UC San Diego
JACOBS SCHOOL OF ENGINEERING
Structural Engineering

STRUCTURAL ENGINEERING





RESEARCH HIGHLIGHTS
2022 - 2023

2022–23 RESEARCH HIGHLIGHTS
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Photo courtesy of UC San Diego Jacobs School of Engineering

CHAIR'S MESSAGE

The Department of Structural Engineering at the University of California San Diego is at the forefront of research in civil and geotechnical structures, aerospace structures and composites, structural health monitoring (including nondestructive evaluation), and computational mechanics. Our research plays a critical role in ensuring the safety and sustainability of the built environment and transportation systems. We are developing a greater understanding of the behavior and physical response of structures across a spectrum of materials and scales, from nano- and micro-structures consisting of particle assemblies or biological structures, to large-scale structures, such as buildings, bridges, aircraft bodies, ship hulls, and naval structures. In turn, our research program is leading to advances in biological structures and human-structure interfaces.

The research of our faculty and students has provided solutions to challenging problems, including the development of new design and assessment methods to improve the earthquake resilience of buildings and civil infrastructure systems; cutting-edge engineering and safety inspection methods for aircraft structures made of advanced composites; new materials and intervention methods to protect structures and human bodies against extreme loading like explosions and impacts; advanced sensing and non-destructive evaluation techniques to detect structural defects and monitor structural health; progressive computational methods to improve the aerodynamics of wind-turbine blades and to enhance geothermal systems for renewable energy production; leading-edge visualization methods for the preservation of heritage structures; and the modeling and visualization of biological structures to develop new treatment methods for diseases.

Our research also addresses emerging interdisciplinary challenges in artificial intelligence, data science, digital twins and surrogate models, convergent systems engineering, visualization at different time rates and spatial scales, structural optimization, additive manufacturing, new sensors, smart materials, micromechanics, fluid-structure interaction, and multi-scale biomechanics. We have state-of-the-art experimental, computational, and visualization facilities, including the Englekirk Structural Engineering Center, the SRMD Laboratory, and the Powell Laboratories, which have received major investments from the department, campus, and external funding agencies. Our Large High Performance Outdoor Shaking Table has been upgraded through a grant from the U.S. National Science Foundation to apply six degrees of freedom motions, which is being used to test the seismic response of innovative structures. Through these facilities, researchers, students, and visiting scholars have access to some of the most advanced research infrastructure in the world.

The unique talents of the Structural Engineering community, along with our vast experimental facilities, have been major resources to private industries and governmental agencies and have contributed to our consistent high-ranking within our field. Our remarkable faculty members have earned numerous awards and hold esteemed positions within their professional societies. They are deeply dedicated to mentoring graduate and undergraduate students. Lastly, our research has made direct impacts on standards and practice in the structural, geotechnical, aerospace, and material engineering fields.

Our department is committed to pursuing excellence in research while providing the best possible education and training for our students to be leaders in their profession. We embrace the interdisciplinary nature of structural engineering through collaborations between civil, mechanical, and aerospace engineers to solve challenging problems at the forefront of research and practice. We provide an open, inclusive, diverse, and welcoming environment for our students, researchers, staff, faculty, and visitors to achieve their best and fulfill their professional goals, as we continue to actively recruit the best and most diverse community. Please enjoy our research highlights!

John S. McCartney
Professor and Department Chair
Department of Structural Engineering, UC San Diego

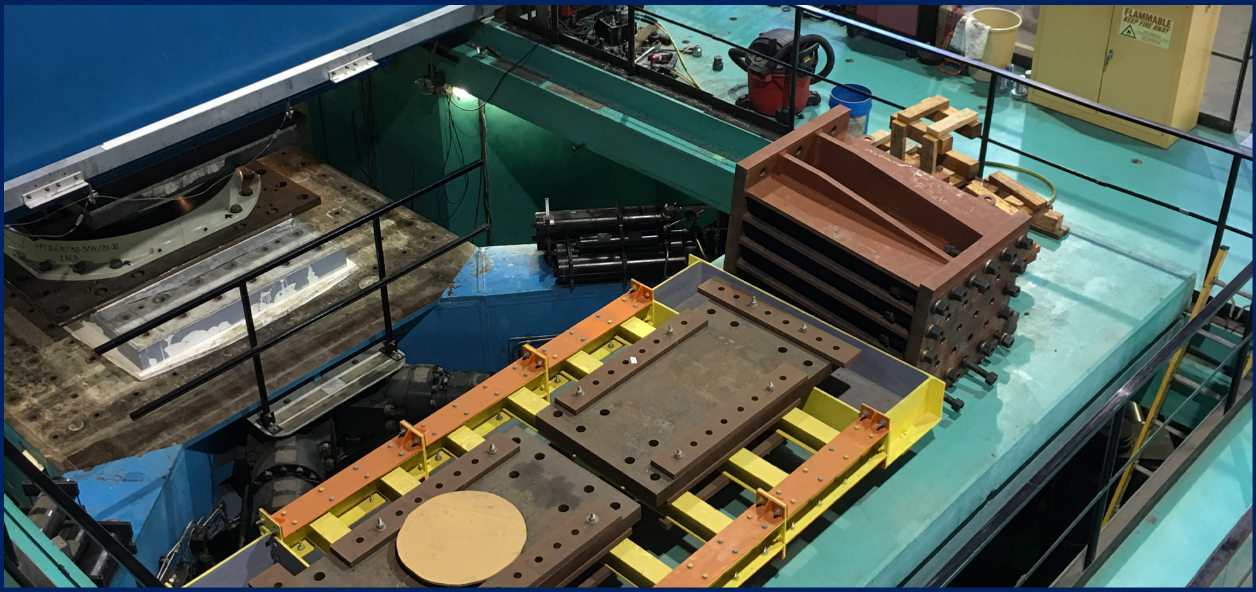
FACILITIES

Our department possesses several valuable assets, namely our state-of-the-art experimental, computational, and visualization facilities. Our location in the Structural and Materials Engineering (SME) building provides us with well-equipped laboratories for geomechanics, advanced composite materials, aviation safety, structural health monitoring and non-destructive evaluation, and computer visualization. Notably, the world-renowned Charles Lee Powell Structural Engineering Laboratories are housed within our department, which offer exceptional experimental facilities to investigate the performance of large-scale structural systems and components under extreme loads, such as earthquakes, impacts, and blasts. Furthermore, we have access to the Caltrans Seismic Response Modification Device (SRMD), a unique testing facility capable of real-time 6-DOF dynamic characterizations of full-scale bearing devices and dampers. The SRMD building also accommodates a 50 g-ton geotechnical centrifuge for physical modeling of geotechnical systems under realistic self-weight and earthquake loads. The Englekirk Structural Engineering Center (ESEC), located 10 miles east of the main campus, houses the world's largest outdoor shaking table for seismic testing of large-scale structures, a blast simulator, and a soil-structural interaction testing facility. Additionally, ESEC boasts large-scale experimental setups for field testing non-destructive evaluation methods that detect defects in train rails, as well as the capability to run field tests of underground geothermal energy storage methods. These innovative and productive research infrastructures are accessible to students and visiting scholars, providing them with unparalleled opportunities to advance their research in a cutting-edge environment.

Photo courtesy of UC San Diego Jacobs School of Engineering

STRUCTURAL AND MATERIAL ENGINEERING (SME) BUILDING

The 183,000-square-foot building houses the Structural Engineering Department, NanoEngineering, the Medically Advanced Devices Laboratory, the EnVision Arts and Engineering Maker Studio, and some of the Visual Arts department. The building includes 62 research and instructional laboratories, 160 offices, Visual Arts studios, an art exhibition, a performance space, and the ASML Conference Center. Frieder Seible, the former Dean of the Jacobs School of Engineering, remarked, "The hope and aspiration for this building is that it is not a physical location for four seemingly disparate academic units, but that it will be transformational for our campus and how we collaborate in our research and educational mission."



SEISMIC RESPONSE MODIFICATION DEVICE (SRMD) TESTING LABORATORY

Gilberto Mosqueda, Director

This unique facility is capable of real-time 6-DOF dynamic characterizations of full-scale bearing devices and dampers. It was developed jointly by the California Department of Transportation (Caltrans), the Department of Structural Engineering at UC San Diego, and the MTS Corporation of Eden Prairie, Minnesota. The geotechnical centrifuge is a 50 g-ton machine used for physical modeling of geotechnical systems under realistic self-weight and earthquake loading.

FACILITIES

THE ENGLEKIRK CENTER

Joel Conte, Director

The Englekirk Structural Engineering Center (ESEC), located 10 miles east of the main campus, houses the world's largest outdoor shaking table for seismic testing of large-scale structures, a blast simulator, and a soil-structural interaction testing facility. The NHERI Large High Performance Outdoor Shake Table (LHPOST6) was recently updated with a $16.9 million grant from the National Science Foundation along with an additional $3.4 million of in-kind support from UC San Diego. The upgrade included adding 6 degrees of freedom (DOF) to the table to recreate ground motions more realistically during strong earthquakes. ESEC has unique large-scale experimental setups for field testing of non-destructive evaluation methods that detect defects in train rails, soil pits to test full-scale foundations, and a facility to test geothermal energy storage.

CHARLES LEE POWELL STRUCTURAL RESEARCH LABORATORIES

Benson Shing, Director

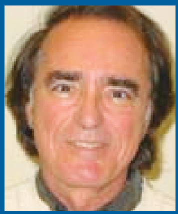
The Charles Lee Powell Structural Research Laboratories are among the largest and most active full-scale structural testing facilities in the world. With its 50-foot-tall reaction wall and 120-foot-long strong floor, the Structural Systems Laboratory is equipped for full-scale testing of bridges, buildings, and aircraft. The Structural Components Laboratory includes a 10 by 16-foot shake table for realistic earthquake simulations. The strong-walls, actuators, and shake table in the Powell Laboratories are used daily to test full-scale transportation and geotechnical structures. The main testing facility was dedicated in 1986. Throughout the years, additional facilities have been added as the scope and nature of the research has expanded.

RAIL DEFECT TEST FACILITY

Francesco Lanza di Scalea, PI

UC San Diego has the only Rail Defect Farm in the West Coast of the United States. This Class I track was constructed by Sopac Rail Inc. under Federal Railroad Administration sponsorship with an in-kind donation of materials by BNSF Railway. The Rail Defect Farm is located at UC San Diego's Camp Elliott Field Station Laboratory, 9 miles away from the main campus. The Defect Farm features 250 feet of 136-pound rail with several natural and artificial defects including detail fractures, transverse fissures, other rolling contact fatigue defects, and vertical and horizontal split heads, among others. The track includes a tangent portion (~125 feet in length) and an 8-degree curved portion (~125 feet in length). It is used for the development of rail defect detection technologies at UC San Diego and elsewhere.

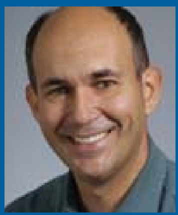
WORLD-CLASS FACULTY AND RESEARCHERS



ROBERT ASARO
Professor
Composite design and manufacturing technologies for large scale structures and marine applications as well as the deformation, fracture, and fatigue of high temperature intermetallics.

