are run both with and without the inclusion of the vertical excitation component to quantify its effect on the system's behavior and overall isolation performance. The inclusion of vertical excitations has the effect of modulating the effective weight of the isolated object, complicating the inherently nonlinear dynamics of the rolling pendulum isolation system. The results of this study will help to inform and determine the necessary solutions and improvements to overcome possible challenges that are found, so that the reliability of the system under the more realistic 3D demands can be improved.

Irregular architected materials with programmable properties

Ke Liu; Peking University; China
Rachel Sun; Massachusetts Institute of Technology; United States
Chiara Daraio; California Institute of Technology; United States

The properties of architected materials, or metamaterials, depend both on their chemical composition and on the geometry of their microstructure. However, most microstructures in architected materials have been designed as periodic repetitions of selected geometrical motifs. The ability to design irregular microstructures, characterized by disordered and non-periodic architectures, could expand the range of properties achievable and provide fundamental understanding of structure-property relationships. Here, we utilize a bio-inspired framework to generate irregular architected materials and study the distribution of their properties. The method is inspired by the bottom-up growth process of biomaterials, which effectively creates diverse disordered microstructures, while allowing us to control continuously and independently their topology and geometry. We demonstrate the ability to tune elastic properties, by defining probabilistic relationship between growth rules and mechanical properties. We construct a database of microstructures and demonstrate the realization of materials that are robust to damage and control the response to external loading.

Kernel ridge regression based force identification in the time domain

Shuo HAO; The Hong Kong Polytechnic University; Hong Kong
Su-Mei WANG; The Hong Kong Polytechnic University; Hong Kong
Yi-Qing NI; The Hong Kong Polytechnic University; Hong Kong

Force identification in the time domain is one of the classical linear inverse problems in the realm of structural dynamics. Since the problem is generally ill-posed, construction of convergent well-posed approximations to the force is the primary concern. Hence, in this paper, we propose a novel method based on the setting of kernel method solutions to construct an approximation of the force in the reproducing kernel Hilbert space. The approach considers prior information concerning the measurement noise and the correlation properties of force histories, which is ignored by the conventionally utilized regularization techniques. By adopting different types of kernels, the proposed method can embed prior information over the correlation properties. When the Kronecker Delta kernel is considered, that is, without correlation between any force value, the proposed method is proved to be equivalent to zero-order Tikhonov regularization. A numerical example on a truss substructure and an experimental example on a cantilever beam are presented. The results highlight the pivotal role of introducing correlation properties to the prior in the precision of time-domain force identification.

Knowledge Discovery from Post-Storm Reconnaissance Data: From Frequentist Inference to Bayesian Knowledge Graphs

Jordan Nakayama; Auburn University; United States
Daniel Yahya; Auburn University; United States
David Roueche; Auburn University; United States

Climatological hazards, specifically hurricanes and tornadoes, continue to cause widespread impacts to many communities and populations. Major hurricanes have made landfall in the US in five of the last six years, while multiple billion-dollar tornado outbreaks have also occurred over the same timeframe. Improved technologies and research infrastructure have captured vast quantities of perishable data produced by these impacts, re-emphasizing the need for improved techniques for transforming the perishable data into structured data, and for subsequently learning from the data to further our understanding of the performance of structures in windstorms. Past efforts to infer relationships between building performance and influencing parameters can broadly be classified as falling within the traditional frequentist or Bayesian frameworks, including techniques such as logistic regression, decision trees, naïve Bayes networks, and support vector machines. Bayesian updating techniques seem particularly promising as they allow for consideration of prior knowledge, learning from new, possibly incomplete, data, and using a forecasting approach that assigns a probability to the hypotheses. However, there lacks substantive comparisons between the frequentist and Bayesian frameworks with application to both the ability to accurately predict windstorm performance and the ability to infer knowledge from post-windstorm reconnaissance data. The objective of this study is to compare the methods and results of commonly used frequentist and Bayesian methods for both predictive- and inference-focused goals. Models are fit and tested using a new, structured windstorm performance database consisting of 4,483 residential structures from four recent hurricanes and four tornadoes. Features of this combined dataset include the record location, building attributes such as year built and number of stories, component-level damage, and design and event-based hazard estimates for all records. Finally, the feasibility of Bayesian knowledge graphs (e.g., Bayesian Networks), which can more readily blend expert judgement and data-driven sources into comprehensive models, for learning from post-windstorm reconnaissance data is presented and contrasted with more traditional approaches.

Knowledge extraction and transfer in data-driven fracture mechanics

Xing Liu; Georgia Institute of Technology; United States
Christos Athanasiou; Georgia Institute of Technology; United States
Nitin Padture; Brown University; United States
Brian Sheldon; Brown University; United States
Huajian Gao; Nanyang Technological University; Singapore

Data-driven approaches promise to usher in a new phase of development in fracture mechanics, but very little is currently known about how data-driven knowledge extraction and transfer can be accomplished in this field. As in many other fields, data scarcity presents a major challenge for knowledge extraction, and knowledge transfer among different fracture problems remains largely unexplored. Here, a data-driven framework for knowledge extraction with rigorous metrics for accuracy assessments is proposed and demonstrated through a non-trivial linear elastic fracture mechanics problem encountered in small-scale toughness measurements. It is shown that a tailored active learning method enables accurate knowledge extraction even in a data-limited regime. The viability of knowledge transfer is demonstrated through mining the hidden connection between the selected three-dimensional benchmark problem and a well-established auxiliary two-dimensional problem. The combination of data-driven knowledge extraction and transfer is expected to have transformative impact in this field over the coming decades.

Knowledge transfer for life-cycle optimization: Applications to the management of bridge networks and ship structures

Jianda Cheng; Huazhong University of Science and Technology; China
Minghui Cheng; Cornell University; United States
Yan Liu; Huazhong University of Science and Technology; China
Jun Wu; Huazhong University of Science and Technology; China
Wei Li; Huazhong University of Science and Technology; China
Dan M. Frangopol; Lehigh University; United States

Life-cycle optimization attempts to achieve a balance between economic efficiency and structural safety by minimizing life-cycle costs. However, it is computationally expensive because some subroutines such as time-variant reliability analysis, finite element modeling, and network analysis, that may be invoked are computationally expensive. Existing studies have developed numerous methods (e.g., surrogate modeling) to accelerate the subroutines. However, there is a lack of research from the perspective of knowledge transfer. This study first briefly introduces the framework of meta-learning-based surrogate modeling. Using model-agnostic meta-learning, this framework can transfer knowledge from existing surrogate modeling tasks to similar surrogate modeling tasks. This framework is applied to life-cycle optimization. In this study, time-based maintenance and adaptive condition-based maintenance are investigated. The former is performed for a bridge network under deep uncertainties. Attention is paid to the latter. Using meta-reinforcement learning, knowledge learned from adaptive maintenance tasks can be transferred to similar adaptive maintenance tasks. This methodology is applied to the management of engineering fleets. Results of two case studies show that knowledge transfer can significantly accelerate life-cycle optimization.

Cheng, M., Dang, C., Frangopol, D. M., Beer, M., & Yuan, X. X. (2022). Transfer prior knowledge from surrogate modelling: A meta-learning approach. Computers & Structures, 260, 106719.

Large Eddy Simulation of Wind Loading on Elevated Low-rise Buildings

Xiangjie Wang; Louisiana State University; United States
Chao Sun; Louisiana State University; United States
Chunsheng Cai; Southeast University; China

Residential buildings in coastal communities are usually elevated to a certain level to avoid flooding and wave-surge impacts. As a result, the local wind speed increases and the aerodynamics vary. Post-event reconnaissance data show that roofs, walls, and floors of elevated residential buildings suffered from serious structural damage during extreme hurricanes. However, the aerodynamic pressures on elevated buildings are poorly understood and the corresponding design specification is limited. In this paper, the Large Eddy Simulation (LES) techniques are adopted to simulate the wind effects on critical structural components of elevated low-rise buildings. The inflow is generated by both the Turbulence Spot Method (TSM) and Discretizing and Synthesizing Random Flow Generation (DSRFG) method. The Smagorinsky Sub-Grid Scale(SGS) model and the Wall-Adapted Local Eddy-viscosity (WALE) SGS model are adopted to represent the effects of unresolved small-scale eddies. Laboratory testing results from the Florida International University Wall of Wind (WOW) Experimental Facility is used to verify the numerical model. It is found that the inflow generation method, SGS models and the discretization schemes can affect the simulation results and need to be carefully selected. Comparison with laboratory testing result indicates that the LES method can well simulate wind pressures on elevated low-rise buildings.

Large Eddy Simulation of Wind Turbulences Over Non-breaking and Breaking Waves

Tianqi Ma; Louisiana State University; United States
Chao Sun; Louisiana State University; United States

Wind-wave interaction involves wind forcing on the wave surface and wave effects on the turbulent wind structures, influencing the wind and wave loading on structures essentially. Existing research on wind-wave interaction modeling ignores the inherent strong turbulences of wind. The present study aims to characterize the turbulent airflow over breaking and non-breaking wave surfaces. This paper develops a high-fidelity two-phase model for simulating highly turbulent wind-wave fields based on the open-source program OpenFOAM. Instead of modeling waves under uniform wind forcing, inherent wind turbulences are prescribed by imposing a temporally and spatially correlated turbulent wind field at the inlet boundary. The developed model is validated by laboratory data of wave surface under wind driving force and air structure above wave surface measured separately. Then the wind-wave interaction under different wave ages and non-breaking and breaking wave conditions is analyzed. Under non-breaking wave conditions, the research results show that when the inherent wind turbulences are considered, the resultant wind turbulence is strengthened and is the summation of inherent and wave-induced turbulence. The moving waves induce wind turbulence and cause the variation of averaged wind velocities with wave phases. The regions of intense turbulence depend on the relative speed between the wind velocity and wave phase speed. Higher wind velocity induces greater turbulences, and extreme wind forcing could increase the maximum turbulence intensity by 17%. The different relative speeds between wind and wave can cause opposite positive-negative patterns of wave coherent velocities. The wave-coherent velocity is nearly proportional to the wind velocity. Under breaking wave conditions, plunging waves significantly influence wind structures near the wave surface. The plunging wave pushes the air to move forward, and a counterclockwise-rotating vortex is generated, resulting in large turbulence kinetic energy below the wave crest. During the wave plunging process, the maximum turbulence kinetic energy increases by over 50% under different wave ages. After the wave plunges, the average wind velocity near the surface is increased because the energy is transferred from the wave to the wind.

Large-Scale Open-Jet Testing to Meet Field Pressures on a Flat-Roof Building

Aly Mousaad Aly; Louisiana State University; United States
Faiaz Khaled; Louisiana State University; United States

Understanding the aerodynamic performance of structures is fundamental to reducing the recurring structural damage caused by frequent and powerful hurricanes. This paper verifies the unique capabilities of an open-jet wind testing facility by investigating exceptionally large-scale models of the Texas Tech University (TTU) experimental building. The test section can produce wind with flow characteristics that mimic the full-scale atmospheric boundary layer profile. We studied the aerodynamic models at different locations in the open-jet test section under a range of Reynolds numbers. We then analyzed the mean and peak pressures from the open-jet experiments, following the same statistical approach. The paper identifies the suitable width, model size, and location in the open-jet test section to meet the physics at full-scale. The findings demonstrate that the open-jet facility can reproduce realistic mean and peak wind-induced pressures on low-rise buildings. This testing approach will augment the prediction of aerodynamic loads for more wind-resilient structures.

Leapfrog in Fracture and Damage Mechanics inspired by Gap Test and Curvature-Resisting Sprain Energy

Zdeněk Bažant; Northwestern University; United States
Houlin Xu; Northwestern University; United States
A. Abdullah Dönmez; Northwestern University; United States
Anh Nguyen; Northwestern University; United States
Yupeng Zhang; Northwestern University; United States

For sixty-one years after Ray Clough's epoch-making finite element analysis of cracks in Norfolk Dam1, there has been no completely satisfactory computational model for fracture and continuum damage. This is evidenced by recent model comparisons with many distinctive2 fracture tests, which are those that cannot be fitted closely by very different models and include the size effect, shear fracture and the new gap test6,7. The distinctive comparisons demonstrated severe limitations of the phase-field models3,4, dismal performance of peridynamics and severe innate inadequacies of the nonlocal models of integral and gradient types, while the crack band model5 (CBM) with microplane M7 constitutive damage law performed well, though less than perfectly. Compared to all models, including the nonlocal and gradient ones, the CBM is the only one that has non-problematic boundary and crack-face conditions. As it transpired, the CBM performance can be enhanced. As it transpired, the CBM performance be enhanced by introducing an energy, named the sprain energy Φ, which augments the strain energy Ψ and characterizes material resistance to the second gradient tensor of curvature of the displacement vector field, named the sprain tensor. This tensor differs from the strain gradient tensor and, importantly, includes the gradient of material rotation tensor. In FE discretization, the derivatives of Φ yield self-equilibrated sets of nodal or body sprain forces opposing excessive localization of softening damage. Subdividing the material characteristic length into a number of finite elements allows resolving the homogenized (or smooth) strain distribution across the width of the FE crack band. This leads to the smooth Crack Band Model8 (sCBM) which, along with M7, is found to capture the big effect of crack parallel stresses on both the fracture energy and the crack front width, as evidenced by the gap test6,7. Examples of FE fits of distinctive2 data are given.

References:

1. Ray W. Clough (1962). The stress distribution in Norfolk Dam. Structures and Materials Series 100, IER Issue 19, Dept. of Civil Eng., Univ. of California Berkeley (134 pp.) (contract DA-03-050-Civeng-62-511, U.S. Army Engineer District, Little Rock).
2. Bažant, Z.P., and Nguyen, Hoang T. (2023), ``Proposal of a model index, MI, for experimental comparison of fracture and damage models." J. of Engrg. Mechanics ASCE; in press.
3. Bažant, Z.P., Nguyen, H.T. and Abdullah Dönmez, A., 2022, ``Critical Comparison of Phase-Field, Peridynamics, and Crack Band Model M7 in Light of Gap Test and Classical Fracture Tests." J. of Appl. Mech. 89: 061008, 1-26.
4. Bažant, Z.P., Luo, Wen, Chau, Viet T., and Bessa, M.A. (2016). ``Wave dispersion and basic concepts of peridynamics compared to classical nonlocal models." J. of Applied Mechanics ASME 83 (Nov.) 111004, 1-16.
5. Bažant, Z.P., Le, J.L. and Salviato, M., 2021, ``Quasibrittle Fracture Mechanics and Size Effect: A First Course" Oxford UP.
6. Nguyen, Hoang T., Pathirage, M., Cusatis, G., and Bažant, Z.P. (2020). ``Gap test of crack-parallel stress effect on quasibrittle frcture and its consequences." ASME J. of Applied Mechanics 87 (July), 071012-1--11.
7. Nguyen, H.T., Dönmez, A. A., Bažant, Z.P., 2021. ``Structural strength scaling law for fracture of plastic-hardening metals and testing of fracture properties." Extreme Mechanics Letters 43, 101141, 1-12.
8. Zhang, Y., and Bažant Z.P., 2023, "Smooth Crack Band Model (sCBM)—a Computational Paragon Based on Unorthodox Continuum Homogenization." J. Appl. Mech.041007.

Learning and prediction of structure-property relationships of cracked metamaterials via deep neural networks

Yunche Wang; National Cheng Kung University; Taiwan
Yichen Hong; National Cheng Kung University; Taiwan
Weilun Hsieh; National Cheng Kung University; Taiwan

Effective properties of mechanical metamaterials in relation to their microstructure are of great importance for real-world applications. In this work, we adopt the finite element analysis to calculate the effective properties, and use the calculated results as the labeled data to train our deep neural networks (DNN's). In addtion to the finite element numerical data, expeirmental data are also used to train the DNN's. Several neural network frameworks, such as the convolution, Xception and the generative adversarial neural network, are stuided for their efficinecy and accurancy. The trained DNN's then are used to generate microstructures for desired effective properties. It is found that the deep neural networks can be trained with high accuracy, and their predictions on effective properties are in agreement with nuemrical and experimental verfications. Furthermore, crack size and direction during propagation in metamaterials can also be learned and predicted by the deep neural networks. The computational cost in tranditional numerical methods can be largely redcued when well trained DNN's are adopted.

Learning nonlinear material constitutive models using machine-infused mechanics-based model training

Mohammad Valikhani; Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV, USA; United States
Kasra Shamsaei; Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV, USA; United States
Hamed Ebrahimian; Dept. of Civil and Environmental Engineering, University of Nevada, Reno, NV, USA; United States

Predicting the responses of a nonlinear structural is challenging when they are subjected to large amplitude dynamic loadings. Large amplitude loadings can cause materials to yield and represent elastoplastic behavior. Although phenomenological and data-driven models have been developed to represent the elastoplastic constitutive relation, these approaches rely on direct measurement of stress and strain data which are not feasible to acquire for operational structures. We propose machine-infused mechanics-based model updating to learn constitutive materials relations using indirect measurement data. A recurrent neural network (RNN) is adopted to represent nonlinear material behavior, and then RNN model is plugged into the finite element model to predict nonlinear structural responses. Parameters of the infused RNN model are estimated using Bayesian data assimilation method from the measured inputs and outputs of the structure. To validate the proposed method, a machine-infused uniaxial finite element model is developed, and parameters of the infused recurrent neural network are updated from measured input forces and acceleration. Results show that the infused recurrent neural network can be trained with a good accuracy from the indirect measurement data.

Leveraging Automation and Surrogate Modeling to Quantify Post-Earthquake Functional Recovery Performance at the Regional Scale

Laxman Dahal; University of California Los Angeles; United States
Henry Burton; University of California Los Angeles; United States

The ability to perform a comprehensive regional-scale assessment of building inventories is one of the essential components of community resilience which is often defined in terms of the functionality of the supporting infrastructure and their interdependencies. Historically, the mandated design codes for residential buildings have been governed by life-safety standards with no emphasis on economic loss or functional recovery. Recent advancements in the earthquake engineering domain have put in motion a national-level initiative to make functional recovery the baseline seismic performance standard. While the importance of resilience-based design standards has been broadly acknowledged by engineers, scientists, and policymakers, there is a need to develop efficient regional-scale computational frameworks. In this study, various computational strategies are leveraged to facilitate the regional risk assessment of thousands of residential woodframe buildings in the city of Los Angeles. First, an end-to-end tool to automate code-confirming seismic design, perform nonlinear dynamic analysis, assess the economic loss, and estimate functional recovery time using the ATC 138 guideline, is developed. Rooted in the performance-based earthquake engineering methodology, the tool (named "Auto-WoodSDA) is equipped to perform a high-fidelity regional risk assessment. However, the Auto-WoodSDA's reliance on explicit three-dimensional numerical modeling makes it computationally expensive and impractical for simulations that involve large-scale inventories. To alleviate the computational burden, machine learning-based surrogate models are developed by utilizing the Auto-WoodSDA as a data generator. The surrogate models are projected to reduce the computational time by a factor of 10. The efficient surrogate models are then implemented to investigate the effect of key seismic design parameters (e.g., response modification factor (R), importance factor (Ie), and displacement amplification factor (Cd)) on regional scale functional recovery performance.

Life-cycle assessment of long-span bridge's wind resistant performance considering multi-source time-variant effects and uncertainties

Xiaolei Chu; University of California, Berkeley; United States
Wei Cui; Tongji University; China
Lin Zhao; Tongji University; China
Yaojun Ge; Tongji University; China

This paper examines the life-cycle wind-resistant performance of a constructed long-span suspension bridge in the coastal region of China, aiming to quantify the multi-source time-variant effects and uncertainties, and offering a reference for designs of long-span bridges in the future. Randomness from modal frequencies, damping ratios, and identification uncertainty of flutter derivatives (FDs) is considered, then their effects on the probability of flutter failure and the probability of exceeding the predefined buffeting response root mean square (RMS) are discussed. Firstly, the results of full-track tropic cyclone (TC) simulation under various climate warming scenarios are reviewed, then the time-variant probability density function (PDF) of annual extreme wind speed is discussed. Secondly, 10-year modal frequencies and damping ratios of a long-span suspension bridge with a center-slotted section are extracted by fast Bayesian FFT method with structural health monitoring (SHM) data, which are utilized to explore the deterioration rules of structural properties. Thirdly, FDs are modeled from a probabilistic perspective based on complex Wishart distribution, which is identified in the turbulent flow and the frequency domain by Bayesian inference. The posterior distributions of FDs, namely identification uncertainty, are quantified by Markov chain Monte Carlo (MCMC) sampling. We find that for flutter-resistant performance, the time-variant effects (i.e., modal frequencies and PDFs of extreme wind speed) will make the flutter failure probability 7 times larger than the initial value; for the probability of exceeding the predefined buffeting response RMS, however, the time-variant effects will make a negligible difference. We also find that the increasing extreme wind speed is the dominant factor for flutter-resistant performance and its effect is more significant for bridges in the southern part of China.

Light stiff instability-tolerant lattice architectures: the topological efficiency of deep sea sponges

Mazdak Tootkaboni; UMass Dartmouth; United States
Ladan Salari; UMass Dartmouth; United States
Lorenzo Valdevit; UCI; United States
Ardalan Nejat; UMass Dartmouth; United States
Alireza Asadpoure; UMass Dartmouth; United States

We search for optimal architectures of 2D lattice materials with optimality defined as achieving minimum weight while rendering a wide range of axial and shear stiffness combinations and dramatically improved stability performance. The search is formulated in the form of a discrete topology optimization problem where the set of constraints on axial and shear stiffness is augmented with constraints that delay elastic instability beyond a predefined strain threshold on the scale of design cell. The design space is explored via a novel ground structure method that is amenable to handling pseudo-modes due to vanishing elements. We identify hierarchical lattices that are not only significantly more efficient than well-known isotropic lattices but also exhibit order of magnitude improved stability performance. We also show that the proposed framework enables the discovery of lattices with practically the same stiffness, but dramatically different elastic instability tolerance at little or no change in density.

Long term slope stability after the 2019 Williams Flats wildfire

Mustafa Demir; North Carolina State University; United States
Idil Deniz Akin; North Carolina State University; United States

The Western United States experiences a high volume of wildfires every year with increasing frequency. Landslides are one of the cascading effects of wildfires that pose a risk to communities and the environment. Vegetation loss and changes in physicochemical, hydrologic, and mechanical behavior of burned soil and ash cause slopes to be susceptible to landslides. This study presents the evolution in shallow landslide susceptibility of a site burned by the 2019 Williams Flats Fire in the Colville Indian Reservation near Keller, WA, USA over the course of three years after the fire. Suction and water content sensors were installed at two locations, one near a burned tree (i.e., dead tree) and one near an unburned tree (i.e., live tree), at three depths (0.3 m, 0.5 m, and 1 m) to evaluate the temporal changes in water retention and corresponding changes to slope stability. Higher saturation and lower suction values were measured at the dead tree location in the first year. Over time, saturation values at the dead tree converged to those of the live tree, and suction values increased at the dead tree location. As a result, shallow landslide susceptibility of the hillslope decreased over time at the dead tree location, whereas remained unchanged at the live tree location. The temporal increase in suction values at the dead tree location was explained through vegetation regrowth, which was quantified through Normalized Difference Vegetation Index (NDVI) generated using Landsat 8/9 OLI satellite imagery and macropore clogging, which was observed at the site over the years and supported by soil temperature data.

Long-term Salt Spray and Electrochemical Corrosion Behavior of Cu-Al-Mn Shape Memory Alloys and Steel Rebar

Huanpeng Hong; University of Southern California; United States
Bora Gencturk; University of Southern California; United States

The use of Cu-Al-Mn (CAM) shape memory alloys (SMAs) as plastic hinge reinforcement has been shown to be an effective method to improve the seismic performance of bridge columns. Despite research on mechanical property characterization at the material and structural scales, there is limited data on the degradation in the properties of CAM SMAs under harsh environmental conditions; particularly, under long-term corrosion that are relevant for civil engineering structures. This research aims to fill this knowledge gap by studying the long-term corrosion behavior of CAM SMAs in comparison with different types of steel reinforcing bars (rebar) used in bridges. Long-term salt spray corrosion testing of CAM SMAs and four types of commonly used steel rebar, namely, mild steel (MS), high chromium steel (XS), epoxy coated steel (ES), and stainless steel (SS), was conducted up to 1,051 days. Three different diameters (U.S. #3, $\Phi = 9.53$ mm; U.S. #5, $\Phi = 15.88$ mm, and U.S. #10, $\Phi = 32.26$ mm) of steel rebar were considered to determine the effect of bar size on the corrosion rate. Mechanical tests were conducted after the specimens reached predetermined corrosion levels. The critical mechanical properties of CAM SMAs and four steel rebar were extracted and analyzed. In addition, electrochemical tests were performed and the Tafel curves were employed to determine the corrosion rates of CAM SMAs, steel rebar and NiTi SMAs. NiTi alloy was used as a reference for being the more traditional composition used as SEAs. It was found that the corrosion resistance of CAM SMAs is higher than MS and XS, but lower than NiTi SMA, SS and ES. The superelasticity, particularly the strain recovery, of CAM SMAs showed almost no degradation after over three years of corrosion. The experimental data and control groups in this research provide detailed evaluation of the corrosion resistance of CAM SMAs and guides the application of CAM SMAs in civil engineering structures subjected to harsh environmental conditions.

Looking into the Void: Detecting and Evaluating Voids Beneath Concrete Slabs-On-Grade

Linda Seymour; Simpson Gumpertz & Heger; United States

Concrete slabs-on-grade rely on the soil beneath them for support. If that soil settles or washes out, it creates voids that may cause the slab to settle, deflect under load, and/or crack, potentially requiring extensive repairs or causing service issues. In some cases, such as the adaptive reuse of buildings, identification and remediation of the sub-slab voids may be required. In this talk, we review the use of ground penetrating radar (GPR) to detect sub-slab voids, evaluate their impact on structures, and discuss how we implement ongoing monitoring to inform repair and maintenance strategies. We use case studies from several sites in New England to illustrate the challenges in interpreting GPR data and how we correlate the data to other investigation techniques to overcome these challenges.

Lowerbound buckling loads of cylindrical shells with periodic imperfections

Rainer Groh; University of Bristol; United Kingdom

The buckling of cyclindrical shells under axial compression is a classical problem of structural stability. Even after 100 years of research the problem still raises interesting research questions. Much effort has been made over the last few years to investigate the buckling response of cylindrical shells with localised, dimple-like imperfections. This interest stems from the fact that the single dimple forms the unstable equilibrium of smallest energy barrier between the pre-buckling and post-buckling regimes. Here, we turn our attention to a more classical question and investigate the buckling onset of axially compressed isotropic cylinders with periodic, eigenmode imperfections drawn from the Koiter circle with different axial and circumferential wavenumbers i and j, respectively. We use fully nonlinear finite element analyses coupled to a general purpose stability solver that couples path-following with direct pinpointing of the limit point load. Interestingly, all combinations of i and j that fall on the Koiter circle reach the same lowerbound value of buckling load for a given Batdorf number. This allows us to rescale the level of knockdown expected for any Batdorf parameter as a function of imperfection amplitude normalised by cylinder radius. Finally, the computed results show excellent correlation with reduced stiffness predictions, where the membrane stiffness of the shell is degraded in a linear buckling analysis.

Machinability Characteristics of Cu-Al-Mn and NiTi Shape Memory Alloys and Common Steels

Huanpeng Hong; University of Southern California; United States
Bora Gencturk; University of Southern California; United States

Cu-Al-Mn (CAM) shape memory alloys (SMAs) are gaining increasing attention in engineering applications. Compared to other types of SMAs, CAM SMAs have a high low-cycle fatigue life and superelastic limit, and a wide temperature application range. The application of CAM SMAs to improve the seismic performance of buildings and bridges have been widely investigated, particularly as dampers in steel structures and as reinforcement in bridge piers. CAM SMAs also show great potential as actuation materials in cryogenic conditions due to their low martensitic transformation temperatures. The wide range of application of CAM SMAs require machining of the CAM SMA bars for connecting with other structural elements. However, to the knowledge of the authors, there is no comprehensive study on the machineability of CAM SMAs in comparison to other metal alloys. This study presents the methods and results of the first systematic research on the machinability of CAM SMAs. The key machinability characteristics of CAM SMAs, such as chip formation, cutting temperature, tool wear, workpiece surface roughness and diameter deviation were quantitatively determined and compared with conventional NiTi SMAs, and commonly used steel: mild steel (MS) and 304 stainless steel (SS). Effects of a wide range of cutting parameters, such as cutting speed, feed rate, and depth of cut, were investigated. The results from this study demonstrated that the tool wear from machining CAM SMA was close to that of SS and slightly higher than that from machining MS but much lower than of that from machining NiTi.

Machine Learning Algorithm to Predict Axial Stress in Continuous Welded Rails

Matthew Belding; University of Pittsburgh; United States
Alireza Enshaeian; University of Pittsburgh; United States
Piervincenzo Rizzo; University of Pittsburgh; United States

In the study presented in this paper, an application of machine learning methods for the long-term safety of continuous welded rails (CWRs) is presented. Specifically, this study presents the latest findings of a non-invasive monitoring technique to estimate the axial stress and rail neutral temperature (RNT), which is the temperature at which the net longitudinal force is zero, in CWR. Using the lowest modes of vibration and the application of machine learning (ML) on the rail of interest, the power spectral densities in the 0-700Hz range of the vibrations' frequencies are used as input features to predict the axial stress. The proposed technique was tested twice in the field where vibrations were induced with an instrumented hammer on two rail sections with concrete and wood ties. Vibrations were detected with wireless and wired accelerometers with the latter validated for replacement via machine learning prediction comparisons. The RNTs predicted by the neural network were compared and showed very good agreement with the temperature estimated by an independent party that used conventional strain-gage rosettes. Additionally, the impact of excluding boundary condition effects in the experimental data on ML predictions is also explored.

Machine Learning with Microtexture Feature Extraction for Automated Pavement Raveling Classification

Haolin Wang; Georgia Institute of Technology; United States
Yi-Chang (James) Tsai; Georgia Institute of Technology; United States

As the most common pavement distress on the U.S. highway system, raveling causes safety issues. Current pavement raveling condition classification is manual, costly, time-consuming, inconsistent, and dangerous. Promising efforts have been made in the artificial intelligence (AI) practice of automated pavement raveling classification using 2D images or 3D laser technology. However, only macrotexture features, like standard deviation and the average value on image level and patch level, which do not directly contain the spatial information of range images regarding the raveling characters, are extracted from the image in prevailing machine-learning methods to perform raveling classification. This research proposes a methodology for utilizing microtexture features of pavement raveling images to improve the AI application. A workflow is presented to extract microtexture features from 2145 labeled pavement range images and is shown how the extracted features are used to train a Multi-layer Perceptron classifier. Grayscale Level Co-occurrence Matrices (GLCM) are introduced to calculate six descriptors of specific pixel pairs based on relative pixel color contrast: contrast, dissimilarity, homogeneity, Angular Second Moment (ASM), energy, and correlation. Specifically, it is described in detail how the microtexture features at the pixel level are extracted using GLCM to directly input spatial information of range images into the model training process. Support for the proposed method is given regarding the improvement of performance metrics as 3% in overall accuracy, 4% in average precision, 3.5% in average recall, and 3.8% in average F-1 score. Support is also illustrated by a 48% reduction in the underestimation through confusion matrices used for four raveling classifications: None, Low, Medium, and Severe. Support is also given by detailed error analysis showing the extraordinary performance of microtexture features at Severe level ravel classification with a reduction of 33%, whose raw data is sparse due to the actual situation. In recent automated pavement assessment research, the poor performance regarding the essential but limited data of Severe level of raveling classification constitutes a significant bottleneck. It is argued that introducing the microtexture features into machine learning for automated raveling classification is helpful and meaningful in highway maintenance.

Machine Learning- Based Virtual Buoys Model for Live Prediction of Wave Height

Eleonora Maria Tronci; Tufts University; United States
Matteo Vitale; Ørsted; Denmark
Therese Patrosio; Tufts University; United States
Seixas Aldrich; Tufts University; United States
Anela Bajric; Ørsted; Denmark
Babak Moaveni; Tufts University; United States
Usman Khan; Tufts University; United States

In the past few years, the wind energy industry has received increased attention from the research community, given the important policy and funding invested in promoting the transition to clean energy. With the diffusion of offshore wind farms, much interest was drawn to looking for efficient strategies to ensure safe and cost-effective offshore operations. To guarantee that the service vessels navigate safe marine conditions, robust and real-time information about the sea conditions must be available. Wave buoys provide such information and represent key instruments in providing the necessary data for ocean navigation. In the case of malfunctioning buoys, it is necessary to predict the marine information at those locations using virtual models to guarantee a robust and real-time data stream of information. The virtual wave buoy aims to predict the marine information should the data source be faulty or temporarily unavailable. The present work investigates the construction of a universal and computationally efficient virtual wave buoy as a machine learning-based model. The virtual buoy learns the historical relationship between the sea state wave height at an existing network of public buoys and other available measurement devices to reproduce them at the target reference buoy. Different models' prediction performance and sensitivity are investigated, such as Random Forest Regressor, Support Vector Regressor, and Long-Short Term Memory neural network model. The goal is to look for the optimal, easy-to-adapt, and cost-effective solution while reducing the prediction error on the wave height prediction. The model strategy and performance are validated using public buoys from the National Data Buoy Center within the National Oceanic and Atmospheric Administration. The study focuses on two groups of sensors located in Massachusetts. The first collects sensors along the coast north of Boston, and the second group is distributed south of the Cape Cod Bay area.

Machine Learning-Enabled Parameterization Scheme for Aerodynamic Shape Optimization of Wind-Sensitive Structures

Shaopeng Li; University of Florida; United States
Brian Phillips; University of Florida; United States
Zhaoshuo Jiang; San Francisco State University; United States

Aerodynamic shape optimization of wind-sensitive structures is becoming increasingly popular due to recent advances in the effectiveness and efficiency of performance evaluation and optimization techniques. However, shape parameterization, as the first step in the pipeline of aerodynamic shape optimization, still heavily depends on empirical judgment. If not done properly, the resulting small design space may fail to cover many promising shapes, and hence hinder realizing the full potential of aerodynamic shape optimization. To this end, it is important to develop a novel shape parameterization scheme that can reflect real-world complexities while being simple enough for the subsequent optimization process. This study proposes a machine learning-based scheme that can automatically learn a low-dimensional latent representation of complex aerodynamic shapes for bluff-body wind-sensitive structures. The resulting latent representation (as design variables for aerodynamic shape optimization) is composed of both discrete and continuous variables, which are embedded in a hierarchy structure. In addition to being intuitive and interpretable, the mixed discrete and continuous variables with the hierarchy structure allow stakeholders to selectively narrow down the search space based on their own interests. As a proof-of-concept study, shape parameterization examples of tall building cross sections are used to demonstrate the promising features of the proposed scheme. This study could serve as a useful guide for future investigation on data-driven parameterization for aerodynamic shape optimization of wind-sensitive structures.

Machine-learning based optimum retrofit scheme development of FRP column jacketing system for seismically-vulnerable RC building structures

Jiuk Shin; Gyeongsang National University; South Korea

Abstract Many existing reinforced concrete building structures with seismically deficient details in columns have premature column failure. This can be prevented from a fiber-reinforced polymer column jacketing system. This retrofit system provides additional confining pressures to the existing columns to shift a failure mode from shear to flexure. To optimize the retrofit details, structural engineers repeated design, modeling and analyzing processes. To reduce the repeated processes, this paper aims to propose a machine-learning based decision-making approach, which can find optimum retrofit details without additional works. The machine-learning based hybrid approach combined an artificial neural network for rapidly generating seismic responses with a genetic algorithm for optimizing the retrofit details relevant to the confinement (jacket thickness and strength) and stiffness (section enlargement and grout material) parameters. The hybrid approach generally maximized the confinement ratio and minimized the stiffness ratio within pre-determined performance levels because the column stiffness is associated with the geometric conditions (e.g. column section size). Above all, the optimum retrofit schemes can be varied depending on the seismic loading scenarios. The machine-learning based approach derived the retrofit scheme for a low seismic hazard level as the high stiffness ratio (maximizing section enlargement in the jacketing system) with the low confinement effect to enhance the initial column stiffness reducing the seismic responses. However, it maximized the confinement effect related parameters (jacket strength and thickness) rather than increasing the geometric conditions under the high seismic hazard levels to enhance the ductility capacity of the reinforced concrete columns.

Acknowledgments This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Ministry of Science and ICT (MSIT) (No. NRF-2021R1F1A1059976) and by the National Disaster Management Research Institute (No. 2022-MOIS63-003).

Machine-precision, complex-variable implementation of the consistent boundary element method in two-dimensional elasticity

Ney Dumont; PUC-Rio; Brazil

The collocation boundary element method has been recently entirely revisited by the author. Arbitrary rigid-body displacements, as for elasticity of a finite domain, are naturally taken into account, and traction force parameters are always in balance independently of problem scale and mesh discretization. For generally curved boundaries, the correct definition of traction force interpolation functions enables the enunciation of a general convergence theorem, the introduction of patch and cut-out tests for precision and accuracy assessments, and, most important, a considerable simplification of the numerical implementations. The formulation is extremely simple to code for two-dimensional elasticity problems in terms of a complex variable, with precision only limited by the machine and less liable to round-off errors than its real-variable counterpart: precision is only conditioned by the Gauss-Legendre quadrature of the regular parts of the integrands. We present the formulation and assess results for topologically highly challenging problems, with source-field distances arbitrarily small – far smaller than deemed feasible in continuum mechanics, as we resort to nothing else than the problem's mathematics.

Manifold Learning to Map Amorphous Microstructural Features to Local Yield Stress

Rahul Meena; Johns Hopkins University; United States
Spencer Fajardo; Johns Hopkins University; United States
Michael D. Shields; Johns Hopkins University; United States
Michael L. Falk; Johns Hopkins University; United States
Dimitris Giovanis; Johns Hopkins University; United States
Thomas J. Hardin; Sandia National Laboratories; United States
Michael Chandross; Sandia National Laboratories; United States
Yannis Kevrekidis; Johns Hopkins University; United States

Amorphous solid failure originates from local plastic rearrangements in the atomic configurations of the material during shear-induced deformation. By assessing the incremental stress needed to cause a local rearrangement, the Local Yield Stress (LYS) approach was recently developed to probe local regions and quantify their susceptibilities to plasticity. While this methodology shows great potential to enhance our understanding of plastic deformation in amorphous solids, because of its computationally demanding nature it is not a viable method for predictive modeling. We propose a manifold learning-based framework to extract microstructural descriptors from atomistic configurations. More specifically, we deploy Diffusion Maps (DMaps, a nonlinear manifold learning technique) to systematically extract low-dimensional structural features from high-dimensional atomic configuration data. We then relate this structure to the LYS approach. In this manifold learning method, each data point corresponds to a geometric conformation of atoms, and thus a meaningful similarity measure between configurations can be devised for capturing the “distance” between two points. We utilize the newly developed Gaussian Integral Inner Product (GIIP) distance metric to measure this similarity. This metric addresses important issues such as noise sensitivity, continuity, smoothness, radial cutoff, and permutation and rotation invariance, making it robust for measuring similarity in randomly distributed atomic structures. We first demonstrate its practicality by identifying defects in a two-dimensional hexagonal crystal with crystallographic defects. Finally, we apply this method to a two-dimensional binary glass-forming system that is deformed with an incremental Athermal Quasistatic Shear (AQS) method. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525 (SAND2022-1056 A).

Mapping component reliabilities to system reliability in flange-angle partially restrained steel moment connections

Trisha Chakravorty; Indian Institute of Technology Kharagpur; India
Aritra Chatterjee; Indian Institute of Technology Kharagpur; India
Baidurya Bhattacharya; Indian Institute of Technology Kharagpur; India

Steel moment connections comprising components such as bolts, welds, plates and angles are part of the load path in lateral moment-resisting frames. Individual limit states as per codal provisions are used to design each component. This, however, ignores system reliability of the connection as a whole, which should be the true indicator of its performance, and which has not received adequate attention in the literature. Connection systems are neither purely series nor parallel systems. Much of the mechanics remain undiscovered today, as do the exhaustive limit states that may potentially contribute to system failure. This work outlines a methodology to estimate system reliability of existing steel connections which have been designed using component-based codal provisions. The methodology is illustrated using a flange-angle partially restrained connection configuration connecting a beam to a column with top and bottom seat angles bolted to beam flange and column flange. A fault tree including all possible modes of failure represents the load sharing network topology of the connection system. Geometrically and materially nonlinear finite element analysis is performed on several combinations of beam-flange and column-flange bolt diameters. Apart from four reliability elements recognized by codes—shear in beam-flange bolts, tension in column-flange bolts, tension in horizontal and flexure in vertical leg of angle—two additional limit states are identified: flexure at angle corner and tension in beam-flange bolts. Flexural demand is increased monotonically up to failure to obtain moment-rotation curves and governing limit states. System parameters (beam-flange and column-flange bolt diameters) are modified such that the analysis captures the (random) most critical limit state for system failure initiation. Stochastic simulations with random yield strengths and bolt diameters are performed to obtain sets of ultimate moment-carrying capacities which are convolved with an assumed load distribution curve to estimate system reliability. A three-dimensional system reliability surface is plotted with component reliabilities of beam-flange bolts and column-flange bolts and system reliability on the three axes. Once a target system reliability is set, system reliability surfaces may be used to optimize component reliabilities using a system reliability sensitivity algorithm. The results indicate that current standards are marginally conservative for the specific load sharing network topology studied. For various connection topologies used in practice, a target system reliability may be set and the proposed methodology applied thereafter to update component design provisions and modify partial safety factors, which could eventually be incorporated into design standards.

Mapping wildfire ignition probability with ensemble-based machine learning models

Qi Tong; Johns Hopkins University, Department of Civil and Systems Engineering; United States
Thomas Gernay; Johns Hopkins University, Department of Civil and Systems Engineering; United States

As wildfires are becoming increasingly destructive, improved wildfire risk management approaches are needed to respond to the rapid changes in climatic and anthropogenic factors that exacerbate the risks to communities. In California, about 6,500 fires occurred and burned 1.7 million acres of land on average over the last five years, causing a dominant threat to the ecosystem, communities, and human beings. To advance wildfire risk management, there is a crucial need for accurate identification of wildfire-inducing drivers, prediction of spatial distributions of wildfire ignitions, and understanding of effect of changes in drivers on ignition probabilities. While improvements in data collection and data analysis have recently enabled progress in these areas, important challenges remain as wildfire ignitions depend on the interconnection of many factors at a fine spatial resolution. Besides, prediction of wildfire ignition is complicated by the imbalanced nature of the data, where the non-ignition instances far outnumber the ignition instances. To address the issue of imbalanced data, this study proposes an ensemble-based machine learning model for the binary classification of wildfire ignitions. An area of 24,867 km2 in northern California is chosen as the study area with a spatial resolution of 3 km by 3 km. The data, which was collected for the study area at a daily resolution from January 2014 to May 2022, includes 76 drivers that cover topographic, land cover, anthropogenic, and weather data. The ensemble-based model is built on seven base classifiers including Random Forest, Support Vector Classifier, DecisionTree, MLP classifier, AdaBoost, LogisticRegression, and XGBoost. The results indicate that the Random Forest model outperformed other base classifiers when using a threshold of 0.65 for binary classification. The model achieved a recall of 0.67 and a specificity of 0.87, surpassing the performance of previous studies on wildfire ignition prediction. Feature importance analysis shows that the Topographic Wetness Index is the most important climatic predictor, while population density and land cover development are also highly rated. However, temperature, wind speed, humidity, and precipitation are not found significant individually in influencing ignitions. Comparison of yearly average of computed daily probabilities with ignition data shows that the model accurately captures the spatial pattern of ignitions, which can reveal high-risk areas. The model is then used in a sensitivity analysis to assess the effect of variations in climatic and anthropogenic predictors on the frequency of wildfire ignitions, revealing increases in ignition probabilities associated with these changes. The model presented in this study can be used to map wildfire ignition risk under changing climatic and anthropogenic conditions, to support wildfire risk management.

Material design for thermal regulation in vascular systems using topology optimization

Kripa Adhikari; University of Houston; United States
Kalyana Babu Nakshatrala; University of Houston; United States

Bio-inspired thermal regulation—fluid flow through a network of embedded vesicles—has been central to the success of several modern technologies: solar probes, hypersonic aircraft, high-power antennas, microelectronics—and the list goes on. Mathematical-driven design plays a crucial role in enhancing efficiency, realizing new functionalities—and even multi-functionalities within a single system, and minimizing costly experimentation. Past and contemporary research efforts focus on vasculature layouts (e.g., spiral, serpentine) and selecting the flowing fluid system (e.g., fluid properties, flow rates). However, the design of the host material itself is not addressed adequately. Our research presents a material design framework—utilizing topology optimization—that considers the host material's thermal conductivity as the design variable. Besides minimizing the mean surface temperature: a popular objective function, alternative objective functions, such as extremizing the rate of dissipation—which has deep thermodynamic underpinning, have been explored. Using representative numerical results, we: (1) Show the efficacy of the proposed material design framework. (2) Compare the material layouts under various objective functions. (3) Describe the modulation of the temperature field by the optimal designs. The main finding is that thermal conductivity could improve thermal efficiency but not always. The proposed mathematical design framework and newfound knowledge will benefit researchers and practitioners in thermal regulation, with far-reaching applications in aerospace, microelectronics, and military sectors.

Maximum principle preserving meshfree methods for linear elliptic equations via nonlocal relaxation

Xiaochuan Tian; UC San Diego; United States
Qihao Ye; UC San Diego; United States

We design a maximum principle preserving meshfree finite difference method for linear elliptic PDEs on point clouds via a nonlocal relaxation method. The key idea is a combination of a nonlocal integral relaxation of the PDE problem with a robust meshfree discretization on point clouds. Minimal positive stencils are obtained through a linear optimization procedure that automatically guarantees the stability and, therefore, the convergence of the meshfree discretization. A major theoretical contribution is the existence of consistent and positive stencils for a given point cloud geometry. We provide sufficient conditions for the existence of positive stencils by finding neighbors within an ellipse (2d) or ellipsoid (3d) surrounding each interior point, generalizing the study for Poisson's equation by Seibold in 2008. Our result represents a significant improvement in the stencil width estimate for positive-type finite difference methods for linear elliptic equations in the near-degenerate regime (when the ellipticity constant becomes small), compared to previously known works in this area. Numerical algorithms and practical guidance are provided with an eye on the case of small ellipticity constant. Numerical results will be presented in both 2d and 3d, examining a range of ellipticity constants including the near-degenerate regime.

Measurements of Rate Effects on Damage and Fracture of Different Ultra-High Performance Concretes

Aidan Carlson; University of Maine; United States
Eric Landis; University of Maine; United States

An experimental fracture study was performed on different types of ultra-high performance concrete (UHPC) with the objective of measuring the changes in damage and cracking patterns as a function of loading rate. The specimens consisted of 50-mm diameter cylinders of UHPC prepared with hooked steel fibers, steel wool fibers, and a combination of steel wool and hooked steel. Specimens were loaded in a split-cylinder configuration at three loading rates ranging from quasi-static to drop weight impact. Each specimen was scanned using x-ray computed tomography (CT) both before and after loading such that internal damage could be measured. Damage measurements were made through a 3D analysis of load-induced crack area using a hybrid edge-detection/connected components analysis. 3D digital volume correlation was applied to measure strains such that damage below the crack detection threshold could be inferred. Preliminary results show quantitative differences in size of damage zone, including number of crack branches and crack widths as a function of loading rate. Such results can be used to tune and validate computational fracture models for such materials.

Measuring 3D Torsional Displacement of Structures by Computer Vision

Mohammad Vasef; University of Central Florida; United States
Mostafa Iraniparast; University of Central Florida; United States
Lin Chen; Tongji University; China
Peng "Patrick" Sun; University of Central Florida; United States

Evaluating the structural performance and monitoring their structural health conditions by vision-based methods have gained significant attention in recent years. Many existing studies are related to obtaining one- or two-dimensional structural displacements, while a limited number of researchers worked on measuring 3D displacement using computer vision techniques. Recently developed vision-based methods such as binocular camera system, motion capture system, physics-based graphic models, structure from motion, and UAV-based infrared sensors are utilized to measure 3D displacements of structural members. However, the methods were validated under some specific conditions with limitations, such as rigid members, static loading, or post-condition assessment. Although efforts have been made to measure 3D displacement of structures using vision-based methods, there are only few research works focused on calculating torsion of a structure employing computer vision algorithms when the structure is subjected to dynamic loads. Therefore, a small-scale aluminum structure instrumented with both vision-based sensors and conventional accelerometers is investigated in this study. The evaluation of the proposed vision-based method is performed in capturing the 3D displacements and torsional movements of structures. In order to measure the torsional displacement of the structure, an experiment is designed with the torsional dynamic mode induced while subjected to a dynamic load from the shake table. In the vision-based method, multiple cameras are used to monitor structural vibration. Checkerboard calibration and Marchand's pose estimation method are used to obtain camera parameters (e.g., intrinsic, extrinsic) for displacement computation. Preliminary results of this study indicate that the proposed vision-based approach is able to capture the torsional movement and 3D displacements of the structure with satisfactory accuracy.

Mechanics of bioinspired and hierarchical tape-springs

Kristiaan Hector; Purdue University; United States
Phani Saketh Dasika; Purdue University; United States
Adwait Trikanad; Purdue University; United States
Julian Rimoli; University of California-Irvine; United States
Nilesh Mankame; General Motors; United States
Pablo Zavattieri; Purdue University; United States

Due to the geometric complexity, and because of their snapping behavior, smooth tape-spring are well suited for potential applications in architected materials; specially for energy absorption and impact protection. Inspired by previous work done on tape-spring and biological materials, we analyze the mechanical behavior of a new family of bioinspired tape-springs and architected materials. In this talk, I am going to present some of our recent advances understanding the addition of geometrical features to improve the mechanical properties of these materials. This includes computational modeling and experiments, and some initial investigation on the application of machine learning.

Mechanics of nanomaterials from first principles

Phanish Suryanarayana; Georgia Institute of Technology; United States

1D and 2D nanostructures/nanomaterials have been the subject of intensive research due to their exciting and novel mechanical, electronic, optical, and thermal properties, which have a number of applications including nanoelectromechanical devices. However, a complete and accurate characterization of many of their properties have been lacking, which limits their technological use. In this talk, the speaker will discuss the development of a novel symmetry-adapted formulation of ab initio density functional theory (DFT) for studying the response of nanomaterials to bending and torsional deformations. In addition, the speaker will discuss a number of physical applications where this formalism has proven to be extremely powerful, including strain engineering and flexoelectricity.

Mechanistic Mapping of Random Fields for Stochastic FE Simulations of Quasibrittle Fracture

Josh Vievering; University of Minnesota - Twin Cities; United States
Jia-Liang Le; University of Minnesota - Twin Cities; United States

Quasibrittle materials often exhibit complex damage mechanisms, such as distributed damage and damage localization, and the transition between them, during the loading process. The localization instability gives arise to the spurious mesh sensitivity in FE simulations of quasibrittle fracture. This study focuses on the issue of mesh objectivity in stochastic FE simulations. The fundamental problem to address is the treatment of random fields of material properties within the FEM framework. In SFEM, material properties are represented by random fields featuring spatial correlations. These random fields must be mapped to the FE mesh (Gauss points). The appropriate method of mapping remains an unsolved question.

The present model introduces physics-based local mapping methods designed to mitigate spurious mesh dependence within a continuum damage mechanics framework. Two localization parameters are used to guide the energy regularization of the constitutive law for each element. These parameters also guide the transition between distributed and localized damage by adjusting the size and location of the damage band within each finite element. The underlying fields of fracture energy and strength properties are then mapped to the Gauss points by averaging over the damage band within each finite element.

The model is applied to simulate the stochastic failure behavior of quasibrittle structures of different geometries featuring different failure processes including damage initiation, localization, and propagation. It is shown that direct local mapping and local averaging over the entire element result in strong mesh dependence on the predicted statistics of structural strength. Mechanism-based mapping of underlying fields of material properties to FE mesh is necessary for mitigating the spurious mesh sensitivity in stochastic FE analysis of quasibrittle fracture.

Mesoscale logic mediates microscale chatter and scientific discovery

Roger Ghanem; University of SOuthern California; United States
Zheming Gou; University of Southern California; United States

We explore the task of extracting useful information from a database. The database is constructed from either numerical or physical experiments, or a combination thereof. We are in particular interested in extracting information that is useful for engineering design and/or scientific discovery. This information can be in the form of specific numerical values or rules. While we may have a well-grounded understanding of the fundamental physics underlying the database, the quantities of interest to us are distinct from the field variables and are typically not governed by known equations, nor can we formulate closure arguments in support of such equations.

Examples of quantities of interest include the location of lagrangian coherent structures in a combustion chamber, or the strain energy absorbed in the glass fibers of a composite material at failure, or a specific sequence of events that triggered power outages in various parts of the country during extreme weather events.

We describe a number of new statistical approaches for inference in such scenarios. These approaches combine data-driven model synthesis with embedded stochastic representations to discover and characterize joint observables relevant to our ultimate inference. These approaches successfully tackle the ``small data'' challenge, the ``non-Gaussian'' challenge, and the ``non-stationarity'' challenge.

Methods of Inspection of Deteriorated Steel Beam Ends using LiDAR & 3D Scanning

Aidan Provost; University of Massachusetts Amherst; United States
Shahrukh Islam; University of Massachusetts Amherst; United States
Georgios Tzortzinis; Technische Universität Dresden; Germany
Chengbo Ai; University of Massachusetts Amherst; United States
Simos Gerasimidis; University of Massachusetts Amherst; United States

Methods of bridge inspection tend to be very laborious and can create many sources of error and variability depending on the damage and accessibility on the bridge. Typical inspection methods on a steel bridge involve the use of instrumentation such as ultrasonic thickness gauges or slide calipers to measure the remaining thickness of the web and flange of a steel beam. Steel beam end corrosion due to water, ice melt chemicals, and malfunctioning expansion joints greatly contribute to section loss and other deterioration among bridges in New England. In the current research work, our team utilized LiDAR and other scanning technologies in order to perform this section loss measurement and to capture the corrosion/damage pattern present for a given beam end. Using our in-house created codes and methods, a thickness contour can be generated and the capacity and failure mode of a deteriorated beam end to be estimated. The resulting contours and heat maps we generate are tremendously detailed and are the result of millions of points extracted from point clouds. We have found that delamination and paint directly impact the scans we conduct and are factors that can lead to error in the mechanical and simulated capacity estimation.

The work is ongoing and our group is utilizing several scanners, methods, and scanning components to investigate the impacts they have on the inspection results. With our vast population of corroded beams on site, we are able to gather extensive data for the deteriorated beam ends and load test them to confirm the capacity and failure mode of the beam. Additionally, the scanning data continues to help with exploration of capacity estimation via the use of AI. Finally, we are utilizing corrosion contours to identify areas of heavy corrosion where additive manufacturing is being explored as a method of beam end repair.

Micromechanical Analysis of Materials with Complex Microstructures: Automated Modeling and Deep Learning Algorithms

Soheil Soghrati; The Ohio State University; United States
Salil Pai; The Ohio State University; United States
Pengfei Zhang; The Ohio State University; United States
Balavignesh Vemparala; The Ohio State University; United States

A integrated computational framework relying on virtual microstructure reconstruction, parallel mesh generation, and deep learning algorithms will be presented for predicting/simulating the multiscale failure response of materials. A NURBS-based virtual reconstruction algorithm is developed for synthesizing heterogenous material microstructures by packing arbitrary shaped inclusions, morphologies of which are extracted from imaging data such as micro-computed tomography images. A genetic algorithm (GA) based optimization phase is then utilized to replicate target statistical microstructural descriptors such as the volume fraction, spatial arrangement, and orientations of embedded inclusions. We also introduce a new AI-based approach relying on Deep Convolutional Degenerative Adversarial Networks (DCGAN) for the virtual reconstruction of complex biomaterial microstructures. Conforming finite element (FE) meshes are generated using a non-iterative meshing algorithm, coined Conforming to Interface Structured Adaptive Mesh Refinement (CISAMR), which transforms an initial structured mesh into a high-quality conforming mesh. CISAMR can handle problems with highly intricate geometries, including material interfaces with sharp edges/corners, as well as mixed-mode fracture problems involving crack merging. We show the application of this integrated reconstruction-meshing framework, together with deep learning algorithm, for predicting the failure response and fatigue life of a variety of materials systems, including particulate composites, fiber-reinforced composites, and biomaterials. Moreover, we show how these algorithms can be used in the realm of computational biomechanics for creating digital twins of human vertebra and predicting the risk of vertebral compression fracture in cancer patients with spinal metastasis.

Micromechanics based homogenization of truss lattices with experimental validation

Kehinde Omotayo; Tennessee State University; United States
Samal Aminashairi; Tennessee State University; United States
Ranganathan Parthasarathy; Tennessee State University; United States

A homogenization scheme has been developed to compute effective elastic properties for truss lattices using an interpolation scheme to develop the required continuum-to-discrete mapping rules for deformation. In the case of bending-dominated truss lattices, for hinged nodes, the lattice reduces to a mechanism for which the individual member rotations in response to deformation at the boundary can be determined from kinematic compatibility alone. For fully rigid nodes, the affine deformation yields fairly accurate results for rotations and axial strains of individual truss members. For a general case, the continuum-to-discrete deformation mapping rule is developed using (a) interpolation between the hinged nodes case and the rigid nodes case and (b) enforcing finite stiffness under axial strain. Using this mapping scheme, strain concentration tensors are developed for individual lattice members in a representative volume element. Subsequently, the granular micromechanics approach is used to homogenize the discrete lattice to an effective classical continuum. The approach has been applied to study different planar lattice microstructures such as diamond, hexagon, re-entrant honeycomb etc. under plane stress condition. It is known that for bending-dominated lattices, affine mapping yields effective elastic properties that differ by orders of magnitude from the true behavior. The scheme developed here is shown to give effective properties that match well with the corresponding full-resolution finite element solutions for both stretch-dominated as well as bending-dominated lattices. Furthermore, in contrast to numerical methods such as finite element approach, it can be used to determine closed form relationships between effective elastic properties and lattice geometry for a given material of construction in a micromechanics framework. Thus, the proposed scheme can be used to identify potential lattice designs for target effective elastic properties. Experimental validation of the interpolation scheme proposed has been performed using monotonic displacement-controlled testing of 3D printed planar truss lattices. The rotational stiffness at lattice nodes was controlled by means of pantographic design.

Micromechanics-guided design of functional cementitious composites for 3D printing

Hongyu Zhou; University of Tennessee, Knoxville; United States
Adam Brooks; University of Tennessee, Knoxville; United States
Zhenglai Shen; Oak Ridge National Laboratory; United States

This research delineates the feasibility of incorporating microencapsulated functional additives into 3D printable cementitious composite materials. A comprehensive experimental program was carried out to evaluate the impacts of encapsulated functional additives on the printability, microstructures, mechanical and thermal properties of cementitious 3D printing 'inks'. Results showed that micro-sized functional additives affected the printability of the cementitious ink material based on its physical properties (e.g., particle size) and volume loading. The results also showed that the inclusion of microencapsulated functional additives influence the printing parameters. In general, the inclusion of higher volume contents necessitates a higher extrusion rate to achieve a desirable extrudability.

Micropestress Theory for the Simulation of Mechanosorptive Effects in Wood

Susan Alexis Brown; Northwestern University; United States
Danyang Tong; Northwestern University; United States
Hao Yin; Northwestern University; United States
Gianluca Cusatis; Northwestern University; United States

Mass timber has gained increasing focus as a sustainable alternative to concrete structures, and recent innovations have allowed timber buildings as high as 25 stories. However, while critical aspects such as fire safety have been studied thoroughly, other facets such as the long-term material performance have been neglected. True sustainability must consider the full service life of a building, including its time-dependent behavior. Deformations in timber elements undergoing these time-dependent effects, namely creep, will have notable implications on the serviceability of a building, and will limit the lifespan of a structure if not accurately predicted. This study proposes a comprehensive model for predicting moisture-dependent creep in timber, considering both shrinkage/swelling and mechanosorptive effects, based on the theory of microprestress in partially saturated porous materials. The model is implemented numerically using a Kelvin-chain approximation for basic creep and mid-point Newton-Raphson integration for mechanosorptive effects, resulting in a computationally efficient approach. Results show the model is able to fully capture the effects of moisture cycling, including effects of hygrothermal gradients. Using both calibrated and estimated parameters the model also predicts with reasonable accuracy the long-term moisture-dependent creep in structural-scale timber elements.

Microstructure and mechanical properties of brucite recovered from reject brine via different precipitating agents

Inderjeet Singh; New York University Abu Dhabi; United Arab Emirates
Rotana Hay; New York University Abu Dhabi; United Arab Emirates
Kemal Celik; New York University Abu Dhabi; United Arab Emirates

Reactive magnesium oxide cement (RMC) is a promising cementitious binder and alternative to ordinary Portland cement (OPC). RMC is primarily produced using two methods: (i) dry route by calcination of magnesite and (ii) wet route by calcination of precipitated brucite (Mg(OH)2 from concentrated brines (e.g., reject desalination brine). However, direct utilization of brucite as a construction material could further reduce the associated CO2 emissions due to the elimination of the calcination requirement to form MgO. Therefore, this study investigates the performance of brucite recovered from reject brine. In the present work, brucite was synthesized from reject brine using different precipitating agents (calcium oxide, sodium hydroxide, ammonium hydroxide, and ethanolamine). The obtained brucite powders were characterized by their microstructure and specific surface area. Compacted pellets of the brucite powders were carbonated under 20% CO2 and 80% RH at 30 °C curing conditions for compressive strength development. This study confirms that brucite synthesized from reject brine possesses the ability to sequester CO2 and attains a compressive strength in the order of 30 MPa, making it a promising and sustainable material for construction applications.

Microstructure transitions from stress field latent features extracted by a Variational Autoencoder

Daniel Chou; Georgia Tech; United States
Chloe Arson; Georgia Tech; United States

Homogenization requires a description of the microstructure by means of inclusion models and inclusion-matrix interaction laws. Inclusions are often defined as cracks, pores, crystals or grains, because these microstructure features can be identified experimentally by imaging. However, there is no guarantee that these physical features are the most relevant to the properties that are being homogenized - typically, the stiffness tensor. Additionally, physical features are altered by localizations, e.g., when cracks coalesce or when pores collapse, which makes it impossible to define a Representative Elementary Volume (REV) that can hold for any loading path. The overarching goal of this research is to design Artificial Intelligence (AI) algorithms to determine the microstructure features that are the most significant to describe the mechanical behavior of a material REV. Here, we present a prototype deep learning model to detect the features that control the mechanical behavior of 2D composites made of a solid matrix, aggregates and cracks. The data set is created numerically, by generating random distributions of aggregates and cracks, and then meshing the domain. Compression loading paths are simulated with the Finite Element Method (FEM), and stress maps are extracted at several loading steps. A prototype Variational Encoder (VAE) is designed to encode these stress maps as vectors of latent features. The decoder that reciprocates the VAE is used to reconstruct stress map series to augment the input data set. The series of latent feature vectors are analyzed to detect any change in feature components or ranking during the loading paths. Detecting these microstructure transitions will be useful to understand the stress regimes that call for different inclusion models in the homogenization theory. Furthermore, we iteratively seek the physical fabric descriptors that best correlate with the latent feature vectors identified by the VAE. This will allow us to determine the fabric tensor variations that are the most significant to explain the variations of the stress tensor in the microstructure. We also propose a strategy to encode time/loading sequences of latent vectors (i.e., latent vectors obtained at consecutive loading steps during the FEM simulations) to gain a more fundamental understanding of the precursors of microstructure transformation upon mechanical loading. To do this, we envision using either a time series analysis or a random forest model. A drastic change in some components of latent fabric vectors indicates that the definition of the REV needs to be adjusted to the emerging significant features, so as to ensure statistical representativity of the microstructure. Future efforts will be dedicated to more complex stress paths and chemo-hydromechanical couplings.

Model-based Unknown Input Estimation via Partially Observable Markov Decision Processes

Wei Liu; National University of Singapore; Singapore
Zhilu Lai; HKUST(GZ); China
Charikleia Stoura; ETH Zürich; Switzerland
Kiran Bacsa; ETH Zürich; Singapore
Eleni Chatzi; ETH Zürich; Switzerland

In this research, we propose a new method for estimating unknown inputs, referring to loads acting on engineered systems. The estimation of unknown inputs is of significance in the context of condition monitoring, since it conveys information on the nature of operational loads the system is exposed to and the corresponding system reaction. Assuming a known or learned system model, we propose a method to identify those system inputs that reproduce the measured outputs, in the form of a Partially Observable Markov Decision Process (POMDP) problem. This problem is then solved using well-established POMDP planning algorithms, specifically the cross-entropy method, which is chosen due to its efficiency and robustness. The proposed method is demonstrated on simulated dynamical systems for structures with known dynamics, as well as a real-world wind turbine with learned dynamics obtained through Neural Extended Kalman Filters (Neural EKF), a deep learning-based method for learning stochastic dynamics, previously proposed by the authors. The results of this study demonstrate the potential of this new approach in improving the safety and performance of engineered systems in the field of structural health monitoring. This method can be leveraged to identify the loads acting on the structure during its operation, which can be used to ensure safety but also for improving the design of structural systems.

Modeling Degrading Hysteretic Systems under Unceratinty with a Bi-fidelity DeepONet

Subhayan De; Northern Arizona University; United States
Patrick Brewick; University of Notre Dame; United States

Data-driven models have been increasingly popular choices for representing non-linear mechanical and dynamical systems. The popularity of these models arises in part from their ability to capture wide variety of complex, non-linear phenomena, such as hysteretic systems that are also subject to degradation. However, even considering this advantage, numerical simulations of complex nonlinear phenomena are often computationally expensive, while experimental measurements are often limited. Conversely, there exists a multitude of relatively low-fidelity representations of these systems, such as analytical descriptions, that capture important aspects of the nonlinear behavior without providing high degrees of accuracy.

This study presents a bi-fidelity approach to modeling degrading hysteretic systems wherein the focus is on modeling the discrepancy between the true system's nonlinear response and some low-fidelity representations. The discrepancy term is modeled through the use of a deep operator network (DeepONet), a type of neural network architecture well-suited to modeling highly complex nonlinear operations. The advantage of this modeling paradigm is that it leverages a low-fidelity model to create numerous network inputs while requiring a smaller data set from the true nonlinear system for training. This approach is applied to two building models of different complexity, one with 4 degrees-of-freedom (DOFs) and the other with 100 DOFs, each equipped with base-isolation devices and subject to different seismic excitations. Further, the results demonstrate that this approach can also handle parametric uncertainty within the nonlinear models.

Modeling fatigue overload behavior in microstructurally short cracks: connecting initiation and long crack behavior

Robert Fleishel; University of Tennessee, Knoxville; United States
Stephanie TerMaath; University of Tennessee, Knoxville; United States

Tensile overloads are known to cause fatigue damage sequencing effects at several stages of material life. In long fatigue cracks, an overload results in a net reduction in crack growth rate, whereas in the crack initiation stage the same overload can accelerate damage. A thorough understanding of the effects of an overload on a short fatigue crack, and under what conditions the transition from accelerating to slowing damage occurs, is currently lacking. A computational short fatigue crack model using crystal a plasticity finite element method and microstructurally sensitive measures of driving force, previously used to simulate short fatigue crack behavior, is applied to study the effects of overloads on cracks of varying lengths. Mechanisms dictating sequencing effects at both crack initiation and long crack growth, such the interaction of crack tips with microstructural barriers, crack closure, and residual stresses, are considered for cracks ranging from grain-scale to linear elastic fracture mechanics validity. Model development, current results, and experimental comparisons are discussed.

Modeling fracture propagation in porous media with assumed enhanced strain method

Fushen Liu; Research Center of Coastal and Urban Geotechnical Engineering, Computing Center for Geotechnical Engineering, Zhejiang University, Hangzhou, China; China

Modeling fracture propagation in porous media is essential to better understand the complex subsurface processes, such as hydraulic fracture, geological fault reactivation, geothermal energy extraction, CO2 sequestration, waste water management and so on. In this talk, the assumed enhanced strain (AES) finite element method is proposed to simulate the fracture evolution in porous media, where air, water and other liquids may exist inside the pore space, and heat transfer may also be an influencing factor to be considered. The method enriches discontinuous functions into the strain fields, allowing fractures to evolve inside the elements. The enriched degrees of freedom (DOFs) can be statically condensed at the Gauss point level, which means the method does not increase the total amount of global DOFs. The satisfaction of balances of mass, energy and linear momentum inside the fracture and bulk rocks is imposed by standard Newton's method. The method is capable of investigating the interactions between water saturation front, heat front and fracture front, as the fracture propagates in the porous media.

Modeling Frictional Contact Between a Blunt Tool and Rock With Anisotropic Damage

Yaneng Zhou; Louisiana State University; United States
George Z. Voyiadjis; Louisiana State University; United States

The mechanism of tool-rock frictional contact is analyzed by considering anisotropic damage using a recently developed anisotropic elasto-plastic-damage model, which has been implemented as a user material subroutine in ABAQUS. The anisotropic constitutive model is described and then illustrated through single-element tests in uniaxial compression. A finite element model is constructed for an idealized plane strain problem of a slightly inclined slider moving on the surface of a rock. The finite element model is validated against analytical solutions in the asymptotic elastic and rigid-plastic regimes, and the mesh sensitivity is regularized using a fracture energy based method. The nature of frictional contact is mainly governed by three dimensionless parameters: an elastoplastic parameter η, a brittleness number ξ, and an anisotropic compressive damage coefficient ζ. The dimensionless elastoplastic parameter η contrasts the magnitude of a characteristic elastic contact stress to a yield strength of a material, and the brittleness number ξ is the ratio of a geometrical length scale over a material length scale. The newly introduced damage coefficient ζ controls the ratio of damage in different directions. The average contact stress generally increases with the elastoplastic parameter η and then slightly varies before leveling off, and it generally decreases with increasing the brittleness number ξ. The average contact stress generally increases with decreasing the damage coefficient ζ from isotropic to anisotropic damage. The current numerical results of the average contact stress compare better with typical experimental results conducted on quasi-brittle rocks.

Modeling of Heat Flow in the Eye

Dipika Gongal; University of Illinois at Chicago; United States
Craig Foster; University of Illinois at Chicago; United States

Understanding the flow of heat in the eye is important for ocular health and many modern biomedical applications. In this research we are examining two such applications: 1) heat production from a projector implant device for corneal blindness, and 2) localized hypothermia for the eye, to preserve it in the case of retinal ischemia until further interventions are possible. In the first case, too much heat can damage the eye tissue. In the second case, enough cooling must reach critical areas, the retina here, to sufficiently cool the tissue. In vivo measurements are obviously challenging for such applications, and hence modeling, supported by laboratory experiments, is critical in evaluating performance.

We develop finite element models of heat transfer in the eye that include heat conduction, metabolic heat generation, free convection in the fluids, and blood flow. In particular, blood flow in the past has been treated with simplified methods such as Pennes' bioheat equation, which assumes constant blood temperature. This method underpredicts the ability of therapeutic hypothermia to cool the eye, where cooled blood returning to the body may help cool the posterior eye. This model is replaced by a two-way flow model with separate blood temperature and convection.

Several finite element simulations are run under different circumstances to validate the model and evaluate the thermal effects of different treatments. A range of parameters is used to examine different scenarios such as amount of blood flow.

Modeling of high strain rate impact of single crystal silica cubes using phase field fracture formulation

Shank Kulkarni; University of Tennessee Knoxville; United States
Timothy Truster; University of Tennessee Knoxville; United States
Ibraheem Gharaibeh; University of Tennessee Knoxville; United States
Khalid Alshibli; University of Tennessee Knoxville; United States
Daniel Casem; Army Research Laboratory at Aberdeen Proving Ground; United States

Granular materials are composed of discrete particles that have complex particle-scale properties and particle-to-particle interaction, of which particle fracture is an underexplored area. They resist applied stress via a network of complex force structures that develop within the bulk of the material. Local particle fracture has a profound effect on the macroscopic behavior of materials made of crushable particles, yet very few studies have explored the combined effect of crystallography, morphology, and high strain rate loading on the behavior of granular materials such as silica sand. As a step along this direction of study, experiments have been performed using a mini-Kolsky bar (MKB) with Army Research Laboratory at Aberdeen Proving Ground to measure the effect of crystal orientation of 1 mm silica cubes upon the impact force and fragmentation pattern. Cubes offer a simple geometry for calibration of the constitutive model and to eliminate the effects of particle morphology. This presentation will compare these experiments against simulations using a recently developed phase field fracture formulation accounting for elastic anisotropy of the silica. This formulation is implemented in ABAQUS Explicit to utilize the available contact formulations of the software platform. The accuracy of the fit between the computational and experimental results will be highlighted, along with the planned extension to simulations of individual sand grain fracture.

Modeling of the Dynamic Interaction between the NHERI@UCSD 6-DOF Large High-Performance Outdoor Shake Table and TallWood Building Specimen

Chin-Ta Lai; UC San Diego; United States
Joel Conte; UC San Diego; United States

The NHERI@UC San Diego Large High-Performance Outdoor Shake Table (LHPOST) was commissioned on October 1, 2004, under the NSF NEES Network. Since then, it was used extensively to conduct a variety of high-quality large- and full-scale structural and geo-structural seismic tests with its significant vertical payload capacity (20 MN) and ability to accomodate specimens of unlimited height. In recent years, the LHPOST was upgraded from its previous 1-DOF to its current 6-DOF configuration with funding from the National Science Foundation and additional funding resources provided by the University of California at UC San Diego. The LHPOST was closed for operations in October 2019 to enable the construction of the upgrade and reopened for operations in April, 2022. The 6-DOF LHPOST, referred to as LHPOST6 to distinguish it from the 1-DOF LHPOST, consists of four horizontal linear actuators (configured in V-shape) and six vertical actuators with pressure balanced bearings to drive the honeycomb steel platen, as wells as three nytrogen-filled hold-down struts to provide the overturning moment capacity. The hydraulic actuators are controlled by high-flow, high-performance servovalves to generate actuator forces and velocities, while the hold-down struts passively respond to the platen motion and introduce elastic restoring forces along their axes. A numerical dynamic model of the LHPOST6 under bare table condition was developed to represent the open-loop dynamics of the shake table system, namely from the servovalve command signals (for the spool displacement) to the achieved platen motion. The model was validated in both open-loop and closed-loop (or controller-in-the-loop) simulation (simulation without and with, respectively, the MTS 469D controller integrated in the shake table model) using experimental data acquired during the acceptance and characterization tests performed on the LHPOST6 in the period July 2021 – April 2022. The LHPOST6 model is also programmed to have the flexibility to interact with structural analysis software via TCP/IP protocol by transferring the platen acceleration along each of its 6-DOFs from the shake table model to the specimen model (developed in the structural analysis software) and from the total base reaction forces and moments of the specimen model to the shake table model. The dynamic model of the LHPOST6 developed in Matlab-Simulink coupled with the dynamic model of a specimen developed in the structural analysis software (e.g., OpenSees) is used to simulate the LHPOST6 under loaded condition. It will be validated by the upcoming shake table tests of the full-scale 10-story Tallwood Building specimen that will be conducted in the period March-May 2023, and will be used to investigate the control-table-specimen interaction during these landmark tests. The validated numerical dynamic model of the LHPOST6 loaded with a test specimen can then be used for: (1) pre-test simulation of shake table tests, and (2) off-line tuning of the shake table controller, It will also be instrumental in developing: (1) hybrid shake testing techniques, and (2) the next-generation of shake table controllers.

Modeling of the environment-dependent microstructure of hydrogel-based concrete (HBC) – for Mars application

Ning Liu; Hong Kong University of Science and Technology; Hong Kong
Jishen Qiu; Hong Kong University of Science and Technology; Hong Kong

The hydrogel can be used as a sand binder to develop concrete, which can provide adequate mechanical strength under extremely low temperatures and near-vacuum air pressure, e.g., Mars's surface. Hydrogel-based concrete (HBC) has a unique porous microstructure, and its type and geometry vary significantly with the curing temperature and air pressure. This study presents a new multi-scale model to predict the effect of environmental factors on the microstructure and composite behavior of HBC. On the micro-scale, the gel particle-to-particle joints are categorized based on their structural types that are particular to the certain environment (e.g., tube, cellular, foam, etc.); their stiffness and load capacity are analytically determined by structural analysis. On the macro-scale, the inter-particle interactions, especially those following the gel joint failure, are calculated with the discrete element method (DEM), where the joint properties are determined by the micro-scale modeling. Both micromechanical and composite tests are included to validate this model. It forms a computational tool for HBC even under frozen or vaporized conditions.

Modeling Plastic Deformation of Granular Materials in Pavements Using the Modified Drucker-Prager Cap (MDPC) Model

Mohammad Rahmani; Texas A&M University; United States
Santosh Kommidi; Texas A&M University; United States
Yong-Rak Kim; Texas A&M University; United States
Dallas Little; Texas A&M University; United States
John Rushing; U.S. Army Engineer Research and Development Center; United States

This study presents a mechanistic model simulation of rutting behavior in the granular layers of pavements using the modified Drucker-Prager Cap (MDPC) model. Results from model simulations were validated using field data from pavements experiencing significant rutting in the unbound layers. The MDPC model can predict the plastic deformation of granular materials with hardening compression. The cap surface in the MDPC model represents a locus of points with the same inelastic strains in the p-q plane (p is the mean stress, and q is the deviatoric stress). The cap aspect ratio determines the maximum extent of required plastic strain to maintain the current stress state when it reaches the cap surface. The position of the cap on the p-axis determines the cap growth with the volumetric plastic strains and ascertains the hardening law for the granular material. The two critical model parameters (i.e., cap aspect ratio and compression-dependent yield stress) of the MDPC model were uniquely identified by an inverse optimization process where material parameters in the finite element model (FEM) were iteratively calibrated to reach a good agreement between the permanent deformation of the base layer obtained by the FEM with the actual field rutting data. Model simulation results indicate that (1) the MDPC model is suitable to predict the significant plastic deformation of granular layers in pavements; (2) the combination of the two model parameters significantly affect the rutting behavior of the granular base; and (3) the lower values of cap aspect ratio lead to early saturation of rutting, while the hardening parameter significantly affects the rutting extent. Through the sensitivity analysis and the inverse optimization process of MDPC model parameters with actual field data, this study could identify the critical material parameters governing permanent deformation characteristics of the granular layer in pavements subjected to cyclic loads.

Modeling the chloride ingress in well cement due to the carbonation reaction underground

Jinliang Liu; Northeast Forestry University; China
Yuxiang Jing; University of Colorado Boulder; United States
Linfei Li; University of Maine; United States

Using a wellbore system to store supercritical CO2 in the geological reservoir for hundreds to thousands of years has become one of the most effective technologies for controlling the CO2 amount in the atmosphere. Nowadays, many investigations have been conducted on improving the leak tightness and the durability of the wellbore systems. Therefore, the long-term durability of the wellbore system has become an important topic. Specifically in a CO2 underground storage system, both the ingress of chloride and the leaking of carbon dioxide (CO2) can lead to severe degradation of the system, including corrosion of steel casing, and carbonation of the cement annulus. In this study, a model was developed to consider the coupling effect of the carbonation reaction and chloride diffusion in well cement. The stoichiometric model was first applied to calculate the chemical compositions change of the well cement during the hydration process and the carbonation process. The chloride diffusion coefficient of carbonated well cement was calculated based on the general self-consistent (GSC) model and pore tortuosity. After that, the concentration of free chloride ions was predicted based on Fick's law, which takes into consideration released bonded chloride in the carbonated cement. The proposed model was validated based on available experimental data, and a comparison was made between the proposed model and other previously published models. The model has great significance for the safe and reliable geological storage of CO2.

Modeling Wildfire Propagation: A Stochastic Level-Set Formulation

Sourangshu Ghosh; Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign; United States
Armin Tabendah; Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign; United States
Paolo Gardoni; Department of Civil and Environmental Engineering, University of Illinois Urbana-Champaign; United States

Future perspectives of climate change tend to favor extreme drought and altered precipitations. These conditions can dramatically increase the likelihood of wildfires, as manifested in recent events for example in California and Australia. Wildfires' behavior features multi-physical processes at a wide range of time and length scales, from pyrolysis at the vegetation scale to atmospheric dynamics at the meteorological scale. Wildfires generally present a front-like geometry that propagates into unburned vegetation. The local propagation speed of the firefront, referred to as the Rate Of Spread (ROS), depends on variables characterizing vegetation properties, weather conditions, and terrain topography. The advection of firebrands also contributes to wildfire propagation, where lofted embers can initiate spot fires far ahead of the firefront. The complex physics of the problem with many sources of uncertainty renders fully physics-based models computationally infeasible, whereas empirical models are too simple to yield accurate predictions. This challenge is addressed in this work by developing a computationally manageable physics-based formulation in which a stochastic Hamilton-Jacobi equation (or level-set equation) governs the evolution of the firefront. In the proposed formulation, the fire-front moves toward the unburned vegetation along its normal at a speed determined based on existing empirical relations for the ROS. Data assimilation techniques with Bayesian inference are also proposed to update the ROS using local data and monitored burning patterns. The Hamilton Jacobi equation is modified to accommodate the effects of fire transport due to downwind advection and hot-air turbulence. Finally, a novel spectral representation of the solution to the formulated stochastic Hamilton-Jacobi equation is developed and numerical methods to find the probability distribution of the evolving firefront are presented.

Molecular Dynamics Study of the Impact Response of Architected Metallic Foam Nanocomposites

Mohammed Saffarini; University of Missouri; United States
Tommy Sewell; University of Missouri; United States
Zhen Chen; University of Missouri; United States

Architected composites offer enhanced impact resistance for defense applications such as explosion-resistant armors and buildings. However, a lack of fundamental understanding of the energy dissipation mechanisms resulting from multiscale and multiphase interactions hinders development of materials with truly tunable performance profiles. Here, we report a molecular dynamics study of bicontinuous nanoporous gold (NPG) nanofoam subjected to shock impact loading. Compared to their non-porous counterparts, metallic foams are known to exhibit improved functionality (e.g., damping capacity) when subjected to high-speed impact loading. A cube-shaped flyer object (L0 = 408.6 Å) composed of full-density f.c.c. gold (FDG) strikes, with impact speed U = 1.0 km/s, an initially stationary equal-sized nanoporous gold (NPG) target, which subsequently transmits a dispersed shock wave into a thin FDG witness specimen located at the downstream end of the target. The NPG target is stochastic, with porosity $\phi = 0.5$ and mean ligament diameter $D = 64 \pm 6$ Å. A corresponding simulation for an FDG target serves as a baseline case. As anticipated, the sharp, planar shock imparted by the FDG flyer rapidly becomes highly curved and broadened in the NPG target. Intense plastic and convective flows (ejecta and jetting) lead to spatially heterogeneous mass flow and energy localization, which persist across the entire length of the NPG target studied. Whereas the shock transmitted into the witness specimen by the FDG target leaves the witness intact and essentially undamaged, the heterogeneous stress and flow fields imparted by the NPG target results in destruction of the witness. Independent simulations for the same cube-shaped NPG target shocked on the three statistically equivalent {100} sample faces reveal modest sample-to-sample variability in the target response and witness outcome. Preliminary results for the case of NPG-target shock transmission into a thick (rather than thin) witness specimen, designed to reveal the evolution of impact-surface induced, sub-Hugoniot Elastic Limit failure in the witness, will also be presented.

Molecular insight on creep of cement-based systems from in situ neutron total scattering experiments

Nishant Garg; University of Illinois Urbana-Champaign; United States
Brendan Kehoe; Princeton University; United States
Daniel Olds; Brookhaven National Laboratory; United States
Joseph Vocaturo; Princeton University; United States
Michelle Everett; Oak Ridge National Laboratory; United States
Katharine Page; University of Tennessee, Knoxville; United States
Joerg Neuefeind; Oak Ridge National Laboratory; United States
Claire White; Princeton University; United States

Pair distribution function analysis (PDF) is well-suited for determining time-dependent local atomic structure changes occurring in amorphous and disordered systems. Sustainable cements, with reduced CO2 emissions compared with Portland cement, fall into this category due to multiple amorphous phases that are known to evolve concurrently during initial formation and over the service life of the material. Viscoelastic relaxation of cement-based systems is known to control macroscopic creep, but the underlying mechanisms responsible for this viscoelastic behavior are still to be fully reconciled. Due to the high penetrating power of neutrons and their sensitivity to hydrated materials, neutron PDF analysis is ideal for uncovering these mechanisms. However, typically PDF analysis assumes isotropic scattering which may not be applicable to cement systems subjected to uniaxial loads.

In this talk we will discuss a unique sample environment setup and data reduction approach that were used on the NOMAD instrument at the Spallation Neutron Source, Oak Ridge National Laboratory, to obtain directional-dependent total scattering patterns and associated PDFs. Alkali-activated slag and hydrated tricalcium silicate cement cylinders were subjected to 40% of their ultimate strength while data were collected in situ for the initial 24 hours, and then at 1, 2, 4, 8, 16 and ~32 weeks. As part of this talk the resulting total scattering patterns and PDFs parallel and perpendicular to the loading direction will be presented to assess uniaxial structural anisotropy, and mechanistic insights on cement viscoelasticity will be discussed. Lastly, key challenges faced as part of the investigation will be outlined.

Molecular simulations study of freezing of water confined in C-S-H, and implications for the cryo-suction process

Xinping ZHU; Navier, Ecole des Ponts, Univ Gustave Eiffel, CNRS; France
Laurent Brochard; Navier, Ecole des Ponts, Univ Gustave Eiffel, CNRS; France
Matthieu Vandamme; Navier, Ecole des Ponts, Univ Gustave Eiffel, CNRS; France

Water freezing in cement-based materials can damage the materials, which is a topic of interest for liquid natural gas reservoirs or civil engineering structures in cold climates. At low temperatures, freezing can occur in pores with a wide range of sizes, down to the C-S-H gel pores. Various processes can contribute to damage: expansion of water upon freezing, hydraulic pressurization, and cryo-suction. Cryo-suction is a thermodynamic-driven process through which ice crystals can become more pressurized than the remaining surrounding liquid water, which could be made possible by the transport of water toward the crystals through the premelted liquid film at the surface of the already frozen pores. This work uses molecular simulations to study water freezing in a C-S-H nanopore between 220K and 260K. We calculate and discuss various properties of the freezing process: the growth rate of ice in confined conditions, the thickness of the premelted liquid film between the ice and the pore surface, and transport properties in this premelted liquid film. We then wonder whether transport through the premelted liquid film is sufficiently fast for cryo-suction to be significant during freezing. From an analytical derivation, we obtain a characteristic time of the cryo-suction process, which depends on temperature, transport properties, the thickness of the premelted film, and pore geometry. Based on the properties obtained from the molecular simulations, we find that this characteristic time is sufficiently small for most pore sizes in cement-based materials for cryo-suction to be an active process in normal freezing conditions.

Monitoring Infrastructure using Augmented Reality in a Network of Microrobots with Visual Data Analysis

Alireza Fath; University of Vermont; United States
Nicholas Hanna; University of Vermont; United States
Yi Liu; University of Vermont; United States
Scott Tanch; University of Vermont; United States
Tian Xia; University of Vermont; United States
Dryver Huston; University of Vermont; United States

Despite advancements in sensing technology for smart infrastructure, monitoring dynamic components such as pipelines, industrial equipment, and transportation systems remains challenging. In this paper, a network of micro-robots equipped with Wi-Fi-compatible cameras is deployed to conduct visual structure inspection in poorly accessible environments. To achieve swarm infrastructure monitoring, ESP32-CAM modules mounted onto HEXBUG nano® V2 bristlebots are deployed to survey their intended area as a mesh network. The camera modules transmit live video to a nearby supervisor robot, which positions the HEXBUGs, processes the visual data, and broadcasts it through a Wi-Fi network. Machine learning algorithms are applied to the raw visual data to differentiate between objects. A Microsoft HoloLens 2 unit, connected to the HEXBUG network via Wi-Fi, scans for QR codes embedded in the surrounding environment and receives broadcast data, allowing a site operator to view processed video streams in first-person and in real-time.

Motion Tape Sensors and the Warfighter Digital Twin for Enhancing Physical Performance

Ken Loh; UC San Diego; United States

Physical, tactical, and field training are critical elements of the military for improving warfighter physical performance and capabilities. These exercises and training events are typically supervised, with trainers assessing how functional movements are being performed, so that individuals can receive feedback as needed. However, group or team training lacks personalized supervision, and it is not possible to oversee and monitor warfighter performance during field events and in forward deployed situations. Commercial wearable sensors (e.g., smart watches, rings, chest bands, and inertial measurement units) and optical motion capture (mocap) systems are available, but the data streams usually correspond to a discrete location on the body and only provide information about whether someone is moving, as opposed to how functional movements are being performed. To fill this technology gap, a self-adhesive, elastic fabric, nanocomposite, skin-strain sensor has been developed, tested in controlled laboratory environments, and validated through human subject studies. It has been found that these "Motion Tape" sensors are able to not only measure skin-strains during functional movements, but its measurements are also correlated with the degree of muscle engagement to produce these functional movements. In this study, human participants wore Motion Tapes at major muscle groups, and exercises that simulated military training activities were performed. Mocap measurements were also obtained in parallel to acquire baseline biomechanical movement data. Individuals were first asked to perform a functional task (i.e., for several repeated trials), before being asked to repeat the task after instructional training (i.e., also repeated numerous times). The outcomes of these tasks were recorded, as well as kinematic data using mocap and movement and muscle engagement response using Motion Tape. Then, a neural network that drives the Warfighter Digital Twin was implemented and trained using labeled Motion Tape datasets, specifically, to classify movement sequences that resulted in positive versus negative task outcomes. The remaining datasets that were not used for training the machine learning algorithm were used to validate the data-driven Warfighter Digital Twin model. Furthermore, the Motion Tape datasets that led to positive outcomes were further analyzed to reveal the primary movement schemes that resulted in higher physical performance. The vision is that such data-driven Warfighter Digital Twins can be used to uniquely assessing the physical performance, health, and capabilities development of military service members, as well as for potentially other use cases such as sports, physical therapy, rehabilitation, ergonomics, and worker safety.

Multi-Axis Shake Table Real-time Hybrid Simulations of Buildings with Floor Isolation Systems

James Ricles; Lehigh University; United States
Liang Cao; Lehigh University; United States
Esteban Villalobos Vega; University of Oklahoma; United States
Scott Harvey; University of Oklahoma; United States
Thomas Marullo; Lehigh University; United States
Faisal Malik; Lehigh University; United States

Damage caused by earthquakes to buildings and their contents (e.g., sensitive and critical equipment) can impact life safety and disrupt business operations. The resulting social and economic losses can be minimized if the seismic demands on building contents are reduced through vibration isolation. In this regard, floor isolation systems (FIS) are a promising retrofit strategy for protecting vital building contents. This presentation presents an overview of an ongoing research effort involving researchers from the University of Oklahoma and Lehigh University. The study consists of real time hybrid simulation (RTHS) tests of FISs on a multi-axis shake table conducted at the Natural Hazards Engineering Research Infrastructure (NHERI) Experimental Facility at Lehigh University. Multi-directional shake table RTHS is utilized to validate the performance of full-scale rolling pendulum (RP) bearings, incorporating multi-scale (building–FIS–equipment) interactions. The unconditional stable dissipative explicit Modified KR-alpha integration algorithm is used to perform the multi-directional RTHS. Parametric studies were performed to assess the influence of different lateral load systems on the performance of the FISs. The lateral load resisting systems included buildings with steel moment resisting frame (SMRF) systems and buildings with buckling restrained braced frame (BRBF) systems. Each building type was subjected to ground motions of different sources and hazard levels. Details of the experimental test set-up, RTHS test protocol and main results on the multi-directional testing of an RP-based FIS are described. Challenges in conducting the multi-axial RTHS, including the nonlinear kinematics transformation, adaptive compensation for actuator-table dynamics, along with the approaches used to overcome them are presented.

Multi-directional Behavior of a Tall Building Equipped with Damped Outriggers using 3D Real-Time Hybrid Simulation

Safwan Al-Subaihawi; Lehigh University; United States
James Ricles; Lehigh University; United States
Thomas Marullo; Lehigh University; United States
Liang Cao; Lehigh University; United States

Real-time hybrid simulation (RTHS) divides a structural system into analytical and experimental substructures that are coupled through their common degrees of freedom. This work implements RTHS to investigate the nonlinear multi-directional multi-natural hazards behavior of a 40-story tall building equipped with damped outriggers. The outrigger system has dampers placed vertically between the outrigger trusses and the perimeter columns to increase the damping of the building. Prior studies have investigated the unidirectional behavior of damped outrigger systems; this study focuses on the multi-directional behavior where a three-dimensional analytical model capable of capturing the nonlinear behavior of the structure is used in the RTHS. The three-dimensional analytical model accounts for the accidental torsion at each floor level that results from eccentricity of the floor mass from the building's center of rigidity, enabling the investigation of the efficacy of the damped outrigger system in suppressing undesirable wind-induced vibrations that include the effects of story twist. The experimental substructure for the RTHS includes a full scale nonlinear viscous damper. Other dampers in the building are modeled analytically using an explicit non-iterative online model updating scheme where the model parameters are identified in real-time using the unscented Kalman filter. The results from earthquake RTHS show that the damped outrigger system reduces the peak roof displacement and twist in the building by 5% and 14.6%, respectively. The results from the wind RTHS demonstrates that the damped outrigger system reduces the peak and root-mean-square (RMS) translational accelerations at the roof by 44.7% and 38.8%, respectively, and the torsional peak and RMS accelerations at the roof by 40.2% and 32.6%, respectively. The half-power testing method was used in conjunction with a RTHS to identify the added damping in the building from the damped outrigger system and was found to be 10.4% and 7.5% for the 1st translational and torsional modes, respectively.

Multi-Disciplinary Simulation-Based Model for Interdependent Seismic Resilience Assessment of Communities

Omar Sediek; Colorado State University; United States
Milad Roohi; University of Nebraska—Lincoln; United States
John van de Lindt; Colorado State University; United States
Nathanael Rosenheim; Texas A & M; United States
Sara Hamideh; Stony Brook; United States

Modern communities comprise multiple physical, social, and economic systems that interact in complex and interdependent ways. A disturbance to one system may cause a cascading failure effect to other systems in the community. Natural hazards are one of the destructive disturbances that may cause these kinds of cascading failures across physical, social, and economic systems and institutions. Of the various natural hazards that a community may face, earthquakes are considered low occurrence, high-consequence events. Therefore, building seismic resilience is of high priority to earthquakes-prone communities. To do so, communities may benefit from the implementation of robust tools for quantifying and improving their seismic resilience. However, most of the available tools for quantifying seismic resilience focus narrowly on specific physical infrastructure systems (e.g., buildings, hospitals, electric power networks, etc.) and frequently neglect the interdependencies between different systems across physical and social dimensions. To address this shortcoming, the present study develops a comprehensive simulation-based seismic resilience model to quantify physical and social impacts by considering the interdependencies between some of the physical and social systems within a community. The modeling begins with hazard analysis to simulate seismic intensity measures, including the distribution of peak ground acceleration and spectral acceleration within the community of interest. The hazard analysis also considers the effect of peak ground displacement caused by liquefaction (lateral spreading and ground settlement) using the liquefaction susceptibility maps to evaluate the probability of liquefaction for a given susceptibility category. Then, the seismic hazard analysis outputs are employed to perform seismic damage and functionality analysis of bridges, buildings, and electric power facilities (including substations and generation plants) by considering the interdependency between the building portfolio and electric power facilities. This interdependency is simulated by estimating the service area for each electric power substation, which is employed for evaluating the functionality of individual buildings given the functionality of their corresponding substations. The social aspect of the problem estimates population stability and stages of housing as a function of building damage and socio-demographic characteristics of residents. This novel simulation provides quantitative physical, social, and economic resilience metrics, which can be used to provide decision-support for a community to weight and consider different mitigation strategies for seismic resilience. This simulation model is illustrated for a hypothetical Mw 7.9 earthquake on Salt Lake County (SLC) in Utah. SLC comprises nearly 285,000 buildings, 670 bridges, 350 electric power substations and 15 electric power generation plants. All the analysis is performed in the open-source Interdependent Networked Community Resilience Modeling Environment (IN-CORE).

Multi-fidelity Monte Carlo for real-time probabilistic storm surge predictions

WoongHee Jung; University of Notre Dame; United States
Alexandros Taflanidis; University of Notre Dame; United States

Probabilistic predictions of storm surge are critical for guiding evacuation and emergency response decisions during landfalling storms. The probabilistic formulation for these predictions is established by considering forecast errors for the intensity, size, cross- and along-track variability of the National Hurricane Center (NHC) advisories. These errors define ultimately the vector of uncertain storm features, with corresponding probability distributions chosen based on historical data. Propagation of the uncertainty in these features, serving as input to a numerical model for predicting storm surge, provides the desired statistical products. This estimation is repeated whenever the NHC updates the storm advisory. The current NHC implementation utilized only the new surge simulations at each advisory to obtain the new statistical products, ignoring past simulations. This paper investigates a multi-fidelity Monte Carlo (MFMC) implementation, leveraging this setup of repeated estimation, and numerical simulations. Specifically, all past numerical simulations are utilized to develop a surrogate model (metamodel) for approximating the storm surge. Gaussian process regression is adopted as surrogate model and an appropriate parameterization of the storm input is considered to accommodate a low-dimensional formulation, as necessitated by the fact that a small only number of simulations are available for the metamodel development. This surrogate model serves as a low-fidelity model and is coupled within a MFMC setting with the original numerical model, corresponding to the high-fidelity, computational expensive model in the MFMC formulation. MFMC leverages the correlation of the two model classes and the computational efficiency of the surrogate model approximation, to establish unbiased Monte Carlo predictions with higher statistical accuracy compared to the implementation that relied strictly on the high-fidelity simulations. The requirement to estimate the storm surge across a large geographic domain, leading to the definition of a large number of quantities of interests (QoIs), poses a challenge in when examining the optimal budget allocation between the low- and high- fidelity models, since each QoI promotes a different allocation. A compromising solution across the QoIs is obtained efficiently using principal component analysis (PCA) as a dimensionality reduction technique. The potential computational savings and accuracy improvement are showcased using different case studies.

Multi-fidelity Physics-informed Generative Adversarial Network for Solving Partial Differential Equations

Mehdi Taghizadeh; Department of Engineering Systems and Environment, University of Virginia; United States
Mohammad Amin Nabian; NVIDIA; United States
Negin Alemazkoor; Department of Engineering Systems and Environment, University of Virginia; United States

We propose a novel method for solving partial differential equations using multi-fidelity physics-informed generative adversarial networks. Our approach incorporates physics-supervision into the adversarial optimization process to guide the learning of the generator and discriminator models. The generator has two components: one that extracts low-fidelity features from the input and another that combines the input and extracted features to generate an approximation of high-fidelity responses. The discriminator identifies whether the input-output pairs accord not only with the actual high-fidelity response distribution but also with physics. The effectiveness of the proposed method is demonstrated through numerical examples and compared to existing methods.

Multi-fidelity Sequential Design with CFD Applications of Twisted Building Design

Fei Ding; NHERI SimCenter, University of California, Berkeley; United States
Jize Zhang; Department of Civil and Environmental Engineering, Hong Kong University of Science and Technology; Hong Kong
Ahsan Kareem; NatHaz Modeling Laboratory, University of Notre Dame; United States

Surrogate modeling has been widely used to understand complex engineering systems involving intensive simulations. Regarding CFD analyses to model wind flows around structures, they can be conducted either through low-fidelity Reynolds-averaged Navier-Stokes (RANS), or through high-fidelity Large Eddy Simulation (LES). Developing a multi-fidelity surrogate model allows using simulations of varying fidelities to enhance model accuracy while maintaining computational efficiency. A major challenge in multi-fidelity surrogate modeling is the sequential design of simulation data from the source of multiple fidelities. In this study, we focus on a global sequential model updating scheme with the commonly used integrated mean squared error (IMSE) criteria.

Another challenge is that the low-fidelity numerical simulations could bring non-physical or ill-conditioned evaluations. For instance, in RANS, violating modeling assumptions involving scale separation or empirical Reynolds stress modeling could result in simulation failure. To take into account such simulation failures, this study considers a probabilistic classification approach to identify the viable areas for the low-fidelity simulation and avoid the low-fidelity samples being casted into the erroneous regions where the low-fidelity observations significantly deviate from their high-fidelity observations.

Finally, the proposed parallel sequential model updating scheme with the embedded classification approach is applied to the aerodynamic shape optimization of twisted tall buildings. A twisted building is considered to be aerodynamically favorable since its floor plan is progressively rotated throughout the height, resulting in vortices being shed irregularly that help break up their structure. However, relationship between the twist angle from the ground floor to the top floor plates and its corresponding aerodynamic loads on buildings has not been systematically and thoroughly investigated yet. This study shows the capability and superiority of the proposed multi-fidelity sequential design approach for the automated identification of the optimal twisted forms of tall buildings.

Multi-Hazard Analysis of Multi-Story Frames with Viscoelastic Semi-Rigid Connections

Alessandro Palmeri; Loughborough University; United Kingdom
Mariateresa Lombardo; Loughborough University; United Kingdom

Energy dissipation is an efficient strategy to mitigate undesirable dynamic effects on engineering structures. Different mechanisms have been successfully used to improve the resilience of buildings exposed to wind and seismic hazards, including friction, plasticity, viscoelasticity, and viscosity.

Viscoelastic (VE) materials such as natural rubber and other elastomers tend to form relatively large hysteretic loops when subjected to cyclic deformations. This principle underpins the use of elastomers in passive control devices. In seismic isolators, the VE materials provide a compliant interface that reduces the transmission of seismic-induced vibrations from the foundation to the structure in elevation. In dissipative braces, constrained layers of VE materials undergo shear deformations that allow dissipating energy over a wide range of vibration frequencies.

Compared to seismic isolators and dissipative braces, relatively less attention has been paid to inserting VE materials in the beam-to-column joints of semi-rigid frames. In this response modification strategy, the rotational discontinuity at the interface between beams and columns is used to dissipate energy. As a result, beam ends are transformed into distributed energy absorbers.

Typically, VE materials exhibit complex temperature-, amplitude- and frequency-dependent behaviors. Notwithstanding this, the dynamic analysis of structures equipped with VE devices is often carried out under simplistic assumptions, e.g., with the so-called Kelvin-Voigt (KV) model, in which equivalent values of elastic stiffness and viscous damping are assigned to the VE components.

Aimed at overcoming the limitations of the KV model, this paper presents a new computational framework in which the so-called generalized Maxwell (GM) model is adopted for the VE rotational dampers. First, the dynamic stiffness matrix of an elastic beam with VE hinges at its ends is derived in the frequency domain. Second, the GM beam model is incorporated into the dynamic stiffness matrix of a multi-story semi-rigid frame, in which the rotational degrees are statically condensed. Third, the resulting set of integrodifferential equations of motion in the time domain is transformed into an enlarged set of state-space governing equations. Finally, the concept of VE modes of vibration and a special variant of the modal acceleration method (MAM) are proposed to reduce the computational burden. The numerical examples validate the proposed approach and demonstrate the effectiveness of VE semi-rigid connections for the multi-hazard protection of medium- to high-rise buildings.

Multi-Objective Optimisation of Origami Bellows

Mengzhu Yang; University of Bristol; United Kingdom
Fabrizio Scarpa; University of Bristol; United Kingdom
Mark Schenk; University of Bristol; United Kingdom

The non-rigid foldability of origami bellows offers a rich design space for structural tailoring, including a tuneable nonlinear response and multi-stability. For these reasons origami bellows have been explored for deployable structures, robotics, meta-materials, etc. Most studies focus exclusively on the axial compression of origami bellows; in this work, we apply a multi-objective optimisation to trade off various mechanical and geometric properties.

Multi-Resolution Physics-Informed Machine Learning Approaches for Digital Twin Applications.

Karan Taneja; University of California, San Diego; United States
Xiaolong He; University of California, San Diego; United States
Qizhi He; University of Minnesota, Twin Cities; United States
J. S. Chen; University of California, San Diego; United States

Machine Learning (ML) approaches offer tools for system identification such as in biological systems, from sensor measurements, e.g., motion data and raw surface electromyography (sEMG), allowing for construction of a subject-specific musculoskeletal (MSK) digital twin system for health condition assessment and motion prediction. Physics-informed ML approaches for dynamical systems can impose conservation laws on the mapping but challenges remain such as in a time-domain mapping between high frequency input and low frequency output, or vice versa. For example, in MSK system, mapping of high-frequency muscle excitation signals to low-frequency joint motion while conserving momentum remains difficult, owing to the large variation in frequency contents between the muscle sEMG signals (input) and motion data (output). This work is an enhancement over the Feature Encoded Parameter Identification Neural Network (FEPI-PINN) [1], where a Multi-Resolution Recurrent Neural Network (MR-RNN) learning algorithm is proposed for effective sequential time domain mapping . In this approach, the fast wavelet transform is first applied to the mixed frequency sEMG signals, decomposing them into nested multi-scale signals. The prediction model is subsequently trained with lower-resolution input signals using a gated recurrent unit (GRU), and the trained parameters are then transferred to the next higher-scale training. These training processes are repeated recursively until the full-scale training (at original scale of input signal) is achieved. Numerical examples demonstrate that the proposed framework can more effectively identify subject-specific muscle parameters with noisy sEMG signals, and the trained physics-informed forward-dynamics surrogate yields more accurate motion predictions of elbow flexion-extension motion of a MSK system compared to the case with single-scale learning and training.

[1] Taneja, K., He, X., He, Q., Zhao, X., Lin, Y. A., Loh, K. J., & Chen, J. S. (2022). A Feature-Encoded Physics-Informed Parameter Identification Neural Network for Musculoskeletal Systems. Journal of Biomechanical Engineering, 144(12), 121006.

Multi-scale characterization of mode-II interlaminar fracture in scaled stitched resin-infused composites using digital image correlation

Jackob Black; Mississippi State University; United States
Wayne Huberty; Advanced Composites Institute; United States
Christopher Bounds; Advanced Composites Institute; United States
Han-Gyu Kim; Mississippi State University; United States

Modern aircraft designs have extensively adopted composites for primary structures to achieve light weight. Composite fuselage and wing structures in high-speed aircraft, however, could be subject to mode-II interlaminar failure induced by aerothermodynamic loading. To address this issue, the work herein is focused on investigating the impact of out-of-plane stitches on enhancing mode-II interlaminar fracture toughness and characterizing damage progression and crack arrestment in stitched resin-infused composites. End-notched flexure (ENF) quasi-isotropic specimens were manufactured using non-crimp carbon-fiber fabric through resin-infusion process. For size effect study, three sizes of specimens were designed by scaling the dimensions. The impact of stitching patterns and yarn types on mode-II delamination was analyzed by comparing the load-displacement curves of stitched and unstitched resin-infused composite specimens. For multi-scale characterization of damage progression and arrestment, two types of digital image correlation (DIC) systems were employed for the ENF tests. For local analysis, a microscopic DIC system was used to capture fracture behaviors and crack arrestment in the vicinities of the initial crack tips and stitches, respectively. On the other hand, a 3D DIC system provided structural-scale data for global analysis by covering the entire specimen areas. Finally, the size effect in the scaled specimens was characterized in two different regimes: quasi-brittle fracture and crack arrestment regimes. This work will contribute to developing a high-fidelity damage model for stitched resin-infused composites.

Multi-scale stochastic modeling and uncertainty quantification of rare events using the switching diffusion model

Zheming Gou; University of Southern California; United States
Xiaohui Tu; Saint Gobian; United States
Sergey Lototsky; University of Southern California; United States
Roger Ghanem; University of Southern California; United States

In many applications, high-fidelity simulations are required to resolve local behaviors such as crack initiation and propagation, and fluid mixing. While multi-scale simulation capabilities have progressed rapidly over the past decades, they are expensive, thus pre-emptying systematic statistical analysis. Given the paucity of data that relate micro-structure to macro-scale behavior, and the unavoidable modeling errors at such scales, the lack of a probabilistic characterization significantly limits the value of expensive numerical simulators. The goal of the present research is to develop a probabilistic model that encodes path-wise relationships between micro and macro scales. Specifically, we develop a switching diffusion model to relate damage evolution, characterized at the micro-scale, to system performance described as a macro-scale property. Micro-scale behavior is modeled as a Markov switching process with finite many discrete states while the macro counterpart is modeled as a continuous-state diffusion process. The interaction between macro and micro scales is captured by the coupling of switching process and diffusion process. Calibrated by data, the switching diffusion model can generate arbitrarily many new sample paths with consistent statistics at a low cost, which could be used as a surrogate model. The proposed method contributes new capabilities and perspectives at the interface of multi-scale simulation, uncertainty quantification, and stochastic modeling.

Multi-scale Toughness via Scratch Testing: From QuasiBrittle to Ductile Materials

Ange-Therese Akono; Northwestern University; United States

Nano and micro composites have gained widespread attention in the industry and in the scientific community due to growing performance requirements. However, the challenge resides in characterizing the fracture resistance at both the microscopic and macroscopic length scales. In fact, although several experimental methods have been implemented to measure the Griffith fracture energy, since 1921, the difficulty remains in providing a measure that is intrinsic and invariant with respect to external factors such as specimen geometry, loading conditions and prescribed rates. The work presented here combines multi-scale experiments and advanced theoretical modeling in order to provide a robust means to characterize the intrinsic fracture toughness at both the macroscopic and the microscopic scales. The scratch test consists in plowing and cutting with a scratch device the surface of a weaker material and it is relevant in many fields of science and engineering, ranging from thin films and coatings, to wear of metals and polymers, and strength of rocks. Furthermore, the scratch test has recently emerged as a powerful yet scalable method to assess the fracture toughness by pulling a hard stylus across the surface of a softer material. In this investigation, an innovative multi-scale experimental framework is presented that blends, design, sensing and controls into a rigorous metric to examine the failure modes of soft and hard materials such as polymers, rocks and metals. The field of applications is vast including nano-composite semiconductors, ceramic-metal composites for biomedical implants, polymer composites for renewable energy generation and metal-matrix composites for automotive and aerospace applications.

Multi-Stage Optimization of Mitigation and Response to Enhance Resilience of Infrastructure Systems

Alice Alipour; Iowa State University; United States
Ning Zhang; UCLA; U.S. Outlying Islands

Natural hazards can result in significant damage and disruption to the physical built environment, including various infrastructure systems and the socio-economic activities that rely on them. Investigations of recent disasters caused by natural hazards have revealed the importance of infrastructure resilience, especially for an integrated safety, performance, and functionality. Infrastructure resilience is defined as the ability to get prepared, plan for, absorb, and recover from actual or potential extreme events. Thus, a thorough understanding of each component associated with this definition is deemed essential to move toward achieving resilient infrastructures. Furthermore, there are three unique attributes in this critical domain that should be synergistically accounted for: (1) infrastructure systems are geographically distributed systems and have a large number of components, (2) natural hazards are highly uncertain both spatially and temporally, and (3) community resources are limited, especially in the aftermath of extreme events. The combination of the outlined considerations underlines the importance of ex-ante and ex-post decisions to promote resiliency not only at the component but also at the system level. For establishing the resilience in the new generation of civil infrastructures, this presentation will introduce the formulation of a nonlinear two-stage stochastic programming model that aims to build a balanced portfolio of ex-ante and ex-post activities to reduce the risk and time of recovery, while minimizing the direct and indirect losses. The developed model benefits from a data-driven simulation environment, which combines scenario reduction, hybrid heuristic method of evolution strategy, and high-performance parallel computing, to find optimal resilience-oriented solutions. By examining the model in a large-scale, geographically-distributed transportation network subjected to flood events, the main capabilities are evaluated. This leads to the recommendations for further implementing such models to transform the resiliency of the built environment under extreme events.

Multi-view deep learning for post-hurricane damage assessment of buildings

Asim Khajwal; Risk Managment Solution, Inc; United States
Chih-Shen Cheng; Texas A&M University; United States
Arash Noshadravan; Texas A&M University; United States

The main goal of this study is to improve AI-assisted post-disaster damage classification of buildings via multi-view image fusion. There has been promising progress in the use of computer vision and deep learning for disaster damage assessment. However, there is a need for developing and benchmarking more reliable AI models that incorporate comprehensive visual dataset for more refined quantitative disaster damage classification according to standard to damage scales. One of the limitations of existing models is that they are often trained based on aerial or satellite imagery with single or limited views, which may not be completely descriptive of the damage scale. This research presents the development of a multi-view deep learning model allowing the fusion of more comprehensive visual data in the form of multiple ground and aerial views of affected buildings. Specifically, a spatially-aware Convolution Neural Network (CNN) architecture is developed that consists of two sequential pipelines made up of different CNN models. First, an object localization model based on semantic segmentation will mask out the irrelevant information and extract the buildings' visual content relevant to damage assessment. Next, the damage state classification will be performed using the proposed composite network that passes the combined feature into a 3D-CNN layer for the final damage level prediction based on the FEMA damage scale. The proposed model is trained and tested on a visual dataset collected by a reconnaissance team consisting of expert-labeled, geotagged images of buildings in the aftermath of Hurricane Harvey. A systematic study of the value of information is conducted to investigate model performance in different scenarios in terms of number and combination of views. This can shed light on the optimal design of the multi-view model to balance accuracy and computational efficiency. This research is a step forward in the advancement of deep learning models for automated quantification of the impact of disasters.

Multi-Vision System for Full-field Strain Measurement and Crack Tracking on UHPC Beams

Mostafa Iraniparast; University of Central Florida; United States
Seyed Sina Shid-Moosavi; University of Central Florida; United States
Peng "Patrick" Sun; University of Central Florida; United States
Tiancheng Wang; University of Central Florida; United States
Georgios Apostolakis; University of Central Florida; United States
Kevin Mackie; University of Central Florida; United States

Monitoring (surficial) mechanical strain is important to track the health conditions of structures (especially the local part) because strain distribution around structural irregularity can reveal the location of potential local damages if these damages are close to surfaces. Hence, experimental monitoring of mechanical strain distribution and crack development on brittle material (e.g., concrete) can provide valuable information to reveal damage development. In order to measure planar or 3D structural response, optical-based measurement methods (e.g., photogrammetry) with multiple perspectives have been developed to measure displacement and strain in a noncontact fashion. Digital Image Correlation (DIC) method has shown its effectiveness in measuring full-field strain on structural surfaces in the past decade. Using this method, the specific location of the crack can be identified, and its advancement may be tracked using the strain map. While a group of camera pairs with arbitrary poses setting (compared to the strict pose setting of only two cameras in DIC) is more versatile for experiments and is investigated in this study to measure both displacement and strain of beams subject to loading. Experiment are performed on Ultra-High Performance Concrete (UHPC) beam components at the lengths of 1-3 meters using a hydraulic loading frame. Videos and images from pairs of industrial cameras at different perspectives are collected synchronously for subsequent displacement computation and strain analysis. Using vision-based techniques, the structural displacement and strain caused by external forces are calculated and compared to contact sensors (e.g., LVDT, strain gage). In addition, image processing algorithms (e.g., wavelet transform, morphological processing) are employed in order to track the growth of cracks. The preliminary quantitative result shows the potential of the proposed method to measure full-field displacement and track cracks on UHPC structural components.

Multiband Red/NIR/SWIR synthesis of $MgGeO_3:Pr^{3+}$ persistent phosphor material

Syed Niaz Ali Shah; King Fahd University of Petroleum and Minerals; Saudi Arabia
Sikandar Khan; King Fahd University of Petroleum and Minerals; Saudi Arabia

Persistent luminescence, also known as afterglow, is a phenomenon in which a material emits light for an extended period, ranging from minutes to hours after the excitation is turned off. Persistent phosphors emitting in the visible spectral region have been extensively studied, and some have achieved commercial success and are widely used as night-vision materials in a variety of applications. In recent years, persistent luminescence in wavelengths beyond the visible spectral region, namely the near-infrared (NIR; 700-900 nm) and short-wave infrared (SWIR; 900-1700 nm) spectral regions, has received considerable attention because longer-wavelength persistent luminescence has many promising advanced applications ranging from infrared night-vision surveillance to biomedical imaging. Here, multiband $MgGO_3: Pr^{3+}$ persistent nanoparticles (NPs) that emit in the visible, NIR, and SWIR wavelength ranges were synthesized using the sol-gel process. We have found that the doping of the Al^{3+} ion significantly increases the afterglow intensity of $MgGeO_3:Pr^{3+}$ phosphor as well as the afterglow decay time of the Pr^{3+} emission. The synthesized materials were applied to background fluorescence-free conditions for ultrahigh sensitive detection in crude oil. The $MgAlGO_3:Pr^{3+}$ NPs can be re-excited in the emulsion and the spectral and imaging acquisition can be made repeatedly. The high sensitivity can provide accurate imaging of the NPs in crude oil, but it also offers long-term monitoring as well as in real-time. Additionally, the $MgGeO_3:Pr^{3+}$ phosphor is anticipated to have interesting applications in biological imaging, night-vision surveillance, and photovoltaics.

MULTIDISCIPLINARY APPROACH FOR THE CROSS-SECTION SHAPE OPTIMIZATION OF HIGH-RISE BUILDINGS

Felix Nieto; University of A Coruna; Spain
Santiago Hernandez; University of A Coruna; Spain
Miguel Cid-Montoya; Texas A&M University; United States

High-rise buildings shape the skyline of large cities over the world. The foreseeable trend for the near future seems to be an increasing interest in this type of structures. Nonetheless, tall buildings are some of the most technically challenging manmade structures, and the need for real estate developers to carefully consider costs, suggests that the application of optimization techniques at the design stage may help to increase the profitability of investments. In tall buildings, the cost of the structure is related with the lateral structural system, responsible for withstanding wind loads. However, wind induced response is strongly dependent on the geometry of the building's cross-section. Only very recently, the shape optimization of the cross-section of high-rise buildings has been addressed considering the aerodynamic response of the structure. These research works relay on CFD simulations to obtain the aerodynamic response of a set of samples that allows training a surrogate model that feeds the optimization algorithm with the information required to evaluate the aerodynamic performance. This work reports the results obtained for the multi-objective optimization that has been conducted for a high-rise building, considering the along-wind response for different wind incidence angles, as well as the economical revenues. The reduced basis approach has been adopted, aiming at substantially reduce the number of required design variables. A Kriging surrogate model is trained based on 12 samples over the considered design domain. The output of this surrogate is the drag coefficient for angles of attack in the range (0, 45º). Based on the information provided by the surrogate, the wind-induced responses are evaluated and the economical revenues assessed. In this research, Pareto optima have been identified for two different application cases, allowing the designer to choose the design that best balances occupant comfort and profitability.

Multifunctional magnetic origami robots

Renee Zhao; Stanford University; United States

Millimeter/centimeter-scale origami robots have recently been explored for biomedical applications due to their inherent shape-morphing capability. However, they mainly rely on passive or/and irreversible deformation that significantly hinders the clinic functions in an on-demand manner. Here, we report magnetically actuated origami robots that can crawl and swim for effective locomotion and targeted drug delivery in severely confined spaces and aqueous environments. We design our robots based on the Kresling origami, whose thin shell structure 1) provides an internal cavity for drug storage, 2) permits torsion-induced contraction as a crawling mechanism and a pumping mechanism for controllable liquid medicine dispensing, 3) serves as propellers that spin for propulsion to swim, 4) offers anisotropic stiffness to overcome the large resistance from the severely confined spaces in biomedical environments. These magnetic origami robots can potentially serve as minimally invasive devices for biomedical diagnoses and treatments.

Multiphase dissipative particle dynamics modeling of dynamic spreading of molten sand droplet on porous surfaces

Zhen Li; Clemson University; United States
Rahul Koneru; University of Maryland; United States
Alison Flatau; University of Maryland; United States
Luis Bravo; DEVCOM Army Research Laboratory; United States
Muthuvel Murugan; DEVCOM Army Research Laboratory; United States
Anindya Ghoshal; DEVCOM Army Research Laboratory; United States
George Karniadakis; Brown University; United States

Upon coming into contact with a solid surface, a liquid droplet spreads rapidly during the early moments due to inertial/capillary effects before the viscous dissipation slows it down. The temporal evolution of the spreading radius depends on the viscosity of the liquid drop. We focus on the spreading dynamics of highly viscous molten sand on porous surfaces and simulate the phenomenon using a multiphase dissipative particle dynamics (DPD) model. The molten sand is a mixture of Calcia, Magnesia, Alumina, and Silicate, commonly referred to as CMAS, and is characterized by large viscosity, density, and surface tension. We carefully calibrated the multiphase DPD model for a molten CMAS droplet at 1260 degree Celsius. Three-dimensional simulations were carried out at different initial drop sizes and equilibrium contact angles. Despite its unique properties, the spreading behavior of molten CMAS is in good agreement with theory and experiments of viscous coalescence of drops. Two distinct spreading regimes, i.e., inertial regime and viscous regime, are observed in the mDPD simulations. Due to the large viscosity, a slower but a nonunique spreading rate is observed in the inertial regime. The spreading radius remains unaffected by the initial drop size and collapses onto a master curve under viscous time scaling in agreement with theory and experiments. For different equilibrium angles, the spreading rate is observed to be nearly identical in the inertial regime. This indicates a universal spreading behavior during the early stages of spreading unaffected by both the initial drop size and the equilibrium contact angle.

Multiphase Fluid-Structure Interaction in Deformable Porous Media at Multiple Scales

Samuel Fagbemi; Georgia Institute of Technology; United States
Pejman Tahmasebi; Colorado School of Mines; United States
Mohammad Piri; University of Wyoming; United States

Fluid-Structure interaction (FSI) is an important field of study in aerodynamics, hydrodynamics, and biomedical engineering. Recently, it has been extended to the area of flow through porous media to examine the interaction between fluids residing in their respective pores, and matrices. Deformation in such systems occurs due to changes in fluid pressure gradients or from external stresses. This type of system could be more complex with the presence of a second fluid phase which introduces a capillary and, in some cases, an electro-chemical effect while interacting with the deformable matrix. The characterization and description of such complex interactions is hence non-trivial, requiring the development of intricate coupling algorithms for interlinking several physical phenomena. In this work, we present a fluid-structure interaction problem for a micro-continuum system that undergoes infinitesimal deformation at the micro-scale. For such a system, we tightly couple the FSI equations and solve them using a partitioned approach. We then carry out a two-scale asymptotic homogenization step to link the deformation in the matrix structure and the fluid velocity in the pores at the microscale to the continuum level to obtain the macroscopic equivalents. Furthermore, a new multiple-fluid phase porous system is developed which couples to a non-linearly deforming matrix by tracking the interface of the fluids with an algebraic technique. The fluid mesh is updated using the Arbitrary Lagrangian-Eulerian (ALE) method while the FSI interface displacements are relaxed using the Interface Quasi-Newton with Inverse Least Square (IQN-ILS) root-finding relaxation method. We show that this multi-phase FSI implementation is stable for low Reynolds numbers and that elastocapillary effects were not significant at small scales. Further verification of the model with a network representation of pore fluid elements showed that both models agree under similar stability conditions.

Multiphysics topology optimization of heat sinks considering additive manufacturing constraints

Ardalan Nejat; Johns Hopkins University; United States
James Guest; Johns Hopkins University; United States

Heat sinks are used in a wide range of applications, such as batteries, electronic chips, and injection molding. The efficacy of the heat sink directly affects the performance capabilities and operating duration of the part. Therefore, high-performance heat sinks such as liquid channel cooling systems are much needed. Topology optimization, thus, is a natural choice for optimizing the configuration of such multiphysics problems. The superior performance of designs obtained by free-form topology optimization have been demonstrated computationally in literature, but results from free-form topology optimization often comprise microchannels to optimize performance. Such vein-like microchannels, however, are extremely difficult to manufacture and/or require significant support structures in the additive manufacturing process. This talk will incorporate manufacturing constraints, such as overhang constraints, within a large-scale parallel multiphysics topology optimization framework. Several examples with different allowable overhang angles will be shown, and the efficiency of the parallel implementation will be discussed.

Multiscale analysis of fiber-reinforced 3D printed concrete

Pouriya Pirmoradi; Eindhoven University of Technology; Netherlands
Payam Poorsolhjouy; Eindhoven University of Technology; Netherlands
Akke Suiker; Eindhoven University of Technology; Netherlands

3D Concrete Printing (3DCP) is quickly gaining popularity as a novel construction technique with significant advantages over traditional casting of concrete. The advantages of 3DCP, similar to those of other additive manufacturing techniques, arise from the unmatched levels of flexibility and control that it offers over material and structural (i.e. topological) complexity. Using 3DCP, perhaps for the first time, structural components can be made with different combinations of materials at desired locations. Further, in order to compensate for the weak tensile behavior of concrete, 3DCP structures are often reinforced with short fibers which enhance their tensile behavior and ductility. While various experimental investigations on the behavior of 3DCP structures exist, their modeling and design is still mostly done using wasteful trial-and-error approaches. In order to take full advantage of the benefits of 3DCP, modeling frameworks that are capable of predicting the behavior of these structures with computational efficiency while considering the effects of their specific microstructural features need to be developed. In this study, we present a multiscale framework based on Granular Micromechanics Approach (GMA) which studies the material as a collection of grains and fibers interacting with their neighbors. In this approach, the macroscopic behavior of the composite material is derived using a statistical analysis of micro-structural features in all generic directions. By careful formulation and calibration of micro-scale constitutive relations describing the behavior of particles and fibers, we have been able to derive the behavior of reinforced concrete structures with remarkable accuracy and low computational demand. This framework is ideally suited for topology optimization of 3DCP structures due to its low computational demand.

Multiscale Characterization to Examine Carbonation of Alkali-Activated Binders in Cementitious Materials

Shayan Gholami; Texas A&M University; United States
Yong-Rak Kim; Texas A&M University; United States
Dallas Little; Texas A&M University; United States
Sukmin Kwon; Land and Housing Institute; South Korea
Jong Suk Jung; Land and Housing Institute; South Korea

Carbonation has been traditionally viewed as a detrimental physiochemical process in cementitious materials in particular with alkali-activated materials (AAM). Dissolution of CO2 in the pore solution of AAM can decrease the alkalinity and disintegrate the solid pozzolanic matrix. However, this process is accompanied by precipitation of carbonate products in the matrix, where under specific conditions, it can compensate for the overall strength. This study aims to examine the governing factors developing different polymorphs of calcium carbonate precipitated, whereby the CO2 capture is beneficial to gain matrix strength. Toward that end, an alkali-activator (sodium metasilicate) was blended with raw precursors such as slag and fly ash for AAM paste. Paste specimens fabricated at different blends and levels of CO2 curing were tested using nano-micro scale mechanical characterization methods: nanoindentation and micropillar compression incorporated with in-situ scanning electron microscopy. Results were also coupled with nitrogen adsorption and X-ray diffraction (XRD) to better understand the carbonation mechanisms. It was seen that carbonation reactions saturated after a certain amount of CO2 exposure and improved the stiffness and strength of AAM. Moreover, AAM binders with both slag and fly ash showed a higher rate of carbonation than AAM with slag only, which presented a higher strength gain and more severe pH drop. It was also concluded that mesopore volume is not a governing factor in the carbonation of AAM binders as fly ash-slag binder exhibited a higher CO2 intake and a lower mesopore volume than slag-only binder. Results in this study indicate that AAM binders could be a promising choice for unreinforced building materials. Moreover, CO2 curing can be used as a supplementary curing regime for precast applications of ambient-cured AAM-based concrete.

Multiscale mechanics modeling by transferring knowledge across scales using a deep convolutional network

Ashwini Gupta; Johns Hopkins University; United States
Lori Graham-Brady; Johns Hopkins University; United States

Designing materials with targeted properties requires efficient modeling of material behavior and properties across different scales. Since modeling these up-scaling (homogenization) and down-scaling (localization) relations by performing a full-scale finite element (FE) discretization of the whole resolution is often impractical, a more efficient multi-scale modeling scheme such as FE-squared (FE2) is often utilized by performing FE discritizations at the macro- and the micro- scale. However, the solution from these multiscale FE approaches is heavily influenced by the choice of the micro-scale boundary conditions. Furthermore, these multi-level discretization approaches introduce errors along element boundaries. To overcome these challenges, a machine learning (ML) driven scheme is proposed, developed, and analysed for bridging scales in multiscale mechanics modeling. The proposed ML-model based on convolutional neural network (CNN) is trained separately to predict the micro-scale stress fields in linear elastic fiber-reinforced composite microstructures. This ML-model learns the underlying physics from the micro-scale simulations and transfers this knowledge to perform multiscale analysis of the macroscopic boundary value problem at a resolution of the micro-scale. The proposed approach is applied to a variety of macro-structure shapes and sizes, loadings, and boundary conditions and the solutions are compared with the traditional multiscale modeling approaches. These examples demonstrate that the proposed ML-driven approach performs multiscale analysis at speed orders of magnitude faster when compared to the homogenization based FE2 analysis. Furthermore, the results demonstrate that the accuracy of the proposed ML-based approach is comparable to the full-scale FE analysis. Broader applications of the proposed approach include efficient multiscale analysis of complex heterogeneous materials, with applications in uncertainty quantification, design, and optimization.

Multiscale modeling of flowslide triggering and runout by accounting for hydro-mechanical feedbacks and granular dynamics

Ming Yang; Northwestern University; United States
Giuseppe Buscarnera; Northwestern University; United States

This contribution proposes a hierarchical multiscale modeling framework to simulate flowslide triggering and runout. The approach couples a sliding-consolidation model resolving hydro-mechanical feedback within a liquefied sand layer with a local solver based on the discrete element method (DEM). This coupling is meant to simulate seamlessly the transition from solid- to fluid-like behavior following liquefaction and thus controlled by the local grain-scale dynamics. First, the features of the sliding-consolidation model are discussed. Based on the standard scheme of infinite slope, the model resolves the coupling between the sliding dynamics and excess pore water pressure transients by making reference to the constitutive response of the sand at the base of a flowslide. By inspecting the model equations, two timescales are identified, namely the external loading rate and pore pressure dissipation rate, showing that their competition leads to different temporal trends of triggering and excess pore pressure longevity. To study the role of the grain-scale interactions, DEM simulations are then used to replace the constitutive model and predict the emergent rate-dependent response of the sand during the inertial regime of motion. For this purpose, an algorithm is performed to ensure the correct passage of the strain rate from the global analysis to the local DEM solver under both quasi-static (i.e., pre-triggering) and dynamic (i.e., post-triggering) regimes of motion. While we find negligible influence of the grain-scale dynamics on the triggering process, micro-inertial feedbacks are found to bear remarkable effects on the runout, where the micro-inertial effects arising from post-liquefaction particle agitation generate spontaneously viscous-like effects that slow down the flowslide propagation. These findings emphasize the important role of rate-dependent feedback for the analysis of natural hazards involving granular materials, both in case of triggering (e.g., transient hydro-mechanical coupling) and post-failure dynamics (e.g., micro-inertial feedback).

Multiscale modeling of heterogeneous porous solids saturated by a thermoviscous fluid: beyond longwave homogenization

Renan Liupekevicius; Eindhoven University of Technology; Netherlands
Hans van Dommelen; Eindhoven University of Technology; Netherlands
Marc Geers; Eindhoven University of Technology; Netherlands
Varvara Kouznetsova; Eindhoven University of Technology; Netherlands

Porous solid materials saturated by thermoviscous fluids are encountered in the fields of rock acoustics and soundproofing materials. Most of these materials have random microstructures. In contrast, the emerging field of dynamic acoustic metamaterials utilizes intelligently designed structures to achieve remarkable properties, e.g., for noise and vibration reduction. As far as acoustic waves are concerned, porous solids may strongly interact with the fluid in which they are embedded, activating fluid-structure interaction. This multiphysics coupling yields neither fluid nor solid behavior, but instead an effective behavior of their mixture. Biot theory has successfully predicted the mechanical response of such porous materials under the longwave assumption wherein microscopic inertial forces are negligible. However, this assumption fails to be satisfied for locally resonant acoustic metamaterials, and a more sophisticated homogenization procedure is required.

In this contribution, we propose a transient computational homogenization framework that gives rise to a generalized continuum with additional field variables to capture the underlying localized dynamics caused by the heterogeneous microstructure, i.e., going beyond longwave assumptions (Biot theory). Adapting the approach proposed in [1], the coupling between the scales is given by a variationally consistent averaging of the governing equations expressed in their weak form, an extension of the Hill-Mandel condition. Numerical examples of fluid-structure locally resonant metamaterials demonstrate the efficiency and suitability of the proposed multiscale approach that is not limited to a plane-wave analysis, handling scattering problems, complicated geometries, and complicated loading conditions.

[1] Sridhar, A., Kouznetsova, V.G. and Geers, M.G.D. Homogenization of locally resonant acoustic metamaterials towards an emergent enriched continuum. Comput. Mech. (2016) 57(3): 423–435.

Multiscale modeling of thermal Young's modulus degradation of concrete at elevated temperatures

Simon Peters; Ruhr University Bochum - Institute for Structural Mechanics; Germany
Günther Meschke; Ruhr University Bochum - Institute for Structural Mechanics; Germany

Driven by the energy-intensive production process, cement is and has been always one of the largest global carbon dioxide emission sources. To reduce the climate impact, civil engineers replace ordinary Portland cement clinker with silica fume, fly ash or other supplements. Despite a polypropylene fibre reinforcement according to Eurocode 2 these modern cements tend to spall under thermal loading in experiments. The origin of this behaviour is still unclear because the multiphysical phenomenon of concrete spalling is difficult to investigate via experiments. Numerical models offer a possible remedy for this or could, at least, lead to important insights into this problem's specifics.

Based on Eshelby-type homogenization techniques, such as Mori-Tanka and Self-Consistent schemes, the Young's modulus of concrete is calculated at elevated temperatures, considering thermal aggregate-matrix mismatch, chemical porosity increase of hydrates, change of C-S-H phase according to variing packing density of C-S-H phases and thermal degradation of aggregates. Four scales of observation characterise the concrete namely hydrates, cement paste, mortar and concrete.

Due to the thermal incompatibility of aggregates and hardened cement paste, cracking in the matrix occurs, described by using a micro-poro-fracture mechanics framework by random distributed and oriented penny-shaped inclusions. A stoichiometric model based on a Arrhenius equation is used to predict the volume fractions of the dehydration products and porosity at hydrate level, to determine the degradation of each constituent. The change of packing density of C-S-H phases and thermal degradation of aggregates is taken out of the literature and experimental results, respectivly.

Concretes with different water to cement ratios and thermal expansion coefficients, aggregate types and C-S-H elasticity are analysed in the context of a sensitivity study comparing the different damage scources of concrete at elevated temperatures. This paper concludes that the chemically induced porosity has a minor and the packing density/thermal degradation of aggregates has the major influence on the Young's modulus until approx. 300°C. At higher temperatures the thermal aggregate-matrix mismatch is the main mechanism driving concrete degradation. Moreover, the thermal expansion coefficient of cement paste induces a strong degradation of concrete at elevated temperatures.