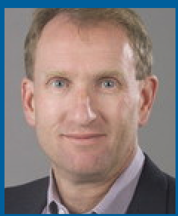
QIANG ZHU
Professor
Ocean engineering, and interdisciplinary investigations that combine offshore engineering and biomechanics.

JIUN-SHYAN (J.S.) CHEN
Professor
Computational solid mechanics, multiscale materials modeling, and modeling of extreme events.



JOEL CONTE
Distinguished Professor
Structural analysis and dynamics, structural reliability and risk analysis, and earthquake engineering.

AHMED-WAEIL ELGAMAL
Distinguished Professor
Information technology, earthquake engineering, and computational geomechanics.



CHARLES FARRAR
Adjunct Professor
Analytical and experimental solid mechanics problems with emphasis on structural dynamics.

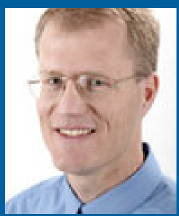
TARA HUTCHINSON
Professor
Earthquake and geotechnical engineering, performance assessment of structural/nonstructural components, and machine learning and computer vision methods for damage estimation.

HYONNY KIM
Professor
Impact effects on composite materials and structures with aerospace and other applications, multifunctional materials, nano-materials, and adhesive bonding.

HYUNSUN KIM
Professor
Structural and topology optimization, multiscale and multiphysics optimization of structures and materials, optimization for composite materials, and aerospace structures.

JOHN KOSMATKA
Professor
Design, analysis, and experimental testing of light-weight advanced composite structures.

PETR KRYSL
Professor, Vice Chair
Finite element computational modeling techniques for solids and structures, model order reduction in nonlinear mechanics, and computer and engineering simulations in multiphysics problems.



FALKO KUESTER
Professor
Scientific visualization and virtual reality, with emphasis on collaborative workspaces, multi-modal interfaces, and distributed and remote visualization of large data sets.

WORLD-CLASS FACULTY AND RESEARCHERS

FRANCESCO LANZA DI SCALEA
Professor
Health monitoring, and non-destructive evaluation and experimental mechanics of structural components using novel sensing technology.

KEN LOH
Professor, Vice Chair
Damage detection and localization, multifunctional materials, nanocomposites, scalable nano-manufacturing, smart infrastructure materials, structural health monitoring, thin films and coatings, tomographic methods, wearable technology.

JOHN MCCARTNEY
Professor, Department Chair
Geotechnical and geoenvironmental engineering, thermo-hydro-mechanical behavior of soils, and design and analysis of thermally active geotechnical systems.

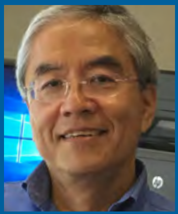
MACHEL MORRISON
Assistant Professor
Seismic safety, materials science, and solid mechanics.

GILBERTO MOSQUEDA
Professor
Earthquake engineering, structural dynamics, seismic isolation and energy dissipation systems, seismic response of structural and nonstructural building systems, and experimental methods including hybrid simulation.

YU QIAO
Professor
High-performance infrastructure materials, smart materials and structures, energy-related materials, and failure analysis for engineering materials and structures.

JOSE RESTREPO
Professor
Seismic design of buildings for improved response during earthquakes.

SHABNAM SEMNANI
Assistant Professor
Characterization and modeling of heterogeneous geomaterials across scales, and microstructure and macroscopic behavior of materials.

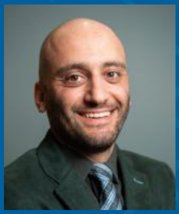


PUI-SHUM SHING
Professor
Earthquake engineering, structural dynamics, inelastic behavior of concrete and masonry structures, bridge structures, finite element modeling of concrete and masonry structures, and structural testing.

MICHAEL TODD
Professor
Structural health monitoring (SHM) strategies for civil/mechanical/aerospace systems, fiber optic and ultrasonic sensor solutions for SHM, nonlinear dynamics and mechanics, and uncertainty and probabilistic modeling for SHM.

INGRID TOMAC
Assistant Professor
Hydro-thermo-mechanical coupled processes in rocks, dense fluid-particulate systems micromechanics and rheology, rock mechanics, hydraulic fracturing and proppant flow and transport in geothermal reservoirs, and induced seismicity and CO2 sequestration.

GEORGIOS TSAMPRAS
Assistant Professor
Engineering mechanics, structural analysis, structural dynamics, structural connections, friction-based structural components, unified design methodologies, natural hazards, damage tolerance analysis, and probabilistic mechanics.

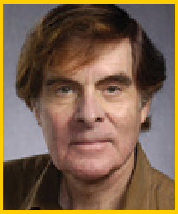


MEHRAN TEHRANI
Assistant Professor
Automated fiber placement and additive manufacturing of polymer composites, multi-functional structural composites, advanced electrical conductors.

CHIA-MING UANG
Professor
Earthquake engineering, and seismic design of steel buildings and bridges.

LELLI VAN DEN EINDE
Teaching Professor
Earthquake engineering data and metadata development, and performance-based earthquake engineering.

CHIN-HSIUNG LOH
Adjunct Professor
Signal analysis, structural health monitoring & system identification, earthquake engineering, and seismic hazard analysis.



GILBERT HEGEMIER
Distinguished Professor Emeritus
Earthquake engineering to retrofit bridges, and roadways and buildings for improved public safety and structural performance.

DAVID BENSON
Professor Emeritus
Computational mechanics and computer methods for solving problems in mechanical engineering.

ENRIQUE LUCO
Distinguished Professor Emeritus
Earthquake engineering, strong motion seismology, and soil structure interaction.

FRIEDER SEIBLE
Distinguished Professor Emeritus
Design and retrofit of buildings and bridges for earthquake safety, new technologies to renew the nation's aging infrastructure, and bomb blast-resistant design of critical infrastructure.

BY THE NUMBERS

#8

Engineering at UC San Diego as a public university, by U.S. News & World Report Rankings

#1

UC San Diego, for engineering research expenditures in California, by U.S. News & World Report Rankings

9,600

Student enrollment at the Jacobs School of Engineering

$245M

in research expenditures at the Jacobs School of Engineering

26

Ladder Rank Faculty

RESEARCH

Figure 1. Modular test bed building fully assembled at LHPOST6 prior to shake table testing: special moment frames in the longitudinal direction, buckling restrained brace frames in the transverse direction.

PERFORMANCE OF A MODULAR TESTBED BUILDING (MTB²) SUBJECT TO 3DOF BASE EXCITATION

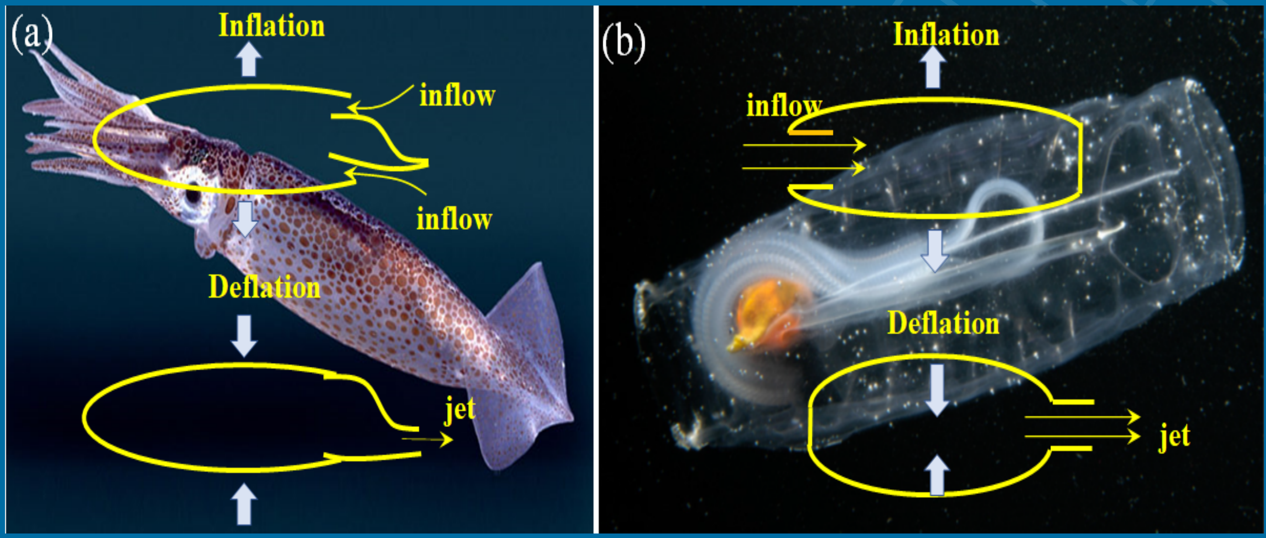
PROFESSOR TARA HUTCHINSON

The 6-DOF Large High-Performance Outdoor Shake Table (LHPOST6) at UC San Diego is a national shared-use facility recently upgraded from a 1-DOF table to facilitate 6-DOF shaking. The Modular Testbed Building (MTB²) is a reconfigurable, steel-framed structure, which can be reused for testing of various structural and nonstructural components and was designed for adaptation to LHPOST6. The first use of the MTB² was to test a variety of structural fuses as forms of energy dissipation in two primary lateral force resisting structural system configurations, namely: Special Moment Frames (SMF) and Buckling Restrained Braced Frames (BRBF). As part of the SMF configuration, a rotationally compliant, modular column baseplate connection is integrated as an additional form of energy dissipation to create the SMF+CB configuration. The test specimen has a uniform floor-to-floor height of 12 feet and sits atop footings 3 feet tall resulting in a total height of 39 feet (measured from the base of the foundation system to the top of the third story). The building has two bays in the longitudinal direction and one bay in the transverse direction, with plan dimensions of 32 feet by 20 feet, with a resulting area of 640 square feet per floor. The building footprint has been selected to nearly encompass the footprint of LHPOST6. Large, open spaces between the transverse girders have been provided to allow for the inclusion of testing stairs, or other vertically spanning egress systems, such as elevators, in future configurations. These floor plans were designed with these considerations in mind to embrace the philosophy of a completely reconfigurable and reusable building. During the test program, each building configuration was subject to 1-, 2-, and 3-DOF simulated earthquake motions individually scaled to interrogate the behavior of the structural fuses installed throughout the structure. Findings from the test program indicate that the structural fuses performed well, dissipating energy as part of the LFRS adopted within each building configuration while providing sufficient ductility. It was also found that the compliant base as part of the SMF+CB configuration reduced peak floor accelerations while also alleviating interstory drift demands on the superstructure.