Multiscale Phase Field formulation for capturing Anisotropy in Network Response of Rubber-like materials

Prajwal Kammardi Arunachala; Stanford University; United States
Matthias Neuner; University of Innsbruck; Austria
Christian Linder; Stanford University; United States

Due to their desirable properties like high stretchability and toughness, rubber-like materials find many applications in fields like stretchable electronics, self-actuators and implantable sensors. Hence, modeling their fracture behavior is paramount for understanding and designing them against failures. Although there are many micromechanically motivated models for capturing their failure characteristics, many utilize network models which predict an isotropic network response, for bridging deformations at the two scales. However, they may not be effective in capturing effects on the fracture behavior of microscale phenomena like strain-induced crystallization, which have been found to produce anisotropy in the network behavior [1]. Therefore, in this study, a multiscale polymer model, which is bridged using the maximal advance path constraint [2] network model, is coupled with the phase field approach for modeling crack propagation in elastomers. At the microscale, non-Gaussian statistics is utilized for modeling the chain behavior while accounting for the internal energy due to molecular bond distortions. The non-affine maximal advance path constraint network model, modified for damaged systems [3], is utilized to bridge the deformations at the two scales. The phase field approach is used for modeling the damage, which is assumed to be caused mainly due to the failure of chain segments. Using micromorphic regularization, dual local-global damage variables are introduced and connected using the augmented Lagrangian method. The performance of the model is validated by comparing the simulation results with experimental data.

[1] P.K. Arunachala, R. Rastak, C. Linder, Energy based fracture initiation criterion for strain-crystallizing rubber-like materials with pre-existing cracks, Journal of the Mechanics and Physics of Solids 157 (2021) 104617.

[2] M. Tkachuk, C. Linder, The maximal advance path constraint for the homogenization of materials with random network microstructure, Philosophical Magazine 92 (2012) 2779–2808.

[3] P.K. Arunachala, S. Abrari Vajari, M. Neuner, C. Linder, A multiscale phase field fracture approach based on the non-affine microsphere model for rubber-like materials, Computer Methods in Applied Mechanics and Engineering (Submitted).

Nano-scale soil-water retention mechanism through MD and machine learning

Zhe Zhang; University of Florida; United States
Xiaoyu Song; University of Florida; United States

We study the nanoscale soil-water retention mechanism of unsaturated clay through molecular dynamics. Series of molecular dynamics simulations of clay at low degrees of saturation were conducted. Soil water was represented by a point cloud through the center-of-mass method. Water-air interface area was measured numerically by the alpha shape method. The soil-water retention mechanism at the nanoscale was analyzed by distinguishing adsorptive pressure and capillary pressure at different mass water content (degree of saturation) and considering apparent capillary interface area (water-air interface area per unit water volume). Water number density profile that distinguishes adsorptive water and capillary water was used to quantify adsorption effect. It has been demonstrated from the numerical results that the adsorption effect is dominated by van der Waals force between clay and water at the nanoscale. With the increase of degree of saturation, the impact of adsorption decreases and capillarity becomes a dominant effect in the soil-water retention mechanism at the nanoscale.

Nanogenerator Mechanical Metamaterial Concrete Systems

Amir Alavi; University of Pittsburgh; United States
Kaveh Barri; Johns Hopkins University; United States
Qianyun Zhang; New Mexico State University; United States
Wenyun Lu; University of Pittsburgh; United States
Jianzhe Luo; University of Pittsburgh; United States

For over forty years, researchers have been studying multifunctionality in concrete via exploring new material compositions, microstructure modifications, or using functional additives. The majority of these studies aim to develop concrete materials with improved strength or ductility. A next technological revolution in this arena is arguably creating a new generation of concrete materials with entirely new functionality via their rational architectural design. In this study, we present a novel class of lightweight composite concrete materials with energy harvesting functionality. The proposed nanogenerator concrete is created via integrating the metamaterial and triboelectrification paradigms. We design a metamaterial concrete system composed of an auxetic polymer lattice encapsulated in a conductive cement matrix. The metamaterial concrete structure is rationally designed to induce contact-electrification between its layers under mechanical excitations. The conductive cement enhanced with carbon fibers serves as the electrode in the proposed system, while providing the desired mechanical performance. Experimental and numerical studies are conducted to investigate the electrical and mechanical properties of the designed prototypes. We further discuss the potential applications of the proposed mechanically-tunable nanogenerator concrete system.

Nanoindentation and micromechanics of dental cement paste

Petr Dohnalik; TU Wien - Vienna University of Technology; Austria
Bernhard Pichler; TU Wien - Vienna University of Technology; Austria
Gilles Richard; Septodont; France
Christian Hellmich; TU Wien - Vienna University of Technology; Austria

We here report a grid nanoindentation campaign with ultra-flat surfaces, on BioDentine, a cementitious material used in dentistry. The corresponding normalized histogram of indentation moduli can be represented by the superposition of three log-normal probability density functions. The latter reveal that calcite-reinforced hydrates are the key to the superior mechanical properties of the investigated material system, while also revealing the existence of defects or cracks: Namely, homogenization bounds for the stiffness of the overall dental material are significantly higher than the macroscopic elasticity derived from ultrasonic experiments. The analysis is complemented by a a self-consistent micromechanics model linking two lognormally distributed microstiffness distributions of infinitely many hydrate to both Biodentine's macrostiffness and the microstress distributions developing within the hydrates. The latter turn out to be beta-distributed. Remarkably, the overall stiffness can be equally well upscaled from only two, piecewise uniform, hydrate phases exhibiting median microstiffness values.

Nanomechanical Characterization of Bacterial Biofilms via Bioindentation and Nanoscratch Tests

Haklae Lee; Northwestern University; United States
Ange-Therese Akono; Northwestern University; United States

Biofilms are communities of microbial cells attached on surfaces and embedded in a self-produced extracellular matrix comprised of nutrients and the extracellular polymeric substance. Biofilms are at the origin of up to 80% of human bacterial infections. The clinical significance of microbial biofilms has accelerated the pace of research on biofilm mechanics in the past few years with recent advancements in microscopic techniques, such as atomic force microscopy (AFM) and nanoindentation. Recent studies have tied biofilm resilience to their mechanical integrity, specifically, their viscoelastic response and cohesive fracture energy. However, quantifying the cohesive fracture energy of biofilms has still remained challenging given that biofilms are thin, soft, and dynamic. Here we show that employing scratch tests enables experimental determination of the cohesive fracture energy of Pseudomonas fluorescens biofilms. We first characterize biofilms as biomaterials through various microscopic analyses and investigate basic mechanical properties using an instrumented bio-indenter. We use a scratch tester and in our tests a diamond Rockwell C probe moves across the surface under a prescribed linearly increasing vertical load. We apply nonlinear viscoelastic fracture mechanics to extract the fracture parameters from scratch tests conducted at various loading rates and scratching speeds. This study is significant to devise a novel method to probe the cohesive fracture energy of biofilms.

Naturally Stabilized Conforming Nodal Integration with Novel Stress Update

Mike Hillman; Karagozian and Case, Inc.; United States
Jiarui Wang; Brown University; United States
Dominic Wilmes; Karagozian and Case, Inc.; United States
Joseph Magallanes; Karagozian and Case, Inc.; United States

Over the past several decades, meshfree methods have proved advantageous in large-deformation problems such as manufacturing, fragment-impact, and natural disasters. However, instability in nodal integration of Galerkin meshfree methods is still an inherent obstacle that must be addressed for effective simulations [1]. Both stabilized conforming nodal integration (SCNI) [2] and direct nodal integration (DNI) [3] suffer from low energy modes of node-to-node oscillation, which can grow dramatically and destroy the simulation solution, particularly in high-strain-rate problems where meshfree methods are adept. While SCNI can alleviate the instability in DNI, severe oscillations can still occur when the discretization is fine. Several methods have been proposed to remedy these instabilities, yet either require high-order derivatives which are computationally expensive, or user tunable parameters which are difficult to choose a priori and thus can yield solutions that are not objective.

In this work, a naturally stabilized conforming nodal integration (NSCNI) is first proposed. In contrast to previous versions, this method employs conforming smoothing cells for strain smoothing and calculation of derivatives, and is inherently variationally consistent, and thus requires no corrections. That is, the method naturally passes the linear patch test and can provide optimal convergence rates for linear approximations. The Taylor's series expansion of strain and Cauchy stress are employed, which finally leads to a supplement of the internal energy to stabilize the original Lagrangian SCNI solution. As a result, the second order gradients of meshfree shape function are required, but are approximated by smoothed first order implicit gradients, which entails far less effort than the computation of the standard explicit second order meshfree gradients. In fact, no derivative calculations are required whatsoever under this framework, yielding high computational efficiency. A novel stress re-interpolation method is further introduced, designed for the stabilization of material with highly nonlinearity, which avoids taking direct differentiation of stress and is favorable for arbitrary constitutive laws. The effectiveness of the proposed methodology is tested with several benchmark problems, including elasticity, near-incompressibility, plasticity, and continuum damage mechanics coupled with plasticity.

References [1] Hillman, M., & Chen, J. S. (2016). An accelerated, convergent, and stable nodal integration in Galerkin meshfree methods for linear and nonlinear mechanics. International Journal for Numerical Methods in Engineering, 107(7), 603-630. [2] Chen, J. S., Wu, C. T., Yoon, S., & You, Y. (2001). A stabilized conforming nodal integration for Galerkin mesh-free methods. International journal for numerical methods in engineering, 50(2), 435-466. [3] Beissel, S., & Belytschko, T. (1996). Nodal integration of the element-free Galerkin method. Computer methods in applied mechanics and engineering, 139(1-4), 49-74.

Neural network-encoded signed distance field for shape representation and computational particle mechanics of granular materials

Zhengshou Lai; Sun Yat-sen University; China

We present a neural network-encoded signed distance field (NetSDF) approach to the shape representation and computational particle mechanics of granular materials. Neural network is employed to learn and represent an SDF which describes a mapping from a point to a signed distance. Specially, the neural network takes point coordinates, along with a piece of latent code that encodes a single shape, as inputs, and outputs the signed distance from the point to the particle surface. The sign indicates the interior and exterior of a particle, and thus, the zeroth isosurface of SDF precisely represents the particle surface. The NetSDF, after trained with a given set of particle samples, could represent an entire class of particles that conform to the featured morphology of this type of granular material. We show the good capability of the NetSDF in representing trained irregular-shaped particles as well as generating newly virtual particles of the same class. It is also directly palatable to the SDF-based discrete element method (Lai et al., 2022, Computational Mechanics) for computational particle mechanics, while demonstrating superiorities in memory consumption and computational efficiency.

Neuromechanical Approaches for Improving Human Movement

Minoru Shinohara; Georgia Institute of Technology (Biological Sciences and Biomedical Engineering); United States

Human motor performance and its improvement through training are influenced by the neural activities that interact with the mechanical properties of the human and the environment. Therefore, the quantification of mechanical properties and the development of interventions to modulate neural activities are essential for the improvement of human movement. We have investigated various neuromechanical approaches to assess the mechanical properties of human muscles and to modulate neural activity to improve human movement. [Topic #1: Muscle Stiffness Assessment] The stiffness of muscles is often assessed manually by clinicians. Manual assessment is subjective and therefore has limited resolution and reliability. In exploring a more reliable method to quantify muscle stiffness with higher resolution, we applied the ultrasound-based analysis of shear-wave propagation velocity in soft tissues to contracting skeletal muscles and validated its applicability (elastography). We also developed a laser-based analysis of shear wave velocity in contracting muscles as an alternative and less expensive approach. [Topic #2: Mechanical Perturbations to Improve Fine Motor Skills] Human movement is sensed by mechanoreceptors in the musculoskeletal system, and the sensory feedback influences the neural command and, thus, motor performance. Interestingly, fine motor skills can be degraded due to abundant sensory feedback from muscle spindles (i.e., Ia afferent input) that sense the length of a muscle. To improve fine motor skills by facilitating neural inhibition of the Ia afferent input, we developed a robotic system that applies mechanical perturbations to a resting finger in a randomized manner for timing and direction. Healthy young adults were trained with this finger perturbation robot and improved their steadiness and fine motor skills with their hands. [Topic #3: Peripheral Mechanical Stimulation Paired with Brain Stimulation] The speed and force of human movement are influenced by neural excitability in the brain and the spinal cord (i.e., corticospinal excitability). Pairing magnetic stimulation of the motor cortex with electrical stimulation of a peripheral sensory nerve at the right timing is known to heighten corticospinal excitability (i.e., paired associative stimulation, PAS). Electrical stimulation to the nerve is limited to the peripheral nerves that are easily accessible from the skin surface. In place of electrical stimulation, we adopted a pneumatically powered mechanical stimulation of the muscle or tendon paired with a magnetic stimulation to the motor cortex. [Topic #4 Synergistic Human-Robot Interaction for Brain Excitability] A reduction in neural excitability in the injured brain is a major cause of motor impairment in stroke survivors. They often have difficulty opening and closing their hand for grasping during reaching and grasping. To compensate for the impaired extension function of the upper limb, stroke survivors often use trunk movements to carry their hand to an object to grasp. We developed a robotic system that can heighten the neural excitability of the impaired hand by adopting this synergistic movement (i.e., trunk activation and hand opening for reaching to grasp). In the system, a human controls the opening and closing of a detached artificial hand by voluntarily activating the associated trunk muscles for compensatory movements for reaching and grasping. The associated synergistic trunk activity is expected to heighten the neural excitability of the resting impaired hand. These topics on neuromechanical approaches to improve human movement will be presented and discussed. Funding: NIH/NINDS (1R21NS118435-01A1)

Non-Deterministic Kriging for Systems with Mixed Continuous and Discrete Input Variables

J Heeralu P Ravindu Jayasekara; Department of Civil and Environmental Engineering, Louisiana State University; United States
Sabarethinam Kameshwar; Department of Civil and Environmental Engineering, Louisiana State University; United States

This study proposes the Non-Deterministic Kriging to approximate probabilistic systems with mixed i.e., a combination of continuous and discrete input variables. The proposed method aims at approximating both epistemic and aleatory uncertainties in addition to the output of a system. As a metamodeling technique, kriging became more popular in approximations related to computational experiments which require a large number of resources and evaluations. Recently, the Non-Deterministic Kriging (NDK) method was derived as a flexible metamodeling method that approximates both epistemic and aleatory uncertainties of systems with continuous input variables. However, the discussed systems are coupled with dependence on discrete design variables as well. Although past studies proposed kriging models for the estimation of design outputs of systems or functions with both continuous and discrete input variables, limited studies covered the approximation of epistemic and aleatory uncertainties of the systems with mixed input variables. Therefore, this study aims at filling the gap in the Non-Deterministic Kriging Method for probabilistic systems with mixed continuous and discrete input variables. This proposed method utilizes a modified kernel with the Gower distance between data samples to incorporate the effect of discrete variables on the variogram calculation for mean estimation. Furthermore, the proposed method employs Locally Weighted Regression for calculating the aleatory uncertainty. Accordingly, data samples were weighted by using a kernel function which is a product between the standard Gaussian kernel for continuous variables and a second kernel for discrete variables. The newly proposed NDK method was tested on a set of numerical test cases with a pre-defined noise in data samples. The quantified errors showed that the estimated mean and variance match the actual trends of test cases. This new kriging methodology can be highly beneficial in computational experiments that consist of mixed types of design inputs with a large number of possible cases.

Nonlinear dimensionality reduction to identify building attributes that influence tornado damage for historic buildings

Saanchi Singh Kaushal; Pennsylvania State University; United States
Mariantonieta Gutierrez Soto; Pennsylvania State University; United States
Rebecca Napolitano; Pennsylvania State University; United States

While there is a great deal of research being done at the intersection of extreme wind loading and structural strengthening, the implications for historic and aging infrastructure, are often neglected . For instance the recent ASCE 7-22 implemented a design code for tornadoes, however presently it does not apply to Risk Categories (RC) 1 and 2 which comprise a large percentage of historic structures. . This research will provide new knowledge and data concerning RC 1 and 2 masonry structures during tornadic loading. For this research, multimodal data about masonry buildings were collected from the December 2021 tornado in Mayfield, KY. The data included point clouds, photographs, inspector field notes about building damage, and LiDAR scans. This work applies non-linear dimensionality reduction techniques in combination with finite analysis to develop a damage prediction model for buildings in tornado-hit regions. The approach involved extracting relationships between building attributes and the disaster, developing and testing supervised dimensionality reduction algorithms to evaluate features influencing the damage. The primary reasoning behind this task is that even though historic masonry structures are susceptible to wind damage, there is limited knowledge about building attributes and their influence on the damage. Simulations are used to validate the claims about specific attribute significance. Identifying the relevant building attributes and simulating their response will provide an insight into building failures, and lead to innovative strengthening techniques for these structures.

Nonlocal micro-polar poromechanics for shear bands and cracks in porous media under dynamic loads

Xiaoyu Song; University of Florida; United States
Hossesin Pashazad; University of Florida; United States

We present a Cosserat periporomechanics paradigm for modeling dynamic shear banding and crack branching in porous media incorporating a micro-structure based length scale. In this micro-periporomechanics framework, each material point has both translational and rotational degrees of freedom following Cosserat continuum. We formulate a stabilized Cosserat constitutive correspondence principle through the energy method through which classical viscous elastic and plastic material models for porous media can be used in the proposed Cosserat periporomechanics. We have numerically implemented the micro-periporomechanics paradigm through an explicit algorithm in time and a Lagrangian meshfree method in space for dynamic problems. Numerical examples are presented to demonstrate the efficacy and robustness of the micro-periporomechanics for modeling shear banding and crack branching in dry porous media under dynamic loads.

Normalizing Flow-based Deep Variational Bayesian Network for Seismic Multi-hazards and Impacts Estimation from InSAR Imagery

Xuechun Li; Stony Brook University; United States
Susu Xu; Stony Brook University; United States

Large-scale disasters, such as earthquakes, often induce multiple cascading hazards, together with ground shaking, leading to consequent building damage. Building damage is one of the most important causes of human and economic losses during disasters. Therefore, immediate details about where and how severe building damage occurs in the affected area are critical for the post-disaster response, rescuing plan, and societal recovery. Traditional approaches, such as building fragility functions, have limited accuracy and resolution due to large uncertainties, limited availability of data, and lack of consideration of compounding building damage causes such as local hazards and geological conditions. Recently, InSAR imagery has shown the potential to provide high-resolution ground surface change information for rapid disaster response. Nevertheless, building damages are inherently causally linked and often co-locate with earthquake-induced ground failures and environmental noises, making it particularly challenging to categorize building damages from the satellite images directly. Here we introduce a novel deep causal Bayesian inference framework to infer the spatial occurrences of multi-class building damage, without any ground truth labels, through the integration of InSAR image-based Damage Proxy Maps as well as prior multi-hazards models and building fragility functions. We model seismic ground failure, building damage, building footprints, remotely sensed observations, and their complex causal dependencies into a holistic causal graph, and formulate the graph as a new family of deep causal Bayesian networks. The deep causal Bayesian network links the multi-layer unobserved intermediate hazards, building damage with causalities, and models the causal dependencies with flow models to better approximate the physical processes of building damage occurrence. We further build our algorithm on variational inference for jointly inferring complex posteriors of intermediate hazards and building damage. We evaluate our framework on multiple earthquake events, including the 2016 Central Italy earthquake, 2019 Ridgecrest earthquake, 2020 Puerto Rico earthquake, 2020 Zagreb earthquake, and 2021 Haiti earthquake. The results show that our framework significantly improves severe building damage detection and quantification compared to fragility functions in FEMA's HAZUS software. We also analyze how incomplete building footprints, satellite image resolutions, and uncertainties in ground truth labels would impact the evaluation of our results.

Novel Lagrange Multiplier Formulation for Imposing Displacement and Traction Discontinuities in Material Microstructures

ARIFUL HASAN; University of Tennessee, Knoxville; United States
Timothy Truster; University of Tennessee, Knoxville; United States

Formulating effective boundary value problems (BVP) for microscale deformation mechanisms of heterogeneous materials with embedded discontinuities is a continuing need for advanced materials design. For example, the embedding of magnetic particles along grain boundaries in metals or fibers of composites could allow for external activation by non-mechanical fields. A novel class of BVP is explored in this talk by extending recent works on generalized interfaces to incorporate externally imposed displacement and traction jumps along grain boundaries in a representative volume element (RVE). Both the displacement jumps and periodic boundary constraints are formulated weakly using Lagrange multiplier fields in a unified fashion. First, a four-field formulation is posed with double-valued multipliers as inspired from domain decomposition methods. Next, a simplified three field formulation is derived by introducing weighted averages of traction and displacement while still retaining uniqueness of the mechanical fields with respect to the fundamental BVP solution. Potential insight to the prescribed interface jumps is explored by linking them with classical models in homogenization theories of heterogeneous materials. Numerical studies using inf-sup stable interpolation combinations are found to reproduce analytical solutions as well as exhibit the local zone of influence of traction and displacement jumps in periodic RVE. Physical interpretations of the jumps are given through two theorems that demonstrate the classical homogenization approaches of Taylor and Sachs can be recovered through suitable expressions of the jump fields.

Novel Polymer-Ceramic Nanocomposites Using Advanced Electrospinning Methods

Yunzhi Xu; Northwestern University; United States
Ping Guo; Northwestern University; United States
Ange-Therese Akono; Northwestern University; United States

Electrospinning is a versatile approach to generate nanofibers in situ. Yet, recently, wet electrospinning has been introduced as a more efficient way to deposit isolated fibers inside bulk materials. In wet electrospinning, a liquid bath is adopted for fiber collection. However, despite several studies focused on wet electrospinning to yield polymer composites, few studies have investigated wet electrospinning to yield ceramic composites. We propose a novel in-situ fabrication approach for nanofiber-reinforced ceramic composites based on an enhanced wet-electrospinning method. Our method uses electrospinning to draw polymer nanofibers directly into a reactive pre-ceramic gel, which is later activated to yield advanced nanofiber-reinforced ceramic composites. We demonstrate our method by investigating wet electrospun Polyacrylonitrile and Poly(ethylene oxide) fiber-reinforced geopolymer composites, with fiber weight fractions in the range 0.1–1.0 wt%. Wet electrospinning preserves the amorphous structure of geopolymer while changing the molecular arrangement. Wet electrospinning leads to an increase in both the fraction of mesopores and the overall porosity of geopolymer composites. The indentation modulus is in the range 6.76–8.90 GPa and the fracture toughness is in the range 0.49–0.76 MPa$\sqrt{m}$ with a clear stiffening and toughening effect observed for Poly(ethylene oxide)-reinforced geopolymer composites. This work demonstrates the viability of wet electrospinning to fabricate multifunctional nanofiber-reinforced composites.

Numerical Analysis of Sequential Tunnel Excavation Inspired by Ants

Meron Belachew; Georgia Institute of Technology; United States
Karie Yamamoto; Georgia Institute of Technology; United States
Chloé Arson; Georgia Institute of Technology; United States
David Frost; Georgia Institute of Technology; United States

Subterranean tunneling is a complex problem in geotechnical engineering be it for subsurface investigation, underground mining, or infrastructure. The stress path dependency of the problem coupled with the complex nature of geomaterials makes it difficult to solve using analytical methods. A few analytical solutions exist for very simple tunnel geometries in elastic or elastoplastic domains, but these are inadequate when considering tunnels with complex geometries or at shallow depths. Experiments and numerical simulations, therefore, become critical to understanding the complex processes and phenomena associated with tunneling. The problem of tunneling can either be viewed from the perspective of post-excavation stability or excavation efficiency. In previous work, we used ant tunnel structures (ant nests) as inspiration and performed FEM simulations to understand and highlight the mechanisms that the ants are utilizing in order to keep their nests stable. Ants were chosen because of the complex and unique underground tunnel structures they build as well as the efficiency with which they excavate them. To address the efficiency of ant tunneling, their excavation sequence and methodology were studied here. Experimental observations of ant tunneling in 2D chambers showed that the diameter of the ant shafts was gradually increasing as the ants advanced the structures instead of being constructed to the final cross—section configuration all at once. In this study, the performance of this excavation mechanism is evaluated in a range of FEM models with different soil parameters and boundary conditions to assess the benefit of using this excavation mechanism as opposed to the single-pass construction method that humans typically use. Finally, we comment on the energy efficiency of the excavation mechanisms.

Numerical Evaluation of Dynamic Responses of Oregon Bridge Rail under Multi-level Vehicular Impacts

Howie Fang; Liberty University; United States
Qian Wang; Manhattan College; United States

Bridge rails are important safety features installed on bridge decks or parapets to prevent vehicles from falling off the bridge and mitigate crash hazards. Currently, all bridge rails and roadside safety devices must be tested to meet the safety guidelines specified by the Manual for Assessing Safety Hardware (MASH) issued by the American Association of State Highway and Transportation Officials (AASHTO). In this study, the crashworthiness of the Oregon rail was evaluated for compliance with MASH under Test Level 4 (TL-4) conditions using finite element (FE) simulations. The dynamic responses and damage characteristics of the Oregon rail under vehicle impacts were studied. The research study consisted of an investigation of critical impact points, evaluation of vehicle snagging and occupant responses, and rail capacity and impact loading according to MASH TL-4 impact conditions. For a better understanding of the complex impact dynamics, two reference points were selected, one being the expansion splice and the other being the post closest to the expansion splice. The FE models of three MASH-compliant vehicles, including a passenger car, a pickup truck, and a single-unit truck, were used in the dynamic crash simulations, to evaluate the performance of the Oregon rail for structural adequacy, occupant risk, and post-impact vehicle trajectories. The FE models of the passenger car and pickup truck were further validated using the results of two full-scale physical crash tests conducted in this study. The simulation results showed that damage to the railing system was minor, and that all the performance metrics were within the MASH safety limits, indicating the Oregon rail passed the safety requirements specified under MASH TL-4 conditions.

Numerical implementation and validation of an advanced Thermo-Elasto-Viscoplastic (TEVP) constitutive model for saturated frozen geomaterials

Dana Amini; University of Manitoba; Canada
Pooneh Maghoul; Polytechnique Montréal; Canada
Amade Pouya; École des ponts ParisTech; France

Ground thermal conditions govern the formation and long-term existence of subsurface ice in northern latitudes. From a poromechanical point of view, a saturated ice-containing geomaterial is composed of a deformable solid skeleton and an interconnected network of pores filled with ice and unfrozen water. The amount and distribution of ice inclusion, which are temperature-dependent, determine the spatiotemporal scales of slow-rate steady-state creep deformation of ice-containing geomaterials. Investigating such time- and temperature-dependent mechanical behavior calls for coupled Thermo-Hydro-Mechanical (THM) physics involving mechanical stability, thermal loading and pore water phase change, and heat and mass transfer within the medium. Furthermore, an advanced constitutive model is also required to thoroughly capture the rate-dependent deformations of such frozen mixture. In this work, as the main core of the THM analysis, the critical-state thermo-elasto-viscoplastic (TEVP) constitutive model developed by the authors and their colleagues for thermal creep deformation of frozen geomaterials is numerically implemented into a finite element platform called DISROC. DISROC is a scientific code developed by Fracsima (a software company in France) aiming at multi-dimensional analysis and simulation of coupled THM phenomena in highly non-linear materials. The predictions of the numerical models are then validated against experimental results available in the literature for well-known lab tests. The developed numerical framework can be employed in different studies to investigate the life-cycle performance of infrastructure affected by climate change. It can also be used to assess the stability of natural environments such as Arctic coasts and natural slopes under different climate scenarios.

Numerical Simulations of Particle Behavior and Breakage within a Pressurized Sand Damper Subjected to Cyclic Loading

Mehrdad Karimipetanlar; Southern Methodist University; United States
Usama El Shamy; Southern Methodist University; United States
Konstantinos Kalfas; Southern Methodist University; United States
Nicos Makris; Southern Methodist University; United States

In this study a numerical model based on the discrete element method (DEM) is presented to better understand the mechanical behavior and particle breakage within a pressurized sand damper (PSD) subjected to dynamic loading. A PSD is comprised of a rod with a sphere attached to the middle of it placed inside a cavity filled with pressurized sand. Computational simulations of the PSD under different initial pressures and stroke amplitudes were conducted and compared to experimental results. Good agreement was achieved between the DEM model and experimental results for different cases. Force-displacement, particle breakage and shear and normal stresses were closely monitored in different areas of the PSD. The grains in the simulations included spherical particles, breakable and unbreakable clusters as sand particles. The performed simulations highlighted the importance of incorporating particle breakage in modeling the damper, as close agreement was only observed when particle crushing was included with the experiments. The results show that the majority of breakage occurs in the vicinity of the center of the PSD and within the first loading cycle. Increasing stroke amplitude had a significant influence on particle breakage whereas the effect of increasing initial pressure was less considerable. In addition, a direct relationship between the PSD's direction of movement with shear and normal stresses was observed. Monitoring these stresses on different sections of the rod indicated an increase in both stresses in sections in front of the sphere's movement direction. Results from shear to normal stress ratios for these sections also showed that steady state was achieved after the first loading cycle.

Numerical Study on Phase Transformation Induced Material Fracture

S. Sindhusuta; University of Illinois at Chicago; United States
Sheng-Wei Chi; University of Illinois at Chicago; United States
Craig Foster; University of Illinois at Chicago; United States

The physical mechanisms triggering intermediate-depth earthquakes remain a puzzle for the scientific community. However, many studies discussed phase transformation as the primary mechanism behind the generation of these hazardous earthquakes. The objective of this work is to numerically study the role of phase transformation-induced failure in intermediate-depth earthquakes. The materials of interest include different groups of minerals found deep in the earth in the mantle transition zone, such as olivine. A thermo-mechanical model approach has been taken to model the phase transformation behavior. A thermodynamically consistent multiscale model, based on Mahnken et al., 2015, has been developed to capture the evolution of phase transformation in such materials under different pressure and temperature conditions. In the model, each material point of the macroscale consists of polycrystals at the mesoscale level which further consists of various phases on the microscopic level. The model also considers visco-plasticity and heat conduction and uses a volume averaging scheme to link different length scales. Implementation of the abovementioned thermomechanical model has been done using a user subroutine in a commercial finite element software ABAQUS. The developed model was first verified with the diffusion-based phase transformation from austenite to bainite. The model was then validated using the phase diagram of the olivine-spinel transition. For the simulation of microstructural failure in the material, the extended finite element method has been used with the abovementioned model. An earlier and higher amount of crack propagation has been observed from the results with phase transformation compared to the case without any phase transformation under the same loading and boundary conditions. Further, a three-dimensional model of an olivine matrix with the inclusion of spinel has been constructed to analyze the spinel transformation under high pressure and study possible damage formation. The results show a transformation band of spinel formed at 45 ° to the direction of compressive loading and a different stress distribution due to phase transformation. The model will be further validated with the data obtained from the laboratory experiments done on the materials of interest to investigate the phase transformation-induced instability leading to the formation of macrocracks.

On the effect of vertical flexibility in objects isolated on pendulum-type systems

Mia Griffin; University of Oklahoma; United States
P. Scott Harvey; University of Oklahoma; United States

Pendulum-type isolation systems are commonly used because their horizontal isolation period is independent of the mass of the object being isolated. The two most common pendulum-type systems are based on sliding or rolling on concave surfaces. The latter, which is popular for light-payload applications (e.g., equipment) because of its inherently lower damping, is the focus of this study. The study explores the effect of vertical flexibility in the isolated object, which is commonly neglected. Both theoretical and experimental approaches are uses. A physics-based mathematical model of a rolling pendulum isolation system is developed incorporating a vertical degree of freedom in the isolated object. Using this model, numerically simulated results characterize the isolation performance in terms of the total acceleration of the isolated mass. Parametric variation is provided by the vertical period of the isolated mass and the percent of the mass that is mobilized. The numerical results are validated through shake table experiments. The experimental setup is comprised of an isolation system with 3D-printed rolling surfaces that supports a sprung mass. Uniaxial (horizontal) shake table tests are conducted, and the horizontal and vertical acceleration responses are measured. Harmonic, pulse-like, and seismic inputs are considered. The results of this study demonstrate when vertical flexibility needs to be considered in the modeling and evaluation of pendulum-type isolation systems.

On the effects of fabric on the instability onset under constant shear drained loading

Srinivas Vivek Bokkisa; Georgia Institute of Technology; United States
Jorge Macedo; Georgia Institute of Technology; United States
Alexandros Petalas; Durham University; United Kingdom

It is well established that loose soils undergo static liquefaction when subjected to monotonic shear loading under undrained conditions. However, several case history failures of slope systems (e.g., water and tailings dams) have shown that the instability can also occur under prevailing drained conditions that can be represented by constant shear drained (CSD) stress paths. In this study, a constitutive model formulated under the Anisotropic Critical State Theory (ACST), SANISAND-F, is used to assess the effect of fabric anisotropy (induced and inherent) and loading characteristics, such as Lode angle and direction of the major principal stress on the instability onset under CSD stress paths in a comprehensive manner. We used Hill's instability criterion to track the onset of instability, which derives into two independent conditions for particulate materials. The first condition requires the change in volumetric strain to be zero at the point of instability, a criterion commonly used in CSD experiments on loose soils. The second condition is the change in mean effective stress being zero. Loose soils exposed to the constant shear drained (CSD) stress path initially dilate but then contract at the point of instability. Numerical simulations reveal that in loose states, dilative elastic volumetric strains are dominant over contractive plastic volumetric strains. However, as the simulation progresses, plastic volumetric strains increase exponentially, transitioning to a contractive volumetric strain and instability. Hence, the tradeoff of the volumetric strain components dictates the instability onset. On the other hand, both elastic and plastic volumetric strains in dense states are dilative throughout the CSD stress path, resulting in continuous dilation, and the instability onset is not associated with the tradeoff of volumetric strain components. The numerical results show an important effect of fabric anisotropy on the stress ratio at the instability point. For conditions representative of common experimental setups, the instability stress ratio decreases with the increase of the Lode angle and the direction of major principal stress relative to the vertical, and the instability stress ratio increases with the increase of initial fabric intensity, consistent with the available experimental evidence. However, these trends can potentially change based on the interaction between the Lode angle and loading/fabric directions, hence, departing from typical experimental observations. Further experimental investigations are necessary to understand these findings better.

On the mechanics of the tooth-stylus-radula systems of chitons: a soft conveying-belt for efficient force transduction

John Connolly; Purdue University; United States
Phani Saketh Dasika; Purdue University; United States
Jungeun Lee; University of California, Irvine; United States
Taifeng Wang; University of California-Irvine; United States
David Kisailus; University of California-Irvine; United States
Pablo Zavattieri; Purdue University; United States

Chitons are mollusks which live on hard surfaces in the sea and use ultrahard magnetite-based teeth to harvest algae from rocky substrates. Their teeth are attached to a radula, a belt-like membrane, by styli, appendages which support the tooth during the zipper-like, rasping action used for feeding. The mechanical properties of the styli and the radula, such as regionally-varied stiffness, and interaction between structural features, enable the rasping of teeth across hard surfaces of varying, unpredictable topography, with sufficient force to remove food for ingestion and flexibility to resist breakage due to overloading. In this study, the structural elements of the chiton's feeding apparatus are characterized, and we employ computational models to define mechanical relationships describing in situ performance. The generalized findings of this work can inform design decisions in lightweight structures, soft robotics, remote sensing, and other modern mechanical fields.

On the modeling of interfaces with resultant-based formulations in composite materials

Ghadir Haikal; North Carolina State University; United States

The multiscale modeling of materials such as fiber-reinforced composites and composite laminates often involve modeling interactions at interfaces between a 2D/3D solid matrix and components best represented with resultant-based formulations such as beams or plates. Resultant-based beam and shell theories do not provide direct estimates of interface stresses, complicating the process of capturing small-scale interfacial damage such as delamination. While computational models for contact interfaces in 2D and 3D solid mechanics have been extensively developed in the literature, beam-solid and plate/shell-solid interface models have received less attention. This presentation discusses the numerical challenges of modeling interfaces that involve resultant-based structural formulations including beams, plates and shells. We propose an interface formulation capable of ensuring continuity between the stress fields on the solid side of the interface, and the moment and shear resultants in the structural element. The result is a robust approach that promotes computational efficiency and can be readily incorporated into available multiscale formulations of composite materials.

On the Use of Alternative Paving Materials: a RILEM research from TC 279 WMR

Augusto Cannone Falchetto; Aalto University; Finland
Lily Poulikakos; EMPA, Swiss Federal Laboratory for Material Science and Technology; Switzerland
Emiliano Pasquini; University of Padova; Italy
Di Wang; Aalto University; Finland
Marjan Tušar; Slovenian national building and civil engineering institute; Slovenia
Jorge Pais; University of Minho; Portugal
Fernando Moreno-Navarro; Universidad de Granada; Spain
Davide Lo Presti; University of Palermo; Italy
Ana Jiménez del Barco Carrión; Universidad de Granada; Spain

Investigating the possibility of incorporating waste, marginal and secondary materials in pavements has become a critical research area in the field of road engineering as, over the years, the sensibility and attention to the sustainability of road infrastructure and valorization of waste materials have increased. At the same time, using diverse potentially valuable materials derived from different production activities and industrial by-products was considered significant for the scientific community and the RILEM cluster F on Bituminous Materials and Polymers. TC 279-WMR was the first technical committee to propose, organize, and perform structured research on Waste and Secondary Materials for Roads. Several materials were investigated: waste Polyethylene (PE), crumb rubber (CR), construction and demolition waste (CDW), recycled concrete aggregates (RCA), and steel slag (SS). The use of PE was first evaluated at the binder level using various test methods, including Multiple Stress Creep Recovery (MSCR) and Linear Amplitude Sweep (LAS) tests showing that PE-modified blends had better resistance to permanent deformation than non-modified binders. LAS fatigue response indicated that PE blends could withstand more loading cycles at lower temperatures under low strains. The dry process was used for the mixture preparation to bypass the stability and inhomogeneity experienced at the binder scale. The PE-modified dense-graded mixtures showed improved workability and increased strength. Higher PE dosage resulted in higher indirect tensile strength (ITS) compared to mixtures without plastic waste, thanks to the enhanced cohesion of the plastic-modified mastic. The stiffness experiments tended to show improved performance with a lower time dependence and a higher elasticity when plastic was added. The cyclic compression tests demonstrated a reduced creep rate and a higher creep modulus thanks to the addition of PE, further confirmed by the wheel tracking test. Furthermore, acceptable and often improved moisture resistance was observed for PE-modified materials. Interlaboratory experiments were performed on four types of CR combined with three base asphalt binders (CRMB). The mechanical and chemical properties of CRMB were investigated. The incorporation of CR affected the overall stiffness spectrum of the original binder with beneficial higher stiffness at high temperatures. This behavior is mainly associated with a physical interaction between CR and binder, as confirmed by the FTIR analysis, with the grade of the binder playing a fundamental role in determining the response of the CRMB. CDW, RCA, and SS were evaluated as replacements for natural aggregates in dense-graded asphalt mixtures. The design process indicated that bituminous mixtures prepared with the investigated alternative aggregates required higher amounts of the binder but had acceptable volumetric properties. Furthermore, they exhibited better mechanical performance, regardless of the source of recycled aggregates. Finally, an exploratory life cycle assessment (LCA) and the development of benchmarks for asphalt mixtures (cradle-to-gate), with and without alternative paving materials, were performed regarding greenhouse gas emissions (GHG) and energy consumption. Based on the benchmark levels, the benefit of incorporating waste and secondary materials depended on the mixture type. The intense and comprehensive research work of the RILEM TC 279 WMR supports the use of alternative paving materials for asphalt mixtures. This result encourages the paving industry toward the target of a zero-waste society and reducing the use of natural resources. However, the adaptation of quality control/acceptance criteria, standardization, pavement design, and the development of specific research aimed at further assessing such materials' environmental viability and life cycle sustainability is vital to the widespread acceptance and implementation of such alternative materials.

Operational Health Monitoring of Bridges Using Bayesian Model Updating and Computer Vision Techniques

Niloofar Malekghaini; University of Nevada, Reno; United States
Farid Ghahari; University of California, Los Angeles; United States
Hamed Ebrahimian; University of Nevada, Reno; United States
Vinayak Sachidanandam; SC Solutions Inc; United States
Eric Ahlberg; University of California, Los Angeles; United States
Matthew Bowers; SC Solutions Inc; United States
Ertugrul Taciroglu; University of California, Los Angeles; United States

This study presents a new solution framework for operational health monitoring of bridges using finite element (FE) model updating. In this framework, the bridge acceleration responses are collected using accelerometers while the traffic on the bridge is tracked using traffic cameras and computer vision techniques. These data are synchronized and integrated with the initial FE model of the bridge through a Bayesian inference. The load of tracked vehicles traversing on the bridge and the unknown FE model parameters are estimated using time-domain Bayesian model updating process. The final estimates of FE model parameters reveal information regarding the location, mechanism, and extent of potential damage in the monitored bridge. This framework is successfully verified in a numerically simulated environment using synthetic data obtained from a finite element model of a prestressed concrete box-girder bridge. Then, the applicability of the proposed method in a real-world setting is evaluated utilizing a pair of full-scale girders as a testbed structure. The results demonstrate the capabilities of the method to diagnose potential damages in real-world bridge structures. Next, the proposed solution framework is carried out on a real-world bridge subjected to traffic excitation due to passage of tri-axle dump trucks. The initial FE model of the bridge is developed using the available as-built drawings. The synchronized acceleration and vehicle tracking data are fed into the Bayesian inference along with the initial FE model. The updated model is used to infer damage in the studied bridge.

Operational Modal Analysis of Two Offshore Wind Turbines in CVOW Wind Farm

Burak Bagirgan; Tufts University; United States
Babak Moaveni; Tufts University; United States
Eric Hines; Tufts University; United States

This study presents the system identification of two offshore wind turbines (OWT) in the Coastal Virginia Offshore Wind (CVOW) farm. Each OWT is instrumented with accelerometers and its continuous vibration measurements are recorded with a sampling frequency of 50 Hz. Modal parameters of the wind turbines, including natural frequencies, damping ratios, and mode shapes are identified using two automated operational modal analysis methods, namely the Natural Excitation Technique combined with Eigen-analysis Realization Algorithm (NExT-ERA) and data-driven stochastic subspace identification (SSI-Data). Modal parameters are extracted using 10-minute windows of data for around 15 days for Turbine 1 and 40 days for Turbine 2. The first bending modes in fore-aft (FA) and side-to-side (SS) directions are the focus of this study. Statistics of identified modal parameters are reported and compared for the two methods.

Optical Properties of Topological Semimetals MX (M = Ti, Zr, Hf, and X = S, Se, Te) Family by DFT Approach

Sami Ullah; King Fahd University of Petroleum and Minerals; Saudi Arabia
Sikandar Khan; King Fahd University of Petroleum and Minerals; Saudi Arabia
Firoz Khan; King Fahd University of Petroleum and Minerals; Saudi Arabia

In the framework of density functional theory, the optical properties of the MX (M = Ti, Zr, Hf, X = S, Se, Te) family with spin-orbital coupling effect have been investigated. The contribution (s, p and d) orbitals have confirmed from the comparisons of optical and electronic properties of MX family. The d-orbital of transition metals has a major impact on absorption performance. The negative portions of the real spectra were associated with strong reflectivity peaks. The energy loss spectrum's high-intensity peaks along the x, y, and z axes match the zero values of the real and imaginary spectra. The energy loss spectra's low peaks correlate well with the imaginary spectra in the high energy area. The imaginary, real, reflectivity, and energy loss spectra of the x, y, and z axes of transition metals M (i.e., Ti, Zr, and Hf) indicate a significant shift from higher to lower energy when the X is changed from S to Te.

Optimal design and mechanical behaviour of root-inspired anchors under combined loading

Fernando Patino-Ramirez; Imperial College London; United Kingdom
Catherine O'Sullivan; Imperial College London; United Kingdom

The impending energy transition relies on the development of cost-effective and reliable foundation systems for floating wind turbines, offshore platforms, and coastal barriers. Contrary to conventional structures where the design of the foundation systems is controlled by the downwards vertical load (bearing capacity), the design of the foundations for these tall, lightweight, and slender structures is controlled by lateral loads, which result in pull-out (tensile) forces and momentum on the foundations.

Currently, offshore wind farms have almost exclusively relied on monopile foundations and/or suction buckets (caissons) that mobilise lateral friction in response to pull-out forces. Still, these foundation systems become technically and economically unviable beyond 40m in length and at water depths beyond 50m. As the industry moves towards locations with increasing wind speeds to harvest more energy, new foundation systems for floating structures are needed to enable the construction of deep-water wind farms and platforms.

In nature, tall and slender trees (from sequoias to palm trees) have evolved to grow complex root systems capable of enduring extreme lateral loads induced by storms and tides. Surprisingly, those root systems are relatively shallow and favour lateral spreading rather than deep growth into the substrate. As a result, these foundations exploit the passive resistance of the soil to bear pull-out and lateral loads, rather than on the lateral friction generated between the structure and the surrounding soil.

In this contribution, we seek to establish the geometry that maximises the pull-out resistance of underground anchors. To this end, we couple the discrete element method with a genetic optimisation algorithm (ACO) to find the optimal trade-off between the depth and width of the anchors. Then, we study the effect of loading angle and anchor depth with interaction diagrams (also known as yield surfaces) for combined loading conditions that couple vertical, horizontal, and moment loading.

Results indicate that for a fixed embedded length, a Y-shaped geometry with about 80% of the length of the anchor installed at an angle close to the Coulomb angle yields the maximum pull-out resistance. In addition, yield surfaces for combined loading show a significant reduction of the ultimate pull-out capacity of the anchors with increasing load angle due to the alteration of the passive failure mechanism generated around the anchor. Lastly, we study the installation process of the proposed bio-inspired anchors, a key step that has deterred the widespread adoption of this kind of anchors in the practice.

Optimal Strategies for Enhancing Healthcare Resilience Under Mainshock-Aftershock Events

Emad Hassan; Colorado State University; United States
Hussam Mahmoud; Colorado State University; United States

Hospitals provide essential services for communities, especially after natural disasters. Major earthquake events can reduce hospitals' capacities and, at the same time, increase their patient demand. These significant earthquakes are followed by many aftershock events that can increase hospital buildings' damage, disrupt their main utilities, and trigger multiple waves of patient surges. Despite the destructive nature of these mainshock-aftershock events, most hospitals are not prepared for such events. In this presentation, we investigate the impact of the mainshock-aftershock earthquake scenario on the hospital network in Shelby County, Tennessee. We model damage, functionality, and recovery of hospitals, residential buildings, and other supporting infrastructure, including water, power, and transportation systems essential for hospital functionality. We then introduce and test different mitigation strategies and estimate optimal resources to enhance hospitals' functionality subjected to the sequential events. The results show that providing alternatives for hospitals' staff, space, and supplies can significantly improve healthcare resilience.

Optimization and machine-assisted Δ-learning for multiscale modeling of polymer nanocomposites

Hamid Ghasemi; Howard University; United States
Hessam Yazdani; University of Missouri; United States

Constructing representative multiscale models and simulating them under different loading conditions is an efficient means to develop processing-statistics-structure-property relations in materials. However, this approach is involved for polymer nanocomposites (PNCs), given the challenges and computational burden associated with capturing and simulating the wide range of compositions, phenomena, and interactions that PNCs feature across several scales of time, length, complexity, and uncertainty. This work addresses this challenge by developing an approach that first combines atomistic simulations, metaheuristic optimization, and machine learning to calibrate coarse-grained force fields (CG-FFs) for polymers and then employs CG-FFs in conjunction with microstructure information to construct multi-tier models that efficiently predict the mesoscale mechanical properties of a PNC. Polyvinyl chloride (PVC) reinforced with carbon nanotubes (CNTs) is used as a representative PNC. A Δ-learning scheme is proposed and employed where support vector regression (SVR) surrogate models are trained on the difference between predictions made for PVC's mechanical properties and density by classical all-atom and CG MD simulations. The SVR is coupled with the particle swarm optimization algorithm to iteratively calibrate a CG-FF for PVC. The generalizability and extrapolability of the CG-FF to unseen system configurations are demonstrated by testing its accuracy in predicting the mechanical properties of large PVC and CNT-filled PVC models. Finally, three machine learning techniques, namely artificial neural networks (ANNs), support vector machines (SVMs), and Gaussian process regression (GPR), are trained and used to predict the strain-stress response of PVC nanocomposites up to 5% of applied strain. The GPR exhibits the highest accuracy, while the ANN model proves to be the most computationally efficient.

Optimization of vascular structure of self-healing concrete using generative deep neural network (GDNN)

Zhi Wan; Delft University of Technology; Netherlands
Yading Xu; Delft University of Technology; Netherlands
Ze Chang; Delft University of Technology; Netherlands
Branko Šavija; Delft University of Technology; Netherlands

Vascular based self-healing concrete has excellent potential to mitigate the environmental impact on construction and transportation. Designing concrete with high self-healing capacity by finding a certain vascular structure configuration is of great importance. Herein, optimization of vascular structure of self-healing concrete is performed with generative deep neural network (GDNN). The optimization objective is a concrete beam with 5 pores out of 40 possible positions in the middle span representing vascular reservoirs for healing agent. To investigate the feasibility of using GDNN for vascular structure optimization (i.e., optimization of the spatial arrangement of the vascular network), structure optimization improving peak load is first carried out. Afterwards, toughness is used to optimize vascular structure for self-healing concrete. Based on the results, we found it feasible to optimize vascular structure by fixing the weights of the GDNN model and training inputs. This work shows that the GDNN model has great potential to be used for optimizing the design of vascular system for self-healing concrete.

Optimized Correlation Between Mean Profile Depth and Pavement Friction

Pavan Chandrasekar; Georgia Institute of Technology; United States
Yichang James Tsai; Georgia Institute of Technology; United States

Skid resistance of pavement is an essential characteristic of road safety which depends on pavement surface texture. However, effective automated methods to analyze the contribution of surface texture on pavement friction still remains a challenge. Automated pavement evaluation methods without significant validation and subjective manual evaluation methods are considered as major limitations in effective pavement evaluation. Hence, there is an urgent need to develop and validate automated pavement evaluation methods, ensuring pavement safety. This study is focused to evaluate the performance of Mean Profile Depth (MPD, a macro texture indicator) calculated as per ASTM E1845–15 and the proposed method to find better correlation with friction value. The proposed MPD calculation method studies the impact of orientation, baseline segment length and statistical representation of calculated MPD using pavement texture data collected from 10 High Friction Surface Treatment (HFST) calcined bauxite spots of different friction value using a high-resolution scanning device, LS-40. From the correlation analysis between calculated MPD and pavement friction (collected using Dynamic Friction Tester). it is found that MPD value calculated from 25mm baseline segment length in vertical orientation with standard deviation as a statistical representation has the highest correlation of 0.76 with friction whereas traditional MPD value calculated based on ASTM E1845-15 has a correlation of 0.51 with friction. Hence, this study recommends 1) studying MPD-friction correlation for various pavement types and 2) developing friction prediction models considering pavement texture, tire condition and water film thickness to provide better practical solutions, addressing friction related pavement safety concerns.

Origami Metamaterials with Near-Constant Poisson Functions over Finite Strains

Siva Poornan Vasudevan; Indian Institute of Technology Madras; India
Phanisri Pradeep Pratapa; Indian Institute of Technology Madras; India

Origami-based structures have gained interest in recent years due to their potential to develop lattice materials, called metamaterials, the mechanics of which are primarily driven by the unit cell geometry. The folding deformations of typical origami metamaterials result in stretch-dependent Poisson's ratios, and therefore in Poisson functions with significant variability across finite deformation. This limits their applicability, because the desired response is retained only for a narrow strain range. To overcome this limitation, a class of composite origami metamaterials with a nearly constant Poisson function, specifically in the range −0.5 to 1.2 over a finite stretch of up to 3.0 with a minimum of 1.1, is presented. Drawing from the recently proposed Morph pattern, the composite system is built as a compatible combination of two sets of cells with contrasting Poisson effects. The number and dimensions of the cells were optimized for a stretch independent Poisson function. The results of the study were validated using a bar-and-hinge-based numerical framework capable of simulating the finite deformation behavior of the proposed designs.

Osmotic Ion Concentration Control of Steady-State Subcritical Fracture Growth in Shale

Anh Tay Nguyen; Northwestern University; United States
Hoang T Nguyen; Brown University; United States
Zdeněk P. Bažant; Northwestern University; United States

The mechanism of formation of natural cracks in sedimentary rocks such as shale in the geologic past is a problem that needs to be understood to improve the technology of hydraulic fracturing as well as deep sequestration of harmful fluids. Why are the natural cracks roughly parallel and equidistant, and why is the spacing of the order of 10 cm rather than 2 cm or 50 cm? Fracture mechanics alone cannot answer this questions. Here it is proposed that fracture mechanics must be coupled with the diffusion of solute ions such as Na+ and Cl-, driven by an osmotic pressure gradient created by dilatancy in the fracture process zone. Tectonically imposed overall viscous shear flow of rock drives horizontally growing mode II shear cracks with approximately vertical planes. The cracks must be subcritical mode II cracks governed by Charles-Evans law. They are considered to be equidistant, with aligned fronts. Frictional resistance to slow crack face sliding is taken into account, and so is the diffusion of pore water. An analytical solution of the crack spacing as a function of solute diffusivity, rock viscosity and dilatancy is obtained. Finally, stability of unlimited parallel mode II frictional crack growth is proven by examining the second variation of free energy. The proposed mathematical framework is also partially useful for extension to osmotic pressure effects in slow growth of hydraulic cracks in shale.

Output-Only Bayesian System Identification for Digital Twinning of Floating Offshore Wind Turbines

Martin Masanes Didyk; University of New Hampshire; United States
Vahid Bagherian; Shiraz University; Iran
Saeed Eftekhar Azam; University of New Hampshire; United States
Mohsen Ebrahimzadeh Hassanabadi; University of Sydney; Australia
Babak Moaveni; Tufts University; United States

This study contributes to the state-of-the-art in structural system identification and facilitates virtual sensing and digital twinning of floating offshore wind turbines (FOWTs) in operational conditions. A key challenge in the development of digital twinning and system identification of operational FOWTs is the variability of system input, e.g. operational loads. Herein a minimum variance unbiased (MVU) linear filtering method is used for an output-only state and input estimation for linear state space systems with direct feedthrough. The adopted MVU method permits state and input estimation for discrete time systems, where no previous assumption is made regarding the input, is addressed. A linearized model of a floating wind turbine system, subjected to wave and wind load time histories is used for assessing the potential of recursive Bayesian estimation for digital twinning of FOWTs. The results of the simulated experiments show a good agreement between the ground truth and the filter estimates. Different sensor configurations are studied to show the effect of collocated measurements. The results are compared with the augmented Kalman filter, in which it is assumed that statistics of the unknown input are known.

Parametric Study to Determine Hydrodynamics Input Parameters in FLOW-3D-Hydro for Crushed Limestones in Nebraska

Basil Abualshar; University of Nebraska Lincoln; United States
Chung Song; University of Nebraska Lincoln; United States

One of the challenges encountered by engineers in Nebraska is the erosion of the shoulder gravels of the highways. In evaluating the erosion behavior of the gravels, the hydrodynamics characteristics of the gravels are critical. The challenge is that there are several hydrodynamic parameters that are not easy to determine. For example, FLOW-3D-Hydro provides a sediment transport model based on empirical and semi-empirical correlations that require several input parameters, such as critical Shields number, sediment density, entrainment coefficient, bedload coefficient, bed roughness/D50 ratio, maximum packed fraction, angle of repose, Richardson-Zaki coefficient, and other factors. This research conducted multiple different erosion tests, conducted extensive back analyses, and evaluated the hydrodynamics parameters. Then these parameters were used to predict the erosion characteristics of given shoulder materials for the given precipitation conditions.

Particle Scale Assessment of Strain Localization in Saturated Sheared Sand

Mohammed Elnur; The University of Tennessee, Knoxville; United States
Khalid Alshibli; The University of Tennessee, Knoxville; United States

Triaxial testing of sand typically results in shear strain localization in zones of intensive shearing known as shear bands. Strain localization in sand is influenced by many factors including specimen density, particle morphology, gradation, boundary conditions, and stress path. Conventional triaxial measurements such as volume change and axial deformation measure the global response and fail to accurately quantify localized deformation. Synchrotron micro-computed tomography (SMT) technique was used to acquire 3D images of the specimen to measure particle kinematics allowing for localized strain quantification at the particle scale in addition to the specimen's global deformation. Three mini-triaxial compression experiments were conducted using GS#40 Columbia uniform angular sand under axisymmetric triaxial loading conditions. The specimens' dimensions are approximately 10 mm in diameter and 20 mm in height. The experiments were performed under dry, drained, and undrained saturated conditions to investigate the role of pore water pressure on strain localization. Saturated experiments were conducted at an effective cell pressure of 50 kPa. Sand particles' contact and morphology were characterized based on the 3D images, and the concept of translation gradient was applied to track the relative movement of sand particles to highlight shear strain localization. The presentation will discuss how the pore water distribution changes as the specimen dilates and how that affects the onset of shear bands.

Particle shape effect on granular materials mechanics under high strain rate

Dawa Seo; Los Alamos National Laboratory; United States
Nitin Pandurang Daphalapurkar; Los Alamos National Laboratory; United States
Darby Jon Luscher; Los Alamos National Laboratory; United States

Particle shape is important in geotechnical engineering because it plays a critical role in establishing the mechanical response and effective properties of granular materials. Despite this importance, most continuum theories for granular materials include only the particle size to represent the grain geometry. This study focuses on the effects of particle shape on the evolution of the fabric (e.g., void volume) via particle rotation and deformation within granular materials subjected to high-strain-rate shock compaction. For this purpose, we perform mesoscale granular simulations of particle ensembles using the continuum hydrodynamics code, FLAG (Free-Lagrange), which has multi-physics capabilities required to model dynamic compaction. This simulation ensemble represents a wide range of grain geometry including a representative size distribution and three representative grain shapes. The particle placement for initial model geometry is obtained via a packing simulation developed to replicate the experimental procedure. To understand the effect of varying void distribution and material particle arrangements on the shock wave during granular compaction, we assess, quantify, and compare the simulated responses at consistent strain intervals. Through those approaches, our study delves into the importance of morphological features in modulating the non-equilibrium dynamic response of granular materials. By providing such fundamental knowledge, this understanding can contribute to addressing other phenomena of extreme events such as planetary impact, seismic activity, and rapid load testing of piles and explosions.

Particle-scale kinematics and kinetics of particle rearrangement in granular materials

Kwangmin Lee; Johns Hopkins University; United States
Ryan Hurley; Johns Hopkins University; United States

Particle rearrangement in granular materials has been widely studied statistically. However, both the kinematics and kinetics of particles at the particle scale during particle rearrangement have not been studied enough. In this study, we first find a linear relation between macroscopic force and interparticle forces in particles that follow affine behavior over small increments of macroscopic strain. Based on kinematics and this linear relationship in kinetics, particles that follow affine and non-affine behaviors in discrete element models are identified. Then, we study the propagation of non-affine behavior from the boundary of affine and non-affine particles and force chain bucking. For this, we consider the sliding and rolling of particles in a granular media. We expect that the proposed study contributes to establishing the first principles of particle rearrangement in granular materials. In the future, this study will be applied to 3D experimental data.

Partition of Unity Neural Network-enhanced Reproducing Kernel Particle Method for Localization Modeling

Jonghyuk Baek; University of California, San Diego; United States
J. S. Chen; University of California, San Diego; United States

Numerical modeling of localizations is a challenging task due to the evolving rough solution in which the localization paths are not predefined. Despite the efforts made over past decades, innovative discretization-independent computational methods to predict the evolution of localizations is in need. In this work, an improved version of the neural network-enhanced Reproducing Kernel Particle Method (NN-RKPM) [1] is proposed. Here, the neural network (NN) approximation is added to the standard RK smooth approximation on the background under the partition of unity framework. The NN approximation is defined by a finite set of automatically evolving NN kernel functions capable of capturing the orientation and shape of localizations automatically, and it is embedded into the NN kernel functions by the weights and biases contained in the parametrization and kernel function neural networks. The proposed method's effectiveness in modeling the complex localization patterns is demonstrated by a set of numerical examples.

REFERENCE

[1] Baek, J., Chen, J. S., & Susuki, K. (2022). A neural network-enhanced reproducing kernel particle method for modeling strain localization. International Journal for Numerical Methods in Engineering, 123(18), 4422-4454.

Past hurricane performance of above-ground storage tanks and their future risk considering sea level rise and subsidence scenarios

Santosh Ghimire; Louisiana State University; United States
Sabarethinam Kameshwar; Louisiana State University; United States

The objective of this research is to study past failures of above-ground storage tanks (ASTs) during hurricane Laura and thereby develop an approach to determine the effectiveness of regional hurricane risk reduction strategies, such as Louisiana's Coastal Master Plan (CMP), for ASTs. Therefore, this study will close a knowledge gap that could be directly relevant to future planning initiatives to lower AST failures. The design guidelines such as the American Petroleum Institute (API) 620 and API 650 do not have provisions to prevent AST failures during hurricane surges and floods. There have been several instances of AST collapses during past hurricanes such as Katrina and Rita, Ike, and Gustav, as well as more recently during hurricane Laura, causing environmentally destructive spills, supply disruptions, and damage to infrastructures. Thus, AST failures have catastrophic consequences that cannot be overlooked. Firstly, to understand the performance of storage tanks during hurricane Laura, 1000 Monte Carlo simulations were done using existing fragility models to predict AST failures considering uncertainties in the fill level of ASTs and the density of stored contents. The tank failures predicted by the models were confirmed using aerial imagery taken before and after the hurricane, thereby validating the approach to predict AST failures during hurricanes. Another set of 1000 simulations was performed with the validated approach to assess the likelihood of tank failures in future years for hurricane events corresponding to different return periods with and without CMP interventions. The effects of AST failures, including repair costs, spill volumes, and cleaning expenses were quantified for all cases. The results were compared using mean values and coefficients of variation to determine whether mitigation measures could reduce the overall consequences of AST failures. The comparison shows that the mitigating measures implemented are insufficient to lower future repair costs and spill volume. Hence, the current regional risk mitigation strategy needs to be improved and risk mitigation strategies should be employed at the level of individual ASTs to improve their performance during hurricanes.

Pathways to Manufacturing Mechanical Metamaterials by Examining Auxeticity in Nonwoven Fiber Networks

Prateek Verma; Georgia Institute of Technology; United States
Anselm Griffin; Georgia Institute of Technology; United States
Meisha Shofner; Georgia Institute of Technology; United States

Auxetic materials and structures have been the subject of extensive study to elucidate the underlying mechanisms and structural features that drive their mechanical response, specifically a negative Poisson's ratio. This counterintuitive behavior, also termed auxeticity, has been suggested as a mechanism to provide enhanced performance in composite materials and energy dissipation structures. While auxeticity may be achieved through intricate structural design, more common materials and structures can display this mechanical response, such as nonwoven fiber networks. Our research has examined a variety of nonwoven fabrics and papers from the viewpoint and found them to possess pervasive and robust auxeticity. The auxetic response has been observed in nonwoven fabrics made by different manufacturing methods and can be induced or enhanced through post-processing heat treatment, reminiscent of early auxetics research to produce reentrant structures in foams. Additionally, the auxetic response in paper has been observed in several types of papers and related to its processing and the resulting structure. In this presentation, we will discuss the processing-structure-property relationships that are related to the auxetic response of nonwoven textiles and paper, including how processing can influence the magnitude of this response and how auxetic behavior changes as a function of repeated deformation. Overall, these results suggest a pathway for producing a class of commodity auxetics which could promote wider use of these mechanical metamaterials as well as a platform for constructing auxetics from high-performance materials.

Pavement Crack Detection Using Machine Learning and a Fusion of 2D & 3D Data

Paul Roeser; Georgia Institute of Technology; United States
Yi-Chang (James) Tsai; Georgia Institute of Technology; United States

Automated evaluation of pavement condition, like cracking, is essential for timely maintenance and management of pavement assets. 3D laser technology has become the mainstream technology in the US for state Departments Of Transportation (DOTs) to collect pavement condition data. However, it is expensive for local transportation agencies to collect them annually or bi-annually. Thus, this paper proposes an innovative idea to combine high-resolution low frequency 3D data, collected once a year or two years with low-resolution high frequency collection from low-cost smartphone with 2D images and Inertial Measurement Units (IMU) data that can be collected quarterly. A case study was conducted using this vehicle, collecting 3D images, 2D images and IMU data simultaneously on a 4.12 miles roadway with interstate highways, city street and state-maintained roadways in Atlanta, US. This data was collected using Georgia Tech Sensing Van (GTSV) that is equipped with 3D laser devices, 3D Lidars, IMU, GPS, cameras by a research project sponsored by US DOTs. The developed methodology and framework to be presented in the conference will provide a scientific foundation to improve the current pavement condition evaluation and forecasting in a much cost-effective manner for local agencies. This paper will also present the optimal utilization of emerging 3D pavement data, collected using 3D laser, with both 2D image and kinetic data collected using low-cost smartphone and a new Machine Learning method with spatial-temporal analysis.

Performance Enhancement of Vibro-Impact Targeted Energy Transfer Within a Random Environment

Rahul Kumar; Georgia Institute of Technology; United States
Daniil Yurchenko; University of Southampton; United Kingdom
Rachel Kuske; Georgia Institute of Technology; United States

In a real engineering system, excessive vibration results in human discomfort and sometimes leads to catastrophic failure of the system. Therefore, it is very important to control such excessive vibration. Targeted energy transfer (TET) is one of the passive approaches for the attenuation of vibration by means of irreversible energy transfer from the primary linear oscillator (LO) to the auxiliary system. In the conventional approach for TET, a tuned mass damper is used which predominantly works for narrow frequency range. However, effective TET can also be achieved by means of a nonlinear energy sink (NES), but this mechanism still requires some optimal tuning. On the other hand, recent studies on TET through vibro-impact (VI) based NES have shown improved performance over a broad spectrum. In VI-NES, where a ball oscillates inside the LO, energy transfers through the impacts and mitigates the vibration of the LO. Previous studies of VI-NES consider limited parameter ranges with the smaller mass ratio and external excitations predominantly near the resonant frequency. This study focuses on the fully non-smooth system behavior, applying novel analytical and numerical analyses of externally excited VI-NES over a broad range of parameters for different periodic and complex dynamics. In general, the external excitations can have random fluctuations, called noise, which have the potential to affect the energy transfer mechanism. Likewise, the impact dynamics may vary randomly due to material variations. The previous studies are restricted to the stochastic analysis for conventional with a nonlinear spring and a linear damper and continuous behavior. Preliminary results for VI-NES and related VI energy harvesters reveal scenarios where certain types of noise improve the performance of the system. This study investigates the stochastic bifurcation structure of the TET phenomenon combining the non-smooth analysis with a probabilistic framework. The results are directly related to several performance measures of VI-NES within the noisy environment.

Performance-based design optimization of uncertain wind-excited systems under life-cycle loss constraint with climate change considerations

Thays Duarte; University of Florida; United States
Imad Alhayik; University of Florida; United States
Arthriya Subgranon; University of Florida; United States

Performance-based wind engineering (PBWE) has become an appealing alternative to the traditional prescriptive design approach because the PBWE frameworks enable a direct propagation of uncertainties through the performance and risk assessment of wind-excited systems. In particular, the integration of PBWE with optimization methods provides a powerful tool to identify designs that are cost-effective while also achieving an acceptable level of wind-induced risk. However, one aspect that is usually not considered in the design process is the climate change effects, which can impact the building's performance on a long-term basis (e.g., over the lifespan of the building system). To this end, a performance-based design optimization framework is proposed for the optimal design of wind-excited building systems constrained by the expected life-cycle loss while taking into account the non-stationarity of hazards driven by climate change. This intensive stochastic optimization problem is solved through an approximation strategy that decouples the optimization and probabilistic analysis. Optimization sub-problems are defined in terms of Kriging metamodels and the Auxiliary Variable Vectors, which can be constructed from the results of a single Monte Carlo simulation. The sub-problems are solved sequentially until optimal designs of two consecutive design cycles converge. The applicability of the proposed framework is demonstrated through the design of a lateral frame of a 37-story building where two scenarios, with and without climate change effects on the hazards, are evaluated and compared. Preliminary findings provide insight into the impacts of climate change on the life-cycle performance of the building system as well as the additional investment required to account for such impacts in the design.