VALVE-CONTROLLED JET PROPULSION INSPIRED BY MARINE INVERTEBRATES

PROFESSOR QIANG ZHU

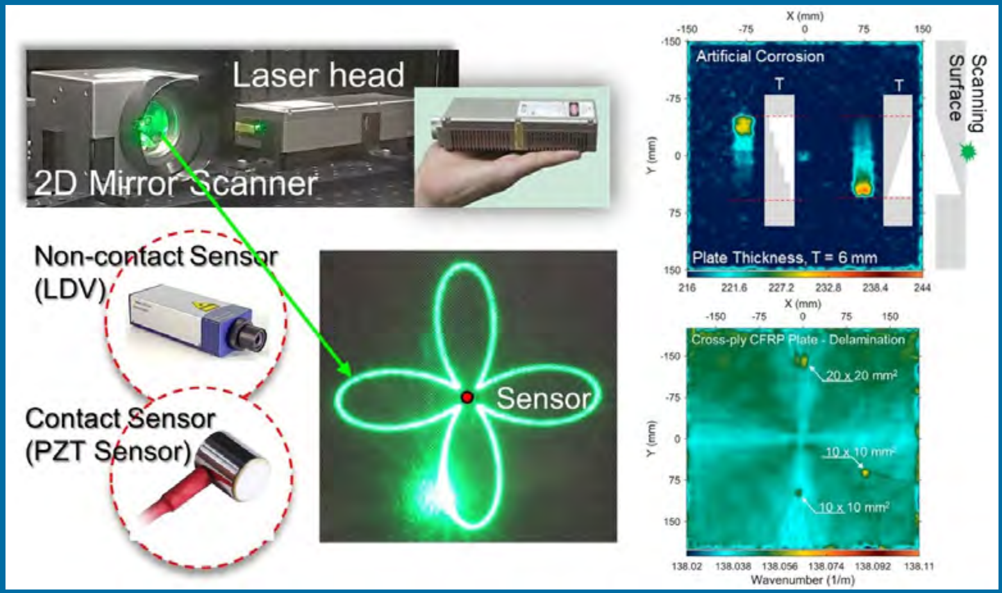
Marine invertebrates such as squid and sea slap have developed a highly effective locomotion method based on jet propulsion. In this method, the body of the animal inflates and deflates periodically to create intermittent jetting for propulsion. To increase energy efficiency, one-way valves are used to control the internal flow. Researchers have developed computational models to understand the underlying physics of this biomechanical problem. This study provides guidance for the development of bio-inspired soft-body robots to be used in various applications, including environmental monitoring, reconnaissance, human- and animal-safe actuation, and deep-sea exploration.



DAMAGE DIAGNOSTICS VIA LASER ULTRASONIC SCATTERING

PROFESSOR MICHAEL TODD

Ultrasonic guided wave interrogation using piezoelectric arrays and full-field laser ultrasonic inspection has evolved into a very active research area. This research focuses on the detection, classification, and prognosis of damage using elastic waves as the interrogation mechanism. The novel approach in this work is the embedding of stochastic models and parametric curve scanning methods to account for uncertainty of model/physical parameters, in order to derive an optimal detection process that supports predictive modeling with quantified uncertainty. Research is focusing on maximum likelihood estimates for detecting and localizing small scatterers in complex composite and metallic structures. Detection is accomplished using generalized likelihood testing, probabilistic imaging methodologies, and optimized data domain transformations.

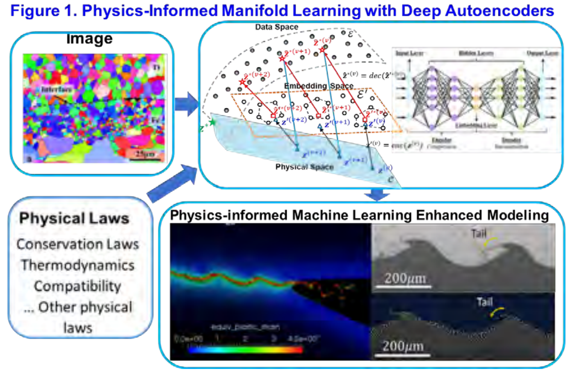


MACHINE-LEARNING ENHANCED DATA-DRIVEN COMPUTING

DISTINGUISHED PROFESSOR J.S. CHEN

The recent advancements in machine learning algorithms and data-driven computing offer new opportunities for modeling multi-scale multi-physics complex problems in science and engineering. As demonstrated in Figure 1, Chen's group developed a physics-informed data-driven constitutive modeling approach by integrating physical constraints, such as energy convexity and objectivity, into data-driven constitutive modeling. To counteract high-dimensionality issues and noise present in data, autoencoders are employed to learn an essential low-dimensional representation of data, from which the mechanisms governing the evolution of path-dependent deformation are extracted and integrated into data-driven path-dependent constitutive predictions for enhanced robustness and accuracy. An application of this computational technology is the numerical assessment of weldability of the explosive welding processes shown in Figure 1.

Figure 1. Physics-Informed Manifold Learning with Deep Autoencoders



A machine-learned physics-informed data-driven constitutive modeling approach has been proposed as demonstrated in Figure 2 for path-dependent materials based on the measurable material states. The proposed data-driven constitutive model is designed with the consideration of universal thermodynamics principles, where the Internal State Variables (ISV) essential to the material path-dependency are inferred automatically from the hidden state of Recurrent Neural Networks (RNN). The RNN describing the evolution of the data-driven machine-learned ISVs follows the second law of thermodynamics. The effectiveness of the proposed method is evaluated by modeling soil material behaviors under cyclic shear loading using experimental stress–strain data as shown in Figure 2. In collaboration with Prof. John McCartney's group, this computational framework will be applied to the constitutive modeling of thermo-hydro-mechanical behaviors of bentonite.

Figure 2. Thermodynamically Consistent

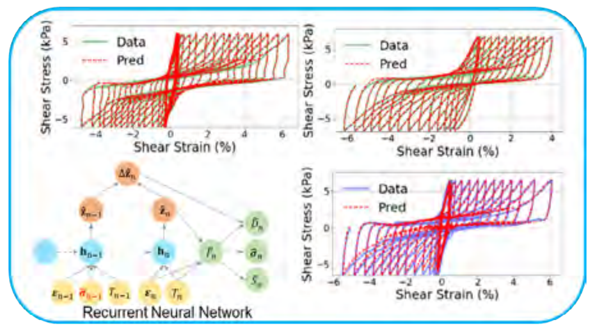
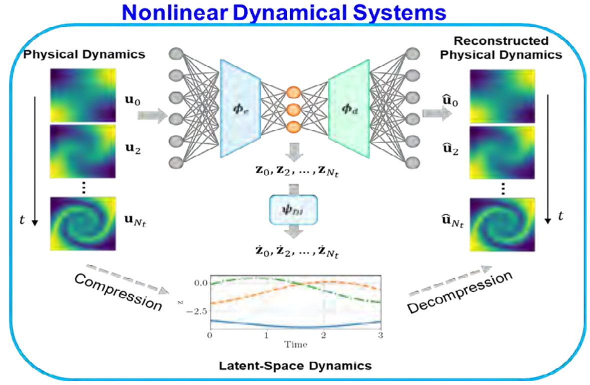


Figure 3. Model Order Reduction of Nonlinear Dynamical Systems

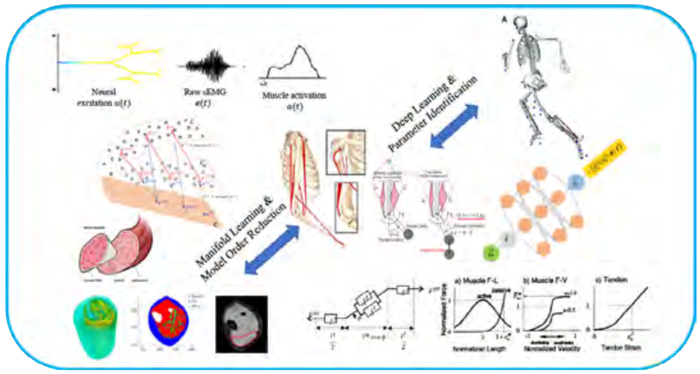


Many physical processes are mathematically modeled by time-dependent nonlinear partial differential equations. Due to the complexity and the domain size of problems, high-fidelity forward physical simulations can be computationally intractable even with high performance computing. As shown in Figure 3, a parametric adaptive greedy latent space dynamics identification (gLaSDI) framework has been developed for accurate, efficient, and robust physics-informed data-driven reduced-order modeling. The developed gLaSDI framework contains an autoencoder for nonlinear projection to discover intrinsic low-dimensional representations of the dynamic systems as well as a set of local Dimension Identification models to capture dynamics in the low-dimensional space for effective reduced order modeling.

Identification of muscle-tendon force generation properties and muscle activities from physiological measurements, e.g., motion data and raw surface electromyography (sEMG), offers opportunities to construct a subject-specific musculoskeletal (MSK) digital twin system for health condition assessment and motion prediction.

Figure 4 displays a feature-encoded physics-informed parameter identification neural network (FEPI-PINN) as developed for simultaneous prediction of motion and parameter identification of human MSK systems. This FEPI-PINN model can be trained to relate sEMG signals to joint motion and simultaneously identify key MSK parameters. The developed framework can effectively identify subject-specific muscle parameters and the trained physics-informed forward-dynamics surrogate yields accurate motion predictions of elbow flexion-extension motion that are in good agreement with the measured joint motion data.

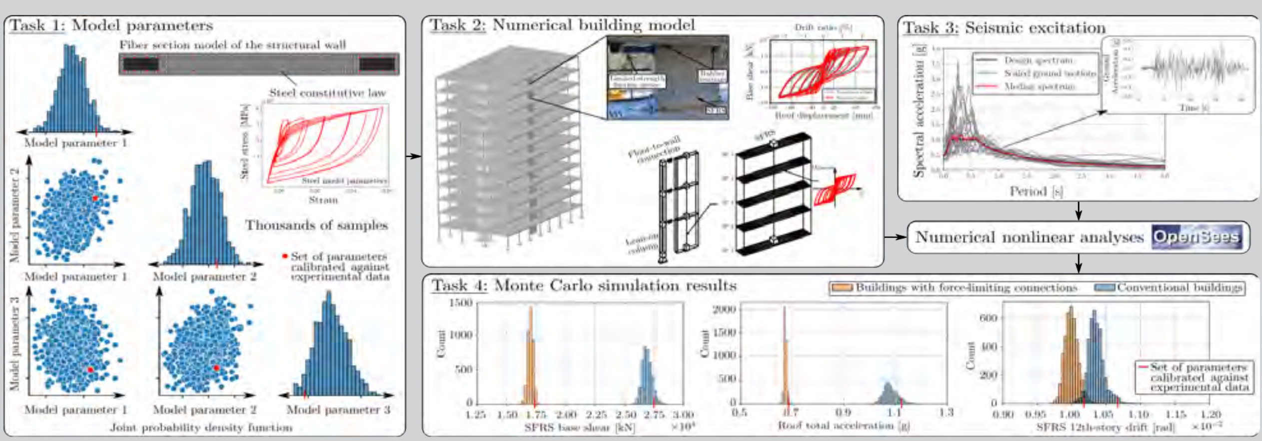
Figure 4. Multi-Scale Machine Learning Enhanced Data-Driven



UNCERTAINTY QUANTIFICATION OF THE SEISMIC RESPONSE OF BUILDINGS WITH FORCE-LIMITING CONNECTIONS

C. FRANCO MAYORGA AND ASSISTANT PROFESSOR GEORGIOS TSAMPRAS

The objective of this research project is to understand and quantify the effect of the uncertainty in the model parameters used to simulate the structural walls in the seismic response of buildings with force-limiting connections between the gravity-load resisting system and the seismic-force resisting system. The first task during research was to identify in the literature the probability density functions that describe the uncertainty in the parameters used to model the stress-strain constitutive relationship of reinforcing steel bars used in reinforced concrete structural walls. Once completed, the next step was to develop a two-dimensional numerical model of a twelve-story reinforced concrete building with a seismic-force resisting system composed of structural walls. Additionally, the research team also validated the numerical model of the structural walls using experimental test results to obtain a set of reference model parameters for the idealized model of the constitutive relationship of the reinforcing steel bars. A set of ground motions were selected that were scaled to simulate design-level earthquakes. Finally, a Monte Carlo earthquake simulation was conducted of the building numerical model with structural walls to quantify the effect of the uncertainty in the model parameters on the seismic responses of buildings with force-limiting deformable connections. The outcome of the research demonstrated that the use of force-limiting connections reduces the magnitude of the force and acceleration responses and reduces the variability in the seismic responses due to the uncertainty of the model parameters. The reduction in the variability of the responses when force-limiting connections are included means higher confidence in the response prediction and in the performance-based design of buildings with force-limiting connections.



SEISMIC RESILIENCY OF REPETITIVELY FRAMED MID-RISE COLD-FORMED STEEL BUILDINGS

PROFESSOR TARA HUTCHINSON

Cold-formed steel (CFS) framed construction has become a popular construction choice in the North American construction industry in the recent years due to an urgent need for low cost, multi-hazard resilient buildings. Use of CFS framing results in lightweight structures with low installation/maintenance costs, ductility, fire and corrosion resistance, and consistency in material behavior. Despite the several benefits, the response of these building under earthquake loads and, in particular, the contribution of portions of the building system not specifically designated by design engineers (such as finished and/or gravity loaded components) to resist seismic loads are not well understood. Additionally, the lack of full-scale system level test data documenting both earthquake and post-earthquake fire response is a significant barrier to increasing the allowable heights and area of CFS-framed buildings in earthquake prone areas. To address these limitations, in the collaborative research program 'CFS-NHERI', mid-rise CFS buildings are de-constructed into their essential components (fasteners, shear and gravity walls, and diaphragms) and investigated on multiple scales using experiments and numerical simulations. At the NHERI Large High Performance Outdoor Shake Table (LHPOST), 4.88 meter long and 2.74 meter tall wall line assemblies, which had shear walls placed in-line with gravity walls, were tested at full-scale first under a sequence of increasing amplitude (in-plane) earthquake motions, and subsequently under slow monotonic pull conditions (for select specimens) (see Figures 1 and 2).

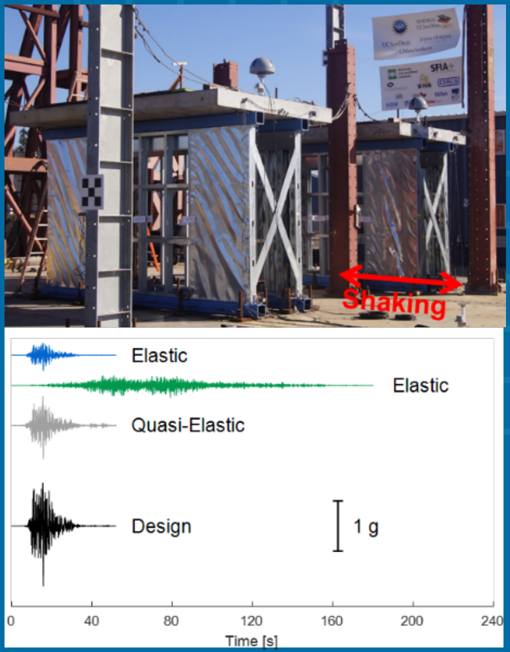


Figure 1. Shake table wall-line experiments: test setup and test protocol.

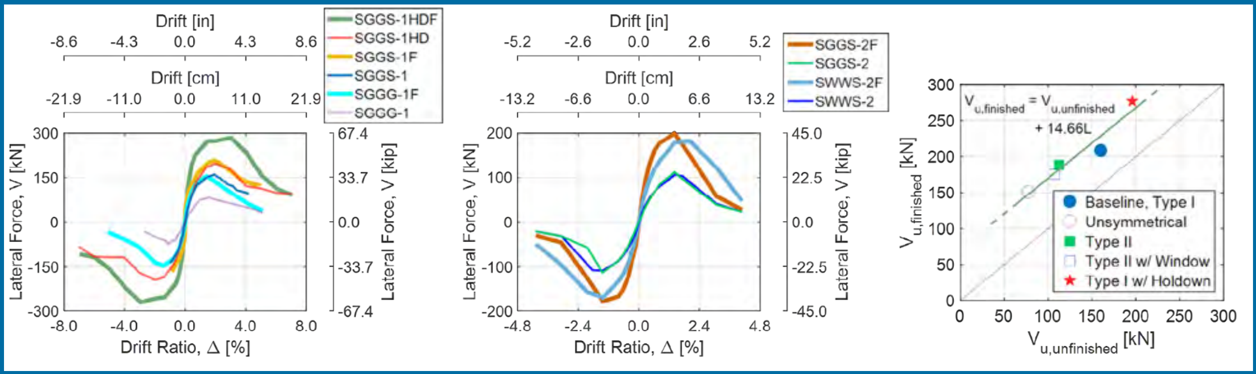


Figure 2. Backbone curve comparisons for Type I and Type II specimens, and effect of finished application on lateral strength.

Figure 3. Test building conceptual drawing

To advance the knowledge of seismic and post-earthquake fire performance of mid-rise repetitively framed cold-formed building systems and support the improvements in future design codes, a 10-story CFS-framed building is planned to be constructed and tested at the newly upgraded NHERI 6-DOF Large High-Performance Outdoor Shake Table Facility (LHPOST6) from April 2024. Notably unique to this tall building will be the integration of complete architectural finishes and the structural height of 100 feet which will exceed the current code building height limit of 65 feet (see Figure 3). The building will adopt the use of prefabricated CFS wall-lines and floor diaphragms and have a plan area encapsulating the LHPOST6 footprint. It will be subject to a suite of increasing amplitude earthquake motions, and scaled to impose service, design, and maximum credible earthquake (MCE) demands. Subsequently, live fire tests will be conducted within the earthquake-damaged building at select floors. Low-amplitude white noise and ambient vibration data will be collected during construction and test phases to facilitate system identification of the evolving dynamic characteristics of the test building.

OPTIMAL SENSING AND DAMAGE DIAGNOSTICS IN AEROSPACE COMPOSITE STRUCTURES

PROFESSOR MICHAEL TODD

Composites have been increasingly used in aerospace structural components due to their light weight, durability, and high performance characteristics. Damage mechanisms, especially when compared to traditional metallic aerospace materials, are less well understood, and monitoring of in-service composite structural components is a solution for informing service conditions. This project seeks to understand how delamination, leading to local material buckling, in a composite aerospace structure may be detected via local strain perturbations measured by fiber optic strain gages. A high-fidelity simulation model is emulated by machine learning to train this fundamentally stochastic problem, leading to probabilistic predictions of delamination size and location in the structure via the strain measurements.

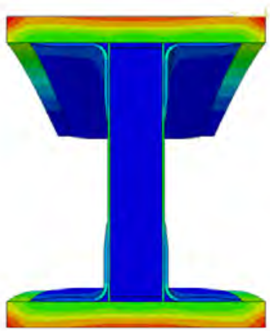
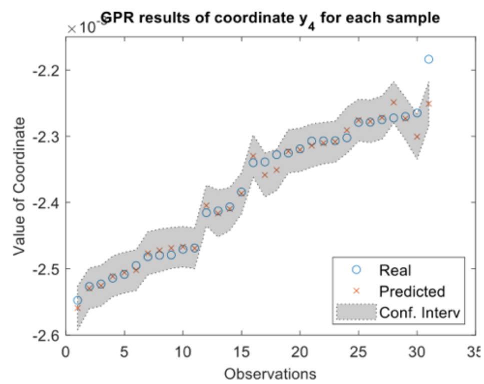
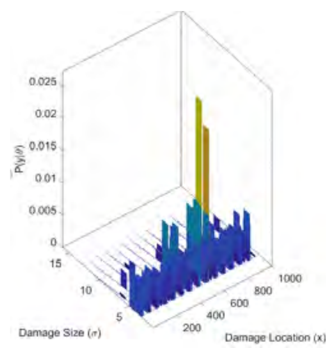


Figure 1. Finite element simulation of an aircraft's composite wing spar.

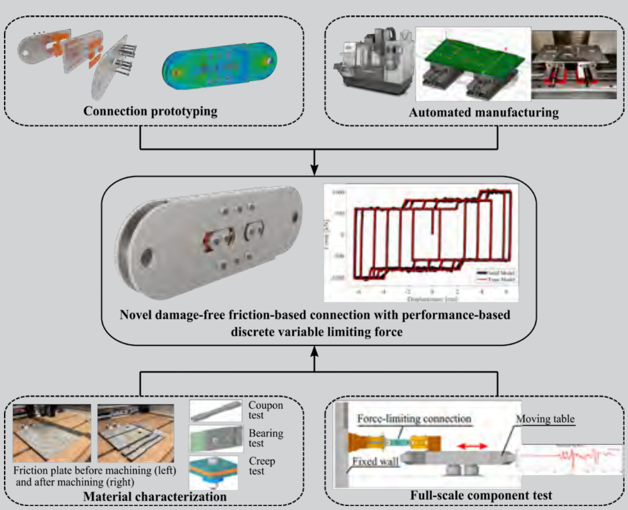




NOVEL DAMAGE-FREE FRICTION-BASED CONNECTION WITH PERFORMANCE-BASED DISCRETE VARIABLE LIMITING FORCE

KAIXIN CHEN AND ASSISTANT PROFESSOR GEORGIOS TSAMPRAS

High-performance buildings have the potential to preserve their functions that are critical for the well-being of our society and reduce the immediate and long-term financial losses after strong earthquake ground motions. This project aims to develop a novel damage-free friction-based connection with performance-based variable limiting force transferred between floors and seismic force-resisting systems in high-performance buildings. The proposed force-limiting connection is practical and simple to manufacture, assemble, and install. It is intended to be subjected to seismic events without damage, and thus, can be immediately reusable after an earthquake. The novel attribute of the proposed connection is that it can be designed to develop predefined limiting forces at target displacements associated with performance-based design objectives. The figure shows the four tasks required for the development of this connection. The four tasks include the prototyping of the physical embodiment of the connection, the automated manufacturing of the parts of the assembly of the connection, the characterization of the mechanical properties of the materials used to form the friction interfaces, and the full-scale component testing of the connection to characterize the kinematics and the force-displacement response of the connection.