Performance-based UAS path planning for automated infrastructure inspection

Yuxiang Zhao; University of Illinois Urbana-Champaign; United States
Binyao Guo; University of Illinois Urbana-Champaign; United States
Mohamad Alipour; University of Illinois Urbana-Champaign; United States

Unmanned Aerial Systems (UAS) are efficient tools for the condition assessment of critical infrastructure. However, the lack of objectively optimized path planning significantly reduces the efficiency and quality of inspections, leading to additional costs and potential safety hazards. Most previous studies on path planning focused on maximizing the coverage and minimizing the path length, while the performance of the inspection is rarely considered. This work proposes a performance-based path planning methodology with UAS. To this end, we augment digitized replica of the infrastructure with artificial textures containing defects to build virtual inspection environments. The candidate viewpoint space is then generated considering safety and sensing specifications, and flight paths are constructed by making a series of decisions on the movement at each viewpoint. Simulation flights are then performed to assess pertinent structural inspection performance metrics. Combining these inspection performance metrics with other contextual metrics (e.g., visual coverage, overlap, and path length), we propose evaluation methods for inspection paths to identify optimal solutions with a sensible trade-off between quality and speed. The proposed framework will provide guidance for inspection tasks and ultimately enhance the automation, reliability, and robustness of the infrastructure inspection industry.

Performance-Based Wind Design of Tall Buildings: Challenges of Implementation

Teng Wu; University at Buffalo; United States
Baichuan Deng; University at Buffalo; United States

The performance-based wind design (PBWD) methodologies attract growing interest in recent years. Industries, in general, welcome this transition since the experience from performance-based earthquake engineering indicates the PBWD may not only improve building response under extreme wind excitations, but also increase structural economy. In addition, this transition to performance-based wind engineering will open a new door for more efficient building design for multi-hazard considerations (e.g., benefits to both performance-based wind and seismic designs). However, there are still some challenges toward the implementation of PBWD for tall buildings. These challenges may result from either the intrinsic nature or the epistemic state of wind-structure interactions. In this contribution, a case study building is designed under the guidance of the ASCE/SEI Prestandard for the purpose of providing a systematic discussion on the challenges of PBWD implementation. Three challenges due to the intrinsic nature of wind-structure interactions are examined. First, the current comfort criteria may make the structure very stiff so that the inelastic behavior and ductility capacity of tall buildings cannot be achieved under winds. A balance between the acceptance criteria for serviceability and safety may need to be maintained to avoid that the wind comfort considerations control the design process across the board. Second, the vortex-induced vibrations of tall buildings may make the wind demands at a relatively low mean recurrence interval (MRI) larger than those at a relatively high MRI. The current performance objectives in terms of MRI may need to be carefully studied with the consideration of building aerodynamics. Third, the location dependence of wind intensity ratio (corresponding to different MRIs) may make the demand-capacity ratios (DCRs) for deformation-controlled actions vary with building sites. The current acceptance criteria for DCR may need to be comprehensively investigated considering its large variability. Three challenges due to the epistemic state of wind-structure interactions are also examined, namely the lack of full-scale wind pressure measurements, the lack of rationally-developed loading protocols for extreme wind performance testing, and the lack of understanding on the material behavior of structural components under long-duration wind loads. Some recommendations to address these challenges are provided at the end of this study.

Peridynamics with stochastic bond strengths for determination of final failure in composite laminates

Ernest Ytuarte; University of Tennessee; United States
Hossam Ragheb; University of Southampton; United Kingdom
Adam Sobey; University of Southampton; United Kingdom
Stephanie TerMaath; University of Tennessee; United States

The stochastic nature of composite materials is evident in the literature that investigates their homogenized properties, deformation, and damage processes. These probabilistic characteristics originate from multiple microstructural sources that can cause stress concentrations and local deformations leading to stochastic behavior at the laminate scale. Examples of parameters characterized by randomness include fiber distribution, fiber/matrix bond strength, micro-crack density, and voids. Each of these parameters must therefore be characterized by a probability distribution function for analysis, and parameter values can vary throughout the composite at the fibre scale. Investigation of the complex interactions between these parameters requires detailed microstructural analysis. Representative volume elements (RVEs) are widely applied to investigate the mechanical properties and behavior of composite materials. To demonstrate a probabilistic approach to evaluate the transverse and longitudinal strengths of a carbon fibre/epoxy composite laminate, a microstructural RVE is formulated and analyzed with peridynamics. By using the peridynamic theory, discontinuities within the RVE are inherently modeled. This model simulates the bond at the bi-material interface, applies periodic boundary conditions, and randomly generates and assigns parameters locally throughout the model. Model formulation and the effects of local parameter variation on laminate strength will be presented.

Phase and Property Evolutions of Alkali-silica Reaction Gels Under Carbonation

Arkabrata Sinha; University of Massachusetts Lowell; United States
Jianqiang Wei; University of Massachusetts Lowell; United States

Alkali-silica reaction (ASR) is one of the key mechanisms of concrete degradation, resulting in the shortened service life of structures. Being referred to as "concrete cancer", ASR can induce excessive cracking in concrete providing rapid pathway for the ingress of other aggressive agents, such as moisture, chlorides and sulfates, and thereby causing secondary degradation in concrete. The key detrimental step of ASR is the swelling of ASR gels, hygroscopic products formed due to the dissolution and combination of amorphous silica from reactive aggregates with the alkalis in cement pore solution. Conventional methods for ASR mitigation mainly involve the addition of supplementary cementitious materials and lithium-based admixtures during concrete mixing to retard the formation of ASR gels in new concrete at the expense of compromising the physical and mechanical properties, whereas the methods for mitigation of ASR in existing concrete structures remains a challenge. The current study investigates the possibility of converting ASR gels into harmless products via carbonation. The phase evolution of synthetic ASR gels, cured at a constant relative humidity of 75% and different CO2 concentrations and temperatures, was investigated via X-ray diffraction (XRD), Fourier transform infrared (FTIR) spectroscopy, and thermogravimetric analysis (TGA). The changes in moisture absorption and desorption behavior after carbonation were investigated via dynamic vapor sorption (DVS). The mechanical properties of the carbonated ASR gel were investigated by measuring the hardness and modulus of elasticity (MOE) via nanoindentation. The results indicate that the ASR gels can be completely converted into calcite, vaterite and sodium bicarbonate after 72 hours of carbonation. Although the rate of carbonation varied directly with the CO2 concentration, it was found to increase from 25oC to 37oC followed by a reduction at a further elevated temperature of 50oC. The moisture absorption of the carbonated ASR gel was found to reduce by only 4.1%, which might be due to the formation of hygroscopic but non-expansive silica gel as a by-product of carbonation. The hardness and MOE of the ASR gels were enhanced indicating that carbonation is a promising approach to convert the expansive ASR products into benign and strong phases in both new and existing concrete structures.

Phase field method-based modeling of wood fracture

Sebastian Pech; TU Wien; Austria
Markus Lukacevic; TU Wien; Austria
Josef Füssl; TU Wien; Austria

Wood, as a naturally grown material, exhibits an inhomogeneous material structure as well as a quite complex material behavior. For these reasons, the mechanical modeling of fracture processes in wood is a challenging task and requires a careful selection of numerical methods. Promising approaches like limit analysis or the extended finite element method (XFEM) in combination with microstructure materials models deliver good but not yet satisfying results. Particularly the latter approach, including XFEM, has severe difficulties with crack paths in regions with complex morphology, mainly around knots. Therefore, in this work, the focus is laid on the recently emerging and very popular phase field method [1]. Especially geometric compatibility issues that limit the use of XFEM can be avoided, as the crack is not discretely modeled but smeared over multiple elements. This allows the formation of complex crack patterns, defined by the underlying differential equations and boundary conditions but not restricted by the mesh geometry. The present implementation [2,3] contains a stress-based split which allows proper decomposition of the strain energy density for orthotropic materials. Furthermore, the geometric influence of the wood microstructure on crack propagation is taken into account by a structural tensor scaling the length scale parameter of the phase field [3]. For solving the system of differential equations, a staggered approach is used where the phase field equation and deformation problem are solved separately. The staggered approach is enhanced with an additional Newton-Raphson loop that ensures convergence. The developed algorithm was tested on various problems. Compared to XFEM more computation time was needed as the phase field method requires a finer discretization. However, crack patterns, including branching and merging, could be modeled very stable and accurately, even in the vicinity of knots where the material structure of wood is particularly complex and interface zones exist.

[1] J.-Y. Wu, „A unified phase-field theory for the mechanics of damage and quasi-brittle failure“, J. Mech. Phys. Solids, Bd. 103, S. 72–99, Juni 2017, doi: 10.1016/j.jmps.2017.03.015

[2] S. Pech, M. Lukacevic, and J. Füssl, „A hybrid multi-phase field model to describe cohesive failure in orthotropic materials, assessed by modeling failure mechanisms in wood“, Eng. Frac. Mech., Bd. 271, S. 108591, Aug. 2022, doi: 10.1016/j.engfracmech.2022.108591.

[3] S. Pech, M. Lukacevic, and J. Füssl, „Validation of a hybrid multi-phase field model for fracture of wood“, Eng. Frac. Mech., Bd. 275, S. 108819, Nov. 2022, doi: 10.1016/j.engfracmech.2022.108819

Phase Transforming Cellular Materials under Concentrated Loading Conditions

Yunlan Zhang; University of Texas at Austin; United States
Phani Saketh Dasika; Purdue University; United States
Nilesh Mankame; General Motors Global Research & Development; United States
Pablo Zavattieri; Purdue University; United States

Phase-transforming cellular materials (PXCMs) are a class of architected materials comprised of numerous multistable unit cells. They can undergo large deformation, and dissipate energy while remaining elastic, which can be referred to as superelasticity. When a class of T- and S-type PXCMs is loaded under multiple directions that are aligned with their axis of symmetry, the superelasticity capacity of these materials is insensitive to these loading directions. This observation contradicts the material behavior at the elementary mechanism level, which is contributed via the unit-cell self-rotation. In this work, we applied the concentrated load to T- and S-type PXCMs. As with uniformly applied uniaxial compressive loading, we observed two competing mechanisms for concentrated compressive loads that contribute to energy dissipation from the numerical and experimental tests. First, a unit cell has higher energy dissipation while the phase transforms through a primary mode. Second, the self-orientation behavior of unit cells can engage more cells to transform through secondary modes which have lower energy dissipation capacity. The trade-off between these two mechanisms causes the energy dissipation capacity of T- and S-type PXCMs under the concentrated loading condition to be insensitive to the loading direction. Moreover, the auxetic behavior of T- and S-type PXCMs was amplified under the concentrated loading condition, thereby enhancing the second mechanism to achieve larger energy dissipation capacity.

Phase-Field Fracture Modeling Informed by Molecular Dynamics Simulation for Investigating Hierarchical Porous Structures

Pania Newel; The University of Utah; United States
Bang He; 2Dassault Systemes Americas Corp.; United States

Hierarchical porous structures with multiple levels of pores spanning from nano- to macro-scale are present in both natural and man-made materials. To fully comprehend the crucial role of structural hierarchy on their macroscopic response, it is essential to have a comprehensive understanding of the wide range of porosity and the mechanical integrity of these porous structures. In this presentation, we aim to explore the mechanical and fracture behaviors of hierarchical porous structures by examining the role of their underlying pore morphology. Our proposed multi-scale approach utilizes molecular dynamics simulations at the atomistic scale and phase-field fracture techniques at the continuum scale to extract material properties and inform our understanding of the mechanical response of these complex materials. Our analysis includes various porosities and pore shapes at the atomistic level, and we highlight how variations in the nanopore structure impact the mechanical and fracture response of the porous structures at the macroscopic level.

Phase-field modelling of fatigue fracture in anisotropic aluminium sheets

Martha Kalina; TU Dresden / Columbia University; Germany
Markus Kästner; TU Dresden; Germany

The design of aircraft fuselages depends greatly on the crack propagation rates of fatigue cracks within the component due to the cyclic expansion and contraction. Our aim is to model fatigue fracture in aluminium sheet material often used for fuselage shells. The phase-field method is a promising approach to model arbitrary fracture phenomena. However, fatigue comes along with high numbers of load cycles, so an explicit simulation of the load path is very expensive. Therefore, time-efficient simulation methods are required. In this contribution, we approach this challenge by combining the phase-field method for brittle fracture with the local strain approach (LSA), an empirical method originally designed for life span estimation of metallic components. In this way, we avoid the explicit simulation of the load cycles by executing a local cyclic damage accumulation. Based on that, the critical fracture energy is degraded locally in order to describe the dissipation due to damage. We now want to take the anisotropy due to the rolling process of the sheets into account. Experiments show the difference in fracture toughness depending on the angle to the rolling direction. This anisotropy is included in the approximation of the crack surface density.

Phononic Bandgap Programming and Fine-Tuning in Stretched Kirigami

Hesameddin Khosravi; Clemson University; United States
Suyi Li; Virginia Tech; United States

This presentation summarizes our recent studies on programming and fine-tuning the elastic wave propagation bandgaps in periodic and multi-stable metamaterials by intentionally and uniquely sequencing its constitutive mechanical bits. To this end, we use stretched kirigami as a simple and versatile testing platform. Each mechanical bit in the kirigami can switch between two stable equilibria with different external shapes (aka. "(0)" and "(1)" states). Therefore, by designing the sequence of these (0) and (1) bits, one can fundamentally change the underlying periodicity and thus program the phononic bandgap frequencies. Naturally, a critical question arises when dealing with such binary sequencing: How many unique (0) and (1) sequences are possible for bandgap programming purposes? To answer this question, we develop a mathematical algorithm to identify these unique periodicities by examining and assembling "n-bit strings" consisting of n mechanical bits. Based on a simplified geometry of these n-bit strings, this study also formulates a theory to uncover the rich mapping between input sequencing and output bandgaps. The theoretical prediction and experiment results confirm that the (0) and (1) bit sequencing is effective for programming the phonic bandgap frequencies. Moreover, one can additionally fine-tune the bandgaps by adjusting the global stretch. Overall, the results of this study elucidate new strategies for programming the dynamic responses of architected material systems.

Photogrammetric Reconstructions for Bridge Inspections: Establishing Performance Metrics for Automated Drone Acquisition Algorithms

Emilie Hollingsworth; Virginia Tech; United States
Ishan Pradhan; Virginia Tech; United States
Michael Sanchez; Sanchez Engineering Services; United States
Rodrigo Sarlo; Virginia Tech; United States

While there is a wide-spread precedent for the usage of data obtained during drone flights to create 3D models via photogrammetry, its application to the structural inspection process is fairly recent. As such, there is a lack of understanding of the trade offs between model quality and utility. In most field applications, it is impractical to create ultra-high-fidelity reconstructions, thus the efficiency of data capture and model creation will largely determine the success of this technology. This work aims to quantitatively investigate and establish key metrics affecting the utility of photogrammetric models for the purpose of localizing bridge inspection photos. These metrics include field-of-view overlap, range, and angular perspective changes, among others. While other work has been done comparing the performance of individual photogrammetry pipelines, this work considers Structure-from-Motion (SfM) performance as affected by specific metrics that can be controlled in the field. These metrics can be used to adapt a drone's path planning in order to maximize the utility of a photogrammetric reconstruction, while avoiding unnecessary detail. This investigation shows the systematic manual collection of several image datasets of individual structural members. The resulting reconstruction models are used to establish qualitative base metrics, such as angular perspective changes, as well as to characterise the behaviour of the SfM pipeline being used. Later, models created from drone data, instead of data collected by hand, are subdivided and characterized to further decode the effect of these metrics on model quality and resolution. In addition, we demonstrate how such metrics can be used to identify low quality locations in a 3D reconstruction in order to aid in path planning for model refinement. Finally, we showcase the methodology with a field use case in collaboration with the Virginia Department of Transportation, where the base 3D reconstruction is used a scaffold to localize images taken manually by inspectors.

Physics and chemistry-based constitutive framework for thermo-chemically aged elastomer using phase-field approach

Aimane Najmeddine; Princeton University; United States
Maryam Shakiba; University of Colorado Boulder; United States

We present a physics and chemistry-based constitutive framework for predicting the stress and brittle failure responses of elastomers subjected to high-temperature aging in the presence of oxygen. The macromolecular network of elastomers undergoes complex chemical reactions, including chain scission and crosslinking, resulting in an increase in effective crosslink density and, therefore, stiffness and ultimately causing brittle failure. The framework changes the material properties within the Arruda-Boyce hyperelastic constitutive equations based on the evolution of effective crosslink density and uses a phase-field model to capture the induced brittle failure through a strain-based criterion. Four material properties that capture the effects of thermo-chemical aging are characterized by changes in the effective crosslink density obtained from chemical characterization tests. The framework is first solved analytically for uniaxial tension in a homogeneous bar to show the interconnection between the material properties. It is then implemented numerically in Abaqus using a user-element subroutine (UEL) to simulate more complex geometries and loading conditions. The framework is validated with a set of experimental results from literature and shown to predict the mechanical response of aged elastomers accurately. Numerical examples illustrate the impact of evolving material properties on specimens with pre-existing cracks.

Physics-Constrained Dictionary Learning with Sensor Fusion for Machine Health Monitoring

Sungjin Hong; Georgia Institute of Technology; United States
Yanglong Lu; The Hong Kong University of Science and Technology; Hong Kong
Sung-Hoon Ahn; Seoul National University; South Korea
Yan Wang; Georgia Institute of Technology; United States

Sensors play an important role in monitoring the health conditions of machines and structures. To improve the accuracy of fault diagnosis, multiple sensors are usually applied concurrently to collect information. However, the costs associated with sensor installation, maintenance, and data transmission are high. There is a practical need to develop cost-effective sensor fusion methods to collect and integrate information. In this work, a new data fusion method based on physics-constrained dictionary learning is introduced for machine health monitoring. In the proposed method, the measurement, basis, and classification matrices are optimized during the dictionary learning process. With the optimized matrices, full-scale signals can be reconstructed from a small number of measurements. The optimized measurement matrix also provides the guidance for the best sensor placement and sampling strategy. In addition, the machine health states can be classified from the sparse sensor measurements. An adaptive weighting scheme is introduced to improve classification accuracy, where data from more accurate sensors have higher weights. The proposed method is tested with an experimental dataset of gearbox vibrations to classify different crack severities. The results show that the usage of 30% of the original data can achieve 95% of diagnosis accuracy. Sensitivity analysis is further performed in the number of measurements and sensors to evaluate the performance of the proposed method.

Physics-constrained Gaussian Process Model for Prediction of Power Generation in Wave Energy Converter Arrays

Suraj Khanal; Colorado State University; United States
Gaofeng Jia; Colorado State University; United States

To achieve maximum power generation from a wave farm (i.e., arrays of wave energy converters (WECs)), its layout needs to be carefully designed. However, predicting power generation from a specific layout of wave farm entails significant computational efforts. The problem becomes even more computationally challenging as uncertainty in the wave condition is introduced in the prediction. To address the computational challenges, a physics-constrained Gaussian process (PGP) model is proposed to replace the original expensive numerical model to predict the probabilistic power generation from WEC arrays with different layouts. Considering that the power generation from a WEC array is invariant to symmetry and permutation of the WECs in the array, a double sum invariant kernel is proposed and used in the PGP model to encode the invariance and the symmetry features. Compared to the standard GP model, the proposed PGP model requires less training data and less computational resources to achieve desired accuracy in predicting power generation of the WEC array. The efficiency, accuracy, and scalability of the proposed approach are demonstrated through an application to prediction of power generation of different sizes and layouts of WEC arrays. The proposed PGP model is used together with efficient global optimization (EGO) to establish optimal layouts that maximizes the power generation.

Physics-Informed Deep Learning for Wind Load Identification on Nonlinear Structures

Haifeng Wang; Washington State University; United States

The accurate identification of wind load on structures is crucial for ensuring their safety and integrity. However, traditional methods for estimating wind load, such as direct measurement and wind tunnel testing, have limitations. Direct measurement is costly and time-consuming, as it requires the installation of a large number of pressure sensors on real structures. Wind tunnel testing, which is the most widely used for wind load identification, can be limited in its accuracy due to difficulties in reproducing exact wind conditions and matching Reynold numbers.

To address these limitations, we propose a new approach for wind load identification that utilizes physics-informed deep learning. This approach uses deep learning to estimate wind load based on nonlinear structural response, which is more efficient and accurate than traditional methods that are only applicable to linear structures. Additionally, by incorporating physical constraints and equations, our proposed model is able to better capture the underlying physics of the system and improve its generalization capabilities.

In this work, the effectiveness of the proposed approach is verified in accurately identifying wind load on structures, even when dealing with nonlinear structural response. We also demonstrate how the use of physics-informed deep learning allows us to overcome the limitations of conventional methods, resulting in more accurate and reliable wind load estimates. The proposed method has the potential to improve the safety and integrity of structures, and ultimately, enhance the community resilience.

Physics-informed few-shot learning for wind pressure prediction of low-rise buildings

Yanmo Weng; Texas A&M University; United States
Stephanie Paal; Texas A&M University; United States

For low-rise buildings, in wind tunnel tests, large-scale models are needed because it is hard to simulate a high enough Reynolds number to neglect the scale effects in a small-scale model. Sometimes, even at larger scales, the Reynolds number can cause deviations from real wind pressure measurements. As these large-scale tests are incredibly expensive, it is important to find an approach to accurately simulate full-scale performance based on small-scale wind tunnel test results. Machine learning (ML) can potentially be utilized to address this challenge. However, traditional ML algorithms (e.g., decision tree, support vector machine, artificial neural network) can typically only solve interpolation problems. Therefore, an efficient method to extrapolate to full-scale wind pressures from low-rise buildings based on existing wind tunnel test data needs to be developed.

In this work, we propose a physics-informed few-shot learning approach to solve the scale extrapolation problem. The physical information refers to the design code's zonal system information. Specifically, ASCE 7-22 divides the roof system into the corner, edge, and interior zones based on observations from a large amount of wind tunnel tests. Within the same effective area, the corner zones usually have the highest external peak pressure coefficients, whereas the interior zone has the lowest values. Few-shot learning is a machine learning technique requiring the machine to learn a new object (e.g., full-scale response) with only a limited number of samples pertaining to that object. This approach employs the Wall of Wind (WOW) dataset containing scaled wind tunnel experiments and the Texas Tech University (TTU) dataset containing full-scale measurements. Meta-learning, used in this research, is a common framework for few-shot learning. The prior physical knowledge related to the zonal information is incorporated with the meta-learning algorithm to cluster the TTU dataset into several clusters and further predict the wind pressure coefficients. In the proposed meta-learning algorithm, the training set only contains model scale data from the WOW specimens. A special subset, named the 'shot set', is used in the proposed algorithm which only contains 3% of the full-scale data (TTU specimens), and the remaining 97% forms the testing set. The proposed meta-learning algorithm is trained on the training set to obtain good initial model parameters. With only a few gradient descent updates based on the data from the small 'shot set', the trained model can achieve good prediction performance for the testing set data. The meta-learning algorithm can guarantee that the maximum amount of full-scale data used in the training set is limited to the size of the shot set (e.g., 3% of full-scale data) while the traditional ML model cannot guarantee adequate performance with a similarly small dataset. The overall results show that with just 3% of the TTU data and all of the model scale data, the mean wind pressure coefficient prediction for the remaining 97% of the TTU full-scale dataset has a coefficient of determinant value equal to 0.856 and MSE loss equal to 0.026.

Physics-informed machine learning for hidden crack localization in concrete structure: Experimental evaluation of multi-fidelity transfer learning approaches

Sarah Miele; Vanderbilt University; United States
Pranav Karve; Vanderbilt University; United States
Sankaran Mahadevan; Vanderbilt University; United States

Detection and localization of internal cracks in aging concrete structures is crucial for ensuring their safety over their intended lifespan. This study presents physics-informed machine learning (ML) techniques for hidden crack localization in concrete specimens and evaluates their performance using vibro-acoustic modulation (VAM) experiments. The diagnostic ML models require labeled training data; however, the lack of sufficient monitoring data for structures with varying degrees of damage poses a challenge in training the ML models. This challenge is addressed using physics-based models to generate the required training data. Two types of artificial neural network (ANN) models are built: a classification model that identifies the presence or absence of damage near a sensor, and a numerical prediction model that enables Bayesian estimation of damage location and size. Computational physics simulations of different fidelity levels are performed for the nonlinear dynamics-based diagnosis process, where fidelity here refers to the dimensionality (2D or 3D) of the computational domain. Data generated from these simulations are used to build multi-fidelity ANN models using the transfer learning technique, where different layers of the ANN are trained using data from simulations of different fidelities. The diagnostic performance of these models is evaluated using VAM test data from plain and reinforced concrete specimens containing hidden (alkali-silica reaction-induced) cracks. The VAM and ML-based damage localization results are compared with petrographic test results for cylindrical cores extracted from the concrete blocks. The physics-informed ANN classification model performance is studied in the context of the computational effort needed to generate the required training data. We find that, in general, low-fidelity physics simulation-driven models, which consider numerous damage and test configurations perform better than a few high-fidelity physics simulation data-driven models. We also find that VAM testing and diagnostic ML models can be successfully used to localize hidden cracks in concrete structures.

Physics-informed Machine Learning for Porous Media

Ruofan Wu; UC San Diego; United States
Shabnam Semnani; UC San Diego; United States

Incorporating physics into machine learning algorithms has been a growing subject of interest. One common approach developed for this purpose involves Physics-informed Neural Networks (PINNs), which were initially developed for fluid mechanics problems and have been applied to porous media. It is known that PINNs involving adding physics-based terms to the loss function have demonstrated convergence issues. This is particularly exacerbated by multi-physics problems involving coupled governing differential equations such as hydro-mechanical coupling in porous media. In this work, we present several strategies to enhance the underlying consistency of PINNs. To compare the performances of these methods with the existing approaches in the literature, various examples including single-physics and multi-physics problems are presented.

Physics-Informed Machine Learning for Structural Metamodeling of Nonlinear Structures

Robert Bond; Northeastern University; United States
Pu Ren; Northeastern University; United States
Hao Sun; Renming Univeristy; China
Jerome Hajjar; Northeastern Univeristy; United States

Modern structural analysis models for nonlinear engineering systems heavily rely on computational methods to solve repeated evaluation of high-fidelity dynamic simulations. Demands of growing model complexity, optimization techniques, and uncertainty propagation are still prohibited by computational power and run time. The physics-informed machine learning (PiML) metamodel presented in this paper incorporates scientific principles and laws of physics into deep neural networks to ease expensive computer analysis. The basic concept is to constrain the solution space of the machine learning model within known physical bounds. The LSTM network is capable of learning order dependence in time-series prediction and the equation of motion confines the solution space to interpretable results. These features reduce the need for large training sets, relieves overfitting issues, and increases the robustness of the trained model for more reliable prediction. The reduced fidelity nonlinear structural model (e.g. the metamodel) is trained on three different case studies all subject to dynamic loading – a SDOF structure with a Bouc-wen type nonlinearity, a MDOF structure with cubic nonlinearity, and the measured response of a 6-Story reinforced concrete structure in San Bernardino, California. The resulting metamodel outperforms existing physics-guided LSTM models and other classical non-physics guided data-driven neural networks.

Physics-Informed Neural Network-based computational Solid Mechanics Model for Problems with Material Heterogeneity

Hyeeun Kong; Penn State University; South Korea
Pinlei Chen; Penn State University; China

Carbon Fiber Reinforced Polymer composites (CFRP) are used in a broad range of applications from aerospace to marine industries due to their high strength-to-weight, high stiffness-to-weight, and high resistance to corrosion and fatigue. The additive manufacturing process accelerates designing CFRP composite; however, it inevitably produces complicated microstructures, high heterogeneous material phases, and complex interfaces. Modeling this type of structural material is challenging because it is difficult to solve the given partial differential equations (PDEs) either analytically or numerically. Recently, Physics-Informed Neural Networks (PINNs) have gained popularity as a replacement for numerical methods for the approximation of PDEs, in which physics laws and equations are integrated into neural networks. PINNs can obtain the approximated solution of PDEs by optimizing parameters such as weight and bias; in other words, minimizing physics-based loss function that can be formulated in different ways based on different physics laws. In this work, we create a PINN-based computational solid mechanics model for linear elastic problems and resolve displacement and stress fields resulting from heterogeneous material. Different loss functions such as the collocation loss function, the energy-based loss function, and the combination of these two are applied and compared in terms of the accuracy of the solution. Also, we are going to investigate the effectiveness of boundary conditions that are enforced either softly or hardly. The main objective of this work is to design a more accurate and robust PINN model that is specialized for material heterogeneity.

Poly-Material Lattice Discrete Particle Model (P-LDPM) for the Multiscale Prediction of Concrete Mechanical Behavior

Matthew Troemner; Cusatis Computational Services; Northwestern University; United States
Elham Ramyar; Northwestern University; United States
Gianluca Cusatis; Cusatis Computational Services; Northwestern University; United States

For many decades, researchers have tried to formulate continuum constitutive equations for plain concrete; but these attempts, although successful in certain ways, failed to capture to full extent the most important aspect of concrete behavior, cracking and fracture. Fracturing behavior is strongly influenced by its heterogeneous internal structures.

At the meso-scale concrete is considered a two-phase composite in which stiff inclusions, the coarse aggregate particles, are embedded in a softer and weaker mortar matrix. At the mortar scale, concrete can be regarded as a three-phase composite composed of a porous matrix, aggregate particles of all size, and a thin layer of material at the interface between cement paste and aggregate pieces, the Interfacial Transition Zone (ITZ). At the scale of cement paste and ITZ, internal structures feature a complex system of pores with sizes spanning several orders of magnitude.

Furthermore, cement paste is intrinsically a composite structure and, in addition to pores, is composed of several components resulting from the cement hydration process. Modeling the effect of the major material heterogeneities is instrumental to capture the intrinsic material characteristic length associated with fracture, and the consequent reduction of the structural strength as a function of the structural size – the so-called Size Effect.

This presentation will introduce a poly-material extension of the Lattice Discrete Particle Model (P-LDPM) which aims to predict material behavior across length scales by only utilizing properties of individual constituent materials and mix proportions. Spatial structures are developed via a novel meshing procedure and are based on voxelated data from NIST's Cement Hydration Modeling Software (CEMHYD3D) and Virtual Cement and Concrete Testing Laboratory (VCCTL). Formulation and calibration of the predictive model is demonstrated for an exemplary concrete mix, and elastic properties are validated at both the mortar and concrete scale via uniaxial unconfined compression and triaxial test data. In addition, prediction of cement scale mechanical properties in both elastic and inelastic regime are demonstrated starting from basic single phase mechanical characterization via micro-indentation.

POMDP inference and solution of railway optimal maintenance and comparisons with deep reinforcement learning

Giacomo Arcieri; ETH Zurich; Switzerland
Cyprien Hoelzl; ETH Zurich; Switzerland
Oliver Schwery; SBB Swiss Federal Railways; Switzerland
Daniel Straub; Technical University of Munich; Germany
Konstantinos G. Papakonstantinou; Pennsylvania State University; United States
Eleni Chatzi; ETH Zurich; Switzerland

Partially Observable Markov Decision Processes (POMDPs) form a potent mathematical framework to model optimal maintenance planning problems. POMDPs account for the uncertainty associated with observations to derive optimal policies, namely a sequence of optimal decisions that minimize the total costs over a prescribed horizon, under stochastic and uncertain environments. However, POMDPs are notoriously difficult to solve and generally only approximate solutions are available. In addition, the transition dynamics and the observation generating process, namely the POMDP model parameters that govern the deterioration, the repairing effects of maintenance actions, and the relation of observations to latent states and variables, can often be unknown and difficult to infer. The available solution algorithms require the knowledge of such a POMDP model, either in full, for directly computing the solution in case of Dynamic Programming (DP) algorithms, or at least partially, for inference purposes, in Reinforcement Learning (RL) methods. In this work, we infer all pertinent transition and observation model parameters via Markov Chain Monte Carlo (MCMC) sampling of a hidden Markov model conditioned on actions, to recover full distributions of plausible values under the available data. We then compare a POMDP solution of the problem via DP algorithms against a deep RL solution. We showcase the application of these methods to real-world data by solving a problem of optimal maintenance planning of railway assets.

Poroelastic Spherical Indentation for Material Characterization

Ming Liu; Georgia Institute of Technology; United States
Haiying Huang; Georgia Institute of Technology; United States

Spherical indentation has been commonly used as a material characterization technique to measure mechanical material properties such as hardness and toughness. Recently, spherical indentation has also been applied to characterize poroelasticity for soft materials such as hydrogel and hydrated bones in the literature. In theory, for a fully saturated porous medium with incompressible constituents, if the indenter is subjected to step loading, elastic constants can be determined from the undrained and drained limits according to the Hertzian contact solution, while hydraulic diffusivity or the coefficient of consolidation can be obtained from the transient response by matching the measured indentation force or displacement as a function of time against a master curve.

Conventional approaches of poroelasticity characterization for low permeability geomaterials in the laboratory are rather challenging and time consuming. Having an alternative such as spherical indentation could therefore be beneficial. To that end, we conduct extensive theoretical and numerical analyses to investigate the feasibility of such a concept. We will first present fully coupled poroelastic solutions derived for frictionless contact between a rigid sphere and a linear poroelastic half space with three distinct types of surface drainage conditions for both step-displacement and step-force loading as well as the master curves constructed for general porous media with compressible constituents. We show that these master curves depend on material properties through a single derived parameter only and this dependence is relatively weak for step-displacement loading. We will then discuss the effect of plastic yielding based on finite element analyses, which suggest that if the material strength is such that there is no plastic strain accumulation during the transient phase, the normalized force relaxation or transient displacement can still be approximated as poroelastic. Finally, implications from our analyses for applying poroelastic spherical indentation as an experimental methodology and its advantages will be discussed.

Porohyperlastic modeling of high-dose subcutaneous injection of monoclonal antibodies using data-driven tissue geometries

Mario de Lucio; Purdue University; United States
Yu Leng; Purdue University; United States
Atharva Hans; Purdue University; United States
Ilias Bilionis; Purdue University; United States
Melissa Brindise; Purdue University; United States
Arezoo M. Ardekani; Purdue University; United States
Pavlos P. Vlachos; Purdue University; United States
Hector Gomez; Purdue University; United States

Subcutaneous injection of therapeutic monoclonal antibodies (mAbs) has experienced a vast and unprecedented growth in the pharmaceutical industry due to their versatility to treat multiple chronic diseases. However, the transport and mechanical processes occurring during and after large-volume injections remain poorly understood. Herein, we develop a high-fidelity, large-deformation computational model to study high-dose, high-speed subcutaneous injection of mAbs. Our model accounts for the anisotropy of subcutaneous tissue by means of a fibril-reinforced porohyperelastic model. We also incorporate the multi-layer structure of the skin tissue, generating data-driven geometrical models of the tissue layers from histological data. We use this model to study the impact of handheld autoinjectors on the injection dynamics for different patient forces. Our simulations show the importance of considering the large-deformation approach to model high-dose injection volumes. This work opens opportunities to better understand the mechanics and transport processes that occur in large-volume subcutaneous injections of mAbs.

POST-BUCKLING CAPACITY OF OF CORRODED STEEL BRIDGE BEAMS UNDER REPETITIVE MONOTONIC LOADING

Shahrukh Islam; University of Massachusetts Amherst; United States
Aidan Q. Provost; University of Massachusetts Amherst; United States
Simos Gerasimidis; University of Massachusetts Amherst; United States

A major challenge of structural engineers is to assess the capacity of deteriorated structures which have aged in the past decades. For steel bridges the main cause of concerns originates from the loss of material due to corrosion at the ends of beams, especially at the bottom of the webs of W-sections. This loss often is so significant that the beams lose a big part of their capacity and there have been instances where the web has locally buckled while the beams are in operation and traffic load is still on the bridge. During inspections, the loss of material is reported, but then the prediction of the remaining capacity is a difficult task because of the lack of data and clear guidelines for these structures. Our group has worked to identify the peak load at which corroded steel beams buckle at by experimentally testing real naturally corroded beam from bridges of the 40's 50' and 60's. The work which will presented involves experiments which include loading of corroded beam ends through buckling, then unloading them, and then subsequently loading the buckled beam again to find what is their post-buckling capacity, if there is any. Interestingly, the buckled beam ends exhibit a significant fraction of the buckling load as a post-buckling capacity. These findings have initiated the presented research, which aims at identifying a maximum safe post-buckling threshold for buckled corroded beam ends. Such a threshold could be useful for engineers in cases when buckled beam ends are found in bridges currently in operation. The experiments show that the beams exhibited post-buckling softening behavior and hysteresis in the loading and unloading cycles. This softening behavior is highly dependent on the load amplitude applied onto the beam end.

Predicting floor response of RC buildings under near-field ground motions using convolutional neural network

Iqra Latif; Indian Institute of Technology Delhi; India
Arnab Banerjee; Indian Institute of Technology Delhi; India
Mitesh Surana; Indian Institute of Technology Delhi; India

Earthquakes pose a significant threat to human lives and economic assets globally. To mitigate this, predicting the response of buildings under seismic activity can assist in the appropriate design of new buildings and timely retrofitting measures for the existing ones. In this work, we present a new deep-learning approach that leverages a convolutional neural network to predict the floor response of buildings, based on input ground motion. We demonstrate its use on a four-story RC building subjected to near-field pulse-like earthquakes. To assess its performance, we compare floor amplification factors extracted from the non-linear time history analysis and using the trained machine learning model and establish its generalizability by showing reasonably well predictions on unknown ground motion inputs.

Predicting Fracture Paths in Heterogeneous Brittle Materials using Deep and Probabilistic Learning

Yen Peng (Ariana) Quek; Duke University; United States
Jin Yi Yong; Monash University; Malaysia
Johann Guilleminot; Duke University; United States

We present methods to reduce the computing cost associated with full-scale fracture simulations in heterogeneous brittle materials that exhibits a spatially varying material property, here taken as the fracture toughness. Several approaches are analyzed to formulate the approximation scheme in the infinite-dimensional setting. Optimal strategies are first explored to encode and decode smooth and non-smooth physical fields, and methods to approximate the forward mapping between the latent spaces are then discussed. A first class of methods involves standard neural network based surrogates, including PCA-Net and the Fourier Neural Operator (FNO). Another class of techniques is next introduced that relies on probabilistic conditioning and generative models on manifolds. The accuracy of these methods is finally assessed by comparing the predicted results with those derived from high-fidelity computations.

Predicting the yield limit of sandstones

Julien Khoury; Université de Pau et des Pays de l'Adour; France
Sébastien Boutareaud; Université de Pau et des Pays de l'Adour; France
Gilles Pijaudier-Cabot; Université de Pau et des Pays de l'Adour; France

Determining the yield limit of granular rocks is crucial for a variety of geomechanical applications since it affects multiple mechanical and physical properties. The objective of this study is to predict sandstone yield curves with an original approach that uses few mechanical properties and microstructural properties as much as possible. Porous rocks are modeled in this work as a set of circular grains subjected to radial and axial stresses. It is assumed that the samples yield when one of the local planes fails. Local plans, in turn, fail when local stresses reach the shear, tensile or compressive limit. A failure based on Mohr- Coulomb criteria is considered for shear and tension with a limitation on the highest possible shear stress. The parameters of the developed yield equations are then divided into two groups. The first family contains parameters of the sample such as porosity, grain radius, intergranular contacts radius and an intensification factor. These are called the microstructural characteristics. The second family contains mechanical properties of the intergranular cement such as the cohesion, the friction angle and the compressive limit. While the first set of properties differs from one sandstone to another, the second set is presumed to be related to the family of rocks that is considered, i.e. it is the same for all sandstones with similar mineral compositions. The experimental data for five sandstones, Berea, Boise, Darley Dale, Diemelstadt and Rothbach was gathered from the literature. All sandstones have similar compositions but differ in their microstructural characteristics. The cement parameters are then calculated by fitting the experimental data related to the Rothbach sandstone. The remaining samples' yield curve are then calculated by modifying just the porosity, the grain radius, the intergranular contacts radius and the intensification factor. The results predicted by this model are matching the experimental data with a relatively good accuracy.

Predicting Wildfire Ignition and Windborne Ember Accumulation on Roofs via Deep Learning (DL)

Mohammad khaled al-Bashiti; Clemson university; United States
Dac Nguyen; Clemson university; United States
Nigel B Kaye; Clemson university; United States
M.Z Naser; Clemson university; United States

The accumulation of windborne embers over the buildings' roofs is often tied to fire ignition. This work adopts artificial intelligence (AI) by means of deep learning (DL) to build a predictive model capable of identifying the susceptibility of a building's roof to accumulate windborne embers during wildland fires. Multiple geometric and dynamic parameters were taken into consideration when creating the model, namely, wind angle, wind speed, roof's slope, and the shape of the roof. More than 250 images were collected from small-scale wind tunnel tests on ember-topped buildings roofs to simulate the locations of embers distribution and accumulation. The collected images were then used to train and validate a deep-learning model to identify the risk of accumulation over the roofs. Our findings reveal that the created DL model can predict ember accumulation on roofs with high accuracy. The rectangular roof with no protrusions was found to have the lowest accumulation. In addition, the accumulation is lowest when the wind angle relative to the building's short axis is approximately 90 degrees, while the ideal slope of roofs to avoid accumulation is 10/12.

Prediction and Multi-objective Optimization of the Three-Phase Particulate Concrete Parameters with Artificial Neural Network and Particle Swarm Optimization

YIJIE CHEN; National University of Singapore; Singapore
Sze Dai Pang; National University of Singapore; Singapore

Material design optimization of composite involves the selection and optimization of material parameters to satisfy the requirements for selected performance objectives, e.g. strength, density, and etc. A computational-based two-step approach is employed in this study to perform material design optimization of three-phase particulate concrete (TPPC). Lightweight concrete using coated lightweight fillers is chosen for illustration. In the first step, the prediction of TPPC mechanical properties was performed using artificial neural network techniques (ANN) with numerical-based datasets, and Sobol's sensitivity analysis was employed to determine the contribution of each input parameter towards the model output variance. In the second step, the relationship between the mixture proportion and the mechanical properties of each phase (input parameters of network) was established based on both empirical and theoretical expressions. The multi-objective optimization model was obtained from the data-driven model and the established relationship. The resulting model was solved using a modified Particle Swarm Optimization (PSO). The performances with regards to the prediction, sensitivity analysis, as well as optimization methods were compared in this paper.

Prediction of Kink Bands and Splitting in Multidirectional Double-edge Notch Compression Specimens

Alexander Faupel; Vanderbilt University; United States
Caglar Oskay; Vanderbilt University; United States

This study presents an investigation of the failure response of a laminated composite specimen under compressive loading conditions. Compression failure in composites is complicated due to the onset and growth of a multitude of failure mechanisms that affect the overall behavior and may potentially interact. These failure mechanisms include fiber splitting, delamination, fiber cracking, and compression kink bands. Among them, compression kink bands are attracting significant attention as they often determine the compression strength of the composite and themselves include complex microstructural features. In order to observe compressive kink band failure initiation and progression, physical tests were performed on double-edge notch compression (DENC) specimens. Experimental analysis of the multidirectional laminates provides quantified characterization of the initiation and growth of both kink bands and surface ply splitting as a function of applied load level. In conjunction with experimental analysis, a multiscale computational model of the composite was used to simulate the compression behavior and characterize the interplay of these critical and subcritical damage mechanisms. The nonlocal multiscale kink band model used in this study explicitly tracks the microstructural failure mechanisms that lead to the formation and propagation of kink bands. Cohesive zone modeling was used to describe the initiation and progression of ply splitting in the DENC specimen. The splitting model was implemented using implicit finite element simulations and deployed with a pre-crack insertion technique to reduce simulation time while preserving prediction accuracy. Split model implementation is verified through studying the effect of crack location and growth characteristics on the model prediction. Deterministic calibration of model parameters yields prediction of damage progression and macroscopic load - strain response which agree well with the experiment results.

Prediction of long-term time-dependent behavior in prestressed concrete structures

Mauricio Pereira; Princeton University; United States
Branko Glisic; Princeton University; United States

Creep and shrinkage in concrete are stochastic processes that depend on the history of ambient conditions and loading, concrete composition, and surface exposure, making prediction difficult even under controlled conditions. Prediction of long-term structural behavior is significantly more challenging in prestressed structures due to concrete-steel interaction, uncontrolled environmental conditions, material heterogeneity and uncertain boundary conditions. Multiple empirical models exist to predict creep and shrinkage in concrete, but they are calibrated on databases of laboratory experiments. It is not clear to what extent those calibrations are informative for a specific structure of interest. Current literature proposes short-term experiments to update compliance or shrinkage model parameters for improved prediction accuracy, but those are still not capable of capturing in-situ effects and are largely limited to rescaling of ultimate values. In contrast, structural health monitoring can provide in-situ data with the potential of improving long-term prediction of structural behavior, even without sophisticated numerical models. In this work, structural health monitoring data is used to calibrate multiple creep and shrinkage models for improved prediction of long-term behavior of a prestressed concrete structure. It is found that a simple model calibrated to one year of noisy, incomplete data can provide accurate long-term prediction strain several years ahead. Prediction of multiple models found in literature are in agreement over the long-term when their calibrations are fitted to two years of data. Accurate predictions, in turn, enable detection of both gradual and sudden anomalies in the monitoring data.

Prediction of Microstructure Evolution with Physics-Constrained Bayesian Neural Networks

Luka Malashkhia; Georgia Institute of Technology; United States
Dehao Liu; State University of New York at Binghamton; United States
Anh Tran; Sandia National Laboratories; United States
Yanglong Lu; Hong Kong University of Science and Technology; Hong Kong
Yan Wang; Georgia Institute of Technology; United States

Although deep learning models such neural networks gained popularity in the recent decade, data sparsity remains as the major obstacle to applying them to solve complex engineering problems, because it is still expensive to obtain a large amount of training data through experiments or simulations. Physics-constrained neural networks, also known as physics-informed neural networks (PINNs), were recently introduced to solve the data sparsity issue, where prior knowledge embodied as physical models is applied as constraints in the training process. However, the model-form and parameter uncertainty associated with the neural networks can still lead to unreliable predictions. Here, we introduce a physics-constrained Bayesian neural network (PCBNN) framework to quantify the uncertainty of PINNs. A new adaptive weighting scheme and a minimax architecture are developed to tackle the training convergence challenge in PINNs. A Gaussian mixture model is further integrated in the PCBNN to more accurately represent probability distributions of outputs without significantly increasing the computational cost. The PCBNN framework is applied to predict grain evolution in metal additive manufacturing. The physics in the Ising model of solid-state transformation and stochastic dynamics in the quantities of interest is incorporated for efficient training and prediction.

Prediction of pressure coefficients on roof soffits and walls of low-rise building using artificial neural networks and ensemble methods

Karim Mostafa; Florida International University; United States
Ioannis Zisis; Florida International University; United States
Amal Elawady; Florida International University; United States

Machine learning (ML) techniques, which are a subset of artificial intelligence (AI), have played a crucial role over the last few decades across a wide spectrum of disciplines, including structural wind engineering. This study implements three ML methods for predicting mean and peak pressure coefficients on the surfaces of roof soffits and adjacent walls of low-rise buildings. The ML models used 240 datasets for training and testing, using existing 6 test samples from the Wall of Wind (WOW) experimental facility for 40 wind directions. Each dataset comprises of the installed pressure taps on each sample at one specific wind direction. Six input variables are used in training the models; x,y,z coordinates of installed pressure taps on the surfaces, wind direction, roof slope, and soffit width. Artificial neural networks (ANN), decision tree (DT), and random forest (RF) methods are used in predicting the pressure coefficients. The predicted response for the trained models is either mean pressure coefficient or peak pressure coefficients. The datasets are split to 90% for training and 10% for testing, which are unseen by the trained model. The performance of each model was assessed using error metric, such as RMSE, R2 and MAE, to assure the accuracy of the model in prediction. The predicted responses from the unseen datasets were compared to the measured experimental data. The used ML techniques were robust enough to accurately predict the mean and peak pressure coefficient using the trained models. The study affirms the capability of ML models in predicting pressure coefficients on different components and cladding surfaces, which may result in minimizing the experimental effort for wind tunnel testing.

Prediction of Wind Profile in Heterogeneous Terrain using Artificial Neural Network

Zihan Mahmood Nahian; Florida State University; United States
Lee-Sak An; Florida State University; United States
Sungmoon Jung; Florida State University; United States

This paper presents a prediction model for the mean wind speed profile over heterogeneous terrains based on an artificial neural network (ANN). The model was trained and tested using wind tunnel testing results along with terrain information from 60 sites in the US. Terrain roughness was incorporated as an input feature to account for the effect of upwind terrain morphology on wind profile. It was assumed that the heterogeneous terrains were represented by some effective roughness lengths. The proposed ANN model can prove to be a reliable alternative to deterministic models as it demonstrated good accuracy in predicting the mean wind speed profile.

Prestressed Concrete Beam Shear Capacity Prediction Models based on Regression and Genetic Programming

Wonsuh Sung; Texas A&M University; United States
Subaib Alfaris; Texas A&M University; United States
Nikhil Potnuru; Texas A&M University; United States
Stephanie Paal; Texas A&M University; United States
Maria Koliou; Texas A&M University; United States
Petros Sideris; Texas A&M University; United States
Anna Birely; Texas A&M University; United States
Mary Beth Hueste; Texas A&M University; United States
Stefan Hurlebaus; Texas A&M University; United States

This presentation will discuss a novel approach for predicting the shear capacity at the onset of diagonal cracking and the shear capacity against failure of prestressed concrete beams using nonlinear regression and genetic programming methods. First, the 2015 ACI-DAfStb database, which combines the database of the ACI 445-D Committee and the database of the ACI-DAfStb Committee, is expanded to include additional, and often more recent, experimental datasets. Subsequently, the database is analyzed and major factors that affect the shear capacity of prestressed concrete (PC) beams are identified, such as beam depth, shear span-to-depth ratio, longitudinal reinforcement ratio, the tensile strength of concrete, level of prestressing, and shear reinforcement properties. These parameters are then used to investigate expressions for the shear capacity of PC beams at the onset of cracking and at failure. Such expressions are pursued in two ways, namely, via nonlinear regression and via genetic programming. In the nonlinear regression approach, a functional form of the shear capacity is assumed based on experimentally observed trends. The coefficients (model parameters) of those expressions are obtained through nonlinear regression. The genetic programming approach does not assume any form of these expressions, thus overcoming this limitation of the nonlinear regression analysis. It rather determines the fittest form through crossover and mutation operations amongst basic/simple functions. The predictions of the shear capacity equations obtained from these methods are compared with predictions obtained from the equation in ACI 318 and AASHTO LRFD. Both the nonlinear regression and the genetic programming models showed better performance than the current provisions in terms of the coefficient of determination and root mean square error. The expressions obtained via genetic programming outperformed all other models and equations.

Prestressed Concrete Piles with GFRP Spirals against Corrosion Hazard

Olayiwola Adegbulugbe; FAMU-FSU College of Engineering; United States
Sungmoon Jung; FAMU-FSU College of Engineering; United States

Prestressed concrete piles are often utilized as foundation elements in coastal structures which are exposed to aggressive environmental conditions. These conditions make steel reinforcements within the piles susceptible to corrosion, which in turn compromises the integrity and life span of the structures. The use of Carbon Fiber Reinforced Polymers (CFRP) and Stainless Steel (SS) as longitudinal and transverse reinforcement alternatives to steel in prestressed concrete piles have been implemented. However, the prohibitive cost of CFRP and SS has limited the widespread utilization of corrosion resistant piles. Consequently, in this study, the more cost competitive GFRP spiral was designed for use in piles by considering the tensile equivalency of the straight portion of the GFRP bar to steel, the strength of the bent region of the GFRP spiral, and spacing considerations for ease of construction. To practically use prestressed concrete piles with GFRP spirals, their response to impact loads and bending needs to be evaluated using full-scale piles. Therefore, three 28 ft.-long 24 square-in. prestressed concrete pile specimens were fabricated. All three piles were reinforced longitudinally with grade 270 prestressing steel following the FDOT standard for 24 square-in. piles. However transversely, one specimen was reinforced with W3.4 steel spiral, while the others had #3 GFRP spirals. From the impact tests, the stress and acceleration responses of the piles were evaluated. Also, the stress responses of the spirals were evaluated and showed the capability of GFRP spirals in confining the concrete core of the pile as the spiral was well within its ultimate stress limit after the concrete spalled. Finally, the moment capacity and ductility of a pile reinforced with GFRP spiral was evaluated and compared to the design using results from the flexural test.

Preventing cracks in continuously reinforced concrete with peridynamic models: temperature/shrinking effects in early-age CRCP, and corrosion-induced fracture

Yupeng Liu; Huazhong University of Science and Technology; China
Ziguang Chen; Huazhong University of Science and Technology; China
Jiangming Zhao; University of Nebraska-Lincoln; United States
Florin Bobaru; University of Nebraska-Lincoln; United States

Continuously reinforced concrete pavement (CRCP) is an excellent long-life solution for highly-trafficked and heavily-loaded roadways, such as interstate highways. Cracks develop in early-age CRCP due to environmental loadings (variable temperature and drying conditions), and, in the absence of pre-notches, or depending on the spacing between them, closely-spaced cracks can form. These types of cracks affect the long-term performance of CRCPs as they can lead to early distress, punchouts, spalls, and further rapid and dangerous deterioration of the pavement. In this talk we present a peridynamic model that includes time-dependent environmental loading and material properties to predict the early-age cracking behavior in CRCP. The simulation results match those from field observations in terms of crack patterns, average transverse crack spacing, and crack width. Further parametric analyses show the effects induced by changing environmental conditions and design parameters on resulting crack patterns. The model is then used to determine optimal placement of pre-notches that can prevent, for given forecasted multi-day temperature and drying conditions, the evolution of closely-spaced cracks, as an active crack control strategy.

We also study cases in which ingression of corrosive agents reach the reinforcing bars and lead to corrosion-induced fracture in concrete. In this case we show that a stochastically homogenized model for the concrete material is necessary to correctly predict the experimentally observed sequence of failure events (e.g. vertical cracks develop from the cover towards the steel bar).

These peridynamic models for fracture and damage in concrete structures allow the introduction of design strategies locally-adjusted to the particular climatic conditions during construction and curing stage to increase the reliability and lifespan of the structure.

Acknowledgements: The work of Y.L. and Z.C. has been supported by the National Natural Science Foundation of China, grant number 11802098, and by the Fundamental Research Funds for the Central Universities, grant number 2021GCRC021. The work of J.Z. and F.B. has been supported by the AFOSR MURI Center for Materials Failure Prediction through Peridynamics.

Probabilistic Analysis of Hurricane-Induced Debris Impacts towards Enhancing Coastal Community Resilience

Kooshan Amini; Rice University; United States
Jamie Padgett; Rice University; United States

The impact of climate hazards, such as hurricanes, on coastal communities presents extreme challenges to their resilience and leads to both direct and indirect economic and social losses. Debris-related impacts, in particular, can result in various consequences, including structural damage, disruption to transportation networks, and hindered recovery of interdependent systems. It is therefore imperative to gain a deeper understanding of the uncertain impacts of hurricane-generated debris on coastal communities. This study proposes a probabilistic methodology to evaluate the impact of hurricane-induced debris on coastal communities, which is essential for conducting a comprehensive resilience analysis. The methodology encompasses interdependent probabilistic models that range from debris volume estimation and its spatial distribution during hurricane events, to debris-induced physical damages and network level performance impacts, as demonstrated by transportation infrastructure, to the disruption of interdependent systems recovery. The proposed methodology is illustrated using testbed community data and input models relevant to the Galveston region in Texas, USA. The results highlight the significance of capturing debris impacts when assessing community-scale resilience metrics such as infrastructure system service availability and recovery, and access equity to emergency facilities and social institutions. This research contributes to the coastal community resilience analysis improvement and serves as a crucial step toward enhancing preparedness and response to future extreme weather events.

Probabilistic digital twin for damage-adaptive rotorcraft control

William Sisson; Vanderbilt University; United States
Pranav Karve; Vanderbilt University; United States
Sankaran Mahadevan; Vanderbilt University; United States

We build a probabilistic digital twin of a rotorcraft to enable planned path tracking after sustaining damage during flight. By fusing rotorcraft health state data obtained using probabilistic diagnosis, the digital twin is the most up-to-date digital replica of the particular rotorcraft. The probabilistic damage estimate and the associated uncertainty are propagated through flight prognosis (rotorcraft dynamics) models to estimate candidate trajectories for the damaged rotorcraft. A stochastic optimization problem is solved to obtain time history of four rotorcraft controls (collective, lateral, longitudinal, and pedal) that minimizes the tracking error for the current damaged state of the rotorcraft. Using training data from Rotorcraft Comprehensive Analysis System (RCAS), we build efficient machine learning surrogate models to expedite the diagnosis, prognosis and control optimization process. We quantify and propagate measurement uncertainty, diagnosis uncertainty and (surrogate) model uncertainty. We demonstrate the proposed methodology by performing numerical experiments for a rotorcraft with stabilizer damage.

Probabilistic Gait Parameters from Floor Vibrations

Yohanna MejiaCruz; University of South Carolina; United States
Juan M. Caicedo; University of South Carolina; United States
Zhaoshuo Jiang; San Francisco State University; United States
Jean Franco Lozada; University of South Carolina; United States

This research proposed a multilevel probabilistic model to estimate gait parameters such as cadence and walking speed using walking-induced floor vibrations. The probabilistic multilevel model was developed and evaluated using the Bayesian analysis reporting guidelines (BARG) to ensure the analysis can be reproduced and corroborated.

The first level predictor, cadence, was evaluated using data from twenty-seven trials in which floor vibration data and wearable sensor data from the ambulatory Parkinson's disease monitoring (APDM) inertial sensor system were recorded. The cadence estimations from the first level were used to make walking speed estimations. The second level predictor was informed using experimental data extracted from the literature and evaluated using APDM estimations from the same twenty-seven trials.

The predictions of cadence and walking speed are presented using 95% high-density posterior (HDP) and evaluated in BARGS utilizing a range of practical equivalence (ROPE) criteria. The results show that in 100% of the cases, cadence estimation can be accepted as the target value for practical purposes. In contrast, walking speed estimations are inconclusive for the combined criteria, even though the reference value is within 95% HDP.

The walking speed level predictor results indicate that the data used is improper or incomplete. The data collected from the literature belongs to a population and does not represent an individual's walking variability, which makes implausible a decisive estimation within the ROPE acceptance.

Probabilistic Operator Learning via Stochastic Processes with Implicit Kernels

Ruda Zhang; University of Houston; United States

Operator learning is a nascent topic in scientific machine learning (SciML), which uses ML approaches for operator approximation. Consider a mathematical or numerical model as a solution operator that maps model inputs (e.g., parameter fields, external excitations) to model outputs (e.g., a solution field, or evolution of the state or quantities of interest), both of which are infinite-dimensional functions or very high-dimensional vectors. Operator approximation aims at approximating the solution operator with another operator that is faster to evaluate. While current operator learning methods have various successes in accuracy and efficiency, few provide uncertainty quantification (UQ), which is crucial for trust and confidence in model predictions. Here we propose a probabilistic method to operator learning via a Bayesian approach to the random feature model (RFM) of operators. The RFM approximates the solution operator within a reproducing kernel Hilbert space determined by a finite basis of random operators (aka random features). The random features implicitly define a kernel, which in turn can be used in a stochastic process model of operators. This approach has multiple advantages. (1) easy training: compared with deep neural nets, it requires much fewer parameters and is trained via a convex program; compared with conventional kernel methods, it is a parametric method and does not work directly with its kernel, which enables massive acceleration. (2) efficient prediction: most of its prediction cost comes from running the random features, which are efficient surrogates. (3) efficient UQ: probabilistic inference comes at a fraction of the prediction cost. We demonstrate this method on several problems in scientific computing.

Producing Heterogeneous Upwind Terrain Dataset for Wind Tunnel Testing Using Image Classification Method

Nasrollah Alinejad; Department of Civil and Environmental Engineering, FAMU-FSU College of Engineering; United States
Sungmoon Jung; Department of Civil and Environmental Engineering, FAMU-FSU College of Engineering; United States

Wind tunnel testing is a standard method to investigate the effect of upstream surface roughness on wind loads on buildings. However, due to the difficulty of reproducing the complex real-world land coverage, investigations on upstream terrain effects have been limited to simple cases such as smooth to rough and rough to smooth roughness transitions. Recently, convolutional neural networks (CNN or ConvNet) have led to significant progress in image classification. This study aims to propose a Convolutional Neural Network that can classify images in a way it can be used in wind tunnel testing. The input to the network will be the satellite image. The image data from Landsat 8 was obtained from the USGS website, and all images were from the 2016 version for consistency. The National Land Cover Database (NLCD) images were used in the neural network as a labeled dataset that classifies different types of land cover and labels them into 20 categories. As the CNN architecture accepts patch-based inputs, samples are extracted as patches with size $15 \times 15 \times 8$ out of multidimensional data and labeled by the classification of the center pixel of each patch. We choose a ratio of 9:1 to split training and validation data. As a result, 7.3 million training samples and 0.8 million validation samples are obtained. In order to improve the NLCD classification of developed areas, we had to review all sites using Google Earth and manually identify the mid-rise buildings. Buildings with 3 stories or fewer were considered as low-rise building, whereas buildings with at least four stories or more were considered as mid-rise buildings. The neural network model improves the prediction of labels in developed areas, and therefore, will have a major impact on the estimation of wind speed and pressure. However, the improvement of the proposed method will depend on the site characteristics.

Progressive Failure of Low-rise Buildings Considering Internal Wind Pressure Change

Zhixia Ding; University of Connecticut; United States
Wei Zhang; University of Connecticut; United States
Dongping Zhu; University of Connecticut; United States
William Hughes; University of Connecticut; United States

The openings due to ventilation purposes or building façade failure change the internal wind pressures and might induce larger wind loadings on walls and roofs, leading to unsafe structural performance and vulnerability assessment. To achieve realistic structural behaviors, progressive failure analysis needs to be conducted with the change of internal wind pressure integrated. The theoretical and empirical formulas in previous studies revealing the relation between the internal and external wind pressure coefficients for buildings with a dominant opening on the windward wall, which is the critical design case yielding the worst loading condition, are summarized and adopted in the transient analysis for buildings. The relations between two sets of non-dimensional parameters in the theoretical formulas are derived and the equivalence of the governing equations under certain assumptions is verified. The internal wind pressure coefficients from these formulas and that from ASCE 7-16 are compared with the wind tunnel experiment results in the NIST database. The formulas provide similar internal wind pressure coefficients to the experimental values under large windward wall opening conditions, but are conservative under small dominant opening conditions. The progressive failure analysis procedure is proposed and conducted on a full-size realistic low-rise wood building model with the sheathing panel effects included and internal wind pressure updated using the theoretical and empirical formulas. The failure initiation of the buildings modeled with sheathing panels is found delayed, but larger failure ratios in buildings are observed at the end compared with the buildings modeled with sheathing elements. The progressive failure processes of a partially enclosed building are captured in all the models with wind pressure updated. The progressive failure progress of buildings with wind pressures updated with different formulas are compared with that in buildings modeled with database-assisted design method. The building roof is found the most vulnerable part and the differences in roof failures in the models are within 10% for structural analysis, and could induce a large difference in vulnerability assessment.

Progressive Wrinkling and Collapse of Lined Pipe due to Cyclic Bending and Reeling

Stelios Kyriakides; University of Texas at Austin; United States
Emile Naous; University of Texas at Austin; United States

Carbon steel tubes and pipe used in power plants and pipeline applications are often lined internally with a thin layer of a corrosion resistant alloy (CRA) in order to protect them from corrosive ingredients. The composite structure is assembled by mechanically expanding the liner inside the carrier tube so that they end up in contact. In several operations, lined pipe is bent plastically, causing the liner to detach from the carrier tube and, under excessive bending, to develop large amplitude wrinkles and local buckles rendering the structure unserviceable [1]. The presented work investigates how repeated bending to presumably "safe" curvatures leads to accumulation of wrinkling and, eventually, the collapse of the liner.

The problem is modeled along the lines of [1] extended to the needs of cyclic plastic loading. The material behavior under repeated tension/compression axial cycling of both the carbon steel carrier and the CRA are measured experimentally. A nonlinear kinematic hardening constitutive model is calibrated to the measured stress-strain responses, ensuring that the Bauschinger rounding of reverse loading is reproduced accurately. The measured properties are used to first simulate numerically the inflation process through which the two tubes develop interference contact. The composite structure is then subjected to curvature-symmetric cyclic bending to a curvature that is a fraction of the value at which the liner collapses under monotonic bending. It is demonstrated that bending leads to differential ovalization, and separation of part of the liner from the outer pipe. The unsupported strip of liner on the compressed side develops small amplitude wrinkles whose amplitude progressively grows with each cycle, eventually causing liner collapse. Results from the related problem of winding and unwinding a lined pipe onto a large diameter reel, of interest to the pipeline industry, will show a similar trend. The rate of accumulation of wrinkle amplitude with the number of cycles is studied parametrically for both problems.

Reference

[1] Yuan, L. and Kyriakides, S., "Liner Wrinkling and Collapse of Bi-material Pipe Under Bending." Int. J. Solids & Structures 51, 1646-1661, 2014. http://dx.doi.org/10.1016/j.ijsolstr.2013.10.026

Propagation of modeling uncertainty in the seismic behavior of specimens employing spines.

Bryam Astudillo; Stanford University; United States
Barbara Simpson; Stanford University; United States

In promoting enhanced seismic performance and seismic resilience, lateral force-resisting systems with novel components and configurations have continuously been explored and, in many cases, adopted. However, the numerical models used to estimate the seismic response of structures are subject to modeling uncertainties, especially if the structure employs less well-characterized components (e.g., with reduced testing data), like elastic spines and force-limiting connections (FLC). Herein, the effects of modeling uncertainty were studied for specimens, composed of moment-resisting frames, elastic spines, and FLC, which were part of a full-scale testing program. Particular interest was given to the modeling uncertainties related to the spine-to-frame connection and how these propagated into the estimates of story drift ratios and floor accelerations. Peak floor acceleration was found to be more sensitive to modeling uncertainty compared to story drift ratio. Correlations between the spine-to-frame modeling conditions at different floors and the building's global response indicated the larger relevance of connections at certain locations over others. These results, in addition to bounding the estimated demands in structural and nonstructural components, could influence future design decisions in enhanced lateral-force resisting systems that employ spines and FLC.

Prototyping of An Edge-Intelligence-Enabled Smart Adaptive Triggering Mechanism for Wireless Vibration-based Structural Health Monitoring

Shuaiwen Cui; Nanyang Technological University; Singapore
Yuguang Fu; Nanyang Technological University; Singapore

The intrinsic constraints of wireless sensing, e.g., limited power budget and network throughput, greatly impede the application of wireless sensing in structural health monitoring. Edge or onboard intelligence is considered a promising solution to alleviate the adverse effect caused by the above constraints and thus to facilitate sustainability and timely assessment as well as decision-making. Based on the sudden event monitoring mechanism developed for wireless IoT sensors, this study proposes an edge-intelligence-enabled smart adaptive triggering mechanism for vibration-based structural health monitoring, which is suitable for edge devices with limited onboard resources and features automatic event identification as well as automatic triggering threshold adjustment. As the proposed mechanism is tailored for wireless IoT sensors, constraints of onboard resources and sensor unit workflow are considered. In the proposed mechanism, automatic event identification is enabled by onboard AI, which provides feedback for threshold adjustment and facilitates power saving by reducing the amount of data transmitting. Based on the results of onboard AI inference, the adaptive adjustment of the triggering threshold is controlled by a closed feedback loop using a customized performance evaluation function synthesizing AI inference precision and recall. The proposed mechanism was simulated with Matlab & Simulink and evaluated in terms of time and power consumption, demonstrating suitability and potential for on-demand wireless vibration-based monitoring.