WEARABLE SENSORS FOR IMPROVING FIREFIGHTER SAFETY AND PERFORMANCE

YUN-AN LIN, TAYLOR PIERCE, SHIH-CHAO HUANG, EMERSON NOBLE, AND PROFESSOR KEN LOH

The Office of Naval Research (ONR) has supported the Active, Responsive, Multifunctional, and Ordered-materials Research (ARMOR) Laboratory, led by Professor Ken Loh, to develop wearable fabric sensors that measure how people move and execute functional tasks. The goal is, through these unprecedented sensing streams, to assess physical capabilities, improve athletic performance, prevent musculoskeletal injuries, and enable active rehabilitation. The patent-pending enabling technology – called Motion Tape – is based on printing graphene strain sensors onto self-adhesive, stretchable, elastic fabric. These low-cost sensors can be manufactured in different sizes and shapes, affixed anywhere on the skin, and connected to a miniature wireless sensing node for data collection and processing (see Figure 1). By measuring skin-strains induced during movement, the data contains rich information about what physical activity is being performed and how specific muscles activate to produce those movements, elicited through various signal processing and machine learning algorithms.

Motion Tape technology has undergone a battery of human subject laboratory and field tests. Earlier studies have focused on having participants wear Motion Tape on different parts of the body (e.g., biceps, triceps, deltoids, lower back, calves, and ankles) while performing a variety of exercise and functional movements (Figure 1). The accuracy of measured skin-strains has been verified against optical motion capture, and Motion Tape signals are strongly correlated with electromyography (EMG) muscle activation measurements, too. Building on these successes, the ARMOR Lab has partnered with the Tritons Golf Team to assess player performance, the Naval Health Research Center to understand chronic ankle instability and rifle marksmanship, and the U.S. Marine Corps to monitor warfighter health during force-on-force training exercises, among others.

The next phase of this work is an incoming ONR project titled SHEPHERD – Sensing Health, Environment, and Performance Holistically during Emergency Response and Damage-Control. The goal is to adapt Motion Tape to design and deploy a wearable sensing system seamlessly integrated with existing uniforms and/or damage control, firefighting, and protective equipment (see Figure 2). The system aims to measure the health, activities, locations, performance, and surrounding conditions of shipboard personnel during damage control and emergency response. In addition to future testing onboard Navy ships, the ARMOR Lab has partnered with the San Diego Fire Department and the Fire Academy to test prototype sensing systems while cadets execute different firefighting training evolutions (Figure 3). Testing sensors in realistic operating conditions will help identify and address technology gaps while streamlining the process for rapid technology transition to the end-users and stakeholders.

Figure 1

Figure 2

Figure 3

SHAKE TABLE TEST OF THE STAIR SYSTEM WITH DRIFT-COMPATIBLE CONNECTIONS: CONTRIBUTION TO THE NHERI TALLWOOD 10-STORY MASS TIMBER BUILDING

PROFESSOR TARA HUTCHINSON

During extreme events such as an earthquake, stairs are the primary means of egress in and out of buildings. Past earthquake events such as the 2008 Wenchuan earthquake and the 2011 Christchurch earthquake, amongst others, continue to highlight the importance of continued functionality of stair systems, while also documenting their vulnerability as manifest in the form of significant damage and collapse of stair systems. Moreover, previous experimental studies report significant damage to stair connections as well as stair flight detachment in some cases below building design target inter-story drift ratios of 2.0-2.5%. Therefore, ASCE 7-16, Section 13.5.10 requires that egress stairs not part of a seismic force-resisting system be detailed to accommodate the relative displacement between two levels without loss of gravity support. Despite such design code guidelines, there remains a paucity in experimental data validating drift-compatible stair connection details. To investigate the seismic performance of stairs with drift-compatible connections, a 10-story operable steel stair system with various connection details will be tested as part of the NHERI Tallwood 10-story mass timber building at the UC San Diego 6-DOF Large High-Performance Outdoor Shake Table (LHPOST6) (see Figure 1). A complementary high-fidelity 3D Finite Element Model (FEM) of the stair system with the range drift-compatible connections proposed is also developed and utilized to enrich the experimental findings (see Figure 2).

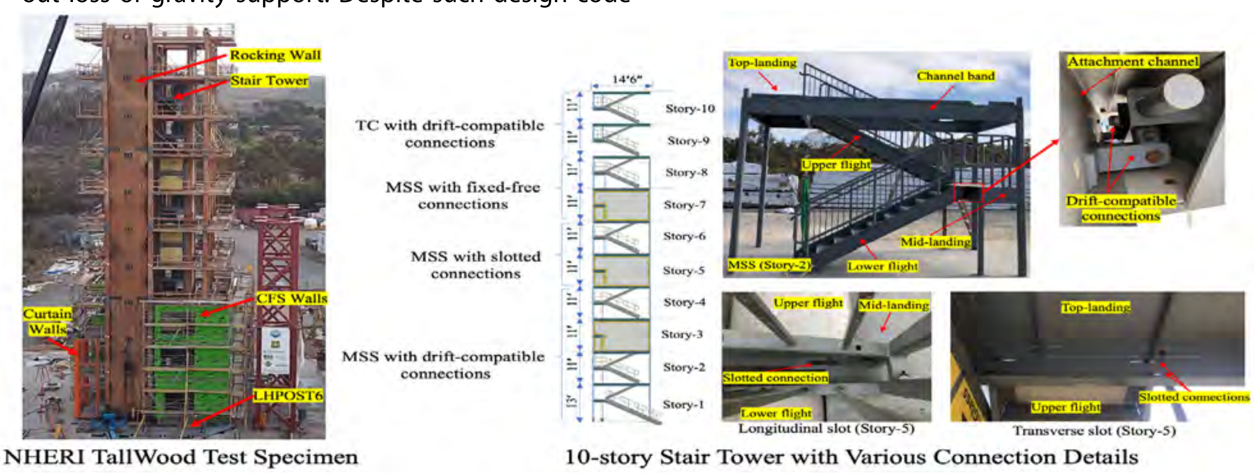


Figure 1: NHERI TallWood 10-story test specimen (left), and the 10-story stair connection details (right).

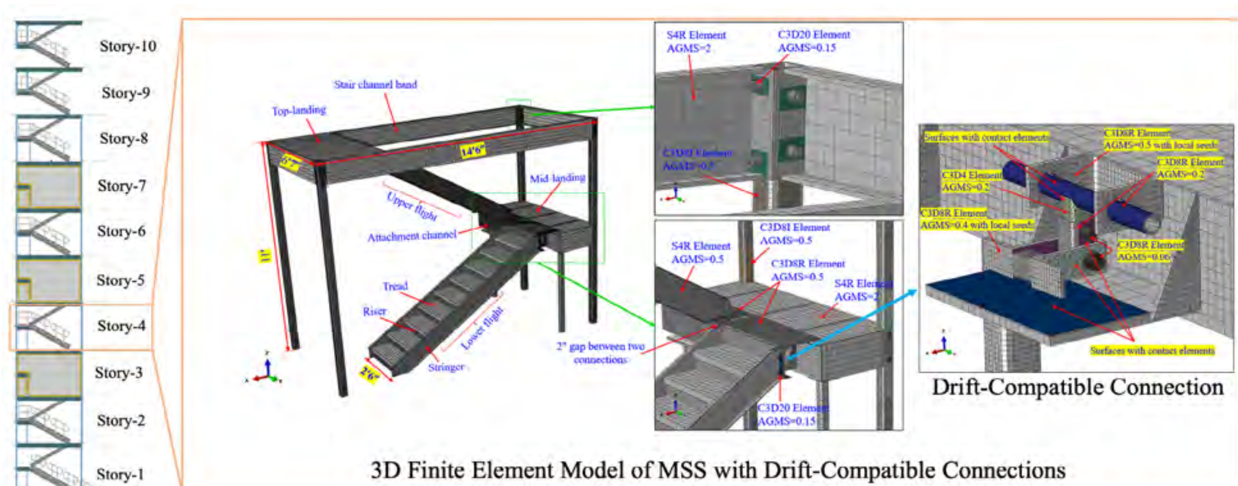
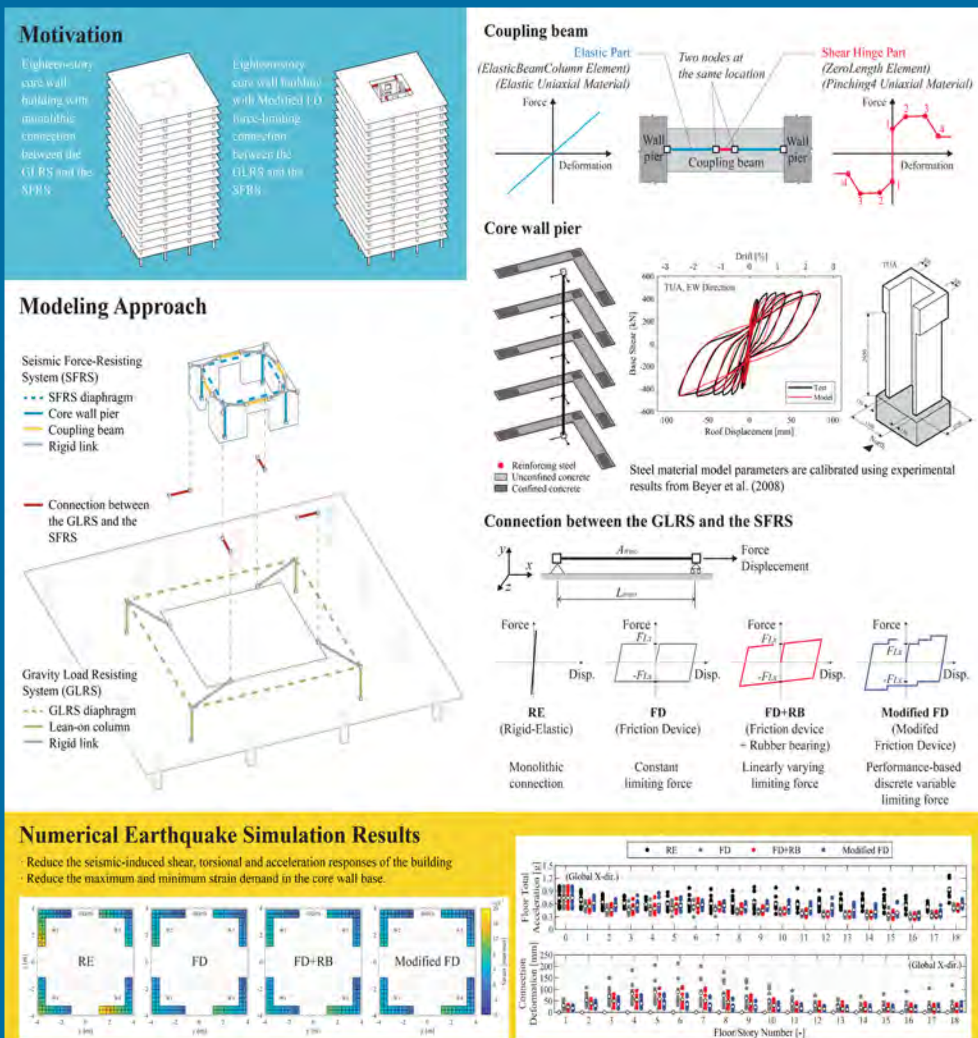


Figure 2: 3D Finite element model details of the Modular Stair System (MSS).