Quantification of the effect of uncertainty in noise on posterior probability values

Yupeng Zhang; California Institute of Technology; United States
Jeffrey Hart; Texas A&M University; United States

Prior information about parameters plays a significant role in Bayesian inference. Previous studies include, for example, Guilleminot and Soize on prior representations of random fields [1], Berger et al. on overall objective priors [2], and Zhang and Shields on the effect of prior probabilities on imprecise probabilities [3]. Here, we talk about the effect of uncertainty in noise on the posterior probability values in a Bayesian approach with analytical analysis, which is significantly attractive since it provides a clear view to understand the relation between posterior probability values and the uncertainty in the inevitable noise contained in measurable signals. To this end, we specifically consider a Bayesian formulation for inference of material properties from experimental signals with a normal likelihood quantifying noise and an inverse gamma prior expressing uncertainty about noise variance. There exists a critical ratio between the mode of the inverse gamma prior and the true variance of the normally distributed noise [4]. This ratio determines how the posterior probability varies with the shape parameter of the inverse gamma prior. Confirmation of the conclusions obtained by asymptotic analysis was made by an analytical expression and numerical simulations, where the identification of creep parameters of solids from constant load and hold indentation tests is discussed. We will recommend an effective choice of prior parameters.

References

[1] Guilleminot, J. and Soize, C., 2013, Prior representations of random fields for stochastic multiscale modeling, Procedia IUTAM, 6, 44-49.

[2] Berger, J. O., Bernardo, J. M., and Sun, D., 2015, Overall objective priors, Bayesian Anal. 10 (1), 189–221

[3] Zhang, J. and Shields, M.D., 2018, The effect of prior probabilities on quantification and propagation of imprecise probabilities resulting from small datasets. Computer Methods in Applied Mechanics and Engineering, 334, 483-506.

[4] Zhang, Y. and Hart, J.D., 2023. The Effect of Prior Parameters in a Bayesian Approach to Inferring Material Properties from Experimental Measurements. Journal of Engineering Mechanics, 149(3), 04023007.

Quantifying the Fatigue Reliability of Ship Hulls with Long Propagating Cracks

Mohamed Soliman; School of Civil and Environmental Engineering, Oklahoma State University; United States
Mohammad F. Tamimi; Department of Civil Engineering, Yarmouk University; Jordan
Somayeh Shojaeikhah; School of Civil and Environmental Engineering, Oklahoma State University; United States

Fatigue cracking has been recognized as one of the main deterioration mechanisms that can affect the safety of ship structures. Ships are generally exposed to millions of load cycles during their service life. This large number of load cycles can lead to fatigue crack propagation which may cause a drop in structural reliability. Existing reliability quantification approaches in literature account only for the possibility of brittle fracture failure and may not be valid when considerable plastic deformation may occur. Furthermore, the resistance to sudden fractures is not properly quantified. In this context, a probabilistic approach for quantifying the reliability of ship hull structures under propagating fatigue cracks is established. Herein, artificial neural networks are utilized to assist in predicting the fatigue crack propagation and accelerate the probabilistic simulations leading to a considerable reduction in computational costs. Climate data are used to estimate the realistic wave-induced loads acting on the hull structure. The failure assessment diagram is utilized to define the limit states considering various failure modes that may occur under hull cracking. The resistance of the hull to sudden fracture is evaluated by applying the Weibull stress criterion. Monte Carlo simulation is used to conduct the probabilistic analysis and quantify the reliability of the ship hulls under the applied loads and propagating crack. The approach is illustrated on a tanker operating in the Atlantic Ocean.

Quantifying Uncertainty in Quantum Approximate Optimization Algorithms

Jungin Kim; Georgia Institute of Technology; United States
Yan Wang; Georgia Institute of Technology; United States

Quantum computers have attracted research interests for scientific computing because of their potentials to efficiently solve difficult problems such as optimization. Over the last three decades, several quantum optimization algorithms have been developed, such as Grover search, quantum annealing, and adiabatic quantum algorithm. However, the applications of these methods have been limited by the noisy intermediate-scale quantum devices, where decoherence is the main challenge. Recently the variational quantum eigensolver and quantum approximate optimization algorithm (QAOA) were proposed for the near-term quantum devices. However, the uncertainty associated with the results from these quantum heuristic algorithms has not been investigated. In this research, we introduce a quantum approximate Bayesian optimization algorithm (QABOA) to improve the exploration-exploitation balance under uncertainty. In addition to the Pauli-gate mixer which perturbs the system to explore the search space, the generalized Grover mixer is introduced to encourage exploitation through amplitude amplification of potential optimal solutions. The uncertainty of QABOA is quantified with the Gaussian process model. We demonstrate the performance of our methodology with several engineering and materials design cases. It is observed that the new method results in a more robust and efficient searching process.

Quantitative Assessment of Particle Characteristics Impact on the Flowability of Granular Biomass in Handling and Feeding Units

Ahmed Hamed; Idaho National Laboratory; United States
Yidong Xia; Idaho National Laboratory; United States
Nepu Saha; Idaho National Laboratory; United States
Jordan Klinger; Idaho National Laboratory; United States
David Lanning; Forest Concepts LLC; United States
Jim Dooley; Forest Concepts LLC; United States
Neal Yancey; Idaho National Laboratory; United States

Feeding and handling represent a substantial challenge in the supply system of lignocellulosic biomass feedstocks, due to the unfavorable properties of the raw biomass materials, e.g., high variability, low bulk density, and poor flowability that renders conventional methods unsuitable with frequent system interruptions caused by process upsets. This, in turn, results in operation under average feeding rates much lower than the design capacity and leads to higher operation cost. Identifying underlying mechanisms controlling the transport behavior of this biomass feedstocks to determine critical parameters is crucial for optimizing materials preprocessing unit operations by engineering favorable granular flowability. Motivated by the quality-by-design approach, the current work investigates the effect of particle characteristics of granular biomass such as rotary sheared pine on the performance of actual handling and feeding units using a combined computational and experimental approach. Three Critical Quality Attributes (CQAs) are used as benchmark metrics to quantify the flowability of the comminuted particles under mechanically driven conditions. These CQAs are 1) mass throughput, 2) driving torque, and 3) specific energy consumption. Experiments and discrete element model (DEM) simulations are conducted to evaluate the impact of one Critical Material Attribute (CMA)–particle size, on the chosen CQAs. The studied particle sizes are in the range between 2 mm and 6 mm, as this range is of interest to several thermochemical and biochemical conversion processes. The impact of an additional CMA, i.e., Particle Size Distribution (PSD) and one Critical Process Parameters (CPPs), namely, shaft rotational speed (rpm), are also investigated using DEM simulations. In agreement with the static AOR, the three flowability metrics used in the present study confirm the superior flowability of the dry particles with smaller size as compared to their larger size counterpart. Moreover, mixing different particle sizes (to resemble a wide PSD) results in overall poorer flowability, which proves the flowability enhancement achieved by the narrower PSD characteristic to the rotary shear system for size reduction. DEM simulations indicate that the PSD-induced degradation in the flowability is attributed to the increase in particle segregation due to mechanical interlocking. Furthermore, higher shaft rpm leads to higher mass flow rate at the cost of higher specific energy consumption due to the flow pattern transition from the rolling to the cascading regime. The good agreement with experiment is achieved by using clumped-sphere DEM particle model. Contrarily, single sphere particle shape model underpredicts the driving torque by several orders of magnitude with marginal improvement accomplished by switching to a coarse-grained DEM contact model reproducing the non-linearly hysteretic strain-hardening behavior of milled pine.

Raman Imaging of Alkali Silica Reaction Product Formed Under Accelerated Conditions

Chirayu Kothari; University of Illinois Urbana Champaign; United States
Nishant Garg; University of Illinois Urbana Champaign; United States

The Alkali Silica Reaction (ASR) is a significant issue in the construction industry, as it leads to expansion and cracking in concrete structures. This reaction occurs between the highly alkaline cement paste and the silica found in some types of aggregates. The ASR products can exist in both amorphous and crystalline forms, and their composition may vary based on the pore solution and the alkali ions involved. This variability can impact crack propagation and concrete durability. To better understand the ASR reaction and its products formed under accelerated conditions, a combination of Raman Imaging and SEM-EDS was used to study the products formed when exposed to NaOH and KOH solutions. The results provide valuable information about the mineralogy and chemical composition of the ASR products, including their presence within cracks in aggregates and air voids adjacent to aggregates. These findings will contribute to a deeper understanding of the structure and composition of harmful ASR products.

Rapid performance evaluation of building structures under seismic excitations based on prior dynamic testing

Luji Wang; Tongji University; China
Jiazeng Shan; Tongji University; China

Performance evaluation is essential to support the safety-evaluation and decision-making procedure for the structures after a damaging earthquake. Current practice in post-earthquake rapid evaluation relies mainly on visual inspection conducted by experts, which is labor-intensive, subjective, and sometimes dangerous. Simulation-based evaluation is therefore urgent needed. In this study, a seismic performance evaluation method is proposed by employing the local seismic measurement, operation modal analysis prior to the seismic event, and the time-history analysis. an SDOF model is adopted to simulate the responses of the structure under these local earthquakes. The linear behavior of the SDOF model is fully calibrated by the dynamic characteristics identified from prior ambient vibration tests. The peak spectral displacement estimated by the model is employed as the damage indicator. The feasibility of the proposed method is validated using the measurements collected from Van Nuys hotel under several earthquakes. It was further applied to assess the condition of buildings located in an earthquake-prone region in China. Results shows that the proposed method can estimate the deformation of the structures with acceptable accuracy and provide a rapid performance evaluation on these buildings.

Rapid Uncertainty Propagation by LSTM Networks and Knowledge Transfer in High-dimensional Nonlinear System subject Stochastic Excitation

Bowei Li; University of Michigan; United States
Seymour Spence; University of Michigan; United States

Propagation of the uncertainty in nonstationary wind excitation involves both load stochasticity as well as uncertainty in intensity, i.e., wind speed and direction, and is of great interest to applications involving the performance assessment of structures subject to windstorms. A vital issue in treating this uncertainty propagation problem through robust stochastic simulation schemes is the vast computational demand associated with the repeated evaluation of generally high-dimensional and nonlinear dynamic systems. To address this, this research proposes a rapid uncertainty propagation framework that is capable of explicitly coping with not only the load stochasticity but also the uncertainty in wind speed and direction. In particular, the high-dimensional problem is first reduced to a low-dimensional mapping from the projected excitation to the projected system response, through basis functions identified by proper orthogonal decomposition (POD). Subsequently, and differently from an intrusive Galerkin scheme, the low-dimensional mapping is learned directly by a long short-term memory (LSTM) network. This LSTM-based metamodeling approach is further embedded in an advanced stratified sampling scheme, therefore, enabling the treating of uncertainty in wind speed and direction. The LSTM- metamodel is trained on data generated based on the distribution of the largest wind speeds belonging to the stratum expected to produce the most extreme responses and subsequently transferred to lower strata with diminished training effort. The framework is illustrated through a full-scale 37-story steel moment-resisting frame subjected to stochastic wind load. Under a directional site-specific wind hazard model, a total of 36 wind directions are considered. The calibrated metamodel exhibited remarkable accuracy and transferability in simulating multiple responses of interest, including residual inter-story drift. In addition, compared with a high-fidelity reference solution determined through direct integration in OpenSees, the metamodel is four orders of magnitude faster. The remarkable accuracy, efficiency, as well as capability of explicit propagation of general wind load stochasticity and uncertainty in intensity, illustrates the potential of the proposed framework.

Rare Event Uncertainty Quantification Using Hamiltonian MCMC and Inverse Importance Sampling Approaches

Kostas G. Papakonstantinou; The Pennsylvania State University; United States
Elsayed Eshra; The Pennsylvania State University; United States
Hamed Nikbakht; Risk Management Solutions Inc.; United States

This work presents the Approximate Sampling Target with Post-processing Adjustment (ASTPA) framework, a computationally efficient method for accurately estimating rare events probabilities, often encountered in reliability analysis of complex engineering systems. The ASTPA framework, as its name suggests, consists of two main stages: (i) constructing and acquiring samples from the approximate sampling target, and (ii) performing a post-processing adjustment to compute the unbiased targeted probability. The approximate sampling target, generally constructed utilizing a cumulative distribution function and the limit-state expression, successfully places greater importance on the relevant regions of interest in the random variable space and manages to accordingly guide the related samples. While the smoothness and continuity of the constructed sampling target allow the use of numerous sampling schemes, Hamiltonian Markov Chain Monte Carlo (HMCMC) samplers have shown exceptional efficiency in this task, particularly through our developed Quasi-Newton mass preconditioned Hamiltonian MCMC (QNp-HMCMC) approach. This efficient HMCMC variant is mainly based on constructing a suitable mass matrix, better describing the structure and topology of the target distribution. After acquiring the samples, the approximate sampling target must be appropriately normalized to correctly compute the targeted probability. This is achieved through the post-processing adjustment step using a devised, original inverse importance sampling (IIS) procedure, that utilizes an importance sampling density properly suggested based on the already acquired HMCMC samples. As shown in this work, the ASTPA framework demonstrates exceptional performance for general static and first-passage dynamic problems, including challenging cases of high-dimensionality, multi-modality, and very small probabilities. Dynamic problems, in particular, are often described by high-dimensional variable spaces, due to the system's inherent uncertainties, as well as the stochastic processes involved in simulating the dynamic excitations. ASTPA can be also successfully applied directly on both Gaussian and non-Gaussian stochastic spaces, providing a significant advantage when the transformation to the favorable and preferred Gaussian space is infeasible. A series of diverse problems are presented, to showcase the capabilities and efficiency of the suggested framework, involving, among others, examples with significant structural nonlinearities and stochastic processes expressed through Karhunen-Loève (K-L) expansion and the Spectral Representation Method.

References

[1] Papakonstantinou, K. G., Nikbakht, H., and Eshra, E., 2023. Hamiltonian MCMC methods for estimating rare events probabilities in high-dimensional problems. Probabilistic Engineering Mechanics (under review), arXiv preprint arXiv:2007.00180.

[2] Papakonstantinou, K. G., Nikbakht, H., and Eshra, E., 2022. Quasi-Newton Hamiltonian MCMC sampling for reliability estimation in high-dimensional non-Gaussian spaces. 13th International Conference on Structural Safety & Reliability (ICOSSAR).

Rare-events simulation using normalizing flows

Agnimitra Dasgupta; University of Southern California; United States
Erik Johnson; University of Southern California; United States

The efficient estimation of rare-event probabilities is challenging since it requires the simulation of rare events likely to have low rates of occurrence. The probability of rare events can be estimated efficiently using variance reduction methods, and importance sampling (IS) remains a popular technique. However, the optimal IS distribution is unrealizable, and designing a good importance sampling distribution can be challenging. We introduce REIN, a new framework for rare-events simulation which uses normalizing flows (NFs) to construct quasi-optimal IS distributions. NFs are generative models capable of exact and efficient probability density evaluations. We also introduce a novel loss function adapted to rare event simulation and use it to train the NFs. We benchmark REIN on reliability estimation problems and apply it to a structural reliability estimation problem, comparing against two widely adopted methods: subset simulation and the improved cross-entropy method. The results show that REIN can handle high dimensionality, extremely low rare-event probabilities, and multiple failure modes while outperforming the other methods.

Reaction cross-diffusion and the long-term behaviour of bio-geomaterials

Manman Hu; University of Hong Kong; Hong Kong
Klaus Regenauer-Lieb; Curtin University; Australia

When geomaterials are subject to thermodynamic forces (mechanical, chemical, electrical, hydraulic, biological) they can respond by sudden failure or deform in a stable controllable manner. In this work we present a new theory based on a reaction-cross-diffusion formalism where the cross-coefficients of the dynamic version of the Onsager matrix correspond to microstructural topological network forming processes that can be used to influence the strength (in terms of dynamic viscosity) of the material. A well-studied example is the rheology of an entangled polymer, where the entanglement of the individual strands of the polymer are directly controlling the viscosity of the polymer structure or the elastic modulus. In polymer applications, the higher degree of entanglement results in a higher elastic stiffness and a higher viscosity. In bio-geomaterials a similar design goal is desired, but the underlying thermodynamic framework is lacking and the existing thermodynamic theories for soft polymeric matter does not directly apply. Here we propose that a reaction-cross-diffusion framework developed for porous media undergoing internal mass-exchange processes can capture the basic processes for new bio-geomaterials. By analogy to the strengthening of polymers through their microstructural entanglement we propose that the method allows macroscopic strength enhancement of the bio-geomaterials. A dynamic renormalization process is used to derive constant cross-diffusion coefficients describing the microstructural topological invariants under a given generalized macroscopic thermodynamic force. We show that the loss of integrity of the new geomaterial in their in-situ environment subject to ratcheting loads can be predicted by a linear stability analysis of the reaction-cross-diffusion formulation.

Reactive chemo-hydro-mechanics for modelling aggressive fluid injection

Xiaojie Tang; University of Hong Kong; Hong Kong
Manman Hu; University of Hong Kong; Hong Kong

Aggressive fluid injection into a rock is frequently encountered in many geo-engineering applications, particularly those concerning extraction of energy from the subsurface in the form of e.g. hydrocarbon and heat, or permanent sequestration of CO2 into geological formations. The latter aims for a safe storage and hence integrity of the caprock. However, in the former, especially for those low-permeability, tight (so-called unconventional) carbonate-rich reservoirs, the technique of hydraulic fracturing is often employed with acidizing treatment incorporated for an enhancement of cracking. During (or after) these applications, highly nonlinear coupled physico-chemical dynamic processes operating across scales are at play, affecting the stress field and matrix permeability. A key research question is how to model cavity expansion in a stressed medium subject to internal fluid pressurization in tandem with infiltration of aggressive agents from the imposed chemical environment. The presentation will demonstrate our unique approach to tackle this fundamental problem by considering the effect of micro-fracturation enhanced chemical erosion, in both the commonly defined elastic and plastic domains of the rock behaviour. Reactive transport processes are coupled with deformation-dependent permeability (and the effective diffusivity as well), and the degradation of the solid matrix via upscaling to a representative elementary volume. Transition of the transport into diffusion-advection is evidenced when local hydraulic conductivity is mechano-chemically enhanced to surpass a critical value. A general framework of reactive chemo-hydro-mechanics is hence formulated, for the investigation of the fundamental problem of cavity expansion in a reactive environment, a situation that a geomaterial often finds itself subject to at a long (e.g. geological) or short (e.g. acidizing engineered) time-scale.

Real-time Hybrid Simulation of a CLT Rocking Wall System equipped with Pressurized Sand Dampers for Seismic Hazard Mitigation

Liang Cao; Lehigh University; United States
Kostas Kalfas; Southern Methodist University; United States
Nicos Makris; Southern Methodist University; United States
James Ricles; Lehigh University; United States

Seismic-induced vibrations in civil infrastructure can produce considerable structural damage and loss of life. Supplemental energy dissipation devices have been shown to be an effective method to limit inelastic structural deformations and damage from seismic hazards, therefore enhancing structural resiliency. Recently, a novel pressurized sand damper (PSD) has been developed to enhance structural performance against natural hazards. The PSD utilizes sand as the energy dissipative material which can be implemented in harsh environments with extremely high or low temperatures that may challenge the use of traditional passive fluid dampers.

The presentation will discuss the results of a study using real-time hybrid simulation (RTHS) to investigate the seismic mitigation performance of a single-story cross-laminated timber (CLT) building with PSDs installed in post-tensioned rocking CLT walls. First, the details of the building are presented. Second, the RTHS approach is introduced. The analytical substructure in the RTHS contains the numerical model of a self-centering (SC) rocking post-tensioned CLT structural wall (SC-CLT wall), while two physical PSDs form the experimental substructure. The SC-CLT wall is numerically modeled using a beam element for the CLT wall, a nonlinear truss element for a post-tensioned steel bar, and nonlinear gap elements for the rocking base. Two PSDs are connected on each side at the base of the SC-CLT wall to enhance energy dissipation. The PSDs are designed and manufactured at Southern Methodist University and placed in the Real-time Cyber-Physical Structural Systems Testing Laboratory (RCPSS) lab at the NHERI Lehigh Experimental Facility for conducting the RTHS tests. Finally, the RTHS results under various earthquake excitations are presented. The structure's base shear and inter-story drift from RTHS tests are compared with numerical simulation results from two different configurations, including a conventional CLT shear wall case and the SC-CLT wall without PSDs case. Results show that the PSD produces a significant reduction in the maximum base shear and inter-story drift.

Real-time hybrid simulation test of mast structure considering fluid-structure interaction

Yucai Chen; Engineering Seismic Research Center Guangzhou University, Guangzhou, Guangdong 510006; China
Xiaojun Zheng; Engineering Seismic Research Center Guangzhou University, Guangzhou, Guangdong 510006; China
X. Shawn Gao; MTS Systems Corporation, 14000 Technology Drive, Eden Prairie, MN 55344; United States
Kun Wang; Research Center for Wind Engineering and Engineering Vibration, Guangzhou University, Guangzhou, Guangdong 510006; China
Jiurong Wu; Research Center for Wind Engineering and Engineering Vibration, Guangzhou University, Guangzhou, Guangdong 510006; China
Huimeng Zhou; Engineering Seismic Research Center Guangzhou University, Guangzhou, Guangdong 510006; China
Pin Tan; Engineering Seismic Research Center Guangzhou University, Guangzhou, Guangdong 510006; China

Real-time hybrid simulation (RTHS) test is an effective method to study the multi-hazard engineering. The simulation of fluid-structure interaction is key technology for RTHS application to the multi-hazard engineering. Different from the traditional RTHS applied for the structure, the fluids are choosing as the numerical substructure for multi-hazard engineering, in which the Eulerian cell scheme is used to model the fluids. In RTHS of fluid-structure interaction, the command from the numerical substructure is the force, while the feedback from the experimental substructure to the numerical substructure is the displacement, instead of the displacement command and force feedback in the traditional RTHS test. The dynamic force loading at the natural frequency of structure pose challenges from control perspective. At the same time, the real-time solving of the Eulerian cell of the fluids is difficult. This study proposes a framework to conduct the RTHS considering fluid-structure interaction, which concludes two key technologies. Firstly, a dynamic control method is applied that uses displacement control in the inner loop and force control in the outer loop. Secondly, a low-order numerical reduced order models (ROM) is obtained by deep learning to improve the computational speed of the numerical substructure. The computational time can be reduced by several orders of magnitude, which makes the ROM possible to be used in real-time testing. To verify the performance of the proposed framework, a RTHS test of the vortex-induced resonance of the mast was conducted, in which a mast model with a geometric scaling ratio of 1/5 is the experimental substructure and the wind field around the mast model is taken as the numerical substructure. RTHS test is conducted in progress.

Realistic Out-Of-Plane Shear Strength of Reinforced Concrete Walls and Slabs for Seismic Probabilistic Risk Assessment Applications

Siavash Dorvash; Simpson Gumpertz and Heger; United States
Greg S. Hardy; Simpson Gumpertz and Heger; United States
John Richards; Electrical Power Research Institute; United States
Tim Graf; Simpson Gumpertz and Heger; United States

In response to the accident at the Fukushima Dai-ichi nuclear power plant caused by March 11, 2011, Tohoku earthquake and subsequent tsunami, the U.S. Nuclear Regulatory Commission (NRC) established a Near-Term Task Force (NTTF) Recommendation 2.1 to reevaluate seismic hazards at operating nuclear power plants (NPPs). A seismic reevaluation approach that became more common in the U.S. nuclear industry after the Fukushima accident is seismic probabilistic risk assessment (SPRA), which is a systematic method for examining and evaluating the risk from earthquake-initiated accidents. The objective of an SPRA is to calculate the best estimate of the seismic risk, and that is based on a realistic evaluation of equipment and structures, rather than conservative estimates that are typically used in the design practice. This distinction is a key consideration in many aspects of an SPRA, in particular in the seismic fragility evaluation of structures and equipment, which characterizes the probability of failure of the component as a function of seismic motion amplitude.

One of the many components of NPPs that are evaluated in an SPRA is reinforced concrete (RC) structures in the plants. The RC walls and slabs of an NPP structure are typically conservatively designed and have traditionally exhibited high seismic capacities within SPRAs. The OOP shear strength of such walls and slabs is often determined based on the criteria for the RC beam shear capacity equations in standards by the American Concrete Institute (ACI) and American Society of Civil Engineers (ASCE), which are design codes and tend to be conservative. In their recent provisions, both ACI 318 (2019) and ASCE 43 (2018) have updated the OOP shear strength equations to account for the possible adverse effect of depth on the shear strength, which particularly affects deep beams. These standards introduced a size correction factor that accounts for the depth of the RC beams. The correction factors are developed based on the results of studies performed in the past two decades using extensive test data collected over decades. Their results suggest that deep beams and walls without transverse shear reinforcing may have lower capacities than determined from the older provisions of the ACI and ASCE standards. However, the primary focus of those studies was on a subset of the test data pertinent to the more common, relatively slender, concrete elements. The updated shear strength equations capture the dependency of strength on depth but do not account for the dependency of strength on the shear span ratio, which is relevant to the beams with a relatively small shear span ratio, such as a beam that characterizes a nuclear plant shear wall. Identifying the conservatism in the code-based shear strength of RC beams with small shear spans becomes important in SPRAs of the NPPs, where the objective is to develop realistic strengths and limit conservatism to provide the best estimates of the risk.

The Electric Power and Research Institute (EPRI) recently studied a broad set of test data on RC beams to illustrate the conservatism in the code-based OOP shear strength equations. Through this study, a new set of equations is developed to characterize the realistic median OOP shear capacity of walls and slabs for use in seismic fragility and margin studies. The OOP shear strength equations developed by this EPRI study account for the differences observed between slender and non-slender beams and each equation considers the shear span ratio.

This presentation will provide a background on the SPRA applications and seismic fragility evaluation for the U.S. NPPs and summarizes the main findings and a sample of results of this EPRI research.

Recent Advances on Multiscale Simulations of Multiphase Interactions under Extreme Loadings with Continuum- and Particle-Based Methods

Zhen Chen; University of Missouri; United States
Andrew Bowman; U.S. Army Engineer Research and Development Center; United States
Mohammed Saffarini; University of Missouri; United States
Hani Salim; University of Missouri; United States

To improve simulations of multiscale and multiphase (solid-liquid-gas or soft-hard media) interactions involving large deformations and failure evolution, particle-based methods such as the material point method (MPM), the discrete element method (DEM), molecular dynamics (MD), and coarse-grained MD have been integrated into a single computational domain via the MPM mapping operation in real time [Jiang et al., 2015; Su et al., 2020; Yang et al., 2017 among others]. Due to the importance of size effect on objective evaluation of failure evolution, a coordinated computational and experimental approach is used to advance the size-dependent, blast-resistant structural design methodology. The digital image correlation technique is being improved for quantifying size effect on localization in brittle and ductile material samples with a focus on the relationship between micro and macro failure mechanisms. The strengths of the MPM and the finite element method (FEM) are being integrated to achieve both accuracy and efficiency in system-level simulations. A physics-based, data-enabled design tool is developed for blast-resistant curtain wall systems and will be presented in the conference to demonstrate the features of the proposed approach via continuum- and particle-based methods.

Distribution A: Approved for public release Permission to publish was granted by Director, Geotechnical & Structures Laboratory.

Jiang, S., Chen, Z., Sewell, T.D., and Gan, Y., "Multiscale Simulation of the Responses of Discrete Nanostructures to Extreme Loading Conditions Based on the Material Point Method," Computer Methods in Applied Mechanics and Engineering, Vol. 297, pp. 219-238, 2015. Su, Y., Tao, J., Jiang, S., Chen, Z., and Lu, J., "Study on the Fully Coupled Thermodynamic Fluid-Structure Interaction with the Material Point Method," Computational Particle Mechanics, Vol.7, pp. 225-240, 2020. Yang, Y., Sun, P., and Chen, Z., "Combined MPM-DEM for Simulating the Interaction between Solid Elements and Fluid Particles," Communications in Computational Physics, Vol. 21, pp. 1258-1281, 2017.

Reconstruction of 3D microstructures from 2D images by using a pre-trained deep neural network in a gradient-based sequential optimization approach

Ashwini Gupta; Johns Hopkins University; United States
Noah Wade; Johns Hopkins University; United States
Lori Graham-Brady; Johns Hopkins University; United States

The prediction of several macro-scale properties of materials requires the study of their 3D stochastic microstructures. Since experimentally acquiring a 3D image is often impracticable, computational microstructure reconstruction approaches such as statistical functions-based and machine learning (ML) based methods are used as alternatives to generate 3D images. However, conventional statistical functions-based methods can be prohibitively slow and restrictive for complex microstructure systems. Moreover, high memory required in ML-based methods is another challenge that limits the reconstruction of large 3D microstructures. To overcome this, we propose a parallelizable optimization-based microstructure reconstruction procedure. Here, the statistical descriptors and feature maps from VGG19, a pre-trained deep neural network are combined into an overall differentiable loss function. This approach efficiently reconstructs a 3D microstructure by performing sequential optimization of 2D slices of an initial 3D image in each orthogonal direction. In this way, this approach requires significantly lower memory compared to the latest ML-based 3D reconstruction approaches and provides excellent scalability. Several numerical examples for the reconstruction of 3D bi-phase porous ceramic material and multi-phase polycrystalline material demonstrate the generalizability of the proposed methodology. This approach for reconstruction of 3D microstructures from 2D/3D images has several applications such as generation of massive datasets of material systems with targeted properties, and microstructure induced uncertainty quantification and propagation.

Reducing Drag, Improving Performance: A Study of V-Shaped Riblets on Shipping Vessel Hulls

Nathaniel Werner; Liberty University; United States
Katherine Rioux; Liberty University; United States
Ryan Pritzkau; Liberty University; United States

The impact of adding V-shaped riblets to shipping vessel hulls is the focus of this study, with the riblets being based on shark skin and capable of reducing drag by 5.1%. The objective is to identify the optimal coverage of the hull from forward to aft and to determine if specific locations are more effective in reducing drag. ANSYS Fluent was used to perform the simulations, and the study's findings will provide valuable insights for improving vessel performance within the shipping industry.

Reducing Heavy Fuel Oil Consumption in Shipping: The Impact of V-Shaped Riblets on Hull Drag

Nathaniel Werner; Liberty University; United States
Katherine Rioux; Liberty University; United States
Ryan Pritzkau; Liberty University; United States

The shipping industry is constantly seeking ways to cut expenses, especially with the year-over-year increase of 180% in the prices of heavy fuel oil (HFO) from 2020 to 2021. To address this challenge, this study aimed to evaluate the effect of adding V-shaped riblets, which are based on shark skin and have been shown to reduce drag by 5.1%, to the hulls of shipping vessels on HFO consumption during a voyage. By reducing the drag force on the hull, the goal was to identify new methods of cutting fuel consumption. The relationships between changes in HFO consumption and non-dimensional parameters such as Reynolds number, Froude number, aspect ratio, and area ratio (including fouling and riblets) were established through simulations using ANSYS Fluent. The focus of the study was to determine the relationship between changes in HFO and the drag force, which is the key factor in fuel consumption. Measurements from multiple trips were averaged for statistical calculations. These results provide valuable insights for the shipping industry on reducing HFO consumption and overall costs.

Reducing Thermal Conductivity of Calcium Silicate Hydrates: New Technological Opportunities provided by Cross-Linking with Organic Molecules

Amir Moshiri; University of Houston; United States
Ali Morshedifard; University of California, Irvine; United States
Damian Stefaniuk; Massachusetts Institute of Technology; United States
Santiago EL Awad; University of Houston; United States
Kamil Krzywinski; Wroclaw University of Technology; Poland
Debora Frigi Rodrigues; University of Houston; United States
Tejasree Phatak; University of Houston; United States
Mohammad Abdolhosseini Qomi; University of California, Irvine; United States
Konrad Krakowiak; University of Houston, Civil and Environmental Engineering Department; United States

We study the conductive heat transport through calcium silicate hydrate (C-S-H) and organically cross-linked C-S-H via experiments, micromechanical homogenization theory, and molecular simulations. We find that C-S-H's intrinsic thermal conductivity falls below its amorphous limit when cross-linked with short-chain organosilanes. The observed reduction correlates with the alkyl chain length of bis-organosilane molecule. To understand the underlying fundamental molecular processes accountable for such a reduction, we construct realistic molecular structures of cross-linked C-S-H and validate them against the spectroscopic and pycnometery measurements. The atomistic simulations indicate that the reduction in the contribution of propagons (propagating heat carriers) and diffusons (diffusive heat carriers) to heat transport, and the amplification of locons (localized vibrational modes), are the main driving factors allowing to limit the heat conduction in C-S-H. Presented findings offer new potential directions to nanoengineering of resilient lightweight cementitious mesostructures for thermally efficient building envelopes.

REPROGRAMMING THE ENERGY LANDSCAPE OF META-STRUCTURES FOR TUNABLE MULTI-STABILITY

Giada Risso; ETH Zürich; Switzerland
Max Kudisch; Caltech University; United States
Paolo Ermanni; ETH Zürich; Switzerland
Chiara Daraio; Caltech University; United States

In the last decade, self-shaping structures have been widely investigated because of their ability to transform into a targeted three-dimensional (3D) shape. However, there are several applications where the properties of the structures need to be tuned post-fabrication. Here, we present a reprogrammable meta-structure that combines flat fiber-reinforced polymer thin composite shells with bi-axially pre-stretched shape memory polymer membranes. The concept allows realizing reprogrammable multi-stable meta-structures, whose energy landscape can be reversibly tuned post-fabrication. The structures possess a high number of stable states. Taking advantage of the 2-way shape memory effect, the multi-stability of the meta-structure can be turned on and off at the user's will, the magnitude of deformations in the structure can be tuned, and new stable shapes can be achieved through controlling the temperature. The tuning of the energy landscape is enabled by applying a temperature gradient to melt the partially cross-linked shape memory polymer and, thereafter, by imposing a desired 3D shape to the meta-structure during cooling. Experimental results show that the reprogramming process is infinitely reversible and offers the possibility for self-actuation. To conclude, being able to tune (post-fabrication) the energy landscape of meta-structures offers the possibility to augment the functionality of existing multi-stable concepts, showing potential for the realization of highly adaptable mechanical metamaterials.

Resilience of Gulf Coast communities under a changing climate

Mohamed Abdelhafez; Colorado State University; United States
Hussam Mahmoud; Colorado State University; United States
Bruce Ellingwood; Colorado State University; United States

Coastal cities in the Gulf Coast region of the United States have seen significant and rapid economic development in the past two decades. The Gulf Coast region supports a large proportion of the country's commercial infrastructure, with three major seaports, riverine navigational routes and many of the nation's largest petroleum refineries, chemical and energy corporations, and aerospace and defense industries. Furthermore, many of these facilities require a large supporting network of industrial service companies of all sizes. Cities in these regions are at increasing risk from concurrent multiple hazards, such as hurricanes and accompanying storm surge, combined with sea level rise (SLR) brought about by the changing climate. These hazards are dynamic and strongly coupled and may damage the built environment and disrupt commercial infrastructure and social institutions if the associated risks are not properly managed through appropriate public policy. Since the character of Gulf Coast communities is distinct from that in other hazard-prone regions of the United States, appropriate decision criteria for performance and resilience will be distinct as well.

Adequate housing, healthcare and education are essential to the stability of coastal communities, providing shelter and essential services to residents and comprising a significant fraction of public and private investment in the built environment. Urbanization in a changing climate brings about increased competition for employment, higher housing costs, and strains on the local housing market and supporting infrastructure. A performance-based engineering approach, considering the impact of climate events with large geographic footprints on the built environment and enabling an analysis of deep uncertainties associated with climate change, provides risk-informed tools to public decision-makers for mitigating risk and preserving stability of coastal communities. Thus, this presentation focuses on engineering approaches to reducing vulnerability of residential buildings, healthcare facilities and schools to climate change using a life-cycle analysis that accounts for the non-stationary features of climate variables during the remainder of the 21st Century into account.

Response evolutionary power spectrum determination of nonlinear oscillators endowed with fractional derivative elements

Vasileios Fragkoulis; Leibniz University Hannover; Germany
Ioannis Kougioumtzoglou; Columbia University; United States
Athanasios Pantelous; Monash University; Australia
Michael Beer; Leibniz University Hannover; Germany

An approximate analytical technique is developed for determining the response evolutionary power spectrum (EPS) of nonlinear oscillators endowed with fractional derivative elements. Specifically, a stochastic averaging/linearization treatment is employed for deriving an approximate closed-form expression for the nonlinear oscillator non-stationary response amplitude PDF [1]. Next, the latter is used for developing an input-output relationship in the joint time-frequency domain. Notably, the derived relationship between the excitation and the response EPS can be construed as an extension of earlier results in the literature [2] to account for fractional derivative elements in the oscillator equation of motion. A nonlinear bilinear hysteretic oscillator with fractional derivative elements is considered as an indicative numerical example. Comparisons with pertinent Monte Carlo simulation data demonstrate the reliability of the developed technique.

References:

[1] Fragkoulis, V. C., Kougioumtzoglou, I. A., Pantelous, A. A. and Beer, M., 2019. Non-stationary response statistics of nonlinear oscillators with fractional derivative elements under evolutionary stochastic excitation. Nonlinear Dynamics, 97(4), 2291-2303.

[2] Kougioumtzoglou, I. A., 2013. Stochastic joint time–frequency response analysis of nonlinear structural systems. Journal of sound and Vibration, 332, 7153-7173.

Response statistics of vibro-impact system via the Step Matrix Multiplication based on Path Integration method

Henrik Tamás Sykora; Institute of Sound and Vibration Research, University of Southampton; United Kingdom
Rachel Kuske; School of Mathematics, GeorgiaTech; United Kingdom
Daniil Yurchenko; Institute of Sound and Vibration Research, University of Southampton; United Kingdom

There are many quantities to characterise the response of dynamical systems to stochastic noise, such as the power spectral density or the probability density function (PDF) of the state variables. In a general case, obtaining these quantities are challenging even for a smooth nonlinear dynamical system subjected to noise. It is even more difficult if there are impacts in the system, such as in vibro-impact systems. However, there are processes and devices with impacts where the effects of noise play a significant role, thus, it is essential to have computationally efficient methods to compute their stochastic characteristics in order to investigate and understand their behaviour.

In this work, we present a novel method to compute the response PDF of vibro-impact oscillators with high accuracy. This method is based on the Chapman-Kolmogorov equation: we transform it into a matrix multiplication through a path integration formulation. This transformation was recently introduced for smooth systems and proved remarkably efficient for accurately computing the response PDF of nonlinear dynamic systems. In this work, we generalise this step matrix multiplication based path integration (SMM-PI) method for systems with impacts. We compare results to Monte-Carlo simulations and show the superior ability of the SMM-PI formulation to compute accurate response PDFs.

We demonstrate the versatility of the proposed method through determining the impact velocity distribution of a stochastic vibro-impact oscillator and computing the energy output of a vibro-impact energy harvester in a noisy environment.

Revisiting Hybrid Simulation with a Cost-Effective Hardware-Software Platform

Juan Meriles; UC Berkeley; United States
Khalid M. Mosalam; UC Berkeley; United States

The experimental method known as Hybrid Simulation, in which a structure is subdivided into an analytical substructure that is modeled in a computer and an experimental substructure that is built and tested in in a laboratory, has gained popularity in the last two decades. Advancements in the method have allowed it to become increasingly versatile, but the method remains expensive and cumbersome. Furthermore, much of the hardware and software used is proprietary and as such, the researcher has limited ability to troubleshoot or innovate. These issues also limit the wide-spread usage of this method in practical applications by the industry. To overcome these limitations, a new hardware-software platform is developed that uses a commonly available microcontroller, the Teensy 4.1, and a microcomputer, the Raspberry Pi 4, along with popular coding languages to achieve comparable results to a typical Hybrid Simulation test at a fraction of the cost. In the developed system, both the experimental (control) and the numerical (simulation) are handled by the microcontrollers. The self-contained Hybrid Simulation platform is presented, and its components are discussed. The software used is validated against several commercial and generally accepted structural analysis platforms. Multiple Hybrid Simulation tests are conducted with and without sub-structuring and the results are compared with purely analytical models and with Hybrid Simulations that use conventional hardware and software. The limitations of the system are discussed along with potential solutions for issues found. Future advancements and potential modifications are considered that will push this platform closer to the cutting edge of Hybrid Simulation platforms.

RGB-D Fusion through Depth Hallucination for Enhanced Deep Learning-based Damage Segmentation

Tarutal Ghosh Mondal; Missouri University of Science and Technology, Rolla, MO; United States
Mohammad Jahanshahi; Purdue University; United States

Recent studies have suggested that the fusion of cross-modal information can enhance the performance of deep learning-based segmentation algorithms. In this context, this study evaluates the benefits of RGB-D fusion with regard to damage segmentation in reinforced concrete buildings. A comparative evaluation of various data-level, feature-level, and decision-level fusion strategies is carried out, and consequently, feature-level fusion is identified to be the most efficient. Additionally, a number of surrogate techniques based on modality hallucination and monocular depth estimation are exploited to eliminate the need for depth sensing at test time without foregoing the benefits of depth fusion. The proposed techniques require depth data only for network training, and at test time, depth features are simulated from the corresponding RGB frames, obliterating the need for real depth perception. The proposed methods are evaluated and are shown to increase the damage segmentation accuracy.

Rheological modeling of recycled asphalt binder blends as fluid mixtures

Saqib Gulzar; North Carolina State University; United States
Andrew Fried; North Carolina State University; United States
Jaime Preciado; North Carolina State University; United States
Shane Underwood; North Carolina State University; United States
Cassie Castorena; North Carolina State University; United States

The asphalt binder from recycled asphalt pavements (RAP), known as RAP binder, plays an essential role in the selection, design, and performance of asphalt mixes that use recycled asphalt materials. This RAP binder has higher stiffness characteristics because of physical and chemical changes that occur over the life of the pavement due to oxidative ageing. In order to compensate for these ageing characteristics, recycling agents (RA) are added in addition to the virgin binder to achieve the desired binder characteristics for the new mix design using recycled asphalt materials. So, a blend of virgin binder, RAP binder, and RA, known as recycled asphalt binder blend, exists as the primary binding component in the asphalt mixes containing recycled asphalt materials. In this study, the rheological characteristics of recycled asphalt binder blends are modelled using fluid mixture rules and micromechanics of its three component systems to gain insights on their mixing mechanisms. Since the rheology of RAs at desired temperatures is difficult to determine, a blend of virgin binder and RA is used along with the RAP binder. Several models and mixing rules are evaluated to predict the norm of complex shear modulus at high and intermediate temperature, and creep stiffness at low temperatures. The preliminary results indicate that these models may help in predicting the properties of recycled asphalt binder blends, thus possibly eliminating the need to test the blended system separately.

Risk Communication of Urban Flood Hazards and Damaging Effects through Augmented Reality

ZhiQiang Chen; University of Missouri Kansas City; United States
Molan Zhang; University of Missouri Kansas City; United States
Chengye Li; University of Missouri Kansas City; United States

Communication of risk due to extreme events remains a practical and analytical challenge to engage the public in understanding natural hazards and their threat. One compounded (practical and analytical) challenge is to provide objective visual analytics through immersive visualization. By 'objective', it implies that the hazards and damaging effects must be physically based; and by 'immersive', the communication should be expected to relate to an individual's immediate built or natural environment. In the case of urban floods, if one aims to understand the risk objectively, the traditional approach involves a chain of numerical computing components and software tools. As such, the ensuing risk communication is restricted to the circles of flood modelers and professionals. The latest visualization technology holds the promise of conducting risk communication with the public, and the Weather Channel has pioneered and widely adopted virtual and augmented reality (VR/AR) technologies. These VR/AR technology suites open a new approach to natural hazards, disaster education, and risk communication toward building a prepared and disaster-resilient urban community. Several gaps exist in VR or AR-based urban flood risk-based education and communication. The technology gap is that existing systems (e.g., those implemented by the Weather Channel) do not enable an immersive experience. Second, the sociopsychology gap is that the effects of such VR/AR-based education are not objectively evaluated. This project first aims to develop an advanced AR software system for revealing urban flood risk by simulating and visualizing 3-dimensional flood effects and impact on buildings. Second, we will conduct a workshop-based survey to evaluate the effects of technology-based flood risk communication. We will report based on our current research progress and demonstrate the iPad-based AR system during the presentation.

Risks and Challenges of Using Earth Rock Mass Classification System on the Moon

Roberto Mendonca de Moraes; Aecom; United States
Antonio Bobet; Purdue University; United States

The last decade has seen a resurgence of interest in lunar exploration and the emergence of countries like China and India as space-fairing nations. In 2004, the US announced a new Vision for Space Exploration, whose objectives focused on human missions to the Moon and then Mars. The near future is likely to see the emergence of a worldwide drive to revisit the Moon as the first step in investigating the Solar System. To date, the Apollo missions provide our only experience of human operations on the Moon or anywhere else beyond Low Earth Orbit. Much was learned from these missions. However, their short duration means that many of the environmental effects that will be important for longer-duration missions could not be quantified. In addition, long-duration missions and infrastructure on the Moon require new technologies and capabilities, which must operate successfully and reliably in this lunar environment. Developing these technologies poses significant challenges for the exploration program. The paper discusses the risks associated with the construction of lunar surface and underground structures (e.g., tunnels, shafts, and caverns) and the challenges to adopting the standards and rock mass classification systems developed on Earth and their applicability to the Moon. Moreover, an exchange of views to explore near-surface geologic and geotechnical profiles of the Moon is emphasized as implications of the lack of knowledge on rock mass characterization of the Moonrock mass, the lack of theoretical/empirical experience on the use of rock mass systems outside Earth, and uncertainties.

Roadmap for fully autonomous robotic visual inspection of bridges

Yasutaka Narazaki; Zhejiang University; China

This research discusses the technical roadmap for replacing the human inspectors for bridge visual inspection by autonomous robots to achieve significantly enhanced efficiency and reliability in the long term. The envisioned autonomous system understands the target structural system (e.g., critical structural components like bridge columns), based on which the robot navigation plan for effective data collection is planned and performed by itself. The collected data is further post-processed to provide information about structural conditions. Preliminary results in those perception (structural component recognition/localization), planning, and data post-processing steps, as well as the synthetic environments developed as a platform for investigating relevant algorithms, are presented. Then, ongoing work to integrate those subsystems into a prototype autonomous system is discussed. Finally, the challenges that need to be addressed to realize such a complex autonomous system that performs tasks in the field environment are discussed. The presenter expects that this work will motivate further investigations to accelerate the ongoing transformation in autonomous structural inspection.

Robotic System to Enable Active and Passive Embodiment for Hand Rehabilitation

Joshua Posen; Georgia Institute of Technology - Mechanical / BioEngineering; United States
Joshua Lee; Georgia Institute of Technology - Mechanical Engineering; United States
Frank Hammond III; Georgia Institute of Technology - Mechanical / Biomedical Engineering; United States
Minoru Shinohara; Georgia Institute of Technology - Biological Sciences / Biomedical Engineering; United States

Stroke survivors experience substantial impairments in hand function. Conventional mental practice such as action observation and mirror therapy can enhance motor recovery with rehabilitation by heightening neural excitability with the sense of embodying a functional hand. To enhance neuromotor adaptations by going beyond this passive engagement, we developed a novel rehabilitation system for the active embodiment of a functional artificial hand by utilizing the neuromechanical synergy in human motor control. Our unique idea is to have a human control (and observe) specific motions of a detached artificial hand, an anthropomorphic robotic hand or a virtual hand, via the synergistic torso activity that is associated with the reaching and retrieving of an object, respectively. For prototypes, a robotic hand was 3D-printed for a standard adult size, and a matched virtual hand was implemented in Robotic Simulation Software (CopelliaSim). Each artificial hand has two functional movements, the extension (synergistic hand opening during reaching) and flexion of the fingers (synergistic grasping and holding during retrieving). These motions are controlled and observed by a user by voluntarily activating their anterior and posterior torso muscles, respectively, for mimicked reaching and retrieving motions. A seatbelt harness acts as the constraint of torso movement to enable the choice and comparison between the independent contribution of neural activation and the combined contributions of neural activation and torso motion. The intent of each motion is determined by the electromyogram in the corresponding torso muscles. The mimicked hand motions were informed by normal human kinematic properties including range of motion (metacarpophalangeal joint 52°, proximal interphalangeal joint 45°, distal interphalangeal joint 15°) and delay between the intent and observed motion of the artificial hand. The motion duration mimicked the slower velocity observed in stroke survivors. In 90 trials (3 subjects), the delay was 44 +/- 25 ms (57.5% CV) for finger extension and 90 +/- 27 ms (30.6% CV) for finger flexion. The motion duration was 2,297 +/- 63 ms (2.8% CV) for extension and 2,097 +/- 80 ms (3.9% CV) for flexion). With this system, the reaction time and strength of human fingers are expected to be enhanced during synergistic torso activity for controlling the artificial hand because of heightened neural excitability for the real fingers. A force transducer and an accelerometer worn on the user's index finger were incorporated into the system to measure reaction time and strength of human finger motion. Our initial design targeted the stoke population coupled with tasks without hand muscle activation, but flexibility and adjustability are possible within this environment. The flexibility in task selection includes with and without paired contraction of the user's hand muscles, the robotic hand being worn, contraction of the torso muscles, and tactile feedback to the user. Similarly, a set of alternative hands can be fabricated to represent pediatric, adolescent, or adult populations (range of motion capability: metacarpophalangeal joint 60°, proximal interphalangeal joint 51°, distal interphalangeal joint 50°). Furthermore, the velocity can be matched to targeted populations (e.g., neurological disorders, able-bodied, and injury rehabilitation). The adjustability of the system will enable researchers to match the characteristics of the embodied hand to their chosen research demographic, and to control multiple independent variables reflecting their area of interest. A potential outcome is that repetitions of "exercise" with this system, accompanied by transiently heightened excitability, may lead to permanently heightened excitability and improving motor recovery in stroke populations. The study was funded by NIH/NINDS (1R21NS118435-01A1).

Rocking of Deformable Bodies on Flexible Ground

Mohammad Daud; SUNY Buffalo; United States
Suparno Mukhopadhyay; Indian Institute of Technology Kanpur; India

Structures standing freely on the ground experience rocking during earthquakes. While rocking of unanchored objects have been studied since the last four decades, most of the work has concentrated on the rocking of rigid bodies, with the rocking of deformable bodies only recently garnering interest. This thesis focuses on modelling the rocking of deformable bodies on flexible ground, and to study the effect of body/ground flexibility on rocking induced instability, viz. overturning. Four sequentially complex models are developed by modelling the rocking body as: (i) a single lumped mass system, (ii) a multiple lumped mass system, (iii) an Euler-Bernoulli beam, and (iv) a Timoshenko beam. In each case, the governing equations of motion are derived using the Lagrangian framework. These highly nonlinear equations of motion are solved using the fourth order Runga-Kutta method. An extensive parametric study is performed to understand the effects of body and ground flexibility on rocking induced instability. It is seen that as the ground flexibility decreases, the possibility of instability during rocking increases. It is also observed that body flexibility plays a crucial role in the instability during rocking due to increased overturning moment.

Role of fault zone complexity in modulating injection-induced seismicity

Md Shumon Mia; University of Illinois at Urbana-Champaign; United States
Mohamed Abdelmeguid; University of Illinois at Urbana-Champaign; United States
Chunhui Zhao; University of Illinois at Urbana-Champaign; United States
Ahmed Elbanna; University of Illinois at Urbana-Champaign; United States

Industrial, environmental, and sub-surface energy activities are associated with increasing risk of induced seismicity. Modeling long-term sequence of induced earthquakes and aseismic slip plays an important role in understanding the mechanism related to spatio-temporal evolution of induced seismicity. We simulate sequence of earthquake and aseismic slip (SEAS) for rate-and-state fault subject to slow tectonic loading and injection-induced pore pressure perturbation. The fault consists of seismogenic velocity weakening (VW) patch and stably creeping velocity strengthening (VS) patch. We employ a hybrid finite element-spectral boundary integral scheme (FEBE) which enables modeling non-linear fault zone with high resolution FEM discretization while replacing the homogeneous elastic half spaces through SBI. We use an alternating quasi-dynamics and dynamics algorithm capturing both slow aseismic deformation and rapid dynamic rupture. During slow aseismic deformation, quasi-dynamics solver is used where radiation damping is added with fault strength to approximate inertia. Dynamics solver accounts full inertia effects during rapid coseismic phase. Switching between the solvers is done based on a threshold velocity.

With an aim to understand the controlling factors behind the spatio-temporal evolution and the size of induced-seismicity, we incorporate fault zone complexity by modeling different cases with off-fault plasticity, frictional heterogeneity, and small secondary faults surrounding the primary fault. Off-fault plasticity is found to arrest the rupture propagation and results in spatio-temporal clustering of seismicity with inter-event time ranging several orders of magnitude. Off-fault plasticity accumulation with resulting stress heterogeneity enables rupture arrest and spatial segmentation of seismic events. Frictional heterogeneity with alternating VS and VW patches are also found to generate seismic complexity through rupture arrest by VS patch. Depending on the fault friction, fault zone strength, and magnitude of pore pressure perturbation, both off-fault plasticity and on-fault frictional heterogeneity can contribute in limiting the size of induced events. Furthermore, in the model with multiple faults, induced seismic events were distributed in a volume and interesting spatial migration patterns, due to the interplay between the primary and secondary faults, were observed. These results contribute to the understanding of the evolution of induced seismicity and help better inform seismic hazard models.

Role of strength and toughness in the indentation problem

Aditya Kumar; Georgia Institute of Technology; United States
Oscar Lopez-Pamies; University of Illinois at Urbana-Champaign; United States

Since the pioneering experiments of Hertz (1882) a multitude of investigators have studied how fracture nucleates and propagates in many nominally brittle ceramics, metals, and polymers when indented. The experiments typically exhibit the nucleation of a ring crack followed by a steadily propagating cone crack. The mechanism of cone crack propagation is relatively well understood and has been shown to depend on the fracture toughness (critical energy release rate). However, the mechanism for the nucleation of cracks, which follows the so-called Auerbach law, has been under intense debate. While various explanations based on the strength and toughness of the material have been proposed, the inability of the classical fracture theories to study nucleation and propagation of fracture in a unified manner in arbitrary geometries under arbitrary loadings has proved to be an impediment in providing a conclusive explanation for nucleation. In a recent contribution, Kumar, Bourdin, Francfort, and Lopez-Pamies (J. Mech. Phys. Solids, 2020) have introduced a comprehensive macroscopic phase-field theory for the nucleation and propagation of fracture in linear elastic brittle materials under arbitrary quasistatic loading conditions. The theory can be viewed as a natural generalization of the phase-field approximation of the variational theory of brittle fracture of Francfort and Marigo to account for the material strength at large. The description of material strength at large, that is, the strength under multi-axial stress states is believed to be the key missing ingredient from the classical phase-field models. The material strength is incorporated into the theory by the addition of an external driving force which physically represents the macroscopic manifestation of the presence of inherent microscopic defects in the material in the equation governing the evolution of the phase field. In this talk, the comparisons between the new theory and the indentation experiments will be presented and the role of strength and toughness will be explained. Its analysis is technically challenging because of the singular or high-gradient elastic fields that they feature prior to the nucleation of fracture. The focus of the comparisons will be on the indentation of borosilicate glass plates with flat-ended cylindrical indenters. Mouginot and Maugis (1985) have reported a complete set of results for this problem with various indenter sizes ranging from 0.05 mm to 2.5 mm. After outlining the calibration of material inputs entering the theory, comprehensive quantitative comparisons with these experimental results will be presented.

Route Travel Time Prediction and Uncertainty Quantification using Hierarchical Bayesian Regression

Sevin Mohammadi; Columbia University; United States
Audrey Olivier; University of Southern California; United States
Andrew Smyth; Columbia University; United States

This research aims to predict the travel time and its variability between any two locations in the urban road network, which has numerous applications in transportation systems such as individual trip planning and evaluating operational transportation systems. With the advancement of technology that allows for collecting and storing large trip data, data-driven travel time predictions have gained significant attention among researchers. However, data-related issues such as data sparsity and noisy measurements can compromise the quality and accuracy of travel time predictions, leading to unreliable results and suboptimal decision-making. Sparse data, for example, may result in incomplete or insufficient information about road conditions. Addressing these challenges requires the development of sophisticated data processing techniques and the use of appropriate modeling methods to overcome these limitations and produce accurate, reliable predictions. The obstacles faced in travel time predictions are addressed in this study through the use of specific feature engineering and data integration techniques. This includes constructing a road network graph to estimate the route path, extracting route-specific features that correlate with the traffic flow in the route, and incorporating road speed profiles and weather data to enhance prediction accuracy. The research uses a hierarchical Bayesian model to estimate the predictive distribution of travel time based on trip features and the posterior distributions of model parameters. In particular, a varying-coefficients regression model is fitted to capture the effect of temporal variations in traffic conditions and the spatial impact of geographic regions on trip travel time. The model is trained with ambulance and taxi trip data from New York City, and its performance is compared to benchmark methods. The proposed probabilistic machine learning methodology has the potential to improve the reliability of decision-making in traffic management and control strategies for smart cities. By capturing the uncertainty inherent in travel time predictions, the methodology provides a robust framework for assessing and mitigating the risks associated with traffic management decisions. This, in turn, can lead to proactive enhancements in transportation systems, ensuring smoother and more efficient traffic flow and, ultimately, a better overall experience for road users.

Scalable Bayesian Optimization with Metaheuristics for Efficiency and Exploitation

Ibrahim Aydogdu; Akdeniz University; Turkey
Michaela Kempner; Georgia Institute of Technology; United States
Yan Wang; Georgia Institute of Technology; Turkey

Bayesian optimization (BO) is a surrogate-based global optimization approach, where a surrogate of the objective is constructed and used to guide the search. The surrogate is updated iteratively as an active learning strategy. Thus, BO can efficiently solve optimization problems with expensive-to-evaluate black-box objective functions with fewer iterations. Gaussian process (GP) is a common surrogate model for BO which also quantifies uncertainty. Although BO with GP (BOGP) performs well in small-scale optimization problems, its effectiveness decreases in high-dimensional optimization problems because the number of samples required to cover the search space increases exponentially. Calculating the inverse of the covariance matrices in GP models is in the cubic order of the number of samples. High computational cost is the major barrier for BOGP to solve large-scale optimization problems. Some special tactics have been developed to reduce the computational cost and improve the scalability of GP, such as kernel matrix approximations (Sang & Huang, 2012; Smola & Bartlett, 2000; Yang, 2020), the Fully Independent Training Conditional method (Csató & Opper, 2002), and Variational Free Energy method (Titsias, 2009) , which show good performance in the learning process of large data sets. However, these techniques mainly focus on how to represent the whole solution space. These methods do not directly help improve the convergence of optimization. Recently some researchers developed scalable GP methods for global optimization by searching for the optimum samples, namely inducing points, for better representation of the solution space (Fortuin, Dresdner, Strathmann, & Rätsch, 2021; Zhang, Yao, Liu, & Wang, 2019). In these studies, the criteria for selecting the inducing points are to maximize the likelihood of data similarity. However, in the optimization process, the potential to reach the best solution is more important than the similarity of the data. Therefore, the exploitation capabilities of these techniques are limited. The performance of BOGP can be improved if the distance to the best solution is considered when choosing the inducing points instead of the similarity between the samples. In this study, a new method called scalable Bayesian optimization with metaheuristics (SBO-MH) is developed to increase the exploitation capability of the BOGP for solving large-scale global optimization problems. In each iteration of SBO-MH, two optimization procedures are taken to update the surrogate and select the next sample. In the first optimization, SBO-MH selects the optimal inducing points that maximizes the probability of finding a better solution than the current best one. In the second optimization, the next sample is selected to maximize the acquisition function. For both optimization procedures, biogeography based optimization (BBO) (Simon, 2008) is utilized, whose efficiency has been proven in many structural optimization problems (Ibrahim Aydogdu, 2017; Ibrahim Aydogdu & Akin, 2015; I. Aydogdu, Carbas, & Akin, 2017). SBO-MH is tested by three benchmark functions with three different dimensions. The obtained results are compared with the full-scale BOGP method with the criteria of statistical consistency, convergence speed, and computational cost.

References Aydogdu, I. (2017). Cost optimization of reinforced concrete cantilever retaining walls under seismic loading using a biogeography-based optimization algorithm with Levy flights. Engineering Optimization, 49(3), 381-400. doi:10.1080/0305215X.2016.1191837 Aydogdu, I., & Akin, A. (2015). Biogeography Based CO2 and Cost Optimization of RC Cantilever Retaining Walls. Paper presented at the 17th International Conference on Structural Engineering, Paris, France. http://waset.org/abstracts/25608 Aydogdu, I., Carbas, S., & Akin, A. (2017). Effect of Levy Flight on the discrete optimum design of steel skeletal structures using metaheuristics. Steel and Composite Structures, 24(1), 93-112. doi:10.12989/scs.2017.24.1.093 Csató, L., & Opper, M. (2002). Sparse on-line Gaussian processes. Neural computation, 14(3), 641-668. Fortuin, V., Dresdner, G., Strathmann, H., & Rätsch, G. (2021). Sparse Gaussian processes on discrete domains. Ieee Access, 9, 76750-76758. Sang, H., & Huang, J. Z. (2012). A full scale approximation of covariance functions for large spatial data sets. Journal of the Royal Statistical Society: Series B (Statistical Methodology), 74(1), 111-132. Simon, D. (2008). Biogeography-Based Optimization. Ieee Transactions on Evolutionary Computation, 12(6), 702-713. doi:10.1109/tevc.2008.919004 Smola, A., & Bartlett, P. (2000). Sparse greedy Gaussian process regression. Advances in neural information processing systems, 13. Titsias, M. (2009). Variational learning of inducing variables in sparse Gaussian processes. Paper presented at the Artificial intelligence and statistics. Yang, A. (2020). Scalable Bayesian Optimization with Sparse Gaussian Process Models. arXiv preprint arXiv:2010.13301. Zhang, J., Yao, X., Liu, M., & Wang, Y. (2019). A Bayesian Discrete Optimization Algorithm for Permutation Based Combinatorial Problems. Paper presented at the 2019 IEEE Symposium Series on Computational Intelligence (SSCI).

Scale dependence of frictional rupture prestress: Implications for earthquake statistics and inferences of fault stress

Valère Lambert; University of California Santa Cruz; United States
Nadia Lapusta; California Institute of Technology; United States
Daniel Faulkner; University of Liverpool; United Kingdom

Characterizing conditions for shear failure within Earth's crust is crucial for assessing plausible societal threats from natural hazards, such as earthquakes, as well as the sustainability of activities such as carbon sequestration and energy resource practices. In particular, improving our understanding of the evolution of stress on faults over periods of slow and fast motion is important for assessing how earthquake ruptures start, grow, and ultimately stop, and hence how big an earthquake is likely to become. Here, we share recent progress using physics-based computational models of dynamic frictional rupture sequences and slow fault slip to bridge laboratory insight and geophysical field observations of fault failure processes. We study the averaged shear stress conditions on a fault prior to the occurrence of simulated earthquake ruptures (average prestress) that spontaneously evolve in numerical simulations of fault models governed by laboratory-derived rate-and-state friction laws supplemented with enhanced dynamic weakening due to shear heating and effects of pore fluids. Such average prestress is one measure of the static fault strength.

We find that the average prestress for dynamic rupture propagation in our models depends on the size of the rupture and how efficiently the fault shear resistance weakens during fast slip. In particular, larger earthquakes on faults that experience increasingly more efficient weakening during rupture can propagate under systematically lower prestress conditions than those required for rupture nucleation. As a result, we find that faults that exhibit efficient weakening tend to host predominantly large earthquakes at the expense of smaller earthquakes, resulting in systematically lower b-values of the frequency-magnitude event distributions. Our findings illustrate how large earthquakes can occur on faults that appear to be under-stressed compared to expected conditions for rupture nucleation and highlight the importance of finite-fault modeling in relating the local friction behavior determined in the lab to field scales. Our findings also support a body of work suggesting that paucity of small earthquakes or seismic quiescence may be an observational indication of mature faults that operate under lower shear stress due to enhanced dynamic weakening. More broadly, our findings support the developing notion that b-values of fault seismicity are significantly affected by fault shear resistance and its evolution with slip, a factor not yet widely considered in studies of b-values.

Scaled Experimental Investigation of the Sensitivity of Strongback Performance to Location of Supplemental Dampers and Stiffness Irregularities

Sima Abolghasemi; University of Tennessee; United States
Nicholas Wierschem; University of Tennessee; United States
Mark Denavit; University of Tennessee; United States

A building's performance can be dramatically affected by soft stories. Soft stories can be found in buildings as a vertical irregularity or can form due to the concentration of damage. One strategy to reduce the impact of soft stories is to provide a load path around the soft story with a strongback. A strongback is a stiff vertical spine that runs the height of the building and is pinned at the building's base. The incorporation of strongbacks in structural systems is relatively new and questions on how they impact performance remain open. In particular, the sensitivity of the performance of buildings with strongbacks to soft stories at different heights and to the arrangement of supplemental dampers is not well characterized. The goal of this study is to fill these gaps by conducting a parametric experimental investigation using a scaled four-story elastic structure with a strongback excited with shake table produced ground motion. Six earthquake records and a shaped white noise loading were used to evaluate the dynamic performance of the structure, with tests conducted with various locations of stiffness irregularities to represent soft stories, viscous damper arrangements, and considering the building with and without a strongback. The results of this study show that, with the strongback, introduction of a stiffness irregularity produced a significantly lower increase in maximum story drift than without a strongback regardless of the location of the stiffness irregularity, and the first natural frequency of the building with a strongback remains much more consistent. Furthermore, the results show that the arrangement of dampers in the structure significantly impacts the performance of the building without a strongback, but with the strongback the maximum story drift remains near constant regardless of damper arrangement. The strongback's ability to protect the structure from soft stories and its insensitivity to soft story location and damper placement give the strongback great potential for new design and as a remediation option for existing buildings.

Scaled Spherical Simplex Filter for finite-element model updating and system identification

Mariyam Amir; Pennsylvania State University; United States
Konstantinos G. Papakonstantinou; Pennsylvania State University; United States
Gordon P. Warn; Pennsylvania State University; United States

This work presents an efficient online system identification approach by integrating a reduced sigma points–based filter with a high-fidelity mechanics-based state-space hysteretic finite-element modeling framework. The efficacy and computational efficiency of any sampling/sigma points–based nonlinear filtering process are conditional on the number of sigma/sample points required by the filter at each time step to quantify statistical properties of the involved quantities, as well as on the accuracy and computational cost of the underlying system model. A developed scaled spherical simplex filter (S3F) with a significantly decreased n+2 sigma points set size is thus presented that is able to achieve similar robustness and accuracy as the state-of-the-art 2n+1 sigma points unscented Kalman filter (UKF) for an n-dimensional state-space, yet with approximately 50% less computational requirements. Detailed theoretical derivations fully explain the effects of the scaling factors, sigma points location and weight selection, and mathematically prove the equivalency between UKF and S3F. Several theoretical examples are also shown, by comparing the estimated mean and covariance outputs of nonlinear functions. While the suggested filtering technique can be effectively employed for numerous applications, in this work emphasis is given to the integration of the filtering framework with our recently developed fully parametrized damage plasticity–consistent hysteretic finite-element modeling approach. The devised model is able to account for distributed plasticity, axial-moment–shear interactions, and degradations in one unified formulation by employing the concepts of continuum damage mechanics and classical multiaxial plasticity. In the presented hysteretic model, the system matrices are constant and do not require updating throughout the analysis, whereas the degradations and inelasticity are updated through element-level hysteretic evolution equations in the form of resultant stress–strain laws. Overall, the system can be presented in a state-space form and can be solved with any first-order ordinary differential equation solver, without any linearization or gradient requirements, rendering the high-fidelity formulation robust and computationally efficient and enabling ideal compatibility in terms of computational implementation with the filtering methodology for online joint state-parameter identification.

References:

Amir, M., Papakonstantinou, K.G., Warn, G.P., 2022, Scaled Spherical Simplex Filter and state-space damage-plasticity finite element model for computationally efficient system identification, Journal of Engineering Mechanics, 148(2): 04021138-1:17.

Papakonstantinou, K.G., Amir, M., Warn, G.P., 2022, A Scaled Spherical Simplex Filter (S3F) with a decreased n+2 sigma points set size and equivalent 2n+1 Unscented Kalman Filter (UKF) accuracy, Mechanical Systems and Signal Processing, 163, 107433-1:25.

Seasonal variation of FWD test results of a concrete-over-asphalt composite pavement: asphalt-related temperature correction of measured deflections

Rodrigo Diaz Flores; TU Wien; Austria
Valentin Donev; TU Wien; Austria
Mehdi Aminbaghai; TU Wien; Austria
Lukas Eberhardsteiner; TU Wien; Austria
Luis Zelaya-Lainez; TU Wien; Austria
Raphael Höller; TU Wien; Austria
Christian Hellmich; TU Wien; Austria
Martin Buchta; Nievelt Labor GmbH; Austria
Bernhard L.A. Pichler; TU Wien; Austria

Falling Weight Deflectometer (FWD) tests are one of the most popular non-destructive techniques used for the evaluation of pavement structures. During FWD tests, a standardized weight impacts the surface of the road, while geophones measure the resulting deflections experienced by the pavement. The interpretation of such deflections is challenging because tests performed on the same structure, but on different times of the year, are usually associated with different measured deflections. This provided the motivation to perform five FWD tests, during summer, winter, and the transition periods, on a concrete-over-asphalt composite pavement structure instrumented with temperature sensors, asphalt strain gauges, and accelerometers. The present contribution refers to the following main innovations: (i) As for in situ characterization of the stiffness of layer materials, so-called "sledgehammer tests" were developed, in which a sledgehammer is used to strike a metal plate, which transmits the impact to the pavement via a rubber pad. The accelerometers are used to capture the time of flight of the generated elastic wave through the cement-stabilized granular layer. The stiffness of this layer is calculated by means of the theory of propagation of elastic waves through isotropic media. The stiffnesses of concrete and asphalt layers are characterized through standard and quasi-standard laboratory tests. (ii) As for the re-analysis of FWD tests, multi-layered elastostatic simulations are performed, using the layer stiffnesses as input and optimizing only the thickness and stiffness of the subgrade. These simulations are performed for all five FWD tests analyzed. The high temperature-dependence of the stiffness of a thin (8 cm) asphalt layer, as well as the mild temperature-dependence of the stiffness of the thick (1.35 m) subgrade layer, are found to be the main drivers of the seasonal variation of FWD test results. (iii) An asphalt-related temperature correction of deflections is proposed with the purpose of separating the contributions of the asphalt and the subgrade. Based on a synthetic database of multi-layered simulations, the correction method is used to translate measured deflections, referring to a specific asphalt temperature measured during FWD testing, to deflections that would be measured provided that asphalt had a temperature of 20°C. The corrected deflections are no longer influenced by the temperature-dependent stiffness of asphalt, and the seasonal variation of the corrected deflections is thus attributed to the temperature-dependent stiffness of the subgrade. This is corroborated by the very good linear relation observed between the modulus of subgrade reaction of the "dense-liquid" model, quantified from the corrected deflections, and the elastic modulus of the subgrade, back-calculated by means of multi-layered simulations from measured deflections. Finally, an alternative correction approach is developed that only requires measured deflections. The proposed method is appealing because it provides corrected deflections that allow for the application of any existing method for the interpretation and/or evaluation of FWD test results, such as deflection basin parameters and structural models.

Seismic Performance of Multi-degree-of-freedom Structures with Variable Inertia Rotational Mechanisms

Anika Sarkar; University of Tennessee; United States
Nicholas Wierschem; University of Tennessee; United States

Many conventional passive control devices utilized in civil infrastructure require relatively large masses to mitigate the dynamic response of structures effectively; however, the incorporation of large additional masses in structures entails an increase in cost and complexity in design. Rotational inertial supplements can be a potential alternative to this as they can use small physical masses to produce large effective inertial mass. To date most studies on rotational inertial supplements have considered a linear version known as an inerter, which produces a constant equivalent inertial mass. Nonlinear rotational inertial supplements are related to inerters but generate equivalent inertial mass that can vary. One way to obtain this variable inertial mass is referred to as a variable inertia rotational mechanism (VIRM). The VIRM features a passive flywheel design that allows masses on the flywheel to move radially within guides, which alters the rotational inertia of the flywheel and the corresponding effective mass provided by the device. The evaluation of the VIRM has thus far been primarily limited to considering single-degree-of-freedom structures that are subjected to stationary loading. This work expands on previous studies and numerically investigates the behavior of a multi-degree-of-freedom (MDOF) structure with single and multiple VIRMs under seismic ground motions. The mechanism and dynamic model of the VIRM and the MDOF structure it is incorporated into are presented. Incremental dynamic analysis was implemented with suites of recorded earthquake ground motions to investigate the impact of the VIRM on structural behavior, with comparisons made to the structure with a device with fixed rotational inertia. Although performance significantly varies for each earthquake, the median results of the incremental dynamic analysis show that multiple VIRMs are more effective in reducing the dynamic effects of seismic excitation compared to a device with fixed rotational inertia. The promising performance of the VIRM in this study paves the way for further study of these innovative nonlinear rotational inertia supplements in earthquake engineering.

Seismic Regolith-Structure Interaction on Proposed Martian Habitats

Hamed Seifamiri; Polytechnique Montreal; Canada
Pooneh Maghoul; Polytechnique Montreal; Canada
Roberto de Moraes; AECOME; United States
Ramesh B. Malla; University of Connecticut; United States

The design and construction of structures to shield astronauts and materials from the hostile environment on Mars and the Moon require specific considerations including seismic sources like meteorite impacts, underground magma pressure, and abrupt temperature variations. A variety of conceptual designs for the lunar and Martian structures such as deployable, 3D-printed, and generic structures have been proposed in the literature. Another alternative that has been proposed includes making use of lunar or Martian lava tubes for a shelter. In this paper, the dynamic behavior of Martian semi-circular structures with several types of regolith covers, such as regolith blankets or buried substructures has been studied. To assess the key characteristics of the dynamic response of various regolith cover systems under seismic excitation, six models of Martian structures under two types of seismic sources have been simulated. First, artificial impact signals depicted as shockwaves emanating from a single source and propagating radially has been considered. Dynamic behaviour of the models is then obtained under vertically propagating SV shear waves using the seismic double couple equivalent force mechanism that is commonly employed to simulate earthquake waves in terrestrial environment. The in-house numerical software, SiteQuake that utilizes Finite Element (FE)/Boundary Element (BE) based computational method was used for this purpose. The Martian structures and their regolith-shielding systems were modeled using FE, while the bedrock and absorbing boundaries were simulated using BE in order to ensure that there are no reflecting waves from the boundaries. Primarily the Spectral Amplification (SA) of the Models and the Dynamic Stress Concentration Factors (DSCF) have been investigated/examined for evaluating the seismic response. The Spectral Amplification for each point is defined as the ratio between the pseudo-acceleration of each simulated spatial point and the pseudo-acceleration of the reference spectrum for frequencies from 0.1 to 20 Hz. The seismic response of a half-space to the same seismic excitation source is considered as the reference spectrum. The results show the intricate nature and complex dynamic interaction of the structures and regolith shielding due to the scattering of seismic waves in different parts of the structure. The findings of this study also show that distinct patterns of amplification occur depending on the topography of the structure's site (whether curved or flat) and the types (or methods) of regolith cover used on the structures. The results suggest that the riskiest structures are those that are not shielded and are located inside a concave topography, such as a crater or pitting. Lava tubes, on the other hand, are thought to be safer because they have the lowest dynamic amplification values both in terms of SA and DSCF. The behaviour of the other structures is in between based on their shielding systems.

Seismic reliability-based retrofitting optimization of non-ductile reinforced concrete frame structures

Antonio Pio Sberna; Politecnico di Torino; Italy
Angshuman Deb; Department of Structural Engineering, University of California, San Diego; United States
Fabio Di Trapani; Politecnico di Torino; Italy
Joel P. Conte; Department of Structural Engineering, University of California, San Diego; United States

Despite being initially developed for seismic safety assessments, the pacific earthquake engineering research center (PEER) performance-based earthquake engineering (PBEE) framework has recently garnered increasing scientific interest in the development of innovative performance-based seismic design (PBSD) frameworks. Noteworthy applications have been developed especially for the design of new buildings (Franchin et al. 2018) and, more recently, on bridges (Deb et al. 2022). In recent years, noticeable attention is emerging on the design of seismic retrofit for existing structures.

In this framework, albeit the full-fledged parametric PBSD method has proven to be a powerful tool for the design considering multiple risk-based performance objectives, it is so computationally demanding that currently it does not seem easily feasible for real-world applications.

This study proposes the application of an optimization procedure to identify the boundary of the feasible design domain without the need for accomplishing a full-fledged parametric performance assessment of the design parameter space. The optimization approach considers both seismic performance and the retrofitting costs of non-seismically conforming reinforced concrete frame structures. The mean return period (MRP) of exceeding at least one limit state (LS) in a selected set of several limit states is considered the seismic performance metric. The optimization procedure aims at finding the optimal retrofit topology and component sizing for which all the MRPs of limit state exceedances are higher than the corresponding target MRP and simultaneously have the minimum cost.

Results will show that the proposed optimization procedure can effectively exploit soft computing for the application of performance-based seismic retrofit design in a computationally efficient framework without significant loss in accuracy.

References:

Deb, A., Zha, A.L., Caamaño-Withall, Z.A., Conte, J.P., Restrepo, J.I., 2022. Simplified Risk-Targeted Performance-Based Seismic Design Method for Ordinary Standard Bridges. J Bridge Eng 27, 04022089. https://doi.org/10.1061/(ASCE)BE.1943-5592.0001916

Di Trapani, F., Sberna, A.P., Marano, G.C., 2022. A genetic algorithm-based framework for seismic retrofitting cost and expected annual loss optimization of non-conforming reinforced concrete frame structures. Computers & Structures 271, 106855. https://doi.org/10.1016/j.compstruc.2022.106855

Franchin, P., Petrini, F., Mollaioli, F., 2018. Improved risk-targeted performance-based seismic design of reinforced concrete frame structures. Earthquake Eng Struct Dyn 47, 49–67. https://doi.org/10.1002/eqe.2936

Seismic Response of Core Wall Building with Force-Limiting Connections

Kyoungyeon Lee; University of California San Diego; United States
Georgios Tsampras; University of California San Diego; United States

Numerical earthquake simulation results of an eighteen-story reinforced-concrete core wall building with force-limiting connections are presented. The seismic force-resisting system (SFRS) and the gravity load-resisting system (GLRS) of the building are solely connected by the force-limiting connections, which allow controlled axial force to be transferred between the two systems. Force-limiting connections for buildings with planar SFRS and core wall SFRS have been developed to limit the magnitude and the variability of the seismic response of the building and accommodate the three-dimensional kinematics between the GLRS and the SFRS. The force-limiting connection developed for core wall buildings is termed Modified FD, where the FD stands for Friction Device. A three-dimensional model of an eighteen-story reinforced-concrete core wall building is developed in OpenSees. Numerical earthquake simulations of the building model are performed considering eleven design-level far-field ground motions. The seismic response of the building model with the Modified FD is compared with the seismic response of the building model with conventional monolithic connections. The numerical simulation results show that the use of the Modified FD reduces the magnitude and the variability of the peak floor acceleration response, the peak base shear response, the peak story torsion response, and the peak wall pier axial strain response without affecting the story drift demands.

Seismic retrofit of low-rise reinforced concrete buildings typical to Haiti using a deterministic and a probabilistic approach.

Marc-Ansy Laguerre; Rice University; United States
Reginald DesRoches; Rice University; United States
Mohammad Salehi; Rice University; United States

Along with widespread research on seismic retrofit of reinforced concrete (RC) buildings across the world, many countries with moderate and high seismic risk have improved their seismic codes and developed methods to retrofit their seismically deficient buildings. However, in Haiti, significant gaps still exist in understanding the vulnerability and identifying viable retrofit approaches to mitigate the widespread damage to RC buildings observed in the past. This paper takes one of the few systematic studies to help address these gaps by presenting a holistic analysis of Haitian buildings and evaluating several retrofit techniques to seismically strengthen them.

In this research, both a deterministic approach and a probabilistic approach are used to analyze Haitian buildings and their retrofits. First, the construction practices in Haiti are characterized and building prototypes presented. Four prototypes are adopted: R1 (residential 1-story), R2 (residential 2-story), C2 (commercial 2-story), C3 (commercial 3-story). The columns and beams of these buildings' prototypes are designed using BAEL (Béton Aux États Limites) which was a French building code widely used in Haiti prior to 2010. The prototypes are numerically modeled with a two-stage approach. First LS-Dyna is used to validate and generate hysteretic curves of column joints. Then a spring model is calibrated based on the high fidelity joint model, and used to perform time history analysis of the building frame in OpenSees. Five retrofit techniques are considered to improve the seismic performance of these prototypes: RC shear walls, steel braces, buckling restrained braces, prestressed tendons, and FRP jackets. A suite of ground motions are selected and scaled to evaluate the effectiveness of the retrofits.

First deterministic analyses are conducted, adopting mean values building properties, such as 9 MPa concrete which is typical of the region, and a constant gravity load. The inter-story drift with and without retrofit is compared to the mean drift limit of this type of structure. After gaining insight on typical behavior, probabilistic analyses are conducted by propagating uncertainty in ground motion, material parameters, and capacity limits to derive fragility curves for four limit states (slight, moderate, extensive, collapse). These allowing evaluation of the retrofits' effect across different prototypes, given uncertain conditions. The work concludes by identifying the most effective retrofit techniques for each prototype and highlighting opportunities for future work to reduce the susceptibility of the Haitian building stock to widespread damage during seismic events.

Self-limited dynamics and patio-temporal complexity of crustal seismicity enabled by elasto-plastic fracture meahanics

Ahmed Elbanna; UIUC; United States
Md Shumon Mia; UIUC; United States
Mohamed Abdelmeguid; Caltech; United States

Earthquakes are among the most damaging natural hazards. Our current understanding of earthquakes suggest that they nucleate as instabilities under slow tectonic loading and propagate as shear fractures mostly at sub-Rayleigh speeds but occasionally as supershear cracks. During an earthquake, the change in the strain energy from the bulk is transformed in fracture energy to facilitate the breakdown processes, heat due to frictional dissipation, radiated energy in the far-field, and inelastic dissipation in the near-field. While significant progress has been made in understanding earthquake source processes in linear elastic domains, the effect of more realistic inelastic rheologies including plasticity is poorly understood. Here, we simulate the sequence of earthquake and aseismic slip of a 2D antiplane rate-and-state frictional interface embedded in a full-space elastic-plastic bulk. We use a computationally efficient hybrid finite element spectral boundary integral scheme that relies on domain decomposition in space and extreme adaptive stepping in time. We show that off-fault plasticity may lead to partial ruptures as well as temporal clustering of seismic events. Furthermore, the interaction of fault slip and off-fault plasticity results in pockets of slip deficit. While the energy dissipated through plastic deformation remains a small fraction of the total energy budget, its impact on the source characteristics is disproportionally large through the redistribution of stresses and viscous relaxation. Our results emphasize the critical role of fault zone strength in controlling multi scale earthquake dynamics and suggest a new mechanism of dynamic heterogeneity in earthquake physics that may have important implications on earthquake size distribution and energy budget.

Self-Powered Sensors for Sustainable Condition Monitoring of Bridges under Traffic-Induced Vibration

Mohsen Amjadian; The University of Texas Rio Grande Valley; United States
Anil Kumar Agrawal; The City University of New York; United States
Hani Nasif; Rutgers University; United States

Over the last few years, energy harvesting (EH) has emerged as one of the key components of sustainable design and maintenance of transportation infrastructures. This is because EH promotes environmentally friendly technologies that can generate electrical power from the available clean energy sources such as the traffic-induced vibration of highway bridges. The average daily vehicle miles travelled in the U.S. is currently more than 5 billion that represents a massive source of such a clean energy which mostly remains unused. EH technologies can be exploited to convert this energy to an electric energy for powering the wireless sensors and other electronic peripherals used for damage detection and condition assessment of highway bridges. The objective of this study is to model, design and test a dual-resonator electromagnetic energy harvester (EMEH) with a high electromechanical coupling for harvesting electric energy from the traffic-induced vibration of highway bridges to power wireless accelerometers. The proposed EMEH consists of three stationary layers of cuboidal permanent magnets (PMs) with alternating-pole arrangements, two thick rectangular air-core copper coils attached to the free ends of two flexible cantilever beams whose fixed ends are firmly attached to the girder of highway bridge oscillating in the vertical motion during the passing traffic. The natural frequencies of the resonators can be tuned to resonate with the fundamental modes of highway bridge to increase the harvested electric energy. The numerical and lab testing of a proof-of-concept of proposed EMEH show that it can generate an average electrical power more than 500 mW at the resonance frequency 4 Hz over a period of 1 sec that alone is more than enough to power a conventional wireless accelerometer. The performance of proof-of-concept prototype will be further evaluated in a field study by mounting it on a RC girder bridge under a real traffic load.

Semi-active cam-lever friction device for structural control of buildings subjected to natural hazards

Alejandro Palacio-Betancur; Penn State University; United States
Mariantonieta Gutierrez Soto; Penn State University; United States

The implementation of damping devices in building structures increase their safety and serviceability during natural hazards like earthquakes and strong winds. Damping devices are categorized into passive, semi-active, and active systems according to their working principle. For instance, passive devices rely on physical mechanisms to dissipate energy, active devices use external power to modify the dissipative capabilities, and semi-active devices combine both principles to dissipate energy with the reliability of passive devices and the versatility to adapt like active systems using smaller magnitude of power consumption. Among semi-active devices, variable-friction dampers have received attention because they only require a variable clamping force to a surface to dissipate mechanical energy into heat. Recently, a new semi-active friction damper was developed to apply a variable normal force using a cam-double-lever mechanism. The normal force applied with slipping bolts is controlled through a varying-radius cam attached to a lever, and a slider-crank mechanism that transforms the rotational movement of the first lever into a linear movement of an actuator. The proposed mechanism provides mechanical advantage to easily adjust the position of the levers and change the tension of the slipping bolts. The alpha prototype of the proposed device, tested under harmonic and earthquake motions, provided insight into the capabilities of the device as well as weaknesses that can be improved. Therefore, this project investigates the performance of beta prototype designs of the semi-active cam-lever friction damper considering manufacturing materials, geometric configuration, and stiffness of components that improve the behavior of the device for applications in structural control. The proposed device is also evaluated experimentally at small-scale, using additive manufacturing of components, and an Arduino microcontroller to change the positions of the levers. The test specimen is subjected to harmonic motions and earthquakes using a shake table. The results show that the device can have additional normal forces applied to the friction surface to increase the passive capabilities of the device if the actuation system malfunctions. Overall, this research encourages the implementation of modern technology in structural engineering to increase efficiency of systems, reduce costs, and add safety and reliability to civil infrastructure.

Sensitivity analysis for the development of class fragility models of transmission towers under hurricanes

Xinyue Wang; Lehigh University; United States
Paolo Bocchini; Lehigh University; United States

Electrical transmission systems are among the most critical infrastructure in modern society. They constitute interconnected networks that cover very large regions and in many cases are exposed and vulnerable to natural hazards, hurricanes in particular. A transmission line consists of two distinct systems: the wire system (e.g., conductors, ground wires, insulators) and the structural support system (e.g., transmission towers). The design of the wire system is governed by the energy demand in transmission network, but their mechanical behavior affects the structural loads on the support system. The support system, designed based on structural performance needs, is to provide reliable support for the wires. Hence, the reliability and resilience of the system depend on the ability of each transmission tower to withstand the high wind loads caused by hurricanes. For regional analysis of transmission systems under hurricanes, class or portfolio fragility models of transmission towers are needed. This study presents the sensitivity analysis for determining the appropriate uncertainty treatment and modeling fidelity, which is a prerequisite for developing class fragility models of transmission towers under hurricanes. A classification scheme based on the structural aspects of transmission towers is first proposed. In particular, the relationships between the wire system and towers are presented, and based on this the uncertainties in the wire system can then be effectively captured and propagated. The structure-related uncertainties are categorized into within-structure uncertainties (i.e., randomness present even if the tower design is perfectly known, such as the material strength) and between-structure uncertainties (i.e., randomness associated with the variability of structures in a class, such as the tower height). For each proposed class, a preliminary screening of all identified uncertain variables is performed by using fractional factorial design. Considering the "high and low levels" of the between-structure uncertain variables (factors), distinct towers are designed. Then, for each archetype tower, the high and low levels of within-structure variables as well as load-related random variables are studied. Finite element analyses (experiments) are then carried out to obtain the structural response. The analysis of variance (ANOVA) is utilized to evaluate the sensitivity of the structural responses to the variation of the uncertain variables. Finally, the significance of each random variable is discussed and suggestions regarding uncertainty quantification for class fragility are presented.

Sensitivity Analysis of Model-Assisted Probability of Detection for Guided-Wave-Based Structural Health Monitoring Systems

Juan David Navarro; The University of Texas at San Antonio; United States
Juan Camilo Velasquez-Gonzalez; The University of Texas at San Antonio; United States
Mauricio Aristizabal; The University of Texas at San Antonio; United States
Harry Millwater; The University of Texas at San Antonio; United States
Arturo Montoya; The University of Texas at San Antonio; United States
David Restrepo; The University of Texas at San Antonio; United States

The Probability of Detection (POD) in wave-guide-based Structural Health Monitoring (SHM) systems is highly sensitive to sensor degradation, and variations in the structures' mechanical parameters, geometry, and boundary conditions. To quantify these effects, in this work we present a novel methodology to compute highly accurate sensitivities of the POD. The methodology couples the Hypercomplex Taylor Series Expansion with the time-domain Spectral Finite Elements Method. For verification, two transducers coupled with a flat plate in a pitch and catch configuration were analyzed. The sensitivities of the setup's POD were compared with Finite Differences. The results show that the accuracy of the method is insensitive to the selection of perturbation step. We posit that access to highly accurate sensitivity information will enable the transferability of POD curves between SHM systems with similar conditions without the need of resampling.

Shape Dependence of Diffusion Creep Behavior in Polycrystalline Materials with Two Strength-Contrasting Phases

Heechen Cho; Liberty University; United States

In this presentation, I report a theoretical development for a solution of diffusion creep of a two-phase mixture where many grains are aggregated (polycrystalline). First, I find the stress state of a single ellipse grain using the Eshelby's inclusion theory that relates a surrounding matrix to a local grain. Based on the stress state of the grain, we apply the diffusion creep theory (particularly, the lattice diffusion namely Nabarro-Herring creep) to determine the viscous stiffness of the grain. The well-known Fick's laws are solved to relate the applied boundary normal stress and its caused intracrystalline vacancy flux (thus, diffusion creep rate). The simulation shows that, as the elliptic grain deforms and elongates, the diffusion creep rate increases due to an increase in concentration gradient within the grain. This behavior is particularly enhanced under remote simple shear loading. This single-grain (surrounded by a matrix) diffusion creep solution is then extended to multiple grains through the self-consistent method. In this approach, the surrounding matrix is assumed to have a homogeneous property that homogenizes the properties of all constituent grains (Homogeneous Effective Matrix (HEM)). This approach allows investigation of how the weakening of local grains by diffusion creep affects the overall effective viscous stiffness of the two-phase aggregate. This study shows that it is crucial to take into consideration the shape-dependence of the diffusion creep deformation when such multiphase polycrystalline materials deform under diffusion-involved thermomechanical conditions such as high temperatures and low strain rates.

Shear Characterization of Particulate Rigid Plastics From Non-recyclable Municipal Solid Waste

Abdallah Ikbarieh; Georgia Institute of Technology; United States
Yimin Lu; Georgia Institute of Technology; United States
Sheng Dai; Georgia Institute of Technology; United States

Energy recovery from combustion and gasification of non-recyclable municipal solid waste (N-MSW), such as paper, cardboard, plastics, and foam, is becoming a potential source of renewable energy and a sustainable alternative to landfilling. However, the waste-to-energy conversion process faces serious handling-related challenges like hopper arching due to poor flowability attributed to their high friction, high compressibility, irregular shape, heterogeneity, and non-trivial cohesion. To better understand the rheology of N-MSW, it is crucial to characterize how they flow under various shear conditions. This study investigates the behavior of particulate rigid plastics, a major component of N-MSW, across different shear regimes. To achieve this end, a vane shear device is designed to shear the rigid plastic particles at different shear rates ranging from quasi-static to dense flow with controlled normal stresses. The impacts of stress history on the shear behavior of particulate rigid plastics are also investigated. The at-rest lateral pressure coefficient of the tested samples is measured to augment the interpretation of measured torque from the vane shear testing. This study advances the knowledge of the flowability of rigid plastic particles and provides a benchmark for simulations and equipment design of handling particulate N-MSW materials.

Simulation of a hot forming tool with a thermoelastic boundary element formulation

Michael Leitner; Graz University of Technology, Institute of Applied Mechanics; Austria
Martin Schanz; Graz University of Technology, Institute of Applied Mechanics; Austria

Hot forming tools have a complicated geometry due to cooling channels and the deformation can be computed based on linear thermoelasticity. Hence, a boundary element (BE) formulation might be advantageous. In the proposed simulation process, a time-domain BE formulation based on the generalised convolution quadrature method (see [1]) is utilised to compute the deformation and temperature of the forming tool. The work piece is modelled by a non-linear elasto-plastic material law and simulated with the finite element (FE) method. The coupling of both is realised with a simple node to segment contact formulation, where the heat transfer coefficient is determined by an heuristic approach, where the pressure dependency is related to the curvature of the geometry. This relation is taken from experiments given in literature.

This proof of concept shows that such an approach can be used to simulate a hot forming process with a coupled BE-FE-formulation.

[1] M. Leitner, M. Schanz: Generalized convolution quadrature based boundary element method for uncoupled thermoelasticity. Mechanical Systems and Signal Processing 150 (2021) 107234

Simulation of large-scale geological carbon sequestration in the Gulf of Mexico using fully coupled flow and geomechanics

Yanhua Yuan; ExxonMobil Technology and Engineering Company; United States
Kevin Dugan; ExxonMobil Information Technology; United States
Prasanna Krishnamurthy; ExxonMobil Technology and Engineering Company; United States
Stephen Morgan; ExxonMobil Technology and Engineering Company; United States
Josh White; Lawrence Livermore National Laboratory; United States

Accurate and efficient simulation of subsurface processes due to CO2 injection is important to guide decisions involved in large-scale carbon storage deployment and monitoring. In this study, we perform numerical simulations of CO2 injection and migration in a reservoir in the Gulf of Mexico. The highly faulted nature of this reservoir combined with geologic heterogeneities make the simulation of coupled flow and geomechanics in this system highly challenging. Therefore, this study provides us a great opportunity to answer many critical scientific questions involved in carbon storage at industrial scales. One of the main goals of this study is to assess the role of faults in affecting fluid flow, pressure build-up and geomechanical responses during and post CO2 injection. We will present our simulation results of fully coupled multiphase flow and geomechanics conducted using GEOSX, an open-source, multiphysics simulator designed to adapt to modern high-performance computing environments. We will show that the high content of clay minerals in the fault zones results in the distribution of low permeability faults, which act as structural traps in the subsurface and thus resulting in localized pore pressure build-up in the early stage of injection. Our simulation results demonstrate the importance of accurately characterizing and modeling subsurface systems with faults using fully coupled physics to successfully execute future carbon storage projects.

Simulation of spontaneous excess pore pressure development during compaction band formation in saturated porous rock

Divyanshu Lal; Northwestern University; United States
Giuseppe Buscarnera; Northwestern University; United States

Porous rocks like sandstone exhibit elusive forms of localized deformation referred to as compaction bands. The interaction between compaction bands and pore fluids is crucial, in that these structures occur in saturated environments and have been found to affect significantly the hydraulic properties of rock by reducing their permeability of several orders of magnitude. In this study, the emergence of hydro-mechanical couplings during compaction band formation is examined numerically. Specifically, Finite Element analyses are conducted to investigate if excess pore water pressure is produced at the onset of compaction bands and whether it can alter the patterns of propagating compaction. First, an elasto-viscoplastic constitutive law has been calibrated to replicate the compaction localization behavior of two porous rocks (Bluerswiller sandstone and Maastricht Tuffeau). Numerical analyses of triaxial compression tests have then been conducted on both materials under dry and saturated conditions. For both rocks, the presence of a pore fluid led to spontaneous excess pore pressure development in response to compaction localization. While the magnitude of such excess pore pressure was small compared to the confinement level and led to minor alterations of the nominal stress-strain response, the emergence of coupled effects was found to produce non-negligible alterations of the band propagation pattern. In particular, Bluerswiller sandstone (which under dry conditions was found to produce discrete compaction bands) was found to suffer transitions from pure compaction bands to a localized deformation mode characterized by mixed shear and compaction strains. By contrast, the simulations conducted for Maastricht Tuffeau (which under dry conditions displays the propagation of a compaction front) revealed that elevated excess pore pressure during deformation abruptly interrupts the propagation of the initial compaction propagation front initiated at the zone of highest porosity and forces a transition of the zone of compaction close to the drainage boundaries. This study highlights the importance of the spatial heterogeneity of hydro-mechanical feedbacks on the formation of strain localization in rocks, especially if localized deformation is coupled with both pore fluid flow and the hydraulic conductivity of the material.

Simulation of vehicle impact with barriers based on the Discrete Element Method

Abinet K. Habtemariam; Fraunhofer EMI & SIRIOS; Germany
Kai Fischer; Fraunhofer EMI; Germany
Luis Brunnabend; Fraunhofer EMI & SIRIOS; Germany
Alexander Stolz; Fraunhofer Institute for High-Speed Dynamics, Ernst-Mach-Institut; Germany

Analysis of vehicle collision with barriers is important to determine the outcome of vehicles crashing into road safety barriers and vehicle ramming attacks into crowds over perimeter protection barriers. The behavior of barriers under vehicle impact has been investigated based on experimental and finite-element (FE) numerical approaches, which are expensive and time-consuming. Several studies have proposed to reduce the computation time of the numerical analysis by substituting the complex FE models of vehicles using simplified mass-spring-damper system models. However, these models have drawbacks since consideration of different vehicle impact angles is difficult and they are unable to correctly simulate the risk of high-speed vehicle collision climbing over the barrier.

In this study, a new approach is proposed to simulate the collision of vehicles with barriers based on the discrete element method (DEM). Here, to save computation time only a handful of 3D non-spherical particles are used to represent the barrier and vehicle. These particles are generated based on the superquadric function, which is capable of generating a variety of shapes needed for the model. The contact detection and evaluation are carried out based on discrete function representation of the particles with uniform sampling. The bond between two discrete elements is defined using a nonlinear cohesive beam model since the distance between the elements is relatively large. The simulation results obtained based on this approach are more accurate and complete than the simplified mass-spring models and computationally more efficient than the FE model.

Simultaneous seismic input and state estimation with optimal sensor placement for building structures using incomplete acceleration measurements

Jian Li; The University of Kansas; United States
Sdiq Taher; The University of Kansas; United States
Huazhen Fang; The University of Kansas; United States

Simultaneous real-time input and state estimation and optimal sensor placements are discussed in this presentation, focusing on systems without direct feedthrough, such as earthquake-excited building structures with absolute floor acceleration measurements. Current studies showed that system properties such as strong observability, strong* detectability (the asterisk distinguishes strong* detectability from strong detectability), and invertibility conditions are crucial to the stability and convergence of unknown input and state estimation, but they can often be violated in practice. Consequently, uncertainties such as modeling errors and measurement noise can greatly degrade the accuracy and stability of the estimations. Estimation in this case has remained challenging due to the above reasons. To fill this gap, this research develops an optimal sensor placement algorithm (OSPA) for real-time unknown input and state estimation, which ensures the required system conditions are met. The developed OSPA is integrated with two optimal real-time Kalman-based filters, a minimum-variance unbiased input and state estimation filter (MVUIS) and an Augmented State Kalman Filter (ASKF), for simultaneous input and state estimation. In particular, the MVUIS is presented in a recursive three-step structure without using the arbitrary matrix in the gain, which makes no assumptions on the input but requires strong* detectability. To avoid the requirement, ASKF is derived from the MVUIS by incorporating prior knowledge of the input. The developed OSPA along with the MVUIS and ASKF provide the optimal input and state estimation in real-time without incurring low-frequency drift or unstable estimations. Notably, the OSPA improves the performance of MVUIS by reducing amplitude errors and enhances the accuracy of ASKF by reducing phase errors. The developed OSPA integrated with the MVUIS and ASKF are validated through numerical and experimental studies as well as a real-world instrumented building structure under earthquakes using incomplete absolute acceleration measurements.

Sintering for ISRU-Oriented Lunar Regolith Densification: Multiscale Characterization and Multiphysics Computational Modeling

Shayan Gholami; Texas A&M University; United States
Young-Jae Kim; Korea Institute of Civil Engineering and Building Technology; South Korea
Xiang Zhang; University of Nebraska-Lincoln; United States
Yong-Rak Kim; Texas A&M University; United States
Bai Cui; University of Nebraska-Lincoln; United States
Hyu-Soung Shin; Korea Institute of Civil Engineering and Building Technology; South Korea
Jangguen Lee; Korea Institute of Civil Engineering and Building Technology; South Korea

Densification of lunar soil is considered a core mission to produce various kinds of infrastructure materials that can build structural components (such as landing/launch pads, protective shields, berms, roads, etc.) on surface of the Moon. Considering a number of challenges in using resources available on Earth to produce proper construction materials for the Moon, this research is particularly directed to the concept of the in-situ resource utilization (ISRU) by targeting to develop a proper densification method that is only based on in-situ resources. Toward that end, we have explored sintering processes to densify lunar regolith for lunar construction. Two different sintering methods, i.e., spark plasma sintering and microwave sintering, were attempted. Spark plasma sintering, unlike conventional sintering processes, employs a pulse electric current, an applied uniaxial pressure, and rapid heating rate in a vacuum atmosphere to sinter materials. Microwave sintering, which is based on a noncontact heating method where the electric field and magnetic field of the microwaves are coupled, has been considered a promising ISRU fabrication technique since it consumes a significantly lower amount of energy and time than conventional oven sintering techniques. This study first presents the sintering capability of each method at different sintering conditions including temperature, heating rate, and dwell time. To better understand the effect of sintering conditions on the densification behavior and resulting physical-mechanical-geometrical properties, multiscale characterization (microstructure, density/porosity, X-ray diffraction, electron microscopy imaging, nanomechanical properties, and strength) was examined. In addition, to account for several coupled phenomena in the process of sintering, a multiphysics finite element modeling was conducted to simulate sintering at varying conditions. While many challenges are still remained to develop a realistically implementable construction method, test-simulation results from this study imply that sintering is considered a promising ISRU method to densify lunar soils for potential space construction and architecture.

Size effect and failure behavior of woven composites under biaxial flexure

Felix Liu; Stony Brook University; United States
Kedar Kirane; Stony Brook University; United States

This study presents an experimental investigation into the failure and size effect exhibited by woven composite plates subjected to biaxial flexure via the ring on ring test. Square shaped, epoxy carbon twill woven composite plates of various sizes, scaled in all three dimensions are considered. The biaxial flexural response of all plate specimens is observed to be strongly ductile and nonlinear. Failure in plates of all sizes is observed to initiate at the edges on the top surface. The failure develops initially as a fiber kink band, kinking in the out of plane direction, and is followed by out of plane fiber shear failure. These combined compression/shear cracks propagate towards the center of the plates, exhibiting a four-fold symmetry, and revealing the tendency for folding into a cone. This failure behavior contrasts with prior observations on similar tests, where failure initiated at the plate center. This likely stems from the higher ductility of the present matrix under biaxial compression, compared to uniaxial compression. FEA based elastic stress analysis is presented to interpret the observations which suggest that the failure initiation is predominantly driven by in-plane compression parallel to the edge. The nominal stress at the onset of non-linearity is found to obey a type I size effect law, exhibiting a marked decrease with increased plate dimensions, and appearing to become constant with increasing size. This size effect must be duly accounted for when designing plate components of woven composites that might be subjected to biaxial bending.

Size effect of glued laminated timber beams predicted by numerical simulations

Markus Lukacevic; TU Wien; Austria
Christoffer Vida; TU Wien; Austria
Josef Füssl; TU Wien; Austria

The effort involved in experimentally testing glued laminated timber (GLT) beams is tremendous. Especially for large beams, they are making experimental investigations of such beams unavailable. However, large GLT beams are commonly used today. Numerical simulation campaigns offer an efficient alternative to study also large GLT beams. To this end, we developed a modeling concept that uses deterministic material properties and advanced modeling concepts, including discrete cracking and plasticity [1]. We use this concept to investigate the size effect of GLT beams in our simulation program with more than 8000 simulations [2]. The developed modeling concept was applied to simulate the bending strength of GLT beams ranging from 165 mm to 3300 mm in depth. The size effect for the two investigated strength classes had about the same extent, and the characteristic bending strength decreased with increasing beam size. The study also shows that the change in the beam length results in a decrease in strength. Furthermore, the influence of different global failure criteria was investigated, with which results from the literature could successfully be recreated [3].

[1] C. Vida, M. Lukacevic, J. Eberhardsteiner, J. Füssl, "Modeling approach to estimate the bending strength and failure mechanisms of glued laminated timber beams", Engineering Structures 255:113862, 2022. https://doi.org/10.1016/j.engstruct.2022.113862

[2] C. Vida, M. Lukacevic, G. Hochreiner, J. Füssl, "Size effect on bending strength of glued laminated timber predicted by a numerical simulation concept including discrete cracking", Materials & Design 225:111550, 2023. https://doi.org/10.1016/j.matdes.2022.111550

[3] C. Vida, M. Lukacevic, G. Hochreiner, J. Füssl, "Size effect of glued laminated timber predicted by simulation concepts – Influence of global failure criterion definition on bending strength and failure mechanism" (in preparation)

Size Effect on Random Structural Strength of Prenotched Quasibrittle Structures

Jia-Liang Le; University of Minnesota; United States
Jan Eliáš; Brno University of Technology; Czechia

This study investigates the size effects on the mean and variance of the nominal strength of prenotched quasibrittle structures. Over the past three decades, the size effect on the mean strength of this type of structures has been studied extensively by various analytical, computational, and experimental means. However, very limited attention has been paid to the size effect on the second moment of the statistics of the nominal strength, which is crucial for the reliability analysis of structures. In this study, we perform a set of stochastic simulations of failure of geometrically similar ceramic specimens of different sizes. The simulation uses a continuum damage model, in which the tensile strength and fracture energy are treated as spatially random variables.

The present numerical analysis yields the size effects on both the mean and variance of the nominal structural strength. It is shown that the size effect on the mean strength agrees well with the well-established scaling model, derived from the equivalent linear elastic fracture mechanics. The simulation predicts a strong size effect on the coefficient of variation (CoV) of the nominal strength. The asymptotic scaling behavior of the CoV at the small-size limit is justified by a plastic analysis, in which the nominal strength is expressed by the local average of the random tensile strength. At the large size limit, the scaling of CoV can be determined by a cohesive crack model, in which the cohesive law exhibits a spatial randomness but yet the size of the cohesive zone (or fracture process zone) is a constant. Based on these two asymptotes, an approximate scaling equation is proposed for the CoV of nominal strength.

Size effect on the thermoelastic behavior of a particulate composite beam - a comparative study of micromechanical models and numerical simulation

Jinming Zhang; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States

S.H. Chu; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States

Chunlin Wu; Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University; China

Huiming Yin; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States

Consider a composite beam containing identical spherical particles. The particle size effect on the overall thermoelastic behavior of a particulate composite reduces with the specimen-particle size ratio (SPR). Therefore, when the size of the representative volume element (RVE) is large enough, the effective stiffness converges. Consequently, the composite can be represented by a homogeneous material. Hill's theorem shows that uniform displacement or stress loads on the RVE lead to the same convergent stiffness of the composite. However, a challenging question is how large an RVE or SPR is adequate to provide convergent results for different loading conditions. This work uses the inclusion-based boundary element method (iBEM) to simulate four loading cases of composite beams, (i) uniaxial loading, (ii) pure bending, (iii)uniform temperature change, and (iv) a uniform transverse heat flow. For each case, given a volume fraction of particles and configuration of the beam, reducing the particle size, the effective deformation is exhibited. The algorithm is verified by the analytical solution for a single particle and the finite element method (FEM) for a few particles; however, iBEM can simulate much more particles with the fast multipole method (FMM) applied to the iBEM. The comparative study between the micromechanical models and numerical simulation shows that the convergent SPR significantly changes with the loading condition. Much larger SPR is required for pure bending and uniform heat flux than the other two cases.

Smoothed particle hydrodynamics development for modeling granular biomass handling

Yumeng Zhao; Georgia Institute of Technology; United States
Whencheng Jin; Idaho National Laboratory; United States
Sheng Dai; Georgia Institute of Technology; United States

As a renewable energy resource, biomass is an alternative carbon-neutral energy to replace fossil fuels. However, granular biomass material handling issues, such as jamming and clogging, hinder the economic feasibility of biomass-derived fuels. Computational tools capable of simulating biomass handling processes are one of the cornerstones to understanding biomass flow physics and addressing the handling issues. Yet, the inherent large deformation associated with handling challenges the conventional mesh-based modeling tools like the Finite Element Method (FEM). In this presentation, we will show that a GPU-accelerated mesh-free Smoothed Particle Hydrodynamics (SPH) code, with a novel frictional wall boundary condition and a hypoplastic constitutive model, is able to successfully capture the mechanical behavior of granular biomass materials. A suite of simulation cases, including an elastic block sliding on a frictional wall, angle of repose, and axial compression, have been performed and compared against physical experiments. A great match was found between the prediction and experimental data, which validates the effectiveness of the developed SPH tool. This tool has the potential to characterize and understand the flow behavior of granular biomass materials and help to guide innovative handling equipment design and operation.

Soft Solid-Liquid Composites in Biomedical Applications: Understanding the Size Effect

Karthik Kundapur; West Texas A&M University; United States
Vinu Unnikrishnan; West Texas A&M University; United States

Soft composites with liquid inclusions can exhibit true multi-functional behavior and such composites have shown promising applications in soft robotics, 3D printing, animal cell biology to name a few. Mathematical modeling of these composite systems is not fully developed due to the complexity of interaction between the participating phases. Conventional micro-mechanical methods consider the matrix and inclusions bulk linear-elastic properties and usually does not account for the energy of interaction of the interfaces, including the surface free energy and surface stresses. In this work, the effective mechanical properties of novel solid-liquid composites will be studied using a micro-mechanics approach considering the effect of droplet size and electro-capillary length scale effects, in addition to the elastic properties of the constituent phases. The developed model will be applied to the study of solid-liquid composites used in various biomedical applications.

Spatial and Computational Analysis to Prioritize Green and Grey Flood Infrastructure under Uncertainty to Increase Resilience

Michelle Reckner; Georgia Institute of Technology; United States
Iris Tien; Georgia Institute of Technology; United States

Communities across the globe are facing increased flooding due to climate change. To reduce flooding impacts, there has been increasing investment in flood infrastructure. The types of flood infrastructure being considered include green (e.g., nature-based), and grey (e.g., hard-scaped) solutions. Not one solution is optimal for every location or application, and there are challenges in selecting what type of solution to implement. Each solution provides different benefits, are space-based, and require a combination of benefit and hazard analysis to support hazard mitigation decisions. Deciding where to invest in green or grey infrastructure across a flood-prone community and finding the threshold between either investment at a particular location is not well understood. Spatial computational approaches enable such detailed analysis to be conducted. Doing so provides a method for communities to place stormwater infrastructure in optimized locations to increase community flood resilience considering flood control and meeting the varying needs of surrounding communities of people. In addition, there is uncertainty in the environmental and population variables and decision-maker preferences that need to be accounted for in the decision-making process. This research proposes a method to prioritize locations for stormwater infrastructure. Compared to prior work, it considers both green and grey infrastructure solutions and analyzes the community in its entirety, rather than one site at a time. The method is based on a spatial mapping approach using quantitative measures and includes a range of factors across a community and the multiple potential benefits of green versus grey infrastructure. It includes decision-maker input to provide communities with a pathway to make infrastructure placement decisions including local community characteristics and stakeholder priorities. The method is applied to the coastal county of Chatham County, GA, a community subject to flooding on the eastern shore of the United States. Results show how the methodology is used to select green or grey infrastructure solutions and highlight locations that should be prioritized for infrastructure investment. Analyses accounting for uncertainties in future climate projections and population estimates are also conducted. The method results in clearly prioritized infrastructure locations and enables the solutions to be adapted as community and decision-maker priorities evolve to increase community flood resilience.

Stability of a novel all-steel modular floor assembly

Rajshri Chidambaram Muthu Kumar; Johns Hopkins University; United States
Sandor Adany; Johns Hopkins University; United States
Benjamin Schafer; Johns Hopkins University; United States

The objective of this work is to investigate the structural stability of a new all-steel modular floor assembly using the open-source finite strip method stability software (CUFSM, stands for Constrained Unconstrained Finite Strip Method). The prototype floor assembly consists of a pair of wide flange beams with a steel plate attached across the top, and a separate raised access floor system installed on top of the floor plate. Currently, the open-source finite strip software CUFSM performs stability analysis of thin-walled members, providing eigen buckling loads and the corresponding buckling mode shapes. The same framework and solvers may readily be extended to vibration analysis, as both are eigenvalue problems, and thus the extended software can provide eigen frequencies and the corresponding vibration mode shapes. To demonstrate the efficiency of having both stability and vibration solutions readily at hand, preliminary assessment of a floor assembly is performed for a variety of parameters, e.g., beam size, plate thickness, and attachment assumptions using the finite strip method as implemented in a custom version of CUFSM. Typically, finite strip analysis employs pre-buckling stresses that are determined a priori – to this end the analyses explore the impact of assuming the plate is stress-free or acts compositely with the beams. The analysis provides an assessment of the plate's ability to influence local and lateral-torsional buckling moments of the floor and the frequency of the assembly. The work is part of a larger effort that is also investigating detailed shell finite element models, experimental strength, vibration, and acoustical assessments of the floor assembly.

Stability of kangaroo rat burrows in the Sonoran Desert: initial evidence of bio-cementation

Sera Tirkes; North Carolina State University; United States
Duygu Aydin; Washington State University; United States
Haluk Beyenal; Washington State University; United States
Clint Collins; Sacramento State University; United States
Idil Deniz Akin; North Carolina State University; United States

Kangaroo rats are keystone desert rodents that construct complex burrow systems in loose desert sand. The burrows of kangaroo rats stay stable in harsh desert environments and survive daily and yearly temperature and RH fluctuations and possibly multiple convective rainfall events or high-intensity storms over the years. Animals that burrow in desert sand typically burrow when the soil is unsaturated to take advantage of increased interparticle attraction due to capillary forces, burrow in compacted sand, or burrow near plant roots for added structural support. However, these mechanisms are not sufficient to explain the tunnel stability of kangaroo rats (Dipodomys deserti). Therefore, this study aimed to understand how kangaroo rat burrows stay stable in loose desert sand, with the goal of transferring this knowledge to human geotechnical systems. A kangaroo rat habitat in the sand dunes of the Sonoran Desert, near Yuma AZ was selected for the study. The site consisted of dozens of active and abandoned burrows. Dynamic cone penetrometer test performed at abandoned burrow sites and no-burrow sites demonstrated layered burrow structure of kangaroo rats in loose sand. Soil samples collected from the ceilings of the burrows and from non-burrow sites were characterized. Brazilian tensile strength test results showed that burrow soil has approximately 3 times greater tensile strength than non-burrow soil at dry state, which indicates increased interparticle attractive forces in burrow ceilings. Scanning electron microscopy and confocal microscopy images provided initial evidence that the increased attractive force in burrow ceilings is due to fungal and microbial biofilms. The burrow biofilms that were grown in laboratory conditions showed potential for burrow biofilms to be used in soil improvement.

Stability of Thin Cylindrical Shells Under Combined Bending and Torsion

Victoria Ding; Johns Hopkins University; United States
Shahab Torabian; Johns Hopkins University; United States
Sandor Adany; Johns Hopkins University; United States
Xiang Yun; Sheffield University; United Kingdom
Ben Schafer; Johns Hopkins University; United States

Cylindrical shells with large diameter-to-thickness ratios (normally around 180) are widely used in wind turbine towers. Stability of these thin-walled shell structures is an essential concern, along with cross-section actions on wind turbine towers involving interactions of compression, bending, shear, and torsion arising from both environmental and operational load case conditions. Combined bending and torsion are commonly the dominant actions in the upper tower segments. The high diameter-to-thickness ratios of these cylinders make them highly imperfection sensitive, which means failure loads and failure modes are highly dependent on initial geometries of the cylinders. Though there have been extensive studies into the stability and design of cylinders subjected to isolated loading conditions (i.e. pure compression or pure bending), investigations into the structural response of thin-walled cylinders under combined bending and torsion remain scarce. To address the knowledge gap, an experimental study was conducted on the stability of cylinders under combined bending and torsion. A total of 48 cylinders with diameter-to-thickness ratios ranging between 127 and 320 were tested under varying bending and torsion combinations. To better understand how imperfections affect the buckling modes of these thin-walled cylinders, a 3D laser scanner was used to determine geometric imperfections of each test specimen prior to testing. The test setup and cylinder structural response, including ultimate resistances, load-deformation characteristics, effects of imperfections, and buckling behavior are reported. Future work will involve establishing high-fidelity finite element models capable of capturing the buckling strength and failure modes of thin-walled cylinders under combined bending and torsion and developing reliable and efficient design approaches for such structural elements.

State-Input-Parameter Identifiability in Output Only Structural Identification

Adrita Kundu; Indian Institute of Technology, Kanpur; India
Suparno Mukhopadhyay; Indian Institute of Technology, Kanpur; India

The success of any structural identification and/or state estimation method depends on the identifiability of the parameters and dynamic states of interest vis-à-vis the instrumentation set-up. Thus, deciding on an instrumentation set-up ensuring identifiability remains an important, although challenging, issue in state-parameter estimation problems. The challenge of ensuring identifiability increases in output only measurement situations, when, along with structural parameters and dynamic states, the unmeasured input(s) may also be of interest and may need to be estimated. In this work, the problem of identifiability in output-only situations is studied using a perturbation approach. Different types of unknown input excitations are considered: input at any one degree of freedom, proportional inputs at all degrees of freedom, and base excitation. Starting with a fully instrumented set-up, the instrumentation is gradually reduced to study how the absence of different types of output measurements, from different degrees of freedom, affects the identifiability of the structural parameters, dynamic states and the unmeasured input(s). The observations from the theoretical study are verified using a suite of numerical simulations of joint state-parameter-input estimation. For the estimation in these simulations, the Unscented Kalman Filter is used, with the unmeasured input(s) to be identified being augmented to the state vector and propagated with a random walk model, and with suitable associated process noise. The results from the numerical simulations are found to corroborate the theoretical observations reasonably well.

Static friction models for a rod deforming on a cylinder

Gert van der Heijden; University College London; United Kingdom
Rehan Shah; University College London; United Kingdom

We develop a comprehensive geometrically-exact theory for an end-loaded elastic rod constrained to deform on a cylindrical surface. By viewing the rod-cylinder system as a special case of an elastic braid, we are able to obtain all forces and moments imparted by the deforming rod to the cylinder as well as all contact reactions. This framework allows us to give a complete treatment of static friction consistent with force and moment balance. In addition to the commonly considered model of hard frictionless contact we analyse in detail two friction models in which the rod, possibly with intrinsic curvature, experiences either lateral or tangential friction. As applications of the theory we study buckling of the constrained rod under compressive and torsional loads, finding critical loads to depend on Coulomb-like friction parameters, as well as the tendency of the rod to lift off the cylinder under further loading. Our results are relevant for many engineering and medical applications in which a slender structure winds inside or outside a cylindrical boundary and also has applications in the filament winding process used in the manufacturing of composite materials.

Statistical Comparison of Resilience for Civil Infrastructure Systems and Application for Rural Distribution System subject to Hurricane Hazards

ZhiQiang Chen; University of Missouri Kansas City; United States
Prativa Sharma; University of Missouri Kansas City; United States

Quantitative research on defining and computing resilience continues proliferating to this end. In most endeavors, resilience as a mathematical measure is calculated as a geometric area quantity under a function curve considering system disruption and restoration. Many efforts acknowledge the uncertainties in resilience computing and resort to probabilistic modeling and statistical analysis methods. However, we recognize a critical gap in quantitative resilience assessment for civil infrastructure systems. Specifically, a theoretical framework is not found for quantifying the differences or migration in system resilience given a parametric infrastructure system subjected to changing conditions. Without an objective resilience-comparing framework, the resilience of a parametric system cannot be compared objectively, primarily when high-level parameters exist and vary their values, including physical system parameters (e.g., degree of aging and intensity of hazards) and socioeconomic, organizational, and technological parameters relevant to resourcefulness. In this work, we propose a set of statistical tools for analyzing the system resilience of civil infrastructure and specifically focus on rural electric distribution systems subjected to hurricane hazards. Under the proposed statistical comparative resilience analysis (SCRA) framework, non-parametric statistical methods, including the adoption of copula analysis and non-parametric distance measures, are presented. Given a hurricane event, we will study the characteristics of rural distribution systems and model resourcefulness parameters in the socio-economic space in the recovery process. Numerical experiments and results are revealed for a rural distribution system that verifies the proposed framework.

Stochastic Buckling Analysis of Geometrically Imperfect Spherical Shells

Zheren Baizhikova; University of Houston; United States
Jia-Liang Le; University of Minnesota; United States
Roberto Ballarini; University of Houston; United States

The behavior and buckling resistance of shells are highly sensitive to the presence of randomly distributed geometrical imperfections. For example, for a spherical shell of radius R and thickness t, the buckling pressure is not determined uniquely by R/t, as predicted by deterministic buckling analyses, but instead shows significant scatter. The design against buckling failure of such structures relies on the "knockdown factor", which is defined as the ratio between the buckling load of the imperfect shell and that predicted by the buckling analysis of the perfect shell. Extensive literature shows that experimentally measured knockdown factors themselves exhibit a significant degree of variability. This suggests that knockdown factors may exhibit a "size effect", thus introducing a buckling resistance that depends on R/t and R/e, where e is a length scale associated with the description of the random shape of the initial imperfection. This study explores the potential presence of this size effect by investigating the statistics of the knockdown factor of imperfect spherical shells with random geometrical imperfections. The spatial randomness of the initial imperfection is modeled by a homogenous random field, first generated on a 2D Euclidean space using Karhunen-Loeve expansion, and then mapped onto the spherical surface. Finite Element Method-based Monte Carlo simulations are performed to determine the mean and standard deviation of the knockdown factor. The computational analysis considers spherical shells of different sizes with the same statistics of the initial geometrical imperfection. The results shows a size effect on the statistics of the knowndown factor, which has important implications for design extrapolation of large-scale shell structures.

Stochastic emulation of seismic structural response using enhanced partial replication strategy

Sang-ri Yi; University of California, Berkeley; United States
Alexandros Taflanidis; University of Notre Dame; United States

Simulation-based seismic risk assessment requires multiple nonlinear time history analyses, which can be computationally taxing. To reduce the computational burden, surrogate modeling techniques can be utilized, and in particular, a stochastic emulator provides a viable tool to accurately capture the aleatory uncertainty in structural responses attributing from the random ground time histories. As one such effort, a recent work proposed a stochastic kriging formulation based on partial replication samples, meaning some training samples are unique in terms of the simulation input, and the other set of samples offer more than one output realization per simulation input. The latter is particularly useful in disaggregating the observation outputs into the pure aleatory uncertainty (noise) and the mean response (signal). In particular, the sample variance is evaluated for each replicated sample set, which is then served as the observations to approximate the heteroscedastic variance-field. However, non-replicated samples have not been utilized in this step because they cannot solely give information on the variance level. To further improve this aspect, in this research, an enhanced training approach is proposed, which fully engages non-replication points by estimating the deviation of each sample from the externally obtained mean estimate and feeding this into the variance-field estimation. This external estimation of the mean is obtained by introducing an auxiliary kriging model to the same training data but with a simplified assumption of homoscedasticity. The numerical examples using real-world building models and earthquake simulation models show that the proposed stochastic kriging approach is capable of emulating underlying heteroscedastic variance of the process with high prediction accuracy, while this improvement of variance prediction further enhances the mean predictions.

Stochastic Lattice Discrete Particle Modeling of Fracture in Pervious Cementitious Composites

Alessandro Fascetti; University of Pittsburgh; United States
John Bolander; University of California, Davis; United States

Highly permeable cementitious composites offer several attractive features for the construction industry, as a result of their large, connected pore structures, resulting in porosity levels ranging from 5 to 30%. These materials can be used for various applications in Civil Engineering (e.g., stormwater management, traffic noise control, and environmental preservation), by making use of their high hydraulic conductivity and low thermal capacity. However, concerns on mechanical performance, such as the relatively low compressive strength, arise from the porous microstructure. In this framework, this talk will present a recently developed Lattice Discrete Particle Model (LDPM) for stochastic simulations of the mechanical behavior of pervious concrete. Digital images of the material microstructure, obtained from test specimens, are used to produce statistically representative descriptors of the pore networks by means of a spatially correlated random field. The random field information is then mapped onto the lattice discrete particle model, linking the topology of the computational network to the local distribution of porosity by means of a ray tracing technique, which is used to evaluate the effective distributions of mass, stiffness, and strength at the lattice level. The proposed LDPM approach is capable of simulating both the large scatter in compressive strength values and the variety of failure modes that are observed when testing physical pervious concrete specimens.

Strain Field Distribution in Asphalt Mixes Using Digital Image Correlation

Babak Asadi; University of Illinois at Urbana-Champaign; United States
Ramez Hajj; University of Illinois at Urbana-Champaign; United States

The large difference between the modulus of asphalt concrete components results in a complicated deformation phenomenon. Isotropic deformation measurement of this heterogeneous material is difficult to achieve through conventional testing methods due to difficulties in capturing local deformation. This study aims to characterize the material behavior by quantifying its strain field at multiscale levels (i.e., the bulk of asphalt concrete, asphalt mortar, and asphalt mastic) using digital image correlation (DIC). Our focus here is on investigating the alteration of material response on the service life. To this end, fracture tests are conducted on short and long-term-aged semi-circular bend edge cracked specimens obtained from a dense graded mix with different air void contents ranging from 2 to 8%. The fracture event is recorded using DIC with a high spatial resolution of around 8 micrometers per pixel. The results of this study help establish a more robust approach to adopting testing conditions for the characterization of asphalt materials.

Strain Transfer Mechanisms of Fiber Optic Sensors and Recent Applications of Distributed Fiber Optic Sensing on Structural Component Testing

Shenghan Zhang; Hong Kong University of Science and Technology; Hong Kong
Matthew DeJong; University of California, Berkeley; United States

To interpret strain sensing data for distributed fiber optic sensing, it is necessary to comprehend the strain transfer mechanism of fiber optic cables. Currently, there is still a lack of understanding of the behavior of fiber optic cables embedded in cementitious materials (e.g., concrete) while sustaining discontinuous displacement boundary condition. In this study, we investigate the strain transfer mechanism for several types of fiber optic cables embedded in concrete cubes and subjected to a boundary condition characterized by a displacement discontinuity, based on which the mechanical properties of the fiber optic cables are presented and discussed. Under cyclic loading, the nonlinear behavior of the force–displacement relation and of the strain distribution in the fiber optic cable are discussed. We also propose a parameter to quantify the strain transfer length. Furthermore, we will discuss the results of some recent applications on structural component testing using distributed fiber optic sensing, in which we evaluate the performance and limitations of the DFOS system using different types of fiber optic cables and under varying drift levels. Structural damage indices are also proposed based on the DFOS results.

Stress and Fracture Analysis of a Perforated Spherical Container under Internal Pressure

Xin He; Columbia University; United States
Huiming Yin; Columbia University; United States

The stress and fracture analysis is critical for the design of spherical containers under high internal pressure. In reality, the spherical container is not completely closed but has a hole acting as an inlet or outlet. The existence of a hole breaks the axial symmetry and increases the complexity as neither plane strain nor plane stress assumption can be employed. Instead, a full 3-dimensional (3D) equilibrium equation should be established and solved. In this study, a 3D elastic theoretical model is developed to study the stress field in the perforated spherical container driven by internal pressure. The displacement and stress fields are explicitly solved and validated with the finite element simulation results. In addition, preliminary fracture analysis is conducted based on the solved displacement and stress fields. The results show that the model presented in this study is able to capture the displacement and stress distributions in the spherical container with a hole and predict the fracture initiation well. Meanwhile, parametric studies are included to investigate the effect of hole size and magnitude of internal pressure on the required thickness of the spherical container, which provides guidance for the safety design of this type of spherical container.

Stress focusing and damage protection in topological Maxwell metamaterials

Caleb Widstrand; University of Minnesota; United States
Chen Hu; University of Minnesota; United States
Xiaoming Mao; University of Michigan; United States
Joseph Labuz; University of Minnesota; United States
Stefano Gonella; University of Minnesota; United States

Advances in the field of topological mechanics have highlighted some special mechanical properties of Maxwell lattices, including the ability to focus zero-energy floppy modes and states of self-stress (SSS) at their edges and interfaces. These phenomena are topologically protected against perturbations in the lattice geometry and material properties, which makes them robust against structural non-idealities, defects, and damage. Recent theoretical work has shown that the ability of Maxwell lattices to focus stress along prescribed SSS domain walls can be harnessed to protect other regions in the bulk of the lattice from detrimental stress concentration and inhibit the onset of fracture mechanisms at stress hot spots such as holes and cracks. This property provides a powerful tool for the design of lattice configurations that are robust against damage and fracture. In this work, we provide a comprehensive experimental exploration of this idea in the context of realistic structural lattices characterized by non-ideal, finite-thickness hinges. Our experiments document the onset of pronounced domain wall stress focusing, indicating robustness of the polarization even in the presence of the dilutive effects of the structural hinges. We also touch on the extension of this material framework to soft structures where dramatic geometrical reconfiguration can occur. This reconfiguration can lead to an observable transition between the topological states of the lattice and cause change in the stress focusing behavior.

Stress-constrained topology optimization of anisotropic structures

Oliver Giraldo-Londono; University of Missouri; United States
Rogelio Muneton-Lopez; University of Missouri; United States
Chadwick Bettale; University of Missouri; United States

Additive manufacturing (AM) enables the fabrication of parts of nearly arbitrary geometry, and thus, the community has almost ubiquitously adopted this manufacturing technique to fabricate structures designed via topology optimization. However, there seems to be a disconnection between theory and practice, as most topology optimization formulations neglect AM-related constraints. Specifically, most topology optimization formulations neglect the anisotropy induced by the layer-by-layer fabrication process that is typical of most AM technologies. To overcome this limitation, here we introduce a stress-constrained topology optimization formulation for the design of lightweight anisotropic structures, which accounts for the anisotropy of the material's elastic properties and its failure behavior. To handle material failure, we consider two anisotropic failure criteria, namely the Tsai-Wu and the Liu-Huang-Stout criteria and derive vectorized expressions that are amenable for implementation in a high-performance computing environment. To solve the optimization problem consistently with the local nature of stress, we adopt a local approach based on the augmented Lagrangian method. In this presentation, we will provide details of the formulation and present several numerical examples to illustrate the effectiveness of the approach to design structures made of anisotropic materials.

Strong and tough fibrous hydrogels reinforced by multiscale hierarchical structures with multimechanisms

Huajian Gao; Nanyang Technological University; Singapore

Tough natural materials such as nacre, bone, and silk exhibit multiscale hierarchical structures where distinct toughening mechanisms occur at each level of the hierarchy, ranging from molecular uncoiling to microscale fibrillar sliding to macroscale crack deflection. An open question is whether and how the multiscale design motifs of natural materials can be translated to the development of next-generation biomimetic hydrogels. Here, I will discuss a recent work [1] on fabricating strong and tough hydrogel with architected multiscale hierarchical structures using a freeze-casting–assisted solution substitution strategy. The underlying multiscale multimechanisms are attributed to the gel's hierarchical structures; hydrogen bond–enhanced fibers with nanocrystalline domains; and cross-linked strong polyvinyl alcohol chains with chain-connecting ionic bonds. This study establishes a blueprint of structure-performance mechanisms in tough hierarchically structured hydrogels and can inspire advanced design strategies for other promising hierarchical materials.

Reference: [1] X. Guo, X.Y. Dong, G.J. Zou, H.J. Gao and W. Zhai, 2023, Science Advances, 9, eadf7075. DOI: 10.1126/sciadv.adf7075

Structural Behavior of 3D Printed Concrete Buildings Subjected to Seismic Loads: Numerical Modeling

Hao Chen; Texas A&M University; United States
Mohammad Aghajani Delavar; Texas A&M University; United States
Sumedh Sharma; Texas A&M University; United States
Petros Sideris; Texas A&M University; United States

Three-dimensional (3D) extrusion-based concrete printing is a novel construction strategy having the potential to revolutionize the construction industry and the structural engineering discipline due to its rapid onsite constructability and low construction cost. One of the first applications of this technology is on providing affordable housing to address the housing crisis as well as homelessness. However, structural behavior of these buildings under natural hazards, like earthquake, has not been studied to ensure code compliant performance. To address this shortcoming, finite element modeling is used to investigate the behavior of low-rise 3D printed concrete (3DPC) structures built toward residential applications under seismic loads. First, detailed numerical model of a recently proposed 3DPC wall system, which is a part of the seismic force resisting system, was developed and validated with experimental results. The proposed 3DPC wall design includes integrated internal RC elements and bed-joint reinforcements. For computational efficiency, the printed concrete was modeled using thick shell elements, the RC elements were modeled using fiber-based beam elements, and the ladder mesh was modeled using truss elements. Then, a simplified numerical model consisting of a single truss element and hysteretic material model was developed to simulate the lateral load performance of the frames consisting of 3DPC wall. The simplified numerical model, which is more suited to run non-linear dynamic analysis, was used to investigate building's lateral performance by using two springs in each orthogonal direction. The detailed and simplified numerical models were used to carry out parametric study which consisted of approximately 90 wall designs and five residential buildings. The modeling strategy and the findings from the parametric study will be discussed in this presentation.

Structural connection with predetermined discrete variable friction forces for high-performance earthquake-resistant buildings

Kaixin Chen; University of California San Diego; United States
Georgios Tsampras; University of California San Diego; United States

We present a simple and practical structural connection able to develop predetermined discrete variable friction forces at target design displacement levels. The connection is termed Modified Friction Device (Modified FD). The Modified FD is developed as the force-limiting connection between the floor diaphragms and the core wall piers in buildings with a core wall seismic force-resisting system. The discrete variable friction forces of the Modified FD (1) limit the force transferred between the floor diaphragms and the core wall piers and (2) provide an equivalent post-elastic stiffness so that excessive connection deformations can be prevented. The schematics of the physical embodiment, the components, and the assembly of the Modified FD are presented. The kinematics of the Modified FD are explained. The design parameters of the Modified FD are discussed. Results from static structural analyses of two types of finite element models of the Modified FD are presented. The first model is developed using solid finite elements and it is used to assess the expected kinematics and the expected force-displacement response of the Modified FD. The second model is developed using a truss finite element and it can be used to efficiently simulate the force-displacement response of the Modified FD in numerical earthquake simulations of structural systems. Numerical earthquake simulations of single-degree-of-freedom systems with inelastic restoring force-displacement response that simulated the Modified FD are conducted. The numerical earthquake simulations assess the effect of Modified FD force-displacement parameters on the ductility demand of the single-degree-of-freedom systems.

Structural Dynamics Learning using a Supervised Variational Auto-Encoder (SVAE)

Kiran Bacsa; Singapore ETH; Singapore
Wei Liu; Singapore ETH; Singapore
Eleni Chatzi; ETH Zurich; Switzerland

In this study, we propose a novel approach for learning structural dynamics using a Supervised Variational Auto-encoder (SVAE). The SVAE is trained on a dataset of sensor measurements collected from a monitored structure, with an auxiliary classification on the basis of structural stiffness parameters. The goal of the primary task is to learn a compact and expressive representation of the dynamics of the structure that generalizes across different stiffness characteristics. This opens opportunities for i) anomaly detection tasks by predicting the normal system performance of a healthy state, but more importantly, ii) transfer learning, where structural performance is predicted for systems of diverse stiffness characteristics. We evaluate the performance of the SVAE by comparing its ability to reconstruct unseen sensor measurements with that of the VAE and the CVAE (Conditional VAE). Additionally, the transfer learning potential is evaluated by comparing the performance of the SVAE on unseen real data after fine-tuning with simulated data. Our results show that the VAE is able to accurately capture the dynamics of the structure and outperforms VAE models in terms of reconstruction accuracy. Furthermore, the learned VAE representation provides a valuable tool for monitoring and controlling the health of dynamic structure and offers a promising potential for transfer learning.