SEISMIC RESPONSE OF EIGHTEEN-STORY CORE WALL BUILDING WITH FORCE-LIMITING CONNECTIONS

KYOUNGYEON (YEON) LEE AND ASSISTANT PROFESSOR GEORGIOS TSAMPRAS



A core wall system is a popular seismic force-resisting system for tall buildings. However, tall core wall buildings have large participation of higher mode response in the total dynamic response which amplifies the floor acceleration and story shear forces. One way to mitigate the higher mode effect is using force-limiting connections. Force-limiting connections allow the movement of the gravity load-resisting system (GLRS) relative to the seismic force-resisting system (SFRS) and limit the seismic-induced horizontal forces transferred between the two systems.

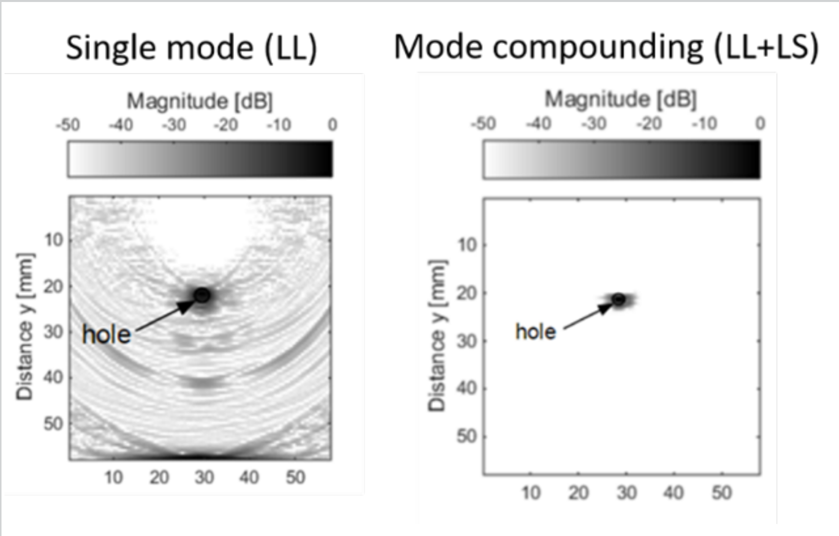
Force-limiting connections have been developed for planar wall buildings. These force-limiting connections consist of a friction device and low-damping rubber bearings (i.e., FD+RB). This study assesses the seismic response of an eighteen-story building with force-limiting connections that are modified (i.e., Modified FD) to accommodate the three-dimensional kinematics in core wall buildings. Three-dimensional earthquake numerical simulations of an eighteen-story core wall building model are performed.

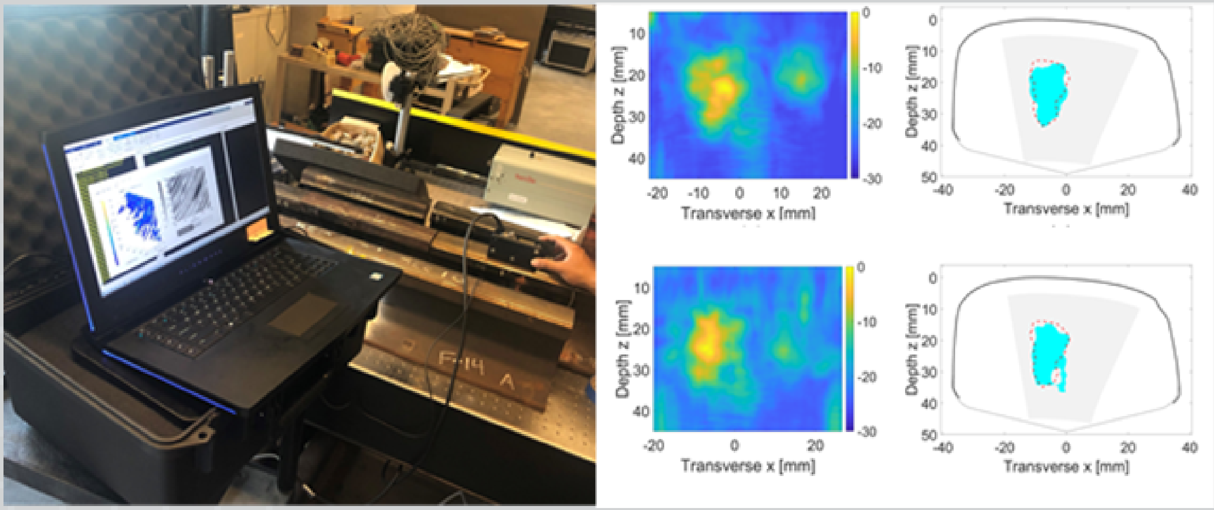
Numerical simulation results show that Modified FD force-limiting connections can be used in core wall buildings to reduce the magnitude and variability of the seismic-induced shear, torsional, and acceleration responses of the building while maintaining a reasonable relative displacement between the GLRS and the SFRS. The Modified FD force-limiting connections also reduce the magnitude and variability of the maximum and minimum strain demand in the core wall base.

ADVANCED IMAGING OF DEFECTS USING ULTRASONIC SYNTHETIC APERTURE FOCUSING TECHNIQUES

PROFESSOR FRANCESCO LANZA DI SCALEA

Synthetic Aperture Focusing (SAF) is a well-established technique to provide imaging of reflective targets of radar and ultrasonic waves. In NDE and SHM, imaging techniques can provide quantitative information of structural defects that are invaluable for informed remedial actions. UC San Diego is working on improving the ultrasonic SAF technique in terms of increased imaging speed and increased imaging accuracy (flaw size and shape). These improvements are being made in both beamforming algorithms and hardware. This research is being applied to imaging internal flaws in applications ranging from railroad tracks to composite aerospace structures.



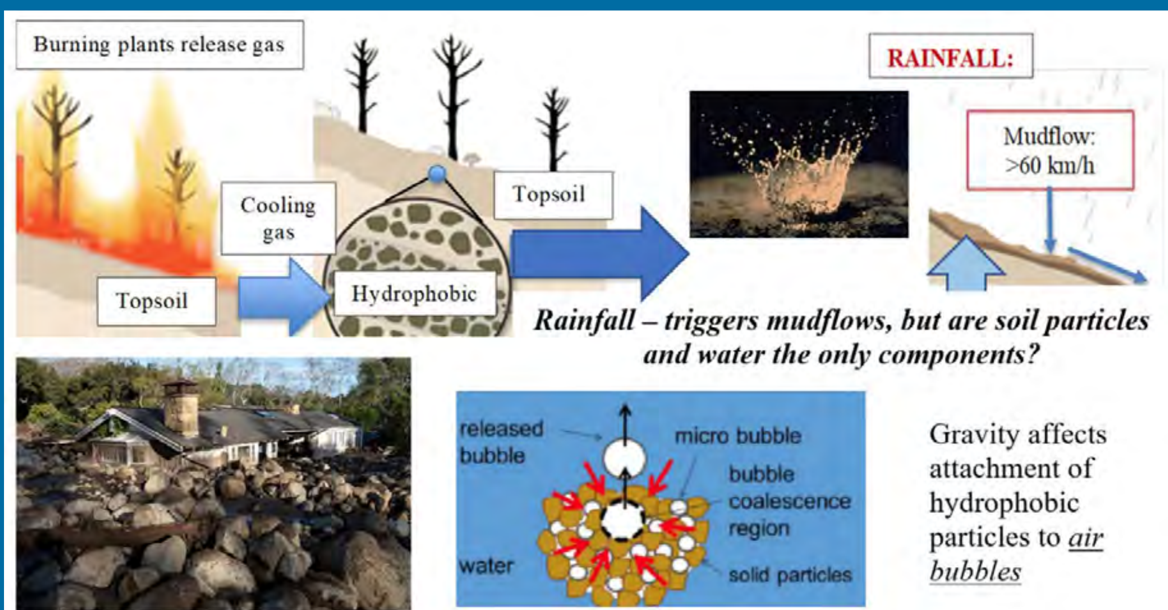


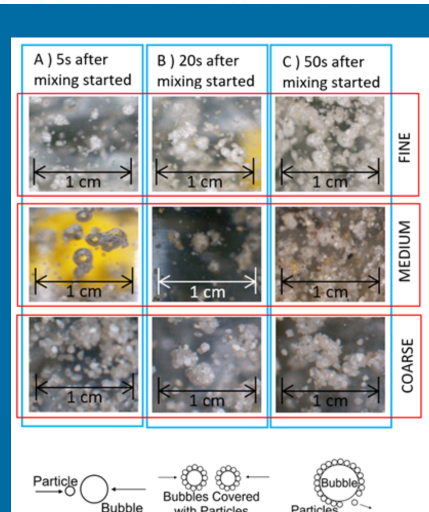
POST-WILDFIRE MUDFLOW AND DEBRIS FLOW RHEOLOGY AND AIR ENTRAPMENT

ASSISTANT PROFESSOR INGRID TOMAC

Understanding the role of gravity in the dynamics of mudflows uses experiments on board the International Space Station (ISS). It is well established that rainfall triggers mudflows on recently burned slopes. After wildfires, the surficial burned soil is water-repellent or hydrophobic, preventing rain infiltration and leading to sudden and rapid mudflows. Post-wildfire gravity-driven mudflows are unpredictable, occur suddenly, and travel rapidly downhill, turning into debris flows and mobilizing large and heavy boulders. In January 2018 in Montecito, California, an intense 15-minute burst turned into a devastating debris flow which caused 21 deaths, led to $421 million in damages, and closed key transit corridors. The experiments examine how the attachment of hydrophobic soil particles to air bubbles leads to the formation of aggregates that may give rise to the unusual flow behaviors observed in mudflows.

Particle-air-water mixtures form interesting structures (bubbles, pipes, and clusters) whose shapes are primarily governed by a balance between gravity and the attractive forces between air bubbles and water-repellent particles. An understanding of the role of gravity on microstructural changes in flowing air-water-particle mixtures and on the formation of particle-bubble agglomerates is crucial for predicting the rheological behavior of mudflows. These experiments focus on how mudflow shear behavior depends on relative amounts of water, trapped air, and particles of various sizes. Understanding the processes of mudslide initiation with respect to rainfall intensity and duration will lead to a more accurate predictive capability for the onset and development of mudslides that could mitigate catastrophic damage.





DEVELOPING CONSTITUTIVE RELATIONSHIPS FOR THE PROPERTIES OF UNSATURATED BENTONITE BUFFERS UNDER HIGH TEMPERATURES

PROFESSOR JOHN MCCARTNEY AND PROFESSOR J.S. CHEN

The safe, long-term disposal of radioactive waste is a major international challenge. The most common disposal approach under consideration is storing waste canisters in deep geological repositories. A key component in a geological repository is the engineered barrier system, which includes a bentonite buffer placed between the waste canister and the surrounding host rock. The bentonite absorbs water from the host rock and tends to swell as it hydrates, generating stresses due to the restraint provided by the host rock and waste canister. Meanwhile, the waste canister will increase in temperature due to the radioactive nature of the waste, leading to thermally induced drying of the bentonite near the heater, as shown in Figure 1. Simulations of the thermo-hydro-mechanical response of bentonite buffers must capture these coupled processes to accurately predict their long-term behavior. The objectives of this project are to characterize the effects of high temperatures (up to 200 °C) on the mechanisms and material properties governing coupled heat transfer, water flow, and volume change in unsaturated, compacted granular bentonite, and to understand and simulate the multiphase hydration process of bentonite buffers. A tank-scale test was designed and conducted to capture the coupled heat transfer and water flow processes during heating of compacted MX80 bentonite to high temperatures (Figure 2a). A temperature of 200 °C was maintained by a cylindrical heating element at the center of a compacted bentonite layer containing an array of temperature, dielectric, and relative humidity sensors. In addition to providing an evaluation of the spatio-temporal variations in temperature, relative humidity, degree of saturation, and global volume, the coupled thermo-hydraulic properties of the bentonite were assessed (Figures 2b and 2c). The soil-water retention curve (SWRC) of the bentonite followed a wetting scanning path before following the primary drying path exhibiting a shift in water retention with an elevated temperature (Figure 2d). Results from the tank-scale test can be used for validation of numerical simulations of drying processes in the engineered barrier system of a high-level radioactive waste geological disposal repository and confirm that a temperature-dependent hysteretic SWRC with scanning paths is required to accurately capture the bentonite response.

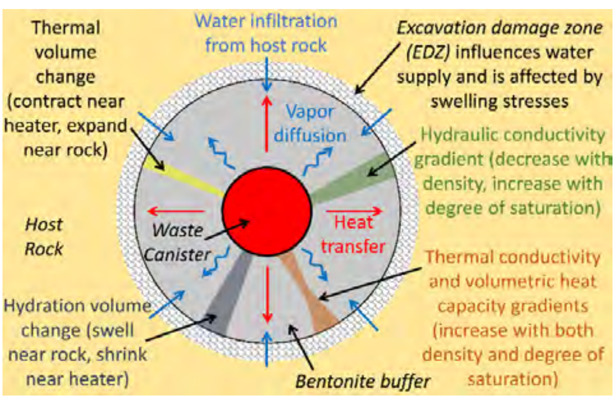
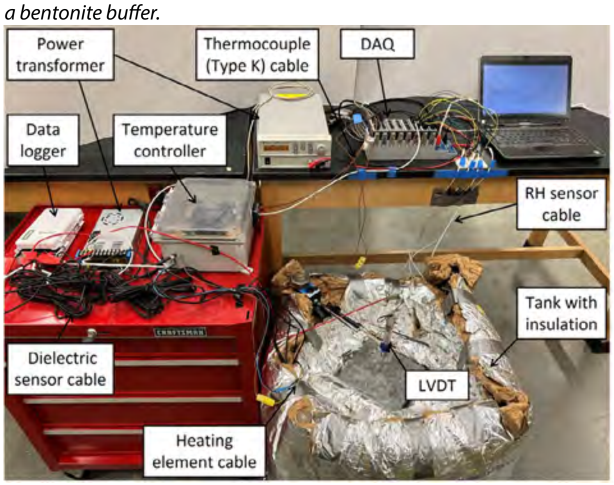


Figure 1. Summary of coupled heat transfer and water flow processes in a bentonite buffer.

a)



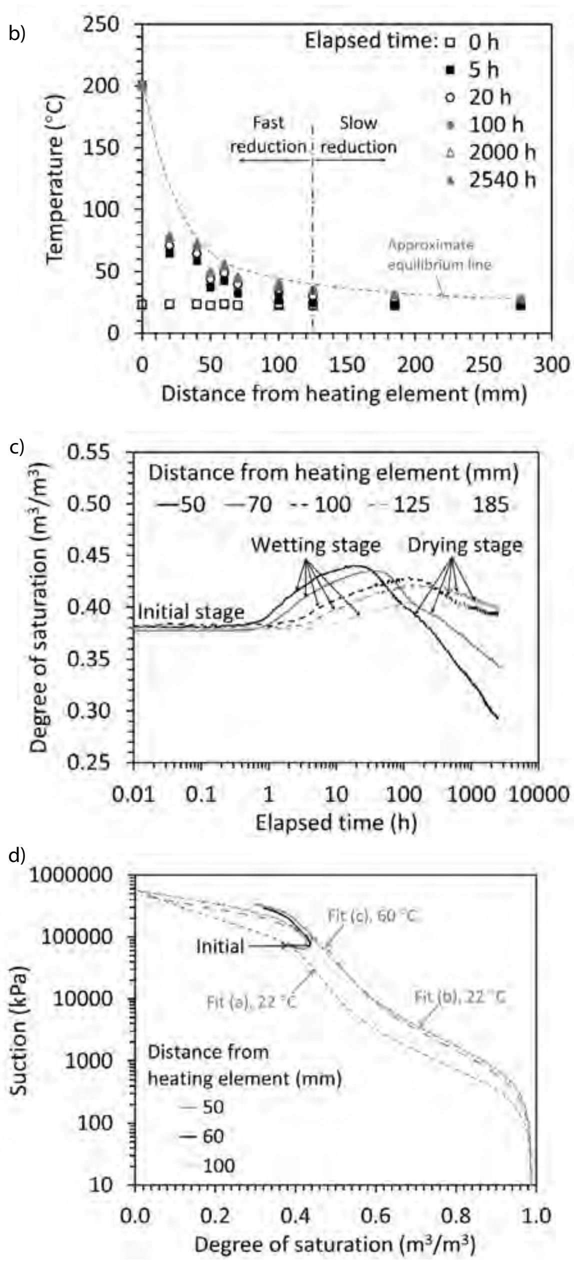


Figure 2. Tank-scale test on compacted MX80 bentonite: (a) Test setup (b) Radial profile plots of temperature (c) Evolution of degree of saturation (d) Suction-saturation curves with wetting and drying path SWRCs.

GROUND IMPROVEMENT-BASED PROTECTION OF TRANSPORTATION INFRASTRUCTURE: VALIDATION OF PERFORMANCE BASED ENGINEERING VIA CENTRIFUGE SHAKE TABLE TESTING

PACIFIC EARTHQUAKE ENGINEERING RESEARCH (PEER) CENTER

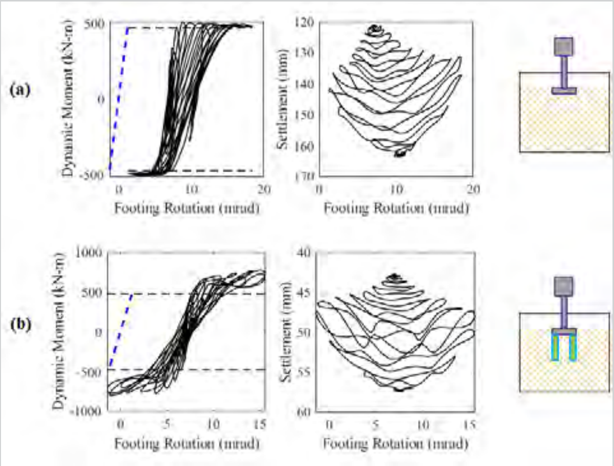


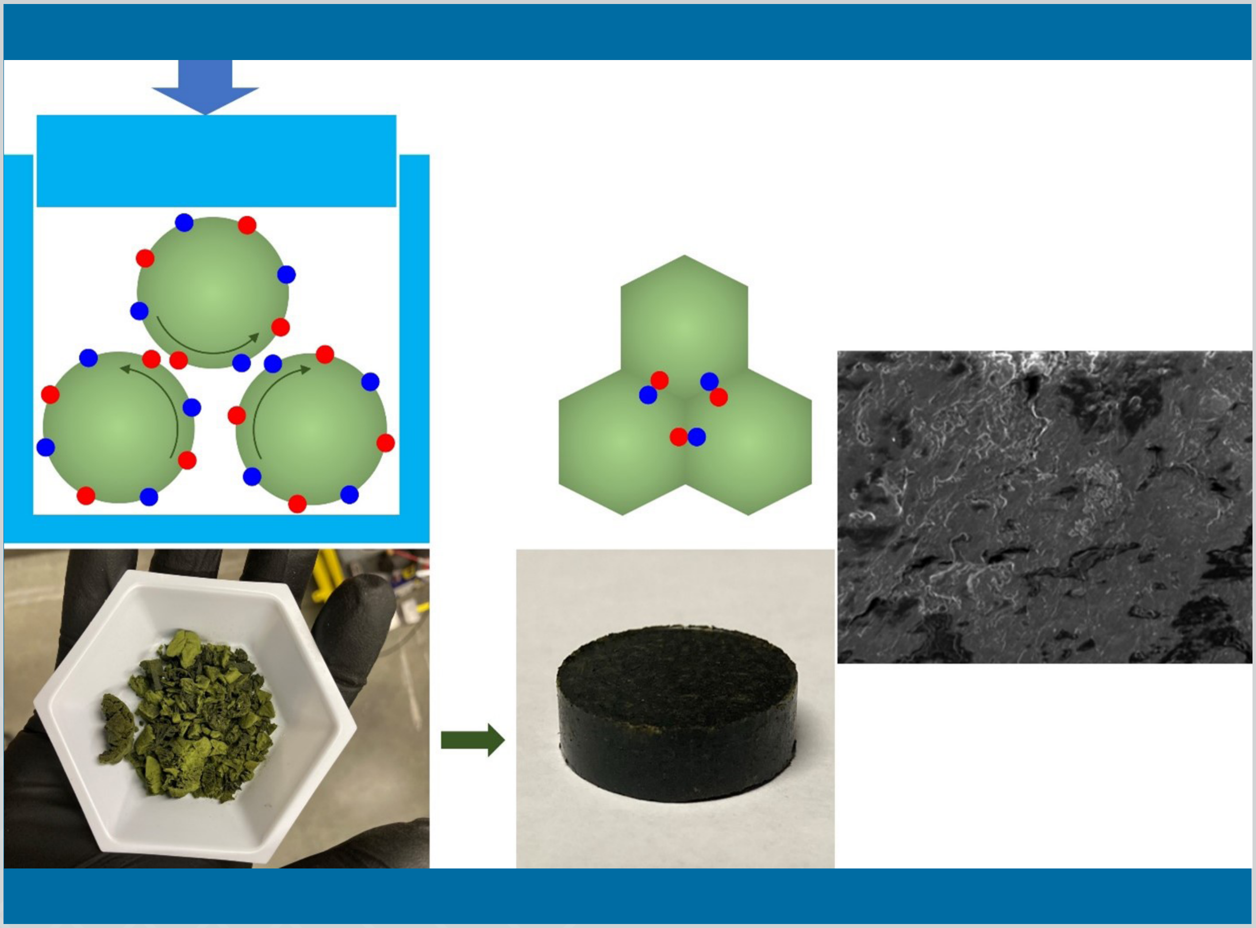
Figure 1. (left) Model footing on the shake table in the UC San Diego centrifuge.
Figure 2. (right) Footing response without ground improvement (a) and with paired cement-mixed columns (b). Note that footing (b) exhibits greater moment capacity, reduced settlement, and improved re-centering.