Structural morphing surfaces based on self-standing, snap-through building blocks

Asifur Rahman; Stony Brook University; United States
Samuele Ferracin; University of Pennsylvania; United States
Sujata Tank; Stony Brook University; United States
Paolo Celli; Stony Brook University; United States

We introduce a self-standing, structural building block composed of a flexible frame and one or more arches, whose geometry can be reconfigured via snap-through buckling. By concatenating many of our units in one direction, or by tiling them in two dimensions, we create beam-like structures and morphing surfaces capable of attaining complex stable shapes -- that can be programmed by engineering the sequence in which we locally snap the individual units. To be able to model arrays of our snapping units and their interactions at a low computational cost, we resort to a discrete elastic rod (DER) framework. DER simulations are then validated via classical finite element simulations of a single building block, and by experiments. Our work introduces a structural, yet shape-reversible analog to soft sheets with locally-bistable shells; thus, it opens avenues for the realization of up-scalable structures that, just like their soft counterparts, can display a vast array of stable states and a dependence of their final shape on the snapping sequence. Owing to their simple geometry, our units can also be used as a template to create programmable, multistable surfaces that are actuated via non-mechanical stimuli.

Structural Vibration Monitoring Via Mobile LiDAR

Adriana Trias Blanco; Rowan University; United States
John Vrabel; Rowan University; United States

Determining bridge structural vibrations is an ongoing target in structural health monitoring, with particular interest in finite element model calibration with the purpose of ensuring that the digital twin provides accurate responses. Current methods for structural vibration monitoring implement the use of accelerometers which, even though they provide accurate and reliable data, their installation requires the disruption of traveling traffic, and the sensor provides a single-point response. Moving towards rapid and contactless monitoring of transportation infrastructures, with the purpose of limiting traffic disruption while improving the quantity and diverse applicability of the data collected, this research uses mobile LiDAR data to detect and analyze bridge vibration and geometry deformations. The metadata available from point clouds generated via mobile LiDAR provides X, Y, Z coordinates of each data point, as well as a time stamp that allows for each point to be paired with a location in time. This provides a snapshot of the structure's deformation/shape throughout the length of the monitoring window. The data can then be converted, just as typical accelerometer data, from time domain to frequency domain to inform on the frequency of the modes of vibrations of the structure. But, unlike typical accelerometer data which is limited to single-point response, mobile LiDAR data provides a full-filed view of the structure which can detect unforeseen behaviors that would be missed when using single-point data collection. Currently, this novel application of mobile LiDAR is being tested in the lab with successful results. The team is preparing to collect data out in the field within the next two month, which results will be presented in the conference.

Study of architected materials exhibiting simultaneously negative Poisson's ratio and negative thermal expansion

Yunche Wang; National Cheng Kung University; Taiwan
Tsechun Liso; National Cheng Kung University; Taiwan

Two dimensional architected solids with curved ligaments consisting of two distinct materials are constructed to exhibit effective negative Poisson's ratio (NPR) and negative coefficient of thermal expansion (NCTE). The finite element analysis is adopted in this study. Geometric parameters, such as the radius of curvature of ligaments, are analyzed to obtain their relations to the effective properties of the architected solids. It is found when the radius of curvature increases, effective NPR is less pronounced. Smaller curvature radius gives rise to larger NCTE for a given set of ligament properties. Larger thermal expansion mismatch in the constituents are required to change overall thermal expansion from positive to negative. In addition, effects of negative stiffness on the microstructure of the architected solids are discussed. Our findings here may provide the foundations for developing novel sensors that are needed in applications requiring simultaneously NPR and NCTE.

Study of Effect of Oxide Layer on the Strength of the Cold Spray Layer

Mobin Vandadi; Worcester Polytechnic Institute; Iran
Nima Rahbar; Worcester Polytechnic Institute; United States
Winston Soboyejo; Worcester Polytechnic Institute; United States

The paper presents the results of a study of the cold spray of different metal powders subjected to cold spray conditions. The deformation and cracking phenomena associated with splat formation are elucidated using a combination of molecular dynamics and finite elements simulations. Molecular dynamics is used to calculate the mechanical properties of topical titanium oxide layers that are revealed using high resolution Transmission Electron Microscopy (TEM). Finite element simulations are then used to study and visualize the process of deformation, heating and cracking phenomena associated with the impact of single powder on similar substrates. Insights from the models are used to explain the evolution of spat shape, temperature and cracking phenomena that give rise to particle attachment to similar substrates. It is seen that this layer has considerable impact on the deposition efficiency and due to existence of this layer, much higher properties must be applied.

Studying Neural Network Constitutive Models in Open-Source Finite Element Analysis Software

Nilay Upadhyay; Pennsylvania State University; United States
Wesley Reinhart; Pennsylvania State University; United States

Materials science has relied on simulation and modeling methods to determine the properties and behavior of materials for a long time. Due to the high computational costs of these methods, data-driven methods in the field of material science have gained prominence in recent years. These methods have proven to considerably speed up research practices which has resulted in rapid growth in their application in several domains of material science. One such practice which is being used today to study the experimental and computational data available in material science is the use of Neural Network Constitutive Models (NNCMs). The application of neural networks to act as a surrogate model (i.e., predicting the material behavior without the use of any prescribed functional form) can enable the prediction of complex material behaviors. Hyperelastic materials are an example of such behavior and are used in applications like rail transportation, automotive industry, and fluid seals where high flexibility is required. In addition, multi-material Fused Deposition Modeling enables the fabrication of complex composites which have an even wider range of applications permitted by the combination of geometric and material freedom during design.

We explore the use of NNCMs to model composites of Thermoplastic Polyurethanes (TPUs) with different intrinsic material properties. After training a neural network in the PyTorch machine learning framework, we implement NNCMs in the open-source finite element software FEniCS and deploy them to model material behavior in new geometries and loading conditions. Specifically, we explore how the training protocol for NNCMs influences the quality of the resulting model under simple cases like uniaxial tension and compression as well as shear loads. We believe the flexibility of NNCMs can help address the complexity of modern materials and manufacturing processes and their implementation can facilitate a more efficient design process for components made from such materials.

Super-sensitivity full-field displacement measurements

Shanwu Li; Michigan Technological University; United States
Yongchao Yang; Michigan Technological University; United States

The sensitivity of incoherent optical methods using video cameras (e.g., optical flow and digital image correlation) for full-field displacement measurements, defined by the minimum measurable displacements, is essentially limited by the finite bit depth of the digital camera due to the quantization with round-off error. Quantitatively, the theoretical sensitivity limit is determined by the bit depth B as $\delta p=1/(2^{B}-1)$ [pixel] which corresponds to a displacement causing an intensity change of one gray level. Fortunately, the random noise in the imaging system may be leveraged to perform a natural dithering to overcome the quantization, rendering the possibility to break the sensitivity limit. In this work we study such a theoretical sensitivity limit and present a spatiotemporal pixel-averaging method with dithering to achieve super-sensitivity full-field measurement of displacements.

Superkagome: a framework for augmented topological lattices

Mohammad Charara; University of Minnesota; United States
Stefano Gonella; University of Minnesota; United States

Maxwell lattices are characterized by a number of degrees of freedom that match the number of constraints. A subset of these systems, dubbed topological lattices, have been shown to localize stress and deformation to opposing edges, displaying a polarized mechanical response protected by the reciprocal-space topology of their band structure. This behavior has been documented for structures with one-, two-, and three-dimensional periodicity. In two dimensions, opportunities for topological polarization have, thus far, been largely restricted to the kagome and square lattice benchmark configurations due to the non-triviality of generating arbitrary geometries that abide by Maxwell conditions. Here, we introduce a family of augmented topological lattices that display full in-plane topological polarization, as validated through analytical calculations, computational simulations, and table-top experiments on a 3D-printed prototype. We showcase the versatility of such augmentation via a generalized lattice generation framework. This work serves to push the paradigm in topological mechanical metamaterials to explore a larger subset of topological lattices that will enrich the design landscape.

Supervised Learning with GPR A-scans for Material Property Prediction in Building Envelopes

Ahmed Nirjhar Alam; Pennsylvania State University; United States
Wesley Reinhart; Pennsylvania State University; United States
Rebecca Napolitano; Pennsylvania State University; United States

Ground Penetrating Radar is a widely used technology in nondestructive evaluation and structural health monitoring applications. An important subclass of problems in this domain is the prediction of material types and thicknesses for layered structures, such as investigating the extent of concrete delamination and erosion in enveloped walls and other building structures.

Layer thickness is a continuous property requiring quantitative analysis; this necessitates an inversion model for the problem. Typically, analytical inversion models for thickness predictions require significant manual effort, such as separate investigations into the dielectric properties of the mediums and tuning of signal processing steps such as deconvolution for solving the thin layer problem found in certain thickness inspections. Thus, a model that can automatically use a frame of reference to calculate variations in thickness would expedite diagnostics.

In this work, a variety of machine learning models are created and benchmarked on classification and regression tasks involving material properties of model-building envelopes from experimental GPR A-scans. Both instance-based and parametric modeling schemes are evaluated to develop a general insight into the problem. Reliable performance is achieved for interpolation between in-domain samples, but extrapolation outside of this domain results in poor performance, especially for instance-based models. Parametric regression models are subsequently used to improve extrapolation results. The impact of feature learning and dimensionality reduction for A-scan preprocessing on the model performance is also explored.

Surface and size effect in nanoporous materials

Gilles Pijaudier-Cabot; Université de Pau et des Pays de l'Adour; France
Dono Toussaint; Université de Pau et des Pays de l'Adour; France
Gyorgy Hantal; Université de Pau et des Pays de l'Adour; France
Romain Vermorel; Université de Pau et des Pays de l'Adour; France

In quasi-brittle nanoporous materials, size effect occurs at the structural scale but also at a smaller scale. Widely encountered in chemical engineering, novel material design, manufacturing and pharmaceutical industries, and construction, such materials (with pore sizes up to 50nm typically) are for instance zeolites, hydrated cement paste or porous silica. For instance, values of the Young's modulus that yields the best fit between FEM simulations and experimental data on adsorption-induced deformation are in MCM-41 silica material are 40% to 70% less than the bulk amorphous silica. We investigate the effect of the thickness of plates made of a Lennard Jones FCC crystal subjected to tension with molecular simulations. The global elastic response of the plate depends on its thickness. The Young's modulus and Poisson's ratio are increasing with the thickness of the plate. The stress distributions for unloaded plates exhibit in-plane tensile stresses, denoted as interface stresses, nearby the free surfaces. We observe that an interface stress that is independent of the thickness of the plate cannot be obtained unless the thickness of the plate is large enough. In a similar way, the fracture energy required to break the plate into strips is not independent from the thickness of the plate. It decreases with decreasing thickness. Finally, the fracture energy of a porous material made of hexagonal cells containing voids is obtained qualitatively. It depends on the void ratio, but also on the void size.

Surrogate Model for CO2 Storage with Coupled Flow and Geomechanics and Its Use in MCMC-based Data Assimilation

Yifu Han; Stanford University; United States
Francois Hamon; TotalEnergies; United States
Su Jiang; Stanford University; United States
Louis Durlofsky; Stanford University; United States

Data assimilation for CO2 storage problems involving coupled flow and geomechanics is computationally challenging as it requires many high-fidelity multiphysics simulation runs. For this reason, deep-learning-based surrogate models have been developed for these applications. In this work, we extend the recurrent residual U-Net surrogate model recently introduced by Tang et al. (2022, IJGGC) to treat realizations drawn from multiple geological scenarios characterized by a set of metaparameters. These metaparameters define the correlation length, mean and standard deviation of the log-permeability field, permeability anisotropy ratio, and constants relating porosity to log-permeability. The new open-source coupled flow-geomechanics simulator GEOSX is used to provide the high-fidelity simulation results required for training. For these runs, the metaparameters are sampled from their prior distributions, and realizations are constructed using geological modeling software. We first consider flow-only systems, with 4 Mta CO2 injected via four vertical wells. The trained surrogate model is shown to accurately reproduce GEOSX simulation results, for pressure and saturation at a set of time steps, for new test-case realizations. The surrogate model is then used in a formal Markov chain Monte Carlo (MCMC) data assimilation workflow, where the goal is to reduce uncertainty in the metaparameters and thus in the plume location and pressure field. The MCMC procedure requires over one million function evaluations, so this approach would not be viable with high-fidelity simulation runs. We show that, with observed data from monitoring wells, uncertainty in some metaparameters is reduced significantly (including mean and standard deviation of the log-permeability field, and permeability anisotropy ratio), while for others little uncertainty reduction is achieved. Coupled flow-geomechanics systems are then considered. We assess the impact of various types of measurements (in-situ pressure/saturation, surface displacement) on metaparameter uncertainty for these cases.

Surrogate Modeling of Highway Bridge Column Earthquake Response Using Probabilistic Learning on Manifolds (PLoM)

Peter Lee; Stanford University; United States
Kuanshi Zhong; University of Cincinnati; United States
Sanjay Govindjee; University of California Berkeley; United States
Gregory Deierlein; Stanford University; United States

Probabilistic seismic risk analysis of the highway bridge system is essential for assessing the potential traffic disruption and travel time increase of the impacted community. Its classical framework involves four progressive steps: developing the regional seismic hazard map (e.g., peak ground acceleration map), evaluating the bridge component damage (e.g., regional bridge damage state map), assessing the network performance (e.g., disruption and travel delay map), and predicting the community impact (e.g., accessibility reduction map). The mapping from seismic hazard to bridge component damage can be achieved by (a) the empirical fragility analysis or (b) simulation-based direct analysis. On the one hand, the empirical fragility analysis is efficient, but its results usually have large variations and may be biased depending on how close between the use case and the empirical data. On the other hand, the simulation-based direct analysis improves the accuracy by removing the averaging effect from mixing empirical data but typically it is computationally expensive. In addition, the uncertainty in ground motion characteristics and bridge design properties makes the problem more challenging. This study develops a surrogate modeling approach using Probabilistic Learning on Manifolds (PLoM) method to efficiently estimate the bridge earthquake responses and damage (e.g., reinforcement rupture) with variations in design/modeling parameters and ground motion characteristics. Numerical models of a set of archetype bridges were built and simulated under a suite of ground motion records with increasing intensity levels until the bridge model collapses. The simulated data are used to train the PLoM surrogate model which predicts bridge responses and damage (e.g., deformation demand and rebar fracture) based on the ground motion intensity measure (e.g., response acceleration and duration) and key design parameters (e.g., reinforcement ratio). Validation studies were conducted to show the accuracy of the developed surrogate model and evaluate its computational efficiency compared to the simulation-based direct analysis. Sensitivity analysis was performed in the model development to select important predictors from candidate design parameters. The work on implementation of the developed surrogate models to regional bridge damage state maps will also be discussed.

Sustainable and Resilient Coastal Infrastructure Amidst A Sea Level Rise and Coastal Storm Environment

George Deodatis; Columbia University; United States
Kyle Mandli; Columbia University; United States
Yuki Miura; Morgan Stanley; United States

Coastal regions are being threatened globally by the combination of sea level rise and storm-induced flooding. Recent tropical cyclones are indicating that the disaster threat is likely to be intensified due to climate change. As resources are limited globally, it is critical to allocate them optimally to protect coastal regions at risk. However, planning effectively for such a dual hazard mitigation is a complex problem, given the lack of adequate and reliable data on the future frequency and intensity of coastal storms, the unpredictability and uncertainty of weather patterns and sea-level rise, the uncertainty in the development of the coastal infrastructure, and the vast search space over potential approaches for protection and adaptation. The objective of this work is to establish a general optimization methodology that determines a technically, financially, and socially sound protective strategy. The proposed methodological framework is composed of four individual modules: 1) probabilistic modeling of future storm intensity and frequency, 2) estimation of flooded areas and flood depth time histories using physical models and geographical information systems, 3) quantification of the associated damage for every infrastructure component within the target region (above- and below-ground), and 4) determination of the optimal protective strategy based on cost-benefit analysis and stakeholder feedback. Eventually, the proposed methodological framework provides an optimal strategy for a selected location and time horizon, given a prescribed budget. Case studies in New York City are provided to demonstrate the capabilities of the methodology.

Sustainable Biobased Coatings for In-situ Repair of Damaged Coated Rebars

Sher Afgan; North Dakota State University; United States
Ravi Kiran; Arizona State University; United States

Various coating systems and corrosion inhibitors are employed in the construction industry to protect rebars in concrete pavements and bridge decks from chloride-induced corrosion. Epoxy-based coatings are proven to have reliable corrosion protection capability. However, they are prone to localized damage during transportation which may lead to ingress corrosion during service conditions. The repairs of damaged epoxy coatings can not be carried out at the site due to safety protocols and the requirement for specialized equipment. Moreover, epoxy-coated rebars produce a weak interfacial transition zone (ITZ) with the surrounding concrete. Recently, sustainable biobased corrosion mitigation techniques have been explored, which are economical and less harmful to the environment. In this study, biobased modified soy-protein (MSP) coating materials are synthesized using a mixture of the soy-protein isolate as a base material, food-grade sorbitol as a plasticizer, and a combination of oxides, i.e., SiO2, Al2O3, and ZnO as abrasives. Five different coating formulations (Control with no abrasives, MSP-10-5-0, MSP-10-0-5, MSP-10-5-5, and MSP-10-10-10) are developed using varying amounts and types of abrasives while keeping the dosage of the base material and plasticizer constant. The abrasives are selected owing to their anti-corrosion performance and production of pozzolanic activity, which improves the bond performance of the MSP-coated rebars with the concrete. The formulated coatings are characterized physically using an abrasion resistance test, mechanically using a pull-out test, and electrochemically via a macrocell corrosion test. It is observed that all the MSP coatings showed negligible changes in surface texture when exposed to silicon carbide abrasive. The bond strength improved in the case of all the MSP coatings compared to the control formulation. MSP-10-10-10 at 7 and 28 days of testing age showed an ultimate bond strength of 11.03 MPa and 14.70 MPa, respectively. Potentiodynamic polarization analysis showed a substantial reduction in corrosion current densities. For instance, MSP-10-10-10 offers a 29% reduction compared to the coating formulation without abrasives. The macrocell corrosion test showed that corrosion protection improved by 50% and 78% in the case of MSP-10-5-5 and MSP-10-10-10, respectively, compared to the coating with no abrasives. The possibility of using the proposed MSP coating for the in-situ repair of damaged epoxy-coated rebars in a chloride-induced corrosive environment will be discussed in the talk.

Tailorable thermoelectricity of cubic lattice-based cellular and granular materials by the configuration stress

Chao Liu; Chao Liu; United States
Huiming Yin; Columbia University; United States

When a cubic lattice packaged and wrapped by a boundary layer is subjected to mechanical and temperature loads, the force and length changes of the bonds are equivalently evaluated by the mean stress and strain of the unit cell. Provided a displacement gradient variation at a certain stress state, the variation of stress related to the strain variation provides the effective stiffness of the material at the corresponding configuration. The singum model adopts the Wigner Seitz (WS) cell of the cubic structure as a continuum particle to represent the material, and provides the closed-form solution of the effective elasticity. It is found that the effective elasticity and thermal expansion coefficient can be tailored by the prestress through the boundary layer, which generates configurational stress. Because the bonds of a cubic lattice depend on the material types, we consider the harmonic potential of springs for cellular lattices and Hertz's contact potential of balls for granular lattices, respectively. The cubic symmetry of effective elasticity is demonstrated for the three types of cubic lattices. By taking the orientational average, isotropic elastic constants can be obtained for randomly oriented lattices. As the bond length changes with the prestress of the boundary layer and control the thermoelastic behavior, a novel design method is developed to fabricate novel lattice-based materials with zero thermal expansion and positive temperature derivative of elasticity.

Tall Building Optimization in Regions of High Seismicity: Balancing Stiffness and Ductility Requirements

Abel Diaz; SOM; United States
David Shook; SOM; United States

Topology optimization algorithms have been employed in tall building design by SOM in numerous built projects to identify optimal load paths that maximize stiffness and inform the configuration of lateral force-resisting systems. This design methodology, applied both at the subsystem and at the global building level, has proven to be efficient in both saving material quantities and obtaining architecturally-expressive system solutions. It is a well understood process for design scenarios that stay primarily within linear elastic design domains, such as the design of tall buildings for wind loads, where maximizing stiffness is typically the main performance objective.

In regions of high-seismicity, economical designs often must rely on a significant amount of energy dissipation via inelastic material behavior and the adherence to strict ductility requirements. The multi-objective design optimization problem is particularly challenging in the 100 to 300 meter height range, with commonly divergent sensitivities for the objective functions, and achieving the delicate balance between stiffness and ductility requirements can be a demanding task for the structural engineer.

This paper presents a series of practical designs by SOM to introduce ductility in seismic systems initially developed to maximize stiffness via topology optimization. Case studies are presented for tall building projects subject to multi-hazard design criteria in California and Mexico City.

TelecomTM: A Fine-grained and Ubiquitous Traffic Monitoring System Using Pre-Existing Telecommunication Cables as Sensors

Jingxiao Liu; Stanford University; United States
Siyuan Yuan; Stanford University; United States
Yiwen Dong; Stanford University; United States
Biondo Biondi; Stanford University; United States
Hae Young Noh; Stanford University; United States

Roadway traffic monitoring can help reduce traffic jams and manage emergency situations by understanding traffic patterns. It can also help monitor and maintain transportation infrastructures by providing traffic characteristics, such as vehicle size and weight. Many existing approaches for traffic monitoring use cameras or pavement piezoelectric sensors, but they are limited due to privacy concerns and/or deployment requirements such as clear line-of-sight and dense (and costly) instrumentation. Crowdsensing approaches using mobile devices have been developed to address these issues, but they only provide limited traffic information, such as vehicle positions.

To this end, we introduce TelecomTM, the first sensing system that measures vehicle-induced ground vibrations using roadside pre-existing telecommunication (telecom) fiber optic cables as a distributed acoustic sensing system to achieve fine-grained and ubiquitous traffic monitoring. Due to its non-dedicated nature and extensively installed pre-existing telecom cables in the cities, TelecomTM can efficiently monitor traffic with fine granularity and low cost, requiring minimum maintenance; however, it faces two main challenges: 1) unknown and heterogeneous properties of the virtual strain sensors (e.g., locations and signal patterns) and 2) large and unpredictable noise conditions. To address these challenges, we first characterize the system through driving tests to estimate the geographic location and analyze the signal pattern of each virtual strain sensor. We then develop a spatial-domain Bayesian filtering and smoothing algorithm to detect, track, and characterize each vehicle. Our approach integrates the spatial dependency of distributed sensors and Newton's laws of motion to combine the distributed sensor data to reduce uncertainties in vehicle detection and tracking. TelecomTM achieved 90.18% vehicle detection accuracy in a real-world evaluation on a two-way road with 1120 virtual sensors. It improved vehicle position and speed tracking by 27× and 5× compared to a baseline method, with wheelbase and weight estimation errors of ±3.92% and ±11.98%.

Temperature Profile on a Lunar Habitat Structure Covered with Regolith Protective Layer

Sachin Tripathi; University of Connecticut, Dept. of Civil & Environmental Engineering; United States
Ramesh Malla; University of Connecticut, Dept. of Civil & Environmental Engineering; United States

The Moon is being considered for long term human missions. However, it is challenging to design and build suitable human habitat structures on the Moon because they will be subjected to several extreme and unfavorable environmental conditions, one of them being the drastic temperature fluctuation during a diurnal cycle. Several researchers have studied the feasibility of using in-situ regolith (lunar soil) as the protective layer because it has been found effective for thermal insulation, radiation shielding, and micrometeorite impact shielding.

In this paper, the thermal analysis of a monolithic dome habitat structure on the moon covered with the regolith at the equatorial line has been conducted numerically to determine the surface temperature and temperature through the wall thickness including the structural self-shadowing effect. The three-dimensional thermodynamic equation of heat diffusion has been solved to determine the detailed temperature profile of the lunar habitat structure. The nonlinear thermal properties of granular regolith has also been incorporated in this study. The explicit finite difference method was implemented to discretize the heat diffusion equation. The direct solar radiation and lunar albedo have been taken as the heat sources on the structure, while the non-blackbody radiation and habitat albedo are considered as heat outputs during the study. The convective boundary condition with the constant habitat interior air temperature of 293.15 K (room temperature) was used. The analysis was conducted using the intial temperature condition of the structure to be 293.15 K. The results from the study show that the external surface of the regolith cover experiences the maximum temperature of around 400 K at the apex location during the lunar noon and the minimum temperature of around 115 K at night time. With just 20 cm thick regolith cover, the maximum and minimum diurnal temperatures are found to be reduced to 295 K and 292 K, respetively, on the apex point at the interface between the dome habitat structure and the regolith cover (i.e. at the habitat structure surface below the regolith layer), thus, exhibiting the strong thermal insulation capacity of the regolith cover. This study provides an effective methodology to determine the temperature distribution on lunar structures with protection layer (regolith or other cover). This, in turn, should help to determine the structural stresses and deflections caused by the extreme lunar temperature swing for the safe and stable design of the structures on the Moon and to determine the heat/temperature regulation within the habitat structures for human survival and comfort.

Acknowledgement: This work was partially supported by a Space Technology Research Institutes grant (number 80NSSC19K1076) from NASA's Space Technology Research Grants Program.

Tensile Behavior of Multi-layered Randomized Architected Material (MLRAM)

Sagnik Paul; University of Illinois Urbana-Champaign; United States
Ann Christine Sychterz; University of Illinois Urbana-Champaign; United States

Architected materials have the potential to achieve properties beyond the ones found in nature and has paved way for reducing the importance of natural material properties for designs. It has also created the opportunity to investigate the mechanical behavior of micro-scale structures at a macro-scale. Architected materials inspired from Cubic-Bravais lattice and crystal microstructures have been inspected for its mechanical properties, and its domain in reconfigurable materials. The technology of 3D printing complements the development of architected material. Computational studies have shown the effect of coordination number and cross-linking density on the stretch behavior of polymer networks for microscopic deformation scale [1]. Inspired from this concept a multi-layered randomized architected material (MLRAM) is proposed harnessing Latin Hypercube Sampling (LHS). This study presents the relation between various parameters of MLRAM and its tensile behavior. It also investigates to capture the effect of randomized geometry versus regular patterns, which helps in obtaining a range of behavior of MLRAM assisting in choosing more fracture-resilient designs. MLRAM is developed by 3D printing using Stratasys Objet500 Connex3 printer with Vero family of rigid materials, which has an approximate Young's modulus value of 2-3 GPa. One layer consists of nearly-regular short-link networks formed by interconnecting random points extracted from Latin Hypercube Sampling (LHS). The other layer consists of relatively longer links that randomly connects any two nodes of the other layer as a reinforcing layer, the length of which can vary from approximately two to eight times the length of the short links. The length of the links is in the order of centimeters. MLRAM is parameterized in terms of coordination number, density of long links and stiffness of long links. A computational model calibrated through experimental testing is developed that mimics the tensile behavior of MLRAM. Using this model, the variation in the tensile behavior in terms of peak tensile capacity and post-peak behavior of MLRAM is studied for various geometry with specific parameters. The properties of the MLRAM are also examined in relation to its parameters such as coordination number, density of long-links as well as ratio of stiffness between the long-links and short-links. The tensile capacity of the MLRAM increases with increase in coordination number.

References

[1] K. Kothari, Y. Hu, S. Gupta, and A. Elbanna, "Mechanical Response of Two-Dimensional Polymer Networks: Role of Topology, Rate Dependence, and Damage Accumulation," Journal of Applied Mechanics, Transactions ASME, vol. 85, no. 3, Mar. 2018, doi: 10.1115/1.4038883

Tension-Compression Asymmetry and Failure of Lattice Metamaterials

Enze Chen; Johns Hopkins University; United States
Shengzhi Luan; Johns Hopkins University; United States
Stavros Gaitanaros; Johns Hopkins University; United States

Brittle architected materials, including ceramic microlattices and carbon foams, are excellent candidates for thermal insulation, energy storage, and filtering applications owing to their high surface area provided by the underlying cellular microstructure. However, due to the brittle behavior of the parent solid, these material systems fail catastrophically under small deformations. In this talk we will discuss results of our recent efforts to analyze the fracture strength of 3D lattice materials by integrating additive manufacturing, multi-scale experiments, modeling, and theory. Experiments to failure are performed to measure their fracture strength and establish its connection to the underlying microstructure, the properties of the parent solid, and the macroscopic loads. Kelvin and octet topologies are designed and tested under tensile and compressive loads, and the responses are compared. The results reveal distinct strength asymmetries, with Kelvin showing higher compressive strength over its tensile counterpart, while the octet showed a larger tensile strength at lower densities but higher compressive strength at higher relative densities. High fidelity multi-scale numerical models that take into account microstructural variations induced from the additive manufacturing process are developed and validated against the experiments. The numerical models show that the strength asymmetry in brittle lattices results from the coupled effect of base material strength and the macro- to microscopic stress relation. By combining the experimental and numerical findings, this study will also provide a unified approach for predicting fracture strength under different loading conditions.

Text mining to predict the impact of wind disasters

Huy Pham; Virginia Tech; United States
Monica Arul Jayachandran; Virginia Tech; United States

Extreme wind events occur more often in the United States than in any other country. Regardless of the good meteorological forecasts, wind events keep having significant effects on infrastructure due to the gap of knowledge between a hazard and its impact. For this reason, disaster managers are increasingly interested in knowing the impacts of wind hazards, which can help increase the resilience of the communities. Impact Based Forecasting (IBF) - a paradigm of Hazard – Exposure – Vulnerability – Impact is a powerful tool to forecast impacts for disasters. In IBF, risk assessments are combined with historical impact data. Even though historical impact data is essential in IBF frameworks, it is often contained in a non-structured manner in briefing reports such as the Emergency Plans of Action documents. As long as this abundantly available unstructured impact data cannot be automatically accessed, it cannot be put to use to enhance forecasts. Therefore, it is important to investigate methods that can distinguish sentences that contain the impact data from sentences that are not of interest in an IBF setting. This research work examines methods that can recognize and extract sentences containing structural impact data. This is important as there is a shortage of available historical impact data related to damage to structures and the known information is divided over many briefing and damage reports. Not only impact information is reported in these reports, but also risk assessments and expected impact. By selecting the relevant impact sentences from reports before extracting the numerical impact data from them, error propagation into future automatically created impact data sets can be avoided. The research is two-fold. The work first focuses on the definition of structural impact data and labeling them to create a ground truth dataset. Secondly, the research focuses on extracting sentences and numbers related to impact data. This extraction task is approached as a classification problem. Sentences from documents are separated and classified on a case-by-case basis. The classification problem is binary: either a sentence contains structural impact data or it does not. A sentence classified to the group of 'impact sentences' can be considered extracted. Not only does this research help take a step in the direction of a structured database of historical wind impact data – perhaps the techniques presented in this research are also relevant in emergency situations. In situations where a disaster strikes, an impact-information summary of unstructured texts written by many different organizations, would save the time of disaster managers.

The Application of Surrogate Modelling Methods to the Calibration of Crystal Plasticity Finite Element Models

Hugh Dorward; University of Bristol; United Kingdom
Matthew Peel; University of Bristol; United Kingdom
Mahmoud Mostafavi; University of Bristol; United Kingdom

Significant progress has been made in developing detailed crystal plasticity simulations of material behaviour that account for the microstructure of the material. Such simulations can account for phenomena including plasticity, cracking, and corrosion. These models require calibration with respect to experimental data, however calibration can be computationally costly due to the number of complex model evaluations required.

There has been an increasing interest in developing surrogate models, sometimes known as response surface models, which can emulate the response of computationally expensive complex simulations. Such models have applications for uncertainty quantification and sensitivity analysis, as well as model calibration.

This work explores using a Gaussian process regression (GPR) to generate a surrogate model of the calibration objective function for a strain gradient crystal plasticity model being calibrated to experimental data from 316L stainless steel. The machine learning algorithm takes as its inputs the model parameters to be calibrated and as its output the mean squared error residual of the simulated tensile curve compared to the experimental tensile curve to approximate the calibration objective function.

A space-filling experimental design is used to create an initial surrogate model of the objective function. An infilling procedure taking advantage of the estimate of uncertainty in the GPR model is then used to more thoroughly explore the objective function near the global minimum. The parameters at the global minimum then provide an estimate of the optimal parameter set for the crystal plasticity model.

The methodology described above is compared with more traditional optimization algorithms which evaluate the complex crystal plasticity model at each iteration. The purpose of this comparison is to investigate the differences in computational time and the number of complex model evaluations required to converge to a suitably accurate prediction for the optimal parameter set.

The Effect of Disorder on the Dynamic Properties of One-Dimensional Metamaterials

Ali Heidari Shirazi; University of Tennessee, Knoxville; United States
Reza Abedi; University of Tennessee, Knoxville; United States

In recent years, metamaterials have gained significant attention in the field of mechanical engineering due to their unique properties and potential applications in various fields. The ability to control and manipulate the band structure of these materials through the tuning of geometric and mechanical properties is particularly intriguing. However, despite the advances in additive manufacturing and 3D printing techniques, the presence of unavoidable disorders caused during the manufacturing process of metamaterials can lead to significant changes in their band structure and consequently overall properties. In this study, the effect of disorder on the band structure and wave mitigation performance of a one-dimensional (1D) periodic metamaterial is investigated. A probability distribution function (PDF) for random geometric and mechanical properties is introduced to an otherwise 1D periodic metamaterial. The stability of stopbands under various disorder schemes, including correlated randomness, is analyzed using numerical simulation. The concept of Representative Volume Element (RVE) is also utilized to study the effect of disorder on the microstructure of the metamaterial. Randomness can lead to the emergence of robust stopbands at high disorder levels, as well as the disappearance of some passbands resulting in stopband overlapping. Additionally, the disorder can cause the red-shift phenomenon and stopband phase mismatching, leading to a broadening of the absorption spectrum and potentially shifting stopbands towards lower frequencies. The outcome of this study offers a comprehensive examination of the effect of disorder on the band structure and wave mitigation performance of 1D periodic metamaterials

The effect of drained cyclic loading on changes in fabric anisotropy using DEM

Tara Sassel; Imperial College London; United Kingdom
Catherine O'Sullivan; Imperial College; United Kingdom

Drained and undrained cyclic loading of a granular materials such as sand can lead to increases in material strength and stiffness. The increases cannot only be attributed to higher initial stress conditions and lower void ratios. These observations have been made in many laboratory experiments where samples have been subjected to small-amplitude cyclic-prehearing or low-magnitude earthquakes, insufficient to induce liquefaction (Finn et al., 1970, Seed et al. 1977 and Dadashiserej et al. 2022). However, in constitutive models and laboratory experiments, this increase in strength is often postulated to be associated to changes in fabric. In the discrete element method (DEM) the macroscopic and microscopic behaviours can be linked to each other. Drained triaxial cyclic loading tests were carried out using DEM where samples of spheres were cyclically loaded at different amplitudes. Snapshots of the samples that recorded the sample state were generated at various instances during the application of the cyclic loading. Subsequently those snapshot samples were sheared monotonically to establish a link between the sample behaviour, the mechanical coordination number and degree of fabric anisotropy.

The Effect of Intraocular and Intracranial Pressure Gradient on Lamina Cribrosa Biomechanics for Subjects with and without Glaucoma

Soumaya Ouhsousou; University of Pittsburgh; United States

Lucy Q. Shen; Massachusetts Eye and Ear, Harvard Medical School; United States

Amin Pourasghar; University of Pittsburgh; United States

Chhavi Saini; Johns Hopkins Bloomberg School of Public Health; United States

Mengyu Wang; Harvard Ophthalmology AI Lab, Schepens Eye Research Institute of Mass Eye and Ear, Harvard Medical School; United States

John C. Brigham; University of Pittsburgh; United States

The increase in intraocular pressure (IOP) in glaucoma alters lamina cribrosa (LC) morphology leading to the loss of the retinal ganglion cell axons and visual field deterioration. To date, little is known about the difference of LC biomechanics in healthy and glaucoma subjects using patient-specific models. Our objective is to assess and evaluate IOP and intracranial pressure (ICP) induced damage on the LC for subjects with and without glaucoma. 20 optic nerve head (ONH) geometries were manually segmented from swept source optical coherence tomography (SS-OCT) scans to construct 3D patient-specific eye mechanical models (10 glaucoma and 10 control). Since the LC thickness was not visible in most scans, 0.19 mm and 0.38 mm were used for glaucoma and control subjects, respectively. The ONH was placed at an offset location within a sphere representing the eye globe with patient-specific axial length. All tissues were assumed linear elastic, isotropic, and nearly incompressible, and specific material parameters were assigned to each component based on published values in the literature. Boundary conditions were set such that free body movement was restricted. IOP was applied on the inner surface of the sphere, and the ICP was applied between the inner surface of dura mater and outer surface of pia mater. Various values of IOP and ICP were used for each subject to simulate the effect of the increase and the decrease of each pressure on the LC's mechanical response. The tensile and compressive strain distributions were qualitatively examined to identify the regions that have relatively high strains in the LC and compared with clinical observations. Nonparametric Mann-Whitney tests were also performed to compare LC principal strain values in the control and glaucoma groups. Point biserial correlation was used to examine the association between glaucoma and strain values. A logistic regression assessed the contribution of strain and axial length in predicting the probability of occurrence of glaucoma. This model has the potential to assess the effect of anatomic variations on the mechanical behavior of the LC under different pressures. Further long-term objectives include studying the global sensitivity of the eye mechanics to various parameters such as the tissues' material properties, the axial length, and the offset of the ONH with an objective to identify the components that have a significant effect on the mechanical response of the eye.

The effect of wrapping force on the transverse stiffness of packed bridge cables: an elastoplastic analysis

Linda Teka; Columbia University; United States
Huiming Yin; Columbia University; United States

Bridge cables use thousands of steel wires packed in a hexagonal pattern and wrapped by bands around the surface. The stiffness in the cross section plays an important role in the structural integrity and safety under transverse loading. The higher wrapping force leads to higher stiffness, but the elastoplastic properties of steel may make the effective transverse stiffness complex. In this paper, we study cylindrical wires packed in a hexagonal arrangement tightened up by wrapping bands at certain stress intervals. The effective stiffness of packed cylinders changes with the stress of the wrapping bands. The relationship between the effective transverse stiffness and the wrapping force is studied. An elastoplastic constitutive model for the hexagonal packing of cylinders is developed using the Singum model. The Singum model, a continuum solid model, enables the transformation of the singular point forces into the contacting stress among the continuum particles. Experimental tests are conducted to validate the potential function. The comparison with the experimental results proves the capability and accuracy of this model.

The Emergence of an Inherent Urban Resilience to Natural Hazards

Nicos Makris; Southern Methodist University; United States
Tue Vu; Southern Methodist University; United States
Gholamreza Moghimi; Southern Methodist University; United States
Georgios Chatzikyriakidis; Southern Methodist University; United States
Eric Godat; Southern Methodist University; United States

In view that cities will continue to house the majority of the world's population at an increasing rate in association with the face of climate change, this paper studies urban resilience by examining the response history of the mean-square displacement of the citizens of large cities prior and upon historic natural hazards strike. The recorded mean-square displacements of large numbers of cell-phone users from the cities of Houston, Miami and Jacksonville when struck by hurricanes Harvey 2017, Irma 2017 and Dorian 2019 together with the recorded mean-square displacements of the citizens of Dallas, and Houston when experienced the 2021 North American winter storm, suggest that large cities when struck by natural hazards are inherently and invariably resilient. The recorded mean-square displacements presented in this study also validate a mechanical model for cities, previously developed by the authors, which is rooted in Langevin dynamics and predicts, that following a natural hazard, large cities revert immediately to their initial steady-state behavior and resume their normal, pre-event activities.

The Evaluation of Explicit Parameters on Eulerian-Lagrangian Simulations of Wave Impact on Coastal Bridges

Arsalan Majlesi; University of Texas at San Antonio; United States
Adnan Shahriar; University of Texas at San Antonio; United States
Arturo Montoya; University of Texas at San Antonio; United States
Ao Du; University of Texas at San Antonio; United States
Adolfo Matamoros; University of Texas at San Antonio; United States

Simply supported bridges along the Gulf Coast are extremely vulnerable to extreme wave conditions and water elevations. Numerical models pose difficulties in terms of reliability and computational burden. On the other hand, experimental models cannot analyze large-scale superstructures because of limited space allocation. Hence, optimized finite element (FE) models are a viable solution to estimate forces applied to these bridge superstructures by simulating the wave-superstructure interactions. The results of the FE simulations are highly dependent on the numerical parameters and configurations implemented in the model. The results' sensitivity to the analysis parameters must be addressed to help scholars and engineers develop a reliable FE model. In this paper, an experimental scaled model built and tested at the O.H. Hinsdale Wave Research Laboratory at Oregon State University was used to calibrate numerical models with a range of explicit parameters (mass scaling factor, damping hourglass control, displacement hourglass scaling factor and bulk viscosity scaling factors) and configurations (mesh size). The results provide a platform to compare numerical outputs and find the parameters that best suit wave-superstructure interaction models. Moreover, the force signals applied to the superstructure experience high oscillations resulting from wave-superstructure interaction and poor choice of explicit parameters and modeling configurations. Different digital filter designs were utilized to remove unwanted oscillations and provide researchers with recommendations on how to develop an optimized model.

The Green's function based thermoelastic analysis of spherical geothermal tanks in a semi-infinite domain

Chunlin Wu; Columbia University; United States
Tengxiang Wang; Columbia University; United States
Huiming Yin; Columbia University; United States

When an underground heat exchanger is subjected to a surface load on the ground and temperature change inside, the stress transfer between the thermal tank and the earth may cause the deformation and destruction of the tank. The bi-material thermoelastic fundamental solution of two-jointed dissimilar half-spaces is applied to elastic and thermal analysis of spherical heat storage tanks, where the continuity equations at the bi-material interface are satisfied. using the Hadmard's regularization in the x3 direction, the two-dimensional bi-material thermoelastic fundamental solution can be obtained. By changing the material constants, the fundamental solution for a semi-infinite domain or an infinite domain with a single material can be recovered. In general, the storage tanks and soil exhibits different thermal and mechanical properties. A dual equivalent inclusion method (DEIM) is proposed to simulate the material mismatch of thermal conductivity and elasticity with a continuously distributed eigen-temperature gradients and inelastic eigenstrains on the tanks, respectively. Using the analytical domain integrals, no mesh is required for inhomogeneities. Due to the boundary effects and inhomogeneity interactions, the eigen-fields are expanded at the center of each inhomogeneity using Taylor series with tailorable accuracy. The DEIM is verified by the finite element method and demonstrated by the geothermal applications using uniform, linear, or quadratic orders of eigen-fields. For a spherical heat exchanger in an infinite homogeneous domain, DEIM provides the exact solutions of the thermoelastic fields for a uniform heat source and a uniform far-field heat flux field.

The impact of data-driven design approaches on shear connector reliability

Hyeyoung Koh; University of Wisconsin-Madison; United States
Hannah Blum; University of Wisconsin-Madison; United States

In the structural engineering industry, it is not unlikely to imagine a future where the design process is navigated by data-driven design tools that can further optimize designs based on data acquired through physical experiments and advanced technical computing systems. However, currently some structural engineering applications have scarce datasets. For example, the design provisions for shear connectors in Chapter I8 of the North American Specification for Structural Steel Buildings, AISC 360, were developed based on the data for deck profiles up to 76 mm (3 inches) and did not account for the variations in deck depth or the stud height above the deck. The latest version of AISC 360 released in 2022 now permits a performance-based alternative for the shear connector design following Chapter K of AISI S100, North American Specification for the Design of Cold-Formed Steel Structural Members, for establishing available strength from test data.

To enhance the information of the existing test data and to update the applicable range of deck profiles, this study parses the data using data-driven analysis approaches and quantifies the impact on resistance factors. A database for the strength of shear connectors welded through steel deck is constructed from the literature. Then, the data is sorted into subsets using two methods: (1) engineering intuition and (2) feature importance techniques, which examine the importance of input parameters and determine influential factors affecting the shear stud strength. The recommended data groupings based on the two methods are compared. In addition, reliability analyses are conducted on each data subset to determine the required resistance factors to meet a specified target reliability index, and the results are compared to the current provisions in AISC 360. The database is searchable and available in the GitHub repository, which comes with a user-friendly data viewer to display data groupings according to the input parameters. The repository can engage researchers and practicing engineers with valuable data for future research and specification development.

The Impact of Modelling Error when estimating the foundation parameters of Offshore Wind Turbines through Bayesian Model Updating

Harry Simpson; University of Oxford; United Kingdom
Imad Abdallah; ETH Zurich; Switzerland
Costas Papadimitriou; University of Thessaly; Greece
Eleni Chatzi; ETH Zurich; Switzerland
Manolis Chatzis; University of Oxford; United Kingdom

Due to the rapid growth of the wind industry and the increasing regularity of extreme weather events, the fatigue assessment of offshore wind turbines has grown in importance. However, there is often high uncertainty associated with the soil properties, resulting in inaccurate estimation of the fatigue life. In order to update these estimates from information from the structure as is, measured data from tower sensors (accelerometers, strain gauges, etc.) can be exploited to update the foundation parameters of offshore wind turbine models. A Bayesian model updating framework is employed to do this, where the outputs of a numerical model are compared to the measured data. In this work, the model outputs consist of the modal parameters (frequencies and mode shapes) and operational modal analysis is used to identify the corresponding modal parameters from synthetically generated accelerometer data. Within the Bayesian model updating framework, the prediction error compares the identified modal parameters against the model estimated modal parameters to determine the parameters which best fit the model outputs to the measured data. In the literature, the prediction error is usually modelled using a zero mean Gaussian distribution. This assumption is often reasonable for the case where there is minimal modelling and/or measurement bias. However, when there is expected to be a bias in the outputs of numerical models, this assumption may not be suitable. In this work two models are considered to investigate how modelling errors impact the identifiability of the foundation parameters. Both models were developed via use of the Simscape environment, which has the advantage of separately modelling the different components of a wind turbine, resulting in a coupled servo-hydro-aero-elastic model of a fixed-bottom offshore wind turbine. The foundation is modelled using linear coupled springs, which comprise translational, rotational, and cross-coupling springs in a series configuration. The first model, referred to as the "True Model", is based on the NREL 15MW reference turbine. This model is used to generate synthetic data and also to investigate the identifiability of the coupled spring foundation parameters for the case when no modelling error is present. The second model, referred to as the "Scaled Model", upscales the blade properties from the NREL 10MW reference turbine. The rest of the model is identical to the "True Model". This upscaling of the blades introduces a bias in the model estimated modal parameters and therefore the "Scaled Model" is used to investigate the impact of modelling errors on the identifiability of the foundation parameters. The results show that the Maxima a Posteriori (MAP) estimates of the foundation parameters are close to their nominal values when using the "True Model" with a zero mean prediction error. However, a bias in the parameter MAP estimates is found when using the "Scaled Model" with a zero mean prediction error.

The Impact of Urban Texture on Flood Hazards

Sarah Balaian; University of California, Irvine; United States
Brett Sanders; University of California, Irvine; United States
Mohammad Javad Abdolhosseini Qomi; University of California, Irvine; United States

With flooding contributing to exorbitant loss of infrastructure, assets, and human life, there exists an urgency to develop mean-field theories that can quantify the impact of urban form on flood hazards. We computationally model synthetic urban textures of varying porosity and disorder, which act as reduced complexity models of cities, and present the results of shallow water simulations. Statistically sufficient data is collected and employed in the theoretical study of flooding. We show the non-dimensionalized flood inundation scales linearly with the packing density and Mermin order parameter for disordered square- and hexagon-like urban textures. We also find the effective mean chord length collapses the simulated inundation data into a symmetry-independent linear relation. The resultant mean-field theory can then be leveraged to probe city-to-city variations in the flood hazard indicators, flood depth and intensity. This opens opportunities for civil engineers, urban planners, and physicists to address urban flooding hazard quantitatively and better understand its impacts on our infrastructure systems.

The influence of fluid injection on energy partitioning during the earthquake cycle

Maryam Alghannam; MIT; United States
Hector Gomez; Purdue University; United States
Ruben Juanes; MIT; United States

During an earthquake, the elastic energy stored in the Earth is released as frictional energy and radiated energy in the form of seismic waves. The partitioning of energy released during an earthquake gives an indication of the overall size of the earthquake and its potential for damage to man-made structures. While several studies have considered estimating the radiated energy and energy partitioning, existing descriptions have not addressed the contribution of fluid pressurization to the energy budget -- a key aspect toward understanding the physical mechanisms behind the link between fluid injection and anthropogenic earthquakes.

Here, we perform an energy analysis of the full anthropogenic earthquake cycle using a single-degree-of-freedom spring poroslider and rate-and-state friction. The model captures stick-slip motion on a fault in contact with a reservoir, where the stick is the interseismic period of elastic strain accumulation and the slip is the seismic wave-producing rupture. Using an analysis of a multi-degree-of-freedom system, we show that seismic radiation can be modeled within the single-degree-of-freedom spring slider by adding a precisely-defined viscous damping term. We then use it to study fluid injection and assess its effects on the energy partitioning during induced and triggered earthquakes.

We find that: (1) the ratio of elastic energy stored in the skeleton to injection energy is low and is influenced by the rate of fluid injection, which indicates that only a small part of the energy supplied by fluid injection has any potential to contribute to the energy released during frictional slip; (2) the seismic efficiency, stress drop, and total slip are directly influenced by the rate of increase in pore pressure; (3) the seismic injection efficiency is low, and is lower for induced earthquakes compared to triggered ones; and (4) fluid injection leads to bigger and potentially more damaging earthquakes overall.

The Influence of Urban Landscape on Firebrand Spotting

Iago Dal-Ri dos Santos; Florida State University; United States
Neda Yaghoobian; Florida State University; United States

During wildfires, a large quantity of burning debris, known as firebrands or embers, is generated. Firebrands can be transported by the wind several meters to kilometers and create new spot fires. The spotting phenomenon is the main mechanism of wildfire propagation to urban areas, and its erratic nature makes fire propagation prediction and its mitigation difficult. In this work, Lagrangian particle transport modeling together with Large-Eddy Simulations were performed to investigate the effects of topography-induced turbulence on the transport, smoldering lifetime, and spotting risk of firebrands. Smoldering particles of different shapes and sizes were released, and their statistics were compared between cases with and without the presence of an idealized urban region. The results indicate that urban topographies significantly influence the firebrands' statistics and risk of spotting due to the complex topography-induced turbulence structures.

The mechanics and adhesion of αvβ3 integrin on biomaterials using steered molecular dynamics simulations

Hanmant Gaikwad; North Dakota State University; United States
Sharad Jaswandkar; North Dakota State University; United States
Kalpana Katti; North Dakota State University; United States
Dinesh Katti; North Dakota State University; United States

Integrin protein as a mechanotransducer establishes the mechanical reciprocity between extracellular matrix (ECM) and cells at integrin-based adhesion sites. This protein plays a critical role in cell-ECM adhesion and cellular signaling. As new biomaterials are being developed for tissue engineering applications, understanding cellular adhesion to engineered surfaces mediated by integrins is critical. We conducted steered molecular dynamics (SMD) simulations to investigate the mechanical responses of integrin αvβ3 with and without ligand binding for tensile, bending, and torsional loading conditions. The ligand-binding integrin confirmed the integrin activation during equilibration by opening the hinge between βA and the hybrid domain. This activation of liganded αvβ3 integrin influenced the molecule's stiffness observed during tensile loading. Furthermore, we observed that the interface interaction between β-tail, hybrid, and epidermal growth factor domains altered integrin dynamics. The deformation of extended integrin models in the bending and unbending directions of integrin reveals the stored folding energy and the directionally dependent stiffnesses of the integrin molecule. Along with available experimental data, the SMD simulation results were used to predict the mechanical properties of integrin and reveal the underlying mechanisms of integrin-based adhesion on polymer clay nanocomposite-based biomaterials. The evaluation of integrin mechanics provides new insights into understanding the mechanotransmission (force transmission) between cells, ECM and the biomaterial substrate.

The Physics of Urban Flooding

Sarah Balaian; UC Irvine; United States
Brett Sanders; UC Irvine; United States
Mohammad Javad Abdolhosseini Qomi; UC Irvine; United States

Urbanization and climate change are contributing to severe urban flooding globally, damaging infrastructure, disrupting economies, and undermining human well-being. We apply shallow-water theory to examine how flooding intensity depends on ground slope and urban form characterized by an urban packing density and Mermin order parameter. We show the non-dimensionalized flood depth scales linearly with the packing density and Mermin order parameter for disordered square- and hexagon-like forms. We also show that a non-dimensionalized flood intensity scales inversely with the square root of an effective mean chord length representative of the unobstructed downslope travel distance. The proposed mean-field theory is applied to probe city-to-city variations in flood hazard indicators globally.

The response of multi-span railway bridges accounting for dynamic soil-structure interaction

Pieter Reumers; KU Leuven, Department of Civil Engineering; Belgium
Geert Lombaert; KU Leuven, Department of Civil Engineering; Belgium
Geert Degrande; KU Leuven, Department of Civil Engineering; Belgium

Dynamic soil-structure interaction (SSI) should be considered when modeling railway bridges on soft soil, as it results in (1) more accurate prediction of the bridge response, and hence, a safer and possibly more cost-effective design; (2) better estimation of the modal characteristics; and (3) improved prediction of ground-induced vibration due to train passages, which is relevant for bridges built in urban areas. The use of 3D element-based models is restricted to a few spans due to computational limits. Therefore, periodic structure theory is employed in this paper to take advantage of the repetitive geometry of the bridge.

The challenging task is the solution of the foundation-soil interaction problem, as most railway bridges are supported by piled foundations embedded deep into the soil. The dynamic SSI problem can be solved with (1) a finite element (FE) formulation in combination with perfectly matched layers (PMLs) or (2) a coupled finite element-boundary element (FE-BE) formulation. The advantage of an FE-PML model is that the system matrices are sparse, while they are of smaller size but fully populated for an FE-BE model. An advantage of an FE-BE model is that the free field response can easily be computed up to large distance, while a large FE mesh would be required when an FE-PML model is used.

A periodic formulation is used to account for through-soil coupling between a row of piled foundations with spacing L, limiting the discretization effort to a single reference cell. A Floquet transform can be employed in combination with either an FE-PML model or an FE-BE model of the foundation, resulting in a solution on the reference cell in the wavenumber-frequency domain. Alternatively, the wave finite element method (WFEM) can be used on an FE-PML model of the reference cell, resulting in a solution in the spatial-frequency domain. The foundation-soil interaction problem can also be solved for a single piled foundation with a 3D FE-PML or FE-BE model, resulting in a frequency-dependent impedance matrix of the piled foundation, disregarding through-soil coupling.

For the superstructure, a Floquet- or WFEM-based model of a single bridge span is made. If through-soil coupling between foundations is deemed important, such model is coupled to the foundation-soil system (in the wavenumber-frequency or spatial-frequency domain). Alternatively, the pre-computed frequency-dependent impedance of a single piled foundation can be added as spring-dashpot connections at the bottom of the bridge piers. The latter results in a very efficient model to compute the bridge response under moving loads accounting for dynamic SSI, but disregards through-soil coupling.

The focus in this paper is on reviewing and demonstrating the aforementioned methods to account for dynamic SSI when computing the response of multi-span railway bridges subjected to moving loads. Results are shown for a continuous concrete box girder bridge supported by piled foundations, and for varying soil stiffness. Furthermore, it is demonstrated how the WFEM-based model can take further advantage of the periodicity of the bridge deck and soil between two piers within a reference cell.

The role of digital twins for predictive maintenance of concrete deck bridges

Manuel Salmeron; Purdue University; United States
Xin Zhang; Purdue University; United States
Shirley Dyke; Purdue University; United States
Julio Ramirez; Purdue University; United States

The use of digital twins for civil engineering assessment can leverage predictive maintenance practices to prolong the life and safety of physical infrastructure. Digital twins are known for computationally replicating the functional properties of real-life systems. However, in contrast to other computational methods, digital twins can be frequently and automatically updated using data from sensors or monitoring systems to generate actionable information. This study presents the development of digital twin technologies for the autonomous predictive maintenance of concrete deck bridges. First, a physics-based model is developed to predict the deterioration stages of a bridge deck due to the effects of corrosion, carbonation, freeze-thaw cycles, and cracking. Next, the predictive physics-based models are improved by using machine-aided inspection image classification to further evaluate and update the structural health condition of the bridge. Finally, a fault diagnosis and maintenance function is developed to prescribe optimal maintenance cycles and preventive or corrective actions. The digital twins' tools from this study can provide bridge asset managers with the functionalities to better monitor and make data-based decisions during the inspection.

The Role of Turbulence and Roughness Length Parameterizations in Improving Major Hurricane Simulations in Weather Forecasting Models

Mostafa Momen; University of Houston; United States
Leo Matak; University of Houston; United States
Meng Li; University of Houston; United States

Recent studies have shown that climate change and global warming considerably increase the risks of hurricane winds, floods, and storm surges in coastal communities. Turbulent processes in Hurricane Boundary Layers (HBLs) play a major role in hurricane dynamics and intensification. Most of the existing turbulence parameterizations in the current numerical weather prediction (NWP) models rely on the Planetary Boundary Layer (PBL) schemes. Previous studies (Zhang 2010; Momen et al. 2021) showed that there is a significant distinction between turbulence characteristics in HBLs and regular atmospheric boundary layers (ABLs) due to the strong rotational effects of hurricane flows. Nevertheless, such differences are not considered in the current schemes of NWPs, and they are primarily designed and tested for regular ABLs.

In this talk, we aim to bridge this knowledge gap by conducting new hurricane simulations using Weather Research and Forecasting (WRF) model as well as large-eddy simulations. We investigate the role of the PBL parameterizations and momentum roughness length in multiple hurricanes by probing the parameter space of the problem. Our simulations have shown that the most widely used WRF PBL schemes do not capture the hurricane intensification properly and underestimate their intensity.

We will present that decreasing the roughness length close to the values of observational estimates and theoretical hurricane intensity models in high wind regimes ($\gtrsim$ 45 m s-1) led to significant improvements in the intensity forecasts of strong hurricanes. Furthermore, by decreasing the existing vertical diffusion values, on average more than 20% improvements in hurricane intensity forecasts were obtained compared to the default runs. Our results provide new insights into the role of turbulence parameterizations in hurricane dynamics and can be employed to improve the accuracy of real hurricane forecasts. The implications of these results and improvements for coastal resiliency and fluid-structure interactions will also be discussed.

The utility of visual document understanding in regional building inventory generation

Rachel Hamburger; University of Notre Dame; United States
Tracy Kijewski-Correa; University of Notre Dame; United States

Homes provide the security necessary for thriving livelihoods, health, education, and other aspects of well-being. Yet, mounting losses of residential infrastructure during hurricanes has created an acute crisis that will only escalate given the increasing frequency and severity of meteorological and climatological hazards. To protect this vital infrastructure class, targeted resilience activities incorporating effective pre-event (preparedness) and post-event (response and recovery) must drive proactive mitigation investments, minimize losses, and when necessary, build back better. The effectiveness of these planning and policy efforts depends on reliable descriptions of building inventories of fidelity sufficient to predict the impact of hazards. Current practices in pre-event building inventory modeling (BIM) leverage large data mined from open-source platforms, such as Google street-view and aerial imagery. Computer vision deep learning techniques, e.g. convolutional neural networks (CNNs) pre-trained for classification and detection tasks, are then used to extract visual building features. This work extends existing BIM workflows through integration of visual document understanding (VDU) with the optical character recognition (OCR) and document parsing use cases. The proposed framework takes unstructured data in PDFs or document scans as input and returns structured datasets with machine encoded text representing building attributes contained in the original documents. Three deep learning models of varying complexity and structure are trained and tested on a dataset of FEMA Elevation Certificates filed in Florida and retrieved from the Florida Division of Emergency Management ArcGIS Map Application.

Theory and Computational Framework for Quantifying Social Capital Derived from Human-Human and Human-Infrastructure Interactions

Maral Doctor Arastoo; Carnegie Mellon University; United States
Katherine Flanigan; Carnegie Mellon University; United States
Mario Bergés; Carnegie Mellon University; United States

Cyber-physical systems (CPSs) have radically transformed engineering solutions over the last decade and garnered considerable attention, improving infrastructure performance through the combination of sensing, computing, and control. CPSs have even expanded to include human-in-the-loop control, where humans serve as operators or supervisors. While these paradigms have been wildly successful for the design and operation of physical systems decoupled from—or weakly coupled to—human social contexts, there are entirely unexplored social benefits derived from infrastructure that have yet to be scientifically understood and exploited. For example, social infrastructure, which is an essential, yet understudied, class of infrastructure supporting social interaction, is not social capital itself, but rather the physical space and infrastructure that determines whether social capital develops. Common examples include parks, community centers, and academic buildings, which support societal quality of life across many social dimensions. Due to dwindling investment in social infrastructure nationwide, there is an urgent need to reimagine current CPS theory, tools, and frameworks to even make it possible to address systems where human behavior is central. We propose this paradigm be radically altered such that physical infrastructure is controlled to meet social, or human-centered objectives that have never before been sensed or measured. This work uses intelligent agents to mimic human behavior in social settings, including human-human and human-infrastructure interactions. The human behavior is emulated using multi-agent generative adversarial imitation learning and the probability distributions of social outcomes are obtained using reinforcement learning as a sampling-based approach. The ability to obtain such probabilistic estimates of the social outcomes enables designers to evaluate their design decisions before implementing them in the real world, setting the stage for extended work focused on optimal design and management for maximizing system performance (i.e., social performance metrics). The framework is demonstrated using Carnegie Mellon University's Porter Hall as a testbed.

Thermal stability and degradation kinetics of polystyrene-layered double hydroxide composites

Farrukh Shehzad; King Fahd Univ of Petroleum & Minerals (KFUPM); Saudi Arabia
Sikandar Khan; King Fahd Univ of Petroleum & Minerals (KFUPM); Saudi Arabia
Mamdouh Al-Harthi; King Fahd Univ of Petroleum & Minerals (KFUPM); Saudi Arabia

In this study, MgAl layered double hydroxides (LDH) have been used as a nanofiller to improve the thermal stability of polystyrene (PS) towards application as an insulating material. PS-LDH and PS-modified LDH composites were prepared by melt blending process with varying compositions of LDH such as 2,5, and 10 wt.%. The resulting composites were characterized for their thermal stability by thermogravimetric analysis. Further insights into the degradation phenomenon were obtained with the help of mathematical modeling of the thermal degradation and the effect of nanofiller (LDH) on the degradation parameters was studied. Moreover, the nanocomposites were also tested for their mechanical properties and thermal conductivity. The findings demonstrate that LDH can be used as a low-cost, non-toxic, and environmentally benign material to enhance the thermal stability of PS.

Thermo-Hydro-Mechanical-Bio (THMB) Modeling of Microbially-Induced Calcite Precipitation (MICP) Technique for Ground Improvement in Cold Regions

Sophie Jung; Polytechnique Montreal; France
Pooneh Maghoul; Polytechnique Montreal; Canada
Amade Pouya; Ecole Nationale des Ponts et chaussées; France

Biotechnology has been used over the past two decades for ground improvement and soil stabilization. For instance, in the Microbially-Induced Calcite Precipitation (MICP) technique relies on a set of biological and biochemical reactions, enzymatic hydrolysis of urea is utilized to produce calcium carbonate bio-cementation within a soil matrix to improve the engineering properties of soils. Here, we aim to present an advanced thermo-hydro-mechanical-bio (THMB) geomechanical model to numerically assess the performance of the MICP-based bio-cementation in cold regions where the shallow subsurface is subject to frost action. The THMB model is implemented into the Finite Element code, DISROC, in order to address the upscaling of the MICP technique. Different climate scenarios will be applied as the boundary conditions to investigate the performance of such techniques for soil stabilization in cold regions at large-scale until 2100. The THMB model is first calibrated and verified by the experimental data obtained by the authors. Furthermore, the THMB model will be used to simulate the application of MICP technique to stabilize the retrogressive thaw slumps (RTS). RTS are landslides caused by the permafrost thaw.

Thermo-poro-mechanical couplings from molecular fluctuations and application to cellulose

Laurent Brochard; Laboratoire Navier (Ecole des Ponts ParisTech, Univ. Gustave Eiffel, CNRS); France

Fluctuations of physical quantities are ubiquitous in molecular simulations at the atomic scale because of the thermal agitation, but these fluctuations become negligible in the thermodynamic limit of macroscopic systems. From a practical point of view, fluctuations are detrimental to the accuracy of average properties estimated by molecular simulations. However, it is possible to take advantage of them to characterize the behavior of a system. Indeed, it is well known that the magnitude of fluctuations of thermodynamic state parameters are related to the second order derivatives of the thermodynamic potential minimum at equilibrium (e.g., compressibility, thermal expansion, and heat capacity for a fluid). Otherwise said, one can fully characterize the constitutive behavior of a system by studying the appropriate fluctuations. While fluctuation formulas are well established for simple systems (e.g., pure fluids), in the field of porous media only the isosteric heat of adsorption is commonly estimated from fluctuations, and the formula considered assumes a rigid solid. In this work, we revisit the Biot-Coussy theory of thermo-poro-elasticity in a framework adapted to derive fluctuation formulas. All the thermo-poro-mechanical moduli can then be characterized by fluctuations of quantities readily accessible during a molecular simulation, i.e., with no additional computational cost and with no need to define the concepts of porosity or specific surface (ambiguous at the molecular scale). Interestingly, these fluctuation formulas are valid irrespective of the nature of the fluid-solid coupling, that is even when the fluid is adsorbed and induced unusual couplings. It is therefore possible to use the formulas to fully characterize the mechanical and thermal effects of adsorption, and conversely to characterize the adsorption response to stress and temperature. This framework is used to revisit the concept of isosteric heat of adsorption in the case of a deformable porous medium. The application of these fluctuation formulas is illustrated in the case of amorphous cellulose submitted to moisture. All the thermo-poro-mechanical behavior is determined from the fluctuations, which highlights the strong moisture-induced couplings and their consequences (negative drained thermal expansion, very high drained heat capacity, negative Biot modulus…).

Thermoelastic Model of Cubic Crystals for Structural Metals

Byung-Wook Kim; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States
Chao Liu; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States
Huiming Yin; Department of Civil Engineering and Engineering Mechanics, Columbia University; United States

Steel and aluminum are common structural materials widely used in high-rise building, deep geothermal, oil wells, and long bridges, which are exposed to wide ranges of pressure and temperature as well as mechanical loading. Although their elastic properties are well documented at the ambient environment, their mechanical behaviors may significantly change at different temperature and pressure. An analytical form of the elasticity depending on temperature and pressure can be very useful for forensic analysis and structural design. The singum model is used to investigate the temperature dependent elastic properties of crystalline solids across the atomic and continuum scales. It employs the Wigner-Seitz cell in the crystal lattice and the interatomic force with its nearest neighbors in order to calculate stress and strain variations given a displacement variation of the lattice, so that the three independent elastic constants are derived in terms of the interatomic potential. The long-range atomic interaction is also considered as a linear expression of pressure, which allows to explicitly describe the three independent elastic constants as a function of the interatomic bond length. The model can estimate the temperature- and pressure-dependent elasticity as the bond length changes with thermal expansion and pressure. Additionally, the interatomic potential can be inversely derived given the elasticity and the equation of state (EOS) of a cubic crystal, and isotropic elastic constants can be obtained for polycrystals by averaging orientation. While the versatility of the model is demonstrated through a case study of copper, predicting the temperature- and pressure-dependent elasticity which can be experimentally measured, the case study can be expanded to other crystalline solids, such as iron, aluminum, nickel, etc. Therefore, the singum model is general for different lattice types and EOS forms, providing a solid physical and mechanical interpretation to correlate the interatomic potential, EOS, and elasticity in the closed formulation.

Thermomechanical Real-Time Hybrid Simulation: Identification, Control, and Experimental Implementation

Herta Montoya; Purdue University; United States
Christian Silva; Purdue University; United States
Shirley Dyke; Purdue University; United States
Manuel Salmeron; Purdue University; United States

Real-time hybrid simulation (RTHS) is an innovative technology that has transformed engineering experimentation and expanded modeling capabilities. The study presented herein is part of a thermomechanical RTHS framework that enables the two-way thermal coupling between a numerical and an experimental subsystem. First, a novel thermal transfer system is introduced to impose a distributed thermal load on an experimental subsystem. The thermal transfer system is identified and modeled as a lumped-capacitance system with mode-dependent continuous dynamics (switching-mode linear system) due to its ability to enforce either cooling or heating loads in one simulation. Next, the interacting multiple model (IMM) estimation algorithm was adopted to estimate the real-time operating thermal transfer system heat exchange mode (cooling or heating). The thermal transfer system estimated mode is an input to a switching control strategy that allows the system to reduce tracking control error under different thermal cycles. Finally, the estimation and control strategies are experimentally implemented for future thermomechanical RTHS execution. The development, control, and implementation of the new thermal transfer system presented in this study contributes to the expansion of hybrid testing to multi-physics problems.

Thin rectangular plate behavior under in-plane harmonic compression

Mehdi Bohlooly Fotovat; Lodz University of Technology; Poland
Przemyslaw Perlikowski; Lodz University of Technology; Poland
Tomasz Kubiak; Lodz University of Technology; Poland

The dynamic response of thin rectangular plates subjected to dynamic compression has been investigated. The considered plate was made of isotropic material, it was simply supported on all edges and subjected to in-plane harmonic compressive load with an excitation frequency equal to the natural frequency for an unloaded plate. The classical plate theory was considered, and equations of motion were derived by Galerkin integrals introducing stress function. Three different deflection functions considering one, two or three simultaneous mode shapes (different numbers of sine half-waves in the direction of load and one sine half-waves in the transverse direction) have been assumed. By performing numerical integration using the Runge-Kutta procedure, the dynamic responses of the plates have been determined. The analytical-numerical solution was verified in a numerical way by employing the finite element method - ANSYS software. The obtained plate response allows for analyzing plate behaviour based on in-time plate maximal deflection, phase portraits, and Poincare maps. The dynamic buckling has been estimated by employing Volmir or Budiansky-Hutchinson criteria. The influence of assumed deflection function i.e., uni- or multi-mode on plate behaviour under dynamic load has been analyzed. Additionally, the effect of mixed mode for equilibrium path determination has been investigated for plates under static load. The obtained results show that the assumed deflection function plays a crucial role in proper results obtaining and that the different functions should be assumed in the case of statical or dynamical loads.

Threat-independent progressive collapse analysis to identify dominant failure sequences and estimate system failure probability

Trisha Chakravorty; Indian Institute of Technology Kharagpur; India
Minangshu Baidya; Techno India University; India
Aritra Chatterjee; Indian Institute of Technology Kharagpur; India
Baidurya Bhattacharya; Indian Institute of Technology Kharagpur; India

The complete or substantial collapse of a structure triggered by the failure of a relatively small part of it is termed as progressive or disproportionate collapse. Identifying weak elements, and weak element failure sequences that may result in progressive collapse should take system level performance criteria and relevant uncertainties into account. This work attempts to develop a reliability-based methodology of assessing threat-independent progressive collapse. Surrogate structures corresponding to each initial damaged state (created by introducing the corresponding damage in the intact structure) are defined. A structure has an ordered set of failed elements at any given point of time, termed as a 'history', not all of which would lead to system failure. Mutually exclusive minimal cut sets consisting of ordered element failure histories, including simultaneous failure of two or more elements, are identified. Only statistically significant ones are followed up to system failure. Since ordering of failure sequences makes the minimal cut sets mutually exclusive, the outlined framework eliminates the need to consider bounds on system failure probability. The proposed framework is applied to two steel truss structures. Load and member capacities are simulated randomly using Latin Hypercube sampling and analysis is carried out incorporating material nonlinearity, geometric nonlinearity and transient dynamic effects due to sudden removal of an element. Failure sequences contributing the most to system failure probability—or dominant failure sequences—are identified. Interestingly, certain elements having a low probability of failure in the intact structure, if removed, have a high probability of triggering progressive collapse up to system failure. This illustrates the significance of studying surrogate structures. Failure sequences starting with these elements would not have a high contribution to overall system failure probability, but are important contenders for 'key elements' that may need to be strengthened to preclude disproportionate collapse. We find that both for the intact and surrogate structures, a few minimal cut sets are major contributors to system failure probability. Ordering of element failures is important in defining the cut sets, since several ordered sequences exhibit asymmetry. Dynamic effects are found to alter failure probability estimates, but not dominant failure sequences. On the other hand, nonlinearities are found to affect the failure probabilities of sequences and may alter or eliminate key elements. Results suggest that strengthening only the least reliable elements of the intact structure, without accounting for failure progression in surrogate structures, may not be sufficient to mitigate progressive collapse.

Tiered Infrastructure Performance Assessment Framework for Field Reconnaissance of Built Environment Across Hazards (Seismic, Windstorm, and Coastal) and Infrastructure Typologies

Mohammad Alam; University of Notre Dame; United States
Tracy Kijewski-Correa; University of Notre Dame; United States
Khalid Mosalam; University of California, Berkeley; United States
Ian Robertson; University of Hawaii, Mano; United States
David Prevatt; University of Flordia; United States
David Roueche; Auburn University; United States

Since its inception in 2018, the Structural Extreme Events Reconnaissance (StEER) Network has assumed a critical role in establishing protocols for systematic, coordinated community-led collection of field observations using a cloud-based mobile app suite suitable for efficient data collection, sharing, and data enrichment. Though it was realized from the outset that collection of standardized field observations (across hazards and structural typologies) is the key to its diverse re-uses and promoting knowledge discovery, a multitude of apps was developed on an ad-hoc basis to assess buildings, other structures, and hazard intensity to speed up StEER's initial operationalization. Unfortunately, the segmentation of structures by class as well as by hazard has resulted in an evolving library of apps that inhibits standardized data collection, is difficult to manage across a growing user base and continues to segregate the hazard community, erecting barriers to multi-hazard assessments (e.g., earthquake-tsunami, hurricane wind-wave-storm surge).

To overcome these challenges, a tiered infrastructure performance assessment framework has been developed that is (i) uniform across hazards (seismic, windstorm, and coastal) and infrastructure typologies and (ii) seamlessly integrates observations of structural performance and hazard context in one user-friendly mobile application. This was achieved through (i) an extensive literature review and landscape analysis of existing post-event structural assessment frameworks/apps/forms, (ii) identification of structural systems, their critical components and response mechanisms to different hazards, and (iii) systematic mapping of essential metadata (e.g., infrastructure geometry, site information, hazard present, geolocation of damage, associated damage measure, etc.) for each hazard to identify commonalities and develop a hierarchy architecture to unify the tiered performance assessments across hazards and levels of forensic detail for implementation into prototype mobile apps. The presentation will focus on the detail of the unified performance assessment framework developed and the resulting pilot app, which was rolled out in the StEER's coastal hazard and infrastructure performance assessment data collection effort in Fort Myers Beach and Sanibel Island, Florida following Hurricane Ian.

Time Domain Analysis of Resonant Microstructured Media under Impact Loading

Erdem Caliskan; University of Tennessee, Knoxville; United States
Willoughby Cheney; University of Massachusetts, Lowell; United States
Weidi Wang; University of Massachusetts, Lowell; United States
Reza Abedi; University of Tennessee, Knoxville; United States
Alireza Amirkhizi; University of Massachusetts, Lowell; United States

The microstructure of a material can be engineered to achieve unique properties not found in nature. Microstructured materials, also known as metamaterials, can exhibit properties utilizing dynamics of heterogeneous microstructure that go beyond the traditional Bragg limit through local resonance. This study analyzed the impact loading response of a low-frequency resonant ceramic metamaterial using the Finite Element Method (FEM). The metamaterial was compared to monolithic slabs and other microstructured designs in terms of stress wave mitigation, peak load retardation, and energy transfer. The results showed that the metamaterial had superior performance in reducing the peak stress wave and improved energy transfer due to its unique effective properties. The study also considered material failure using the Johnson-Holmquist constitutive model for ceramics and found that the favorable properties of the metamaterial design were maintained even with material failure. A reduced order model (ROM) was utilized to improve computational efficiency while maintaining accuracy. The study concluded that resonant ceramic metamaterials are a promising new class of materials with unique and tunable properties that can be used for protective and structural applications.

Topological Interlocking Materials with Tunable Mechanical Properties

Ziran Zhou; California Institute of Technology; United States
Tracy Lu; California Institute of Technology; United States
Anna Gorgogianni; California Institute of Technology; United States
Chiara Daraio; California Institute of Technology; United States
Jose Andrade; California Institute of Technology; United States

The mechanical properties of structured fabrics are governed by both the properties of their constituents, as well as the topology of their arrangement. Most often, both these factors remain unchanged upon design, resulting in constant mechanical properties of the fabrics. In this study we investigate, initially through physical experiments, ways to construct structured fabrics with tunable bending stiffness, by exploiting the combined effects of the constituents' shape and arrangement. We present a type of topologically interlocked materials (TIM), made with woven wire-connected truncated tetrahedrons, that exhibit tunable bending modulus under different levels of applied tension. Upon actuating the tension in the wires, the particles transition into an interlocked state and become an order of magnitude stiffer than in their relaxed configuration. Different levels of interlocking are achieved by architecting truncated tetrahedrons of different dihedral angles. The experiments are modeled by Level Set Discrete Element Method (LS-DEM) simulations, which can reproduce both the constituents' shape as well as their evolving configuration during interlocking. The simulations are able to capture the experimental results of mechanical behavior reasonably well. We thus use the numerical simulations to extensively explore the mechanical properties of this type of TIM subjected to different levels of wire tension, different friction coefficients and tetrahedron dihedral angles. We show that increasing friction coefficient and wire tension have a positive correlation on the bending modulus. Tetrahedrons with the smallest dihedral angles display the strongest interlocking mechanism and hence the greatest bending stiffness. Furthermore, the higher the degree of constituents' interlocking, the higher their resistance to other unfavorable changes, such as the relaxation of the tensile forces in the wires. Such predictive numerical models can be used to reverse-engineer optimal shapes for the most desirable mechanical properties.

Towards real-time digital twins for post-earthquake damage assessment of masonry buildings

Bryan German Pantoja-Rosero; Earthquake Engineering and Structural Dynamics Laboratory (EESD); Switzerland

Radhakrishna Achanta; Swiss Data Science Center (SDSC); Switzerland

Katrin Beyer; Earthquake Engineering and Structural Dynamics Laboratory (EESD); Switzerland

Currently, post-earthquake assessment is performed visually, which implies that inspectors visit the damaged buildings and, based on their expertise, assign a damage grade. Yet, visual inspection is subjective, time-consuming and difficult to document. In this work, we present a novel and end-to-end framework to automatically generate 3D geometric digital twins of masonry buildings containing damage information and its characterization allowing inspectors to make on-site decisions about the assets safety and the required interventions. Our developed pipeline not only significantly reduces inspection time, but it also reduces the subjectivity of decision making because of human judgment. We plan to implement this framework as real-time system to be used in a variety of portable devices to be applied in real-world scenarios.

Towards self-healing concrete using protein encapsulated hydrogels

Elvis Baffoe; University of Miami; United States
Ali Ghahremaninezhad; University of Miami; United States

Concrete is the most widely used construction material globally due to its low cost and high compressive strength. During the life span of concrete, it is subjected to different unavoidable mechanical and environmental conditions that lead to the formation of cracks. These mechanical and environmental conditions can take the form of shrinkage, freeze-thaw, excessive loading etc.. The formation and growth of cracks serve as pathways for deleterious substances to be transported into the reinforced concrete leading to the loss of durability and structural integrity. In this study, hydrogels encapsulated with urease and proteins were designed to impart self-healing to cracked cementitious materials. The mineralogy of the healing products formed on artificial cracks and surrounding cementitious matrix was studied using Fourier transform infrared spectroscopy (FTIR), thermogravimetric analysis (TGA), X-ray diffraction (XRD), and scanning electron microscopy (SEM). The release of proteins from the hydrogel to cement pore solution, calcium chloride solution and surrounding cementitious matrix was studied using Uv-vis. Flexural and compressive strength tests were utilized to study the strength recovery of the healed samples. The amount of healing products formed was shown to increase in artificial cracks in the case of samples modified with hydrogel encapsulated with urease. The SEM and optical imaging results revealed the filling of cracks of the cement paste samples mixed with hydrogel encapsulated with urease and proteins and that translated into a higher strength recovery compared to the control samples.

Tracking Spatiotemporal Evolution of Cementitious Carbonation via Raman Imaging

Nishant Garg; University of Illinois at Urbana-Champaign; United States

Carbonation of cement systems is a growing area of interest as it offers a permanent solution to store CO2. Various analytical techniques like measuring pH changes and calcite content over time have been used to study this dynamic process. However, these methods rely on bulk measurements, which may miss the fine microstructural changes that occur during carbonation. In this talk, I'll explore the use of Raman imaging to follow the carbonation process in cement pastes at a micron-scale resolution. Results show that 40% of the sample surface was covered with calcite after 2 weeks of exposure and portlandite content declined from 15% to 5%. These findings suggest that other hydration products such as calcium silicate hydrate and ettringite also undergo carbonation simultaneously along with calcium hydroxide, opening up the possibility of using Raman imaging to understand the nature and kinetics of complex dynamic phenomena.

Transfer Learning Enhanced Neural ODEs for Adaptive Digital Twin Modeling

Yujie GAN; The Hong Kong University of Science and Technology (Guangzhou); China
Zhilu LAI; The Hong Kong University of Science and Technology (Guangzhou); China

As the virtual replica of physical engineering systems, digital twins have emerged as promising interactive models for a real physical asset throughout its lifecycle. Recent developments in digital twins have emphasized the need for monitoring and predicting physical structure behaviors. The objective of this study was to adaptively twin the dynamic properties of civil engineering structures. We present a framework of adaptive modeling for structural dynamics based on transfer learning enhanced Neural ODEs. By transferring learned prior knowledge from a trained baseline model, we aim to achieve faster model updating (adaptive twining) with high accuracy when the properties of the structure have changed (due to factors such as damage and boundary condition changes). We validate the framework using both numerical and experimental studies. The results indicate that transfer learning enhances the efficacy of adaptive twining.

Transfer Learning Genetic Expression Programming for Reduced Data Modeling of Civil Engineering Systems

Jacob Murphy; Texas A&M University; United States

Civil engineering can benefit from a greater understanding of novel applications of materials, both in regard to the form of commonly used materials and the use of new materials and composites. Models must be created to describe the behavior of these systems, with a substantial investment of time and money required to collect more data. As such, there are often cases where sufficient data is not available. In civil engineering applications, the interpretability of a model is of great importance; the relationships between features need to be clearly presented for use in design and analysis. A machine learning method that minimizes the necessity of new data while also maximizing interpretability appears to be a solution that satisfies these two conditions for addressing civil engineering problems. Genetic expression programming, a sub-algorithm of genetic programming, is an evolutionary algorithm that can produce an interpretable model describing the relationships between the input features and the response variable. GEP models are highly interpretable taking the form of a mathematical expression, addressing the requirement. Transfer learning leverages existing data in adjacent domains to improve performance in the target problem space, alleviating the issues caused by the difficulty of obtaining data in many civil engineering problems. An algorithm combining transfer learning and GEP has the potential to create highly accurate and interpretable models from less data than is currently required to establish less accurate models. Limited research has been conducted into the application of genetic programs for symbolic regression transfer learning purposes. A model that can predict the behavior of beams in one loading configuration using primarily data from a sperate configuration demonstrates the ability of the algorithm to create models that can capture the general knowledge of the system from the source dataset and achieve a positive transfer to the target problem space with different behavior than the source specimens. This would reduce the number of tests that have to be conducted on new systems without sacrificing accuracy. A python-based relational transfer learning technique for genetic programs with and without simple feature augmentation has been developed, and these techniques have successfully been applied to a civil engineering problem.

TRANSIENT RESPONSE OF FRAME STRUCTURES INTERACTING WITH SOIL PROFILES BY MODIFIED MODAL BASIS

Amauri Ferraz; University of Campinas - FEM; Brazil
Lucas Pacheco; University of Campinas - FEM; Brazil
Ronaldo Carrion; University of São Paulo, Dept. of Mining and Petroleum Engineering; Brazil
Euclides Mesquita; University of Campinas - FEM; Brazil

The dynamics of structures coupled to the soil is studied in this work, in which modal analysis is used to determine the transient responses of the structure considering the influence of the soil. The combination of the Finite Element Method (FEM), for modeling the structure, and the Boundary Element Method (BEM), for soil modeling, is used to obtain the Frequency Response (FRF) functions of the structure with soil effects. The soil-structure system is divided into two subsystems (structure and soil), and after obtaining the responses for each subsystem, the coupling between the responses is performed by the balance of forces and displacements at the soil-structure interface. The FRFs of the coupled system are used to extract the modal parameters of the structure using the Rational Fraction Polynomial Method (RFPM). This extracted modal base contains the soil influence and is used in the equations of motion of the system, which are integrated directly in the time domain to determine the transient responses. This methodology allows the analysis for any soil arrangement, as long as the free response of the soil in the frequency domain is known. Different soil arrangements are used to analyze the influence on the structure response. For modeling the structure, frame elements are used.

Transportation Asset Management With Incorporation Of Traffic Operations Adaptation Using Deep Reinforcement Learning

Mohammad Saifullah; Department of Civil & Environmental Engineering, The Pennsylvania State University; United States
Kostas Papakonstantinou; Department of Civil & Environmental Engineering, The Pennsylvania State University; United States
Shelley Stoffels; Department of Civil & Environmental Engineering, The Pennsylvania State University; United States
Weiwen Zhou; Sid and Reva Dewberry Department of Civil, Environmental and Infrastructure Engineering, George Mason University, Fairfax, VA; United States
Elise Miller-Hooks; Sid and Reva Dewberry Department of Civil, Environmental and Infrastructure Engineering, George Mason University, Fairfax, VA; United States

Preserving structural integrity through inspections and maintenance (I&M) is a recurring and expensive process involving complex decisions strategically taken over space and time. Optimal management of large networks renders the decision-making process particularly challenging due to the substantial number of involved assets that also have intrinsic interdependencies and correlations. In a transportation network, these dependencies are, among others, manifested through the global effects that I&M policies have on traffic, since the involved assets, with their individual contributions to traffic capacity, affect the overall system performance. Thus, determining the potential system impacts of combinations of I&M decisions on all associated assets becomes a complicated process. In this study we develop relevant methodologies to quantify and optimize the overall effects of I&M decision-making processes on transportation networks through Deep Reinforcement Learning (DRL) algorithms. Further, the connection of I&M plans to traffic operations and management is being studied, quantifying and controlling the repercussions of traffic-related system effects, and establishing a joint decision-making process for I&M operations and traffic management. The optimization framework is based on Partially Observable Markov Decision Processes (POMDPs) integrated with DDMAC (Deep Decentralized Multi-agent Actor-Critic), an originally developed DRL approach [1], supported by a Centralized Training and Decentralized Execution (CTDE) paradigm for scaling-up to larger networks [2-3]. A transportation network application example is presented to showcase the efficiency and applicability of our suggested framework. The analyzed network includes several bridge and pavement components characterized by nonstationary deterioration, budget constraints and risk targets, traffic delay considerations, and traffic operations adaptation capabilities. It has been found that DDMAC-CTDE significantly outperforms traditional asset management strategies, and traffic adaptation has an additional notable effect on the computed optimal asset management policies.

References

[1] Andriotis, C. P. & Papakonstantinou, K. G., 2021. Deep reinforcement learning driven inspection and maintenance planning under incomplete information and constraints. Reliability Engineering & System Safety, Volume 212, p. 107551.

[2] Saifullah, M., Papakonstantinou, K. G., Andriotis, C. P. & Stoffels, S. M., 2023. Multi-agent deep reinforcement learning with centralized training and decentralized execution for transportation infrastructure management. Under review.

[3] Saifullah, M., Andriotis, C. P. , Papakonstantinou, K. G., and Stoffels S. M. 2022. Deep reinforcement learning-based life-cycle management of deteriorating transportation systems. In Bridge Safety, Maintenance, Management, Life-Cycle, Resilience and Sustainability, pp. 293-301. CRC Press, 2022.

Truncated Unscented Kalman Filter for Incorporating Constraints in Joint State-Parameter Estimation

Adrita Kundu; Indian Institute of Technology, Kanpur; India
Suparno Mukhopadhyay; Indian Institute of Technology, Kanpur; India

In joint state-parameter estimation using the Unscented Kalman Filter (UKF), considerable tuning of the initial state vector and covariance matrices may be required to ensure proper convergence. Constraints on the parameters, e.g. bounds on stiffness values, which may be known a priori from physics or engineering judgement, can be incorporated to have improved and more controlled convergence. In this work, the Truncated Unscented Kalman Filter (TUKF) is introduced to handle such constraints within the UKF framework. The constraints are enforced by appropriately truncating the conditional posterior probability density functions of the system states. The method is illustrated using two different classes of systems: 1) shear frames with hysteretic Bouc-Wen elements exhibiting degradation and pinching; and 2) train-bridge systems, which can behave as linear time-varying systems because of the moving heavy train masses. Numerical examples are used to illustrate the robustness of the TUKF against noisy measurements and high uncertainty in the initial state vector. For the hysteretic models, it is shown that a complex model class may lead to numerical instabilities or incorrect estimation of some states. This might be possibly owing to insensitivity or unidentifiability associated with the model parameters. However, in such cases, assuming a simplified, albeit inaccurate model class, can still lead to tracking of the resultant hysteretic forces and dynamic states (displacement and velocities) with high accuracy. Further, shake table tests on a reinforced concrete frame, progressive damaged using inputs of increasing amplitude, are used to illustrate the effectiveness of the method in assessing the level of damage through estimated damage indices. For the train-bridge system also, the method is illustrated using experimental data from a lab-scale two-span continuous bridge, excited using a moving train. Overall, the results show that the TUKF improves on the convergence of the UKF, while maintaining the same level of accuracy in the state and parameter estimates.

Tube-Based Multifunctional 3D Origami-Architected Metamaterials

Hannah Kim; Princeton University; United States
Glaucio H. Paulino; Princeton University; United States

Periodic plate- and shell-based lattice metamaterials have dominated the technical literature, however, those lattices may suffer from limited recoverability owing to premature failure due to stress concentrations at discrete member junctions. To circumvent this problem, origami architectures have emerged as a promising pathway to augment the accessible design space by enabling highly deployable and tunable assemblies endowed with unusual mechanical properties, such as tunable anisotropy, large degree of shape recoverability, and scalability toward small scales. Here we address origami-architected metamaterials and concentrate on tube-based assemblies, namely zipper and interleaved. First, we show the results achieved with 3D direct laser writing fabrication, and in-situ scanning electron microscopic mechanical characterization of microscale origami metamaterials, based on the multimodal assembly of Miura-ori tubes. Then, we investigate the interleaved tube origami metamaterial, which exhibits flat foldability in two directions and high stiffness in the third direction. Model designs are explored for different methods of fabrication such as multi-material 3D printing and assembling from stacked sheets at the centimeter-scale, while considerations are made toward miniaturization of such particular assembly. Our findings and ongoing research underscore the scalable and multifunctional nature of origami designs and pave the way toward harnessing origami engineering at small scales.

Tuned-inerter dampers in vibration control of semi-submersible offshore wind platforms to improve system lifespan and energy harvesting

Lauren Hall; Virginia Tech Center for Energy Harvesting Materials and Systems; United States
Duncan Lambert; Virginia Tech Center for Energy Harvesting Materials and Systems; United States
Ryan Okuda; Virginia Tech Center for Energy Harvesting Materials and Systems; United States
Lei Zuo; University of Michigan; United States
Biao Fang; GE Global Research; United States
Yifan Luo; Hunan University of Science and Technology; China
Javad Javaherian; University of Michigan; United States

Floating platforms are necessary for wind turbines installed in deep-water applications. This foundation design introduces more degrees of freedom in the system and as a result, greater system vibrations. Stabilization of the platform may help reduce stresses on the turbine, particularly in the tower and connection point to platform. This reduction will improve longevity of the structure and reduce maintenance costs. Efficiency may also be improved by maintaining a more consistent blade alignment into the wind. This study explores the feasibility of using tuned inerter dampers (TIDs) to dampen vibrations of floating offshore wind turbines. Vibrations of a semi-submersible offshore wind platform are modeled using Lagrangian analysis for three scenarios: baseline system, a simple TMD system, and a TID system which replaces the TMD damping with a combination of generator damping, inertance, and additional stiffness. These models are validated using NREL's FAST tool, which simulates the dynamic response of turbines under both wind and wave loads, as well as through physical wave tank experimentation. Current results show that a TID performs better than a TMD with the same mass ratio under most load cases. Ongoing optimization of the system parameters will ensure that vibration reduction is maximized while maintaining stiffness, damping, and inertance values that are physically attainable for both the prototype- and full- scale system. System fatigue, lifespan, and energy harvested are modeled in each scenario, and the potential for supplementary power harvesting from the TID generators is assessed.

Two dimensional problem of an elastic matrix containing multiple Gurtin-Murdoch material surfaces along straight segments

Rohit S Patil; University of Minnesota, Twin Cities; United States
Sofia G Mogilevskaya; University of Minnesota, Twin Cities; United States

In this talk, we present the study of the plane strain problem of an infinite isotropic elastic medium subjected to a far-field load and containing multiple Gurtin-Murdoch material surfaces located along straight segments. Each material segment represents a membrane of vanishing thickness characterized by its own elastic stiffness and the residual surface tension. The possible applications of the problem are in the area of modeling materials that use ultra-thin and stiff membranes as reinforcements. We provide a brief overview of the governing equations and bound- ary conditions for the problem, present analytical integral represen- tations for elastic fields everywhere in material system, formulate the boundary integral equations in the dimensionless setting for the un- known density functions involved in these representations. The numer- ical algorithm and several results of the numerical simulations will be presented to demonstrate the effectiveness of the proposed approach and study the influence of dimensionless parameters involved.

Uncertainty Quantification of CO2 Leakage and Risk Analysis of Induced Seismicity for Large-scale Geological CO2 Sequestration

Hannah Lu; MIT; United States
Lluis Salo Salgado; MIT; United States
Ruben Juanes; MIT; United States
Youssef Marzouk; MIT; United States

Geological CO2 sequestration is an important strategy for reducing greenhouse gas emissions to the atmosphere and mitigating climate change. One of the most important assessments during the process is the coupling between mechanical deformation and fluid flow in fault zones, which is a key determinant of fault instability, induced seismicity and CO2 leakage [1]. A recently developed methodology, PREDICT [2], provides stochastic modeling of clay smears in fault zones and an improved prediction of anisotropic fault permeabilities that accounts for geologic uncertainty. In this study, we build a comprehensive set of fault permeability scenarios from PREDICT and investigate the effects of uncertainties from the fault zone on reservoir simulations of large-scale CO2 sequestration. To alleviate the prohibitively expensive computational costs of repeated runs in uncertainty quantification, we develop a deep-learning-based surrogate model capable of predicting flow migration, pressure buildup and geomechanical responses in CO2 storage operations. We also compare our probabilistic estimation of CO2 leakage and fault instability with previous studies based on deterministic estimates of fault permeability. The results highlight the importance of including uncertainty and anisotropy in realistic modeling of complex fault structures and provide more accurate scientific information for better safety management in CO2 sequestration operations.

[1]. Cappa, Frédéric, and Jonny Rutqvist. "Impact of CO2 geological sequestration on the nucleation of earthquakes." Geophysical research letters 38.17 (2011).

[2]. Saló-Salgado, Lluís, J. Steven Davis, and Ruben Juanes. "Fault permeability from stochastic modeling of clay smears." Geology (2022).

Uncertainty-aware time-lapse monitoring of geological carbon storage with learned surrogates

Ziyi Yin; Georgia Institute of Technology; United States
Rafael Orozco; Georgia Institute of Technology; United States
Mathias Louboutin; Georgia Institute of Technology; United States
Ali Siahkoohi; Rice University; United States
Felix Herrmann; Georgia Institute of Technology; United States

Time-lapse seismic monitoring of CO2 sequestration is computationally expensive as it involves modeling of both fluid-flow physics and wave physics. It also requires differentiation through the solvers with respect to properties of interest in the subsurface. In this talk, we present a learned end-to-end inversion framework, which uses a pre-trained Fourier neural operator as a learned surrogate for the fluid-flow simulator in order to greatly reduces the cost associated with fluid-flow modeling and differentiation through the solver. Through synthetic experiments, we demonstrate the efficacy of this framework on inverting the subsurface permeability of the reservoir and on monitoring CO2 plumes. We further quantify the uncertainty of the permeability and CO2 plumes with conditional normalizing flow. With this framework, we can also forecast the growth of CO2 plumes in the future with uncertainty estimation without any acquired seismic data.

Understanding Gait Biomechanics through Structural Mechanics: Foot-Floor Contact Modeling using Footstep-induced Structural Vibrations

Yiwen Dong; Stanford University; United States
Hae Young Noh; Stanford University; United States

This study aims to understand gait biomechanics through structural mechanics by modeling the foot-floor contact during walking using footstep-induced structural vibrations. Understanding gait biomechanics is critical in providing quantitative gait health assessment for patients who suffer from musculoskeletal injuries or neuromuscular disorders, the elderly who have a high risk of falls, and athletes or people who are generally interested in learning about their physical performances. Modeling and analyzing the foot-floor contact is a fundamental step to understand the health status of their gaits. Existing studies use various sensing devices to capture gait information, including cameras/wearables and force plates. However, the former only captures kinematic aspects, and the latter has limited coverage of the walking path. In this study, we leverage the structural vibrations induced by footstep forces to infer the type and time of foot-floor contact, which enables kinetics-informed and wide-ranged gait health monitoring. The main challenge is the unknown force transfer mechanism between the foot and the floor surfaces, leading to difficulty in reconstructing the force and contact profile during foot-floor interaction using structural vibrations. To overcome the challenge, we first characterize the floor vibration during foot strike and foot off to understand the types of footstep forces (friction force vs. normal force) and vibration waves (surface wave vs. body wave). Then, we infer the foot-floor contact type (heel vs. toe) and time by modeling the effect of force transfer during foot strike and foot off. Finally, gait anomalies, including dragging and limping, are detected by comparing the predicted foot-floor contact type and time with the healthy gait. To evaluate our approach, we conducted a real-world experiment with 20 subjects. Our approach achieves 94.2% and 96.7% accuracy in predicting contact type and time, leading to 98.1% accuracy in detecting gait anomalies, including dragging and limping.

Understanding the role of magnesium in modifying structure and properties of calcium silicate hydrate

Amirhossein Madadi; University of Massachusetts Lowell; United States
Jianqiang Wei; University of Massachusetts Lowell; United States

The incorporation of magnesium (Mg) into the structure of calcium silicate hydrate (C-S-H) has been of great interest given the increasing need for durable cementitious materials and sustainable infrastructure. This study aims to investigate the possible partial substitution of Ca2+ by Mg2+ ions in the C-S-H structure via a double-decomposition synthesis method. Mg-modified C-S-H samples with varying Ca/Si ratios (i.e. 0.8, 0.7, 0.6 and 0.5) and Mg/Si ratios (i.e. 0, 0.1, 0.2 and 0.3) at a constant (Ca+Mg)/Si of 0.8 were investigated. The changes in phases, molecular structures and properties of the C-S-H in the presence of Mg were studied via X-ray diffraction (XRD), thermogravimetric analysis (TGA), Fourier transform infrared (FTIR) spectroscopy, Raman spectroscopy, solid-state nuclear magnetic resonance (NMR) spectroscopy, nanoindentation, and thermodynamic modeling. The results indicate that a portion of Mg2+ ions can be incorporated into C-S-H and decrease the degree of crystallinity of C-S-H. The addition of Mg2+ up to Mg/Si of 0.15 strengthens the possible formation of C-(M)-S-H with improved properties due to an appropriate substitution of Ca2+ by Mg2+ ions. However, a further increase in Mg/Si ratio to 0.2 or higher resulted in decreased stability and mechanical properties of C-S-H due to the co-existence of C-S-H and magnesium silicate hydrate (M-S-H).

Understanding the training dynamics of PINNs for the non-local gradient damage equation

Panos Pantidis; New York University Abu Dhabi; United Arab Emirates
Mostafa Mobasher; New York University Abu Dhabi; United Arab Emirates

PINNs is a machine learning technique which utilizes neural networks as the surrogate approximation for the solution of partial differential equations (PDEs). In our recently proposed I-FENN framework (Integrated Finite Element Neural Network), we demonstrated how PINNs can be directly embedded in the finite element level and solve the non-local gradient equation in the context of continuum damage mechanics. Here we delve into the training dynamics of PINNs, and we explore a) their convergence properties, and b) how does their shape impacts their predictive accuracy, simulation cost and robustness within I-FENN. Analogous to the well-established convergence of FEM against the element size, we uncover a similar behavior of PINNs convergence against the network size as well as in the training sample limit. Also, while maintaining the same total number of neurons, we illustrate several pros and cons of utilizing either very deep vs very shallow networks. For example, very deep networks can potentially get stuck during the Adam training stage and are computationally slower, whereas very shallow networks tend to overestimate local frequencies and require greater effort in the L-BFGS stage. Our conclusions are tailored towards the application-oriented use of PINNs and provide a holistic view for the industrial end-user on the optimum design strategies of PINNs in the context of I-FENN and non-local gradient damage.

Unified surface poromechanics theory capturing condensation-induced contraction of mesoporous materials

Yida Zhang; University of Colorado Boulder; United States
Mohammadali Behboodi; University of Colorado Boulder; United States

Adsorption-induced deformation is ubiquitous in natural (wood, coal) and engineered (cement, MOFs, porous polymers) porous materials. As the partial pressure of adsorbate vapor increases, the strain isotherm of these materials can exhibit complex nonlinear and non-monotonic characteristics. At low partial pressures, most porous materials exhibit volumetric expansion, which is attributed to the reduction of surface stress and thus the relaxation of adsorption stress felted by the solid skeleton. This is the so-called "Bangham effect" and can be described by the surface poromechanics formulation (Zhang, 2018). For microporous materials, early adsorption can lead to abnormal shrinkage, which is shown to be associated with the development of negative disjoining pressures in nanopores under the same theory (Eskandari-Ghadi and Zhang, 2021). The surface poromechanics framework, however, has yet to capture the sudden contraction of mesoporous media at high vapor pressure levels induced by capillary condensation. This contribution reports our progresses towards a unified surface poromechanics formulation that satisfies the following requirements: 1) It considers the phase transition of adsorbate from vapor to liquid and the appearance of liquid-vapor interface. 2) It recovers the retention characteristic curve that is unique to the porous system. 3) It captures the early Bangham expansion (no condensation) as well as the large contraction due to condensation in a consistent manner. 4) The asymptote of the theory at degree of saturation equals 0 and 1 recovers the usual poromechanics theory for biphasic porous media.

REFERENCES:

Eskandari-Ghadi, M., Zhang, Y., 2021. Mechanics of shrinkage-swelling transition of microporous materials at the initial stage of adsorption. International Journal of Solids and Structures 222, 111041. Zhang, Y., 2018. Mechanics of adsorption-deformation coupling in porous media. Journal of the Mechanics and Physics of Solids 114, 31-54.

Universal principles of flexible mechanical metamaterials

Zeb Rocklin; Georgia Institute of Technology; United States

Ongoing advances in manufacturing techniques have permitted the production of mechanical metamaterials with a single uniform low-energy deformation mode, such as networks of counter-rotating square pieces capable of undergoing dilation. However, under generic loading conditions such structures undergo complex, spatially varying deformations that are difficult to control experimentally or characterize numerically. Here, we present an analytic theory that describes how the uniform deformation mode can be used to predict the complex deformations. This simple, universal theory corresponds closely to experimental observations. The approach is extended to general mechanisms and to structures such as origami sheets that can fold into the third dimension.

Unpaired Image-to-Image Translation of Structural Damage

Subin Varghese; University of Houston; United States
Vedhus Hoskere; University of Houston; United States

The condition assessment of civil infrastructure traditionally relies heavily on the expertise of an inspector which can be time consuming, unsafe, and has been shown to be variable between inspectors. Advances made in deep learning provide methods to automate crucial condition assessment tasks such as damage and context identification. These methods allow for a faster, safer, and unbiased condition assessment. However, a critical challenge in creating robust and generalizable Deep Neural Networks (DNNs) is the difficulty in obtaining a large and diverse dataset of damaged structures. To improve the efficiency of available data many data augmentation methods have been proposed such as using synthetic images generated by Generative Adversarial Networks (GANs). A critical limitation of GANs however is the limited diversity of data that can be produced, as GANs are only able to interpolate between samples of damaged structures. Unpaired image-to-image translation using Cycle Consistent Adversarial Networks (CCAN), which have not been investigated for applications in condition assessment, provide a means of extending the capabilities of GANs by leveraging the vast amount of data on undamaged structures that can be translated into damaged structures. We present EIGAN, a novel CCAN architecture for generating realistic synthetic images of damaged structures from an image of an undamaged structure. Images generated by EIGAN retain properties of the input undamaged structure such as building shape, layout, color, size, etc. We also release a new unpaired dataset of damaged and undamaged images of structures taken after the 2017 Puebla Earthquake. This dataset is used to test several state-of-the-art CCANs against EIGAN specifically for damage translation using both qualitative and quantitative measures. A new methodology is also proposed to explore the latent space of EIGAN allowing for control of properties of the images generated by EIGAN. The results demonstrate that CCANs are an effective means of data augmentation to improve a networks performance.

Unsupervised Damage Detection for Smart Extraterrestrial Habitats Using Autoencoders and Information Fusion

Zixin Wang; Purdue University; United States
Mohammad Jahanshahi; Purdue University; United States
Ilias Bilionis; Purdue University; United States
Amin Maghareh; Purdue University; United States
Yuguang Fu; Nanyang Technological University; Singapore
Shirley Dyke; Purdue University; United States

In the context of sustainable and resilient extraterrestrial habitats, the structural health monitoring (SHM) of habitats is crucial and challenging due to the harsh space environments, including extreme temperatures, meteorite impacts, radiation, etc. Damage detection is critical to maintaining the safety of human beings and the normal operation of space habitats. Therefore, it is an urgent need to develop a damage detection algorithm for extraterrestrial habitats. Data-driven methods based on machine learning paradigm have been broadly utilized in different SHM tasks in recent years, which can be mainly divided into supervised learning and unsupervised learning methods. Supervised learning requires the labeled data under both healthy and damage states of the structure, which is difficult to collect in real-world applications. However, unsupervised learning only needs the data under the healthy state to train the damage detection algorithm. In this work, an unsupervised damage detection algorithm using autoencoders (AEs) and information theory has been developed. Continuous wavelet transforms (CWTs) of acceleration signals are utilized to train AEs. Information fusion strategies are proposed to enhance the robustness of the algorithm to both aleatory and epistemic uncertainties. Two unsupervised learning approaches developed by standard AE and variational autoencoder (VAE) are systematically compared. Numerical study based on an ASCE benchmark problem and experimental study based on a geodesic dome testbed have been carried out to validate the damage detection performance of the proposed algorithm. The feasibility of using VAE in data augmentation and threshold detection for unsupervised damage detection has been investigated.

Use of Alkali-activated Slag Binder and Shape-stabilized Phase Change Material to Develop an Energy-efficient Multifunctional Cementitious Composite in Buildings

In Kyu Jeon; Texas A&M University; United States
Abdullah Azzam; Texas A&M University; United States
Hussein Al Jebaei; Texas A&M University; United States
Yong-Rak Kim; Texas A&M University; United States
Ashrant Aryal; Texas A&M University; United States
Juan Carlos Baltazar; Texas A&M University; United States

In the building sector, an enormous amount of energy has been consumed and a huge amount of CO2 has been emitted to maintain a comfortable indoor temperature. To reduce the current level of CO2 emissions, using eco-friendly alternative binders instead of Ordinary Portland Cement (OPC) and improving the building's energy efficiency is indispensable. Phase change materials (PCM) have been utilized to improve the thermal properties of cementitious composite via its latent heat capacity. While there have been studies to understand the energy saving, mechanical properties, and durability performance of using PCMs in cement composite, most attempts have used OPC as a binder material. Even though there are some attempts have been made to analyze the thermal properties of alkali-activated slag (AAS) composite with PCM, their environmental impact has not been extensively investigated, as most analyses are based on limited thermal-mechanical properties. This study aimed to evaluate the multifunctional effect of AAS binder and shape-stabilized PCM on thermal-mechanical properties and environmental impact by using the experimental-computational method and case study. The experimental results demonstrated that AAS binder and the presence of thermal energy storage aggregate (TESA) improve the thermal properties of cementitious composite by reducing thermal conductivity and heat transfer rate. In addition, the AAS-based composite indicated much lower CO2 emission than the OPC-based one, while the incorporation of TESA increased the initial CO2 emission. Improved thermal properties of cementitious composite with TESA can offset the initial CO2 emission by saving annual energy consumption. The findings of this study infer the potential application of AAS binder and TESA as eco-friendly energy-saving building construction materials.

Use of characteristics method for fragmentation analysis of 1D heterogeneous quasi-brittle materials

Reza Abedi; University of Tennessee; United States
Giang Hyunh; University of Tennessee; United States

Fracture response of materials is highly sensitive to microstructural details and defect distribution. Accordingly, in fragmentation analysis and some other fracture examples, the use of deterministic and homogeneous material properties can result in nonphysical responses. The use of random fields as underlying material properties has been shown to address this problem to some extent. We use random fields with varied one- and two-point statistics as input elastic or fracture properties. Cohesive model is used to represent fracture at material interfaces for fragmentation analysis.

A method of characteristics is formulated to advance the solution along the potential contact/fracture interfaces. The contact condition is strongly reinforced. The inputs of the model are loading rate, and nondimensional elastic and fracture parameters such as nondimensional fracture strength and displacement scales. For the heterogeneous material properties, the input includes the values of this field at a specified positions for a uniform spatial grid. The outputs include mechanical solutions, e.g., displacement, stress, and damage, at the same locations at later times and the histories of various energies and average forces in time, as well as their values at specific stages of the solution, such as maximum load or failure stage. Two of the objectives of this study are to better understand the effect of spatially correlated material heterogeneities on its fragmentation response and the interaction of these heterogeneities with loading rate.

Use of time-temperature shift factors for waveform-based viscoelastic measures in asphalt binder systems

Saqib Gulzar; North Carolina State University; United States
Shane Underwood; North Carolina State University; United States

The current methodologies for characterizing asphalt binders in the United States involve the utilization of peak-to-peak oscillatory shear stress-strain data alone. While a sinusoidal waveform is applied during testing, only the peak responses are recorded, measured, and subsequently used for material characterization. This study posits that, given the increased prevalence of modified asphalt binder systems, it is essential to record and analyze the complete waveform data under both small and large strains to effectively differentiate between materials. To this end, four modified binders were tested using Large Amplitude Oscillatory Shear (LAOS) at varying strain levels and the complete waveform data was recorded. This data was subsequently analyzed utilizing orthogonal stress decomposition techniques to study the linear and nonlinear viscoelastic properties of the binders. The time-temperature dependency under both linear and nonlinear regimes was also examined and time-temperature shift factors derived from the linear regime were successfully applied in the nonlinear regime. The results indicate that all tested binders displayed strain stiffening and shear thinning behavior under most testing conditions. This study provides valuable insight into the nonlinear viscoelastic behavior of modified asphalt binders and can serve as a benchmark for future research in this field.

Using Nanomaterials to Improve the Performance of Recycled Aggregate Concrete

Nathanial Buettner; Northwestern University; United States
Ange-Therese Akono; Northwestern University; United States

Recycling demolition and natural disaster concrete waste for new concrete production is a sustainable approach that is currently actively pursued in many countries such as Germany, France, Denmark, United States, China, and Japan. Recycling concrete presents multiple advantages including: (i) reduction in landfill space, (ii) savings of an estimated 25M tons of mineral res ources, and (iii) addressing the exponential demand for new structures. However, in practice, only a small fraction of concrete rubble is reutilized, primary for land stabilization purposes. A major limitation is the lower values of the tensile and compres sive strength, reduced durability, and unfavorable rheological properties of recycled aggregate concrete compared to conventional concrete. We employ nanoscale mechanical testing and analytical characterization methods to understand the difference in mecha nical properties between ordinary concrete and recycled aggregate concrete. We found that recycled aggregate is surrounded by an irregular layer of residual hardened cement with lower mechanical modulus than the original aggregate. As a result, recycled ag gregate concrete exhibits a higher capillary porosity and a lower fraction of hard grains compared to ordinary concrete. In addition, the average indentation modulus and indentation hardness of recycled aggregate concrete are significantly lower than that of ordinary concrete. Moreover, we are currently investigating the use of carbon-based nanofillers to yield improved performance recycled aggregate concrete. We will show that both nanosilica and multiwalled carbon nanotubes lead to a better quality of the cement. This study is important to guide future efforts aimed at improving the performance of recycled aggregate concrete.

Validation of an analytical model for estimating debris trajectories in a tornadic wind field

Connell Miller; Northern Tornadoes Project; Canada
Gregory Kopp; Northern Tornadoes Project; Canada

Although the damage indicators in the EF-scale cover a wide range of structural damage, it mostly does not consider the wind-induced movement of large compact objects such as vehicles, construction materials, and large appliances, which are often found in the aftermath of ground and drone surveys. Since there is no guidance in the EF-scale on the wind-induced movement of large compact objects, these observations are currently not being utilized to provide an estimate of the potential wind speeds. The objective of this paper is to provide an advanced analytical debris model for large compact objects in a tornadic wind field and validate the model by comparing these results to a wind tunnel study on vehicles performed by Haan et al. (2017), Overall, the analytical model shows good agreement for determining threshold sliding and lofting speeds of heavy compact objects and can be used to determine trajectories for lofted objects. In the future, this model will be applied to debris data obtained by the Northern Tornadoes Project to make recommendations for the application of this debris analysis method to supplement damage indicators found in the EF-scale.

Vibration effects on assisting penetration into granular materials

Mahdi Alaei; University of Manitoba; Canada
Pooneh Maghoul; Polytechnique Montreal; Canada
Nan Wu; University of Manitoba; Canada

Typical geotechnical drilling tools are not applicable for subsurface investigation of the lunar surface due to payload limitations. Vibration can be used to reduce the required axial force and design a more compact drilling tool for remote subsurface investigations. Here, we studied the effect of bending resonance modes on the penetration of a probe into granular materials. Piezo patches were attached to a probe to create lateral vibrations. Experimental modal analysis was used to determine the resonance frequencies of the probe. The probe was then pushed into different granular materials, with and without lateral vibrations, and the required vertical forces were measured. Our tests show that the bending vibration modes of the probe can be influential in reducing the required vertical force to push the probe into the granular soil samples.

Viscoelastic characteristics of nacre-like materials

Li-Wei Liu; National Taiwan University; Taiwan
Yuan-Jyun Shih; National Cheng Kung University; Taiwan

Nacre performs the superior property of mechanics due to the sophisticated arrangement for its hard and soft ingredients. The protein matrix contains the mineral inclusion, which is called the brick-and-mortar architecture, exhibits significantly better than the sum of their parts and it defects the rule of mixtures. The shear-lag model or its simplified version, the tension-shear-chain (TSC) model have been proposed to investigate elastic properties of nacre. In this study, we propose a viscoelastic TSC model which demonstrates acceptable results in comparison with the experiment. Based on the viscoelastic TSC model, we explore the viscoelastic features of a bio-inspired structural material with the brick-and-mortar architecture which is called nacre-like materials. The analytical responses of the nacre-like materials under stepwise, monotonic, and cyclic loadings are obtained to investigate the influence of the strain rate and geometric parameters, such as the aspect ratio as well as the volume fraction of mineral part, on the viscoelastic behavior of the material. Furthermore, several performance indices with respect to different loading types are developed. Based on the performance index, some conditions of optimal design for the nacre-like material are provided.

Viscoelastic properties of an LC3-paste: ultrasound pulse transmission and hourly repeated minute-long creep testing

Sophie J. Schmid; Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Karlsplatz 13, 1040 Vienna, Austria, EU; Austria

Luis Zelaya-Lainez; Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Karlsplatz 13, 1040 Vienna, Austria, EU; Austria

Olaf Lahayne; Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Karlsplatz 13, 1040 Vienna, Austria, EU; Austria

Martin Peyerl; Smart Minerals GmbH: Franz-Grill-Straße 9/O214, 1030 Wien, Austria, EU;/ ALAS Minerals GmbH: Unterthalham Straße 2, Ohlsdorf 4694, Austria, EU;; Austria

Bernhard L.A. Pichler; Institute for Mechanics of Materials and Structures, TU Wien (Vienna University of Technology), Karlsplatz 13, 1040 Vienna, Austria, EU; Austria

Limestone calcined clay cements (LC^3) are a promising alternative to traditional ordinary Portland cements (OPC) because of their improved eco-efficiency and global availability of raw materials. Macroscopic mechanical experiments, namely ultrasound pulse transmission tests [1] and hourly-repeated minute-long creep experiments [2,3,4], are performed under isothermal conditions to quantify the viscoelastic properties of an LC^3-paste and of an OPC-paste, both produced with an initial water-to-binder ratio = 0.45. The mass of the LC^3-binder consists of 70% OPC, 15% limestone, and 15% calcined clay. The evolution of the elastic stiffness and of the creep properties of both types of cement pastes is characterized from approximately one day to seven days after material production. At the end of this age interval, the creep modulus of the LC^3-paste is by 46% larger than that of the OPC-paste, implying that LC^3 is significantly less creep active than OPC. Three days after production, the modulus of elasticity of the LC^3-paste is by some 20% smaller than that of the OPC-paste. However, from a material age of 5 days onwards, the elastic stiffness of the LC^3-paste is virtually equal to that of the OPC-paste. It is concluded that LC^3 is a particularly suitable binder when low creep activity is desirable, e.g. in building construction rather than in tunneling.

[1] Kohlhauser, C. and Hellmich, Ch. Ultrasonic contact pulse transmission for elastic wave velocity and stiffness determination: influence of specimen geometry and porosity, Engineering Structures 47 (2013) 115–133.

[2] Irfan-ul-Hassan, M., Pichler, B., Reihsner, R., and Hellmich, Ch. Elastic and creep properties of young cement paste, as determined from hourly repeated minute-long quasi-static tests. Cement and Concrete Research 82 (2016): 36-49.

[3] Ausweger, M., Binder, E., Lahayne, O., Reihsner, R., Maier, G., Peyerl, M., and Pichler, B. Early-age evolution of strength, stiffness, and non-aging creep of concretes: Experimental characterization and correlation analysis. Materials 12.2 (2019): 207.

[4] Binder, E., Königsberger, M., Díaz Flores, R., Mang, H., Hellmich, Ch., Pichler, B. Thermally activated viscoelasticity of cement paste: Minute-long creep tests and micromechanical link to molecular properties. Cement and Concrete Research 163 (2023): 107014.

Viscous behavior of shale rocks due to dissolution and precipitation processes

Ravi Prakash; Texas A&M University; United States
Arash Noshadravan; Texas A&M University; United States
Sara Abedi; Texas A&M University; United States

The dissolution and precipitation of various mineral phases in the chemo-mechanically loaded shale rocks result in a redistribution of the stress field in the surrounding phases. This stress transfer, which depends on the rate of dissolution/precipitation processes, leads to deformation of the rock composite. This study aims to establish a link between the microstructural evolution and the creep behavior of shale rocks under chemical and mechanical loading. Microstructural models of unreacted and reacted shale samples are coupled into a finite element model to calculate the creep deformation. Experimental studies on shale rocks exposed to CO2-rich and N2-rich brine under high temperature and pressure conditions are carried out to experimentally characterize the microstructural and mechanical alteration of the samples. A finite element model then uses the experimental results to simulate the creep behavior due to dissolution and precipitation processes. Once the viscoelastic deformations of the shale composite are obtained, the time-dependent stress and strain fields in different reaction regions are computed. The results of the proposed methodology signify the substantial role of dissolution/precipitation processes on the viscous behavior of rocks when subjected to harsh environments.

Wavelet-based modal identification of bridges using field mobile sensing data

Liam Cronin; Lehigh University; United States
Debarshi Sen; Southern Illinois University Carbondale; United States
Shamim Pakzad; Lehigh University; United States

Mobile sensing has emerged as an efficient paradigm for bridge monitoring and condition assessment as an alternative to traditional fixed sensor networks addressing issues such as scalability and resolution. In conjunction with crowdsourcing, mobile sensing has the potential to facilitate bridge condition assessment at an unprecedented scale. This entails using vibration response sensed from inside vehicles using smartphones, and then isolating bridge vibrations for bridge dynamic characterization. Earlier studies on mobile sensing were limited to demonstrations involving numerical simulations and laboratory experiments. In this work, we present a wavelet synchrosqueezed transform-based method that effectively identifies absolute mode shapes (mode shape vectors without phase information) from field data. Furthermore, we introduce an extension to the framework that can perform a complete bridge modal identification using crowdsourced mobile sensing data. The proposed framework will help transform the traditional approach to continuous bridge response sensing and monitoring, by ensuring scalability and enhanced resolution for ensuring infrastructure resiliency.

What Goes Up On a Roof Can Come Down ….. But It Will Cost You. Understanding the Sustainable Design Indent of Green Roof Growing Media

Chuck Friedrich, PLA, GRP; Expanded Shale, Clay and Slate Institute (ESCSI); United States

During the past twenty years in the United States, the performance of green roof growing media has been evaluated and it was determined that the most crucial physical properties of the growing media is good drainage and maintaining a sustainable lightweight bulk density. From a structural engineering necessity, a saturated maximum compacted weight of the growing meeting must be established through testing prior to the media is acceptance. This requires that the mineral and organic components be proportioned to meet long term dead load calculations and horticulture objectives. Horticulturally, when selecting a growing media for a green roof system it must be understood that the performance of the plant material is affected by the micro-climate. Many shallow extensive green roof systems around the country are designed without irrigation; plants that are not drought tolerant cannot survive the summer heat. Extensive green roofs are mostly designed to grow in media formulated for only sedums, grasses and succulents. Installing irrigation will allow less tolerant plants to thrive but this defeats the purpose for what we define as an "extensive green roof". This is made more challenging with the desire for green roof systems to retain additional water to not only reduce irrigation needs but also reduce and cleanse runoff in urban areas. Nutrient rich media that is designed to encourage lush growth make plants more susceptible to drought stress. With all the environmental focus on extensive green roof systems, let's not dismiss the benefits of intensive green roof systems. Intensive green roofs or "roof gardens" provide many additional benefits, sometimes even at ground level. Green space over structures in urban centers, for both private and public access, provides not only environmental benefits but social and economic as well. This presentation will showcase ASTM standards for growing media and methods of installing the media. Case studies will be reviewed showing how the selection of growing media can impact success or failure. The goal is to obtain the knowledge to select the proper media to maximize sustainability while meeting the expectations of the design intent. Case studies will unlock the myths and truths of extensive and intensive green roofing in the southeast.

What is shape? Characterizing particle morphology with genetic algorithms and deep generative models

Robert Buarque de Macedo; Caltech; United States
Slavish Monfared; Niels Bohr Institute; United States
Konstantinos Karapiperis; ETH Zurich; Switzerland
Jose Andrade; Caltech; United States

Engineered granular materials have gained considerable interest in recent years. For this substance, the primary design variable is grain shape. Optimizing grain form to achieve a macroscopic property is difficult due to the infinite-dimensional function space particle shape inhabits. Nonetheless, by parameterizing morphology the dimension of the problem can be reduced. In this talk, we study the effects of both intuitive and machine-picked shape descriptors on granular material properties. First, we investigate the effect of classical shape descriptors (roundness, convexity, and aspect ratio) on packing fraction ϕ and coordination number Z. We use a genetic algorithm to generate a uniform sampling of shapes across these three shape parameters. The shapes are then simulated in the level set discrete element method. We find that subtle changes in mesoscopic properties can be attributed to a continuum of geometric phenomena, including tessellation, hexagonal packing, nematic order and arching. Nonetheless, such descriptors alone can not entirely describe a shape. Thus, we find a set of 20 descriptors which uniquely define a morphology via deep generative models. We show how two of these machine-derived parameters affect ϕ and Z. This methodology can be leveraged for topology optimization of granular materials, with applications ranging from robotic grippers to materials with tunable mechanical properties.

Whitening-curvelet-based Filter for SNR Enhancement of Distributed Acoustic Sensing Data

Naveed Iqbal; King Fahd University of Petroleum and Minerals; Saudi Arabia
Sikandar Khan; King Fahd University of Petroleum and Minerals; Saudi Arabia

Distributed acoustic sensing (DAS) is a new seismic monitoring technology. DAS generates a large amount of data, necessitating the development of new technologies to allow for cost-effective processing and handling. The raw DAS data is noisy and must be processed. Typical data exhibit correlated and uncorrelated noise. The curvelet transform is a generalized higher-order type of wavelet transform that can be used to present 2D data at different scales and different angles. It basically overcomes the problem of missing directional selectivity of the wavelet transforms in images. The curvelet transform is an excellent choice for processing DAS data due to its localized nature time, frequency and phase-domain, as well as its frequency and dip characteristics. However, its capabilities are limited in case of noise other than white (correlated). This paper proposes a denoising method based on a combination of the curvelet transform and a pre-whitening filter, as well as a procedure for estimating noise variance. The whitening filter is included to improve the performance of the curvelet transform in both coherent and incoherent noise cases, as well as to simplify the noise estimation method and make it easier to use standard threshold methodology without delving into the curvelet domain. Two data sets are used to validate the suggested technique. Pseudo-synthetic data set created by adding noise to the actual noise-free data collection from the Netherlands offshore F3 block and the on-site data set (with ground roll noise) from east Texas, USA. Experimental results demonstrate that the proposed algorithm achieves the best results under various types of noise. Hence, suitable in the area of DAS processing and monitoring. Furthermore, the method is independent of the type of noise and can be applied to a variety of data sets.

Wind Load Estimation of an Operational 6 MW Offshore Wind Turbine: a comparison of physics-based vs. data-driven approaches

Azin Mehrjoo; Tufts University; United States
Finn Rüdinger; Orsted; Denmark
Ross McAdam; Orsted; Denmark
Babak Moaveni; Tufts University; United States
Eric Hines; Tufts University; United States

Considering our increasing dependence on offshore wind energy, developers, operators, and investors will benefit from stronger assurances of offshore wind turbines' reliability through structural health and performance monitoring. Offshore wind turbine (OWT) structures experience dynamic wind and wave loading during their lifetime. The cyclic characteristic of the loads contributes largely to the fatigue life of the monopile support structures which underlines the importance of input load estimation. This paper compares the performance of two frameworks in estimating the input load of an OWT using output-only measurements, namely (1) a physics-based framework through recursive Bayesian inference, i.e., Augmented Kalman filtering (AKF), and (2) a data-driven framework, i.e., long short-term memory (LSTM) neural network. AKF is a recursive Bayesian inference method for estimating the state and input of a dynamic system. In the application of the AKF, a linear elastic finite element model of the turbine is used together with acceleration and strain measurements of the turbine tower. LSTM is a special kind of Recurrent Neural Network (RNN) with the ability to handle time-series datasets. LSTM is implemented using not only the vibration measurements but also information available from SCADA. Eliminating the need for a physics-based model can help in situations where the model is not accessible, or modeling uncertainties are expected to be large. The two frameworks are applied on weeks of actual data measured on an offshore wind turbine.

Wind-Borne Debris Façade Impact Design: Validation of a 2D Monte Carlo Numerical Model

Angela Mejorin; Western University; Canada
Gregory Kopp; Western University; Canada

Wind-borne debris is one of the major causes of building envelope damage in windstorm events [1]. Past tornadoes and tropical cyclones showed how façades are a vulnerable building component when it comes to wind-borne debris impacts. Standard test requirements for wind-borne debris resistance were developed to improve cladding impact resistance, based on empirical observations and on typical construction types [2]. Roof tiles, shingles, and sheathing panels have been recorded to fail and fly in extreme wind events [3], but such building components are still not used as projectiles to set façade impact test requirements. A 2D Monte Carlo numerical model for debris failure and flight analysis is presented and validated in this study. This model considers the roofing element fixing technologies and the "source building" aerodynamics. The failure mechanism and the flight assessment are, therefore, used to ultimately calculate the impact energy on the final target façade. The failure mechanism considers the "source building", where the wind-borne debris could originate from, and the technical installation of the object, and therefore a probability of failure. The "debris flight" depends on the equations of motions that have been developed in the existing literature [4] and on experimental simulations that took to the estimation of the probability function [5], depending on various aerodynamic parameters such as the Tachikawa number [6]. Based on current knowledge of the aerodynamics of roofing components, wind-induced failures, wind loading, and impact dynamics, a performance-based design framework for wind-borne debris impact-resistant façades is proposed. The tool's generalization will enable designers to consider case-specific building settings for impact-resistant building envelope design.

References:

[1] Minor, J.E., 1994. Wind-borne debris and the building envelope. In: Journal of Wind Engineering and Industrial Aerodynamics 53, pp. 207-227.

[2] Lin, N., Letchford, C., Holmes, J.D., 2006. Investigation of plate-type windborne debris. Part I. Experiments in wind tunnel and full scale. In: Journal of Wind Engineering and Industrial Aerodynamics 94, pp. 51-76.

[3] Kordi, B., 2009. Aerodynamics of windborne plate debris. Ph.D. thesis. Department of Civil and Environmental Engineering, Faculty of Engineering Science, University of Western Ontario.

[4] Tachikawa, M., 1983. Trajectories of flat plates in uniform flow with application to wind-generated missiles. In: Journal of Wind Engineering and Industrial Aerodynamics 14, pp. 443-453.

[5] Kordi, B., Traczuk, G., Kopp, G.A., 2010. Effects of wind direction on the flight trajectories of roof sheathing panels under high winds. In: Wind and Structures 13 vol.2, pp. 145-167.

[6] Holmes, J.D., Baker, C.J., Tamura, Y., 2006. Tachikawa number: A proposal. In: Journal of Wind Engineering and Industrial Aerodynamics 94, pp. 41-47.

Working towards a modular, fully-coupled phase field fracture model integrating elasticity, plasticity, and damage

Chiraag Nataraj; Sandia National Labs; United States
Andrew Stershic; Sandia National Labs; United States

Many phase field fracture models that have been implemented to date are opinionated regarding the choice of elastic model, plastic model, damage model, etc. While this enables easier development of the formulation itself, the resulting model is inflexible and often only applies to a subset of problems of interest. Further, if a change in model is desired, it may be required to redo much of the derivation and implementation. This work aims to develop and implement a generalized, variational, fully-coupled, and modular phase field fracture formulation capable of handling a diverse range of problems. Multiple internal variables and flow tensors are allowed, and both are solved using nonlinear constrained optimization techniques. Constraints on the flow tensors, internal variables, and phase variables are allowed to be coupled, enabling a far richer space of potential models than conventional approaches allow. While this approach brings its own challenges, it also enables classes of models which were previously tedious to implement, thus allowing the exploration of more complex problems.

In this presentation, we detail this modular approach from analytical derivations through to implementation in SIERRA, a robust multi-physical finite element code developed at Sandia National Laboratories. The approach will be demonstrated for several canonical model forms, including linear-elastic and elastic-plastic fracture mechanics.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC., a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

WRF-Fire for Landscape-Scale Wildfire Simulation: Sensitivity Analysis, The Role of Fuel Characteristics and Fire Spotting, and Data Assimilation

Kasra Shamsaei; University of Nevada, Reno; United States
Timothy W. Juliano; National Center for Atmospheric Research; United States
Matthew Roberts; University of Nevada, Reno; United States
Hamed Ebrahimian; University of Nevada, Reno; United States
Branko Kosovic; National Center for Atmospheric Research; United States
Neil P. Lareau; University of Nevada, Reno; United States

Accurate wildfire simulations are an essential piece in mitigating increasing wildfire losses, benefiting both pre-ignition mitigation and preparedness as well as post-ignition emergency response management. However, the accurate simulations face several challenges considering the highly multi-physics nature of the problem. In this study, we start by evaluating the performance of WRF-Fire, a fully coupled wildland fire-atmosphere simulation platform in simulating the 2018 Camp Fire. The model setup follows the setup typically used in operational applications of WRF-Fire by Colorado Fire Prediction System. The simulated fire perimeter is evaluated with estimated fire perimeters from NEXRAD weather radars observations, showing non-negligible differences between the simulated and observed fire perimeter in terms of rate of spread and propagation direction. Next, the sensitivity of the simulated fire perimeter to several modeling parameters and assumption governing the simulated wind field is investigated. The results highlight the need for better forcing models than currently available models as well as the need for high resolution simulation domain for closer-to-reality simulated fire perimeter. In the next step, the effects of fuel bed representation on the simulation results are investigated. To this end, a canopy heat release parametrization is developed for WRF-Fire, and an improved scheme is developed to release fire heat and smoke in the atmosphere. The effects of these are investigated in the simulated fire perimeter and fire weather of the 2018 Camp Fire and the 2021 Caldor Fire by comparing the simulated fire perimeter and plume with the estimated fire perimeter and observed reflectivity of NEXRAD radars, respectively. Moreover, the characteristics of the simulated temperature and vertical velocity is compared to the observed characteristics during various prescribed burns. This analysis highlights the effects and the need for more realistic fuel bed representation in the simulation domain compared to the current practice, which only includes surface fuels, to achieve realistic fire weather simulation. Next, the effects of addition of fire spotting simulation in the simulation results of the 2018 Camp Fire and the 2021 Caldor Fire is investigated. For this analysis, the recently added fire brands generation and transport parametrizations in WRF-Fire is coupled with a spot fire ignition model, and the simulation results are compared to the NEXRAD-derived fire perimeters. Lastly, a computationally efficient data assimilation is proposed to improve the accuracy of the simulation results of WRF-Fire. In this approach, the observed fire perimeters is imposed in WRF-Fire simulations at different timestamps for the 2018 Camp Fire case study to evaluate the effectiveness of this method for improved operational wildfire simulation capabilities.

Yielding and fracture in the nucleation of frictional slip

Miguel Castellano; ETH Zürich; Switzerland
Flavio Lorez; ETH Zürich; Switzerland
David Kammer; ETH Zürich; Switzerland

Although friction is reduced in textbooks to a simple friction coefficient, reality is much more complex than it seems. The transition from static to dynamic friction, which is of great importance in engineering, happens through a nucleation process which involves the yielding or fracture of contact asperities that form dry solid interfaces. However, little is known as to what the dominant underlying process is or what the implications are for nucleation dynamics and the onset of frictional instability. In this work, we show that frictional heterogeneity, modeled through the correlation length and the amplitude of frictional strength along interfaces, plays a key role in determining the driving force behind the nucleation of frictional slip. In particular, we found that a transition from yielding to fracture is triggered above a certain level of heterogeneity, which is responsible for the generation of frictional instabilities whose magnitude increases with the correlation length and decreases with the amplitude of the frictional strength profile. Moreover, high levels of heterogeneity are shown to favor stability and delay the onset of dynamic friction. Overall, our results demonstrate how heterogeneity influences the nucleation of frictional slip by determining whether yielding or fracture dominate the process. This bridges the gap between the two most common theories for nucleation, which apply only to the yielding or the fracture phase, exclusively.

Author Index