Rocking shallow footings have been proven to be effective in dissipating energy and reducing damage to the bridge superstructure during seismic events, yet their adoption has been limited by the concern that they may experience excessive settlement and rotation as a result of being allowed to uplift while rocking. To alleviate these concerns, this project implemented a variety of ground improvement (GI) techniques, including cement-mixed columns and 3D-printed geogrids, scaled for use in centrifuge shake table testing and tailored to specifically control the kinematics of the rocking footing. Two different single-degree-of-freedom (SDOF) structures, each quite heavily loaded and supported by a relatively small rectangular shallow footing on dry, medium loose, pluviated sand were tested. It was found that a pair of cement-mixed columns placed at the footing ends, extending to about two footing widths depth, and mixed to a strength at least two times greater than is typical in a field application, reliably reduced settlement to just 30% of an identical footing without GI through a demanding series of seismic events. Meanwhile, a 3D-printed geogrid with strength and stiffness significantly greater than a commercial product was found to preserve re-centering especially well when placed near the bottom of the footing, and to reduce settlement especially well when placed at about one footing width below the bottom of the footing. Most importantly, both techniques preserved the beneficial aspects of uplift and energy dissipation of their non-ground-improved analogs. While each of these GI techniques required greater strength and stiffness to achieve these high performance metrics, associated construction costs could be expected to be quite reasonable owing to the limited geometric extent; that is, the ground improvement is localized to a small zone immediately surrounding the footing. Future tests might investigate GI geometries capable of being installed as a retrofit around an existing footing's footprint. Ultimately the suite of tests and moment-settlement-rotation performance curves for footings with and without GI (shown in the figure) provide the basis for adoption of rocking footings in design code and increase the likelihood that such a design concept will be embraced by the engineering community.

ULTRALOW-BINDER-CONTENT CARBON-BASED ARTIFICIAL TIMBER

KIWON OH, HAOZHE YI, RUI KOU, AND PROFESSOR YU QIAO

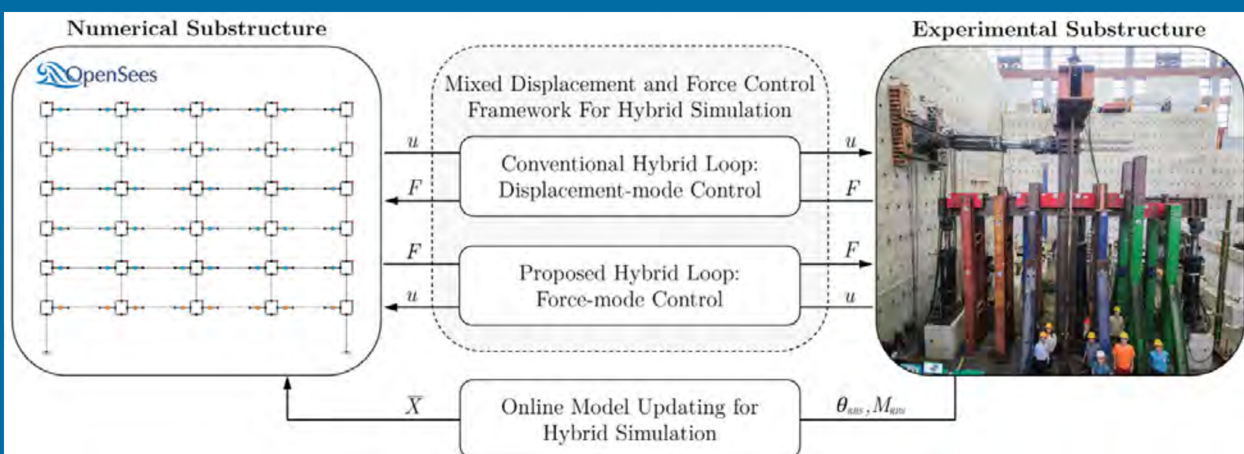
Algae-based artificial lumber is a promising next-generation carbon-negative structural material. In the past decade, a number of breakthroughs were made in the timber industry, e.g., mass timber. However, forestry has reached its limit. A new direction is algae. It grows 20 times faster than trees and is almost everywhere worldwide. Its production is fast and low cost; it does not use much land or cause deforestation. Yet, currently, the application of algae is limited to relatively small-sized markets (e.g., food and fertilizers), which has greatly constrained its potential. We have developed a simple technology to produce artificial lumber. It is a composite material containing more than 98% algae and 1-2% fiberglass, without any binder. It may open the door to a new industry of algae cultivation (for large-scale carbon sequestration) and a new area of green construction. A similar processing approach can be used to fabricate green and highly durable concrete. The durability of modern concrete is not satisfactory. A significant portion of modern concrete structures in the U.S. need major retrofitting within 40 years. Furthermore, cement production emits a large amount of carbon dioxide (~8% of total human-related carbon emission) and is energy consuming (~5% of total industrial energy use). In view of these issues, we are developing low-binder-content green and durable concrete. In a cost-efficient manner, by using multiple thermodynamic driving forces (chemical force, mechanical force, and thermal force), the concrete microstructure is densified, and the content of binder can be largely reduced by nearly 50%. Hence, the overall carbon emission is more than halved, and the concrete durability is greatly enhanced.

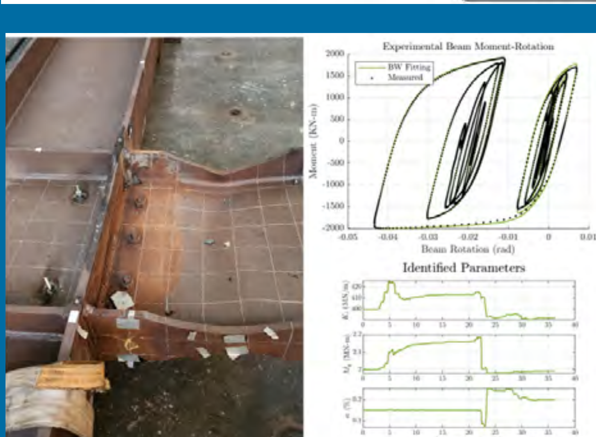


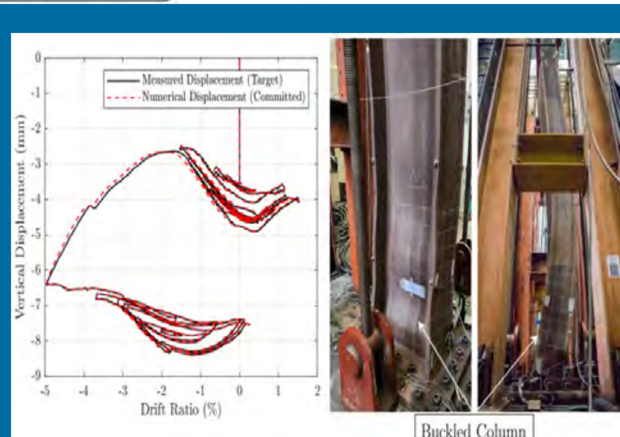
HYBRID SIMULATION FRAMEWORK WITH MIXED DISPLACEMENT-FORCE CONTROL AND ONLINE MODEL UPDATING FOR SEISMIC PERFORMANCE EVALUATION OF STEEL MOMENT FRAMES WITH DEEP COLUMNS

CLAUDIO SEPULVEDA, PROFESSOR GILBERTO MOSQUEDA, AND PROFESSOR CHIA-MING UANG

Wide flange steel column elements are widely used in the design and construction of steel moment frames in seismic regions. To economically comply with drift limit requirements, deep and slender columns are often selected to maximize the moment of inertia of the section. However, deep columns are susceptible to local buckling and lateral-torsional buckling, causing subsequent axial shortening when subjected to a combination of high axial forces and cyclic lateral loads. The effects of shortening columns on the surrounding structural framing system and the subsequent redistribution of axial loads is not well understood. To experimentally evaluate this interaction, hybrid simulations with a full-scale steel moment frame subassembly have been conducted. New hybrid simulation algorithms were developed to conduct these experiments including a mixed displacement-force control framework that enforces compatible displacement including column shortening between the numerical and experimental substructures. In addition, the experimental cruciform substructure includes beam-to-column connections that develop plastic hinges with a complex nonlinear response. Online model updating is used to monitor the behavior of the experimental plastic hinges and update parameters in the nonlinear numerical beam models. This research is part of a collaborative project funded by the National Institute of Standards and Technology (NIST) and includes researchers from UC San Diego, the National Center for Earthquake Engineering Research in Taiwan, the University of Michigan, and UC Berkeley.







SHAKE TABLE TESTING AND COMPUTATIONAL FRAMEWORK FOR SEISMIC RESPONSE OF UTILITY-SCALE BUCKET FOUNDATION OFFSHORE WIND TURBINES

PROFESSOR AHMED-WAEIL ELGAMAL

Shake table testing was conducted to document the seismic response of a bucket foundation offshore wind turbine (OWT) system. The salient response of the system's soil-structure interaction effects is presented and discussed. Excess pore pressure fluctuation within and around the soil-bucket domain is thoroughly addressed, including the strong tendency for the soil dilation excursions driven by the induced cyclic strains. The experimental data is used to calibrate a numerical model with a dynamic soil response simulated by a coupled solid-fluid formulation. The calibrated model is extended to investigate the seismic response of a prototype utility-scale OWT, with and without added wind loading effects. Overall, the research outcomes indicate that: i) excess pore pressure fluctuations in the vicinity of the bucket play an important role in dictating the extent of potential permanent base rotation, ii) consideration should be given to wind loading that might further exacerbate this base rotation, and iii) it is of importance to model the turbine tower as a system of discrete masses, rather than the simplified proposed for practice equivalent top mass idealization.

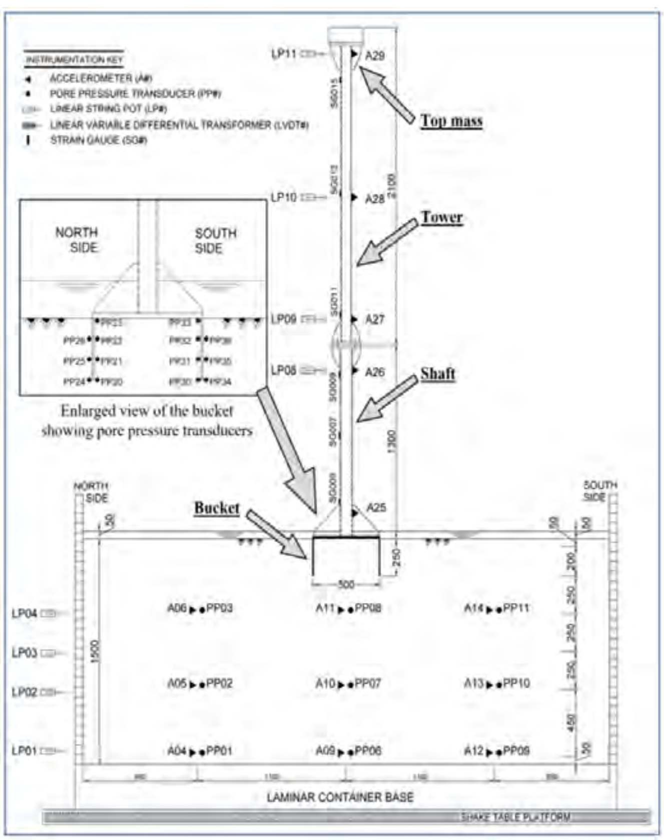


Figure 1. Testing configuration and instrumentation layout (dimensions shown in mm).

Figure 2. Deployment of the bucket in the saturated soil with lower part of the tower.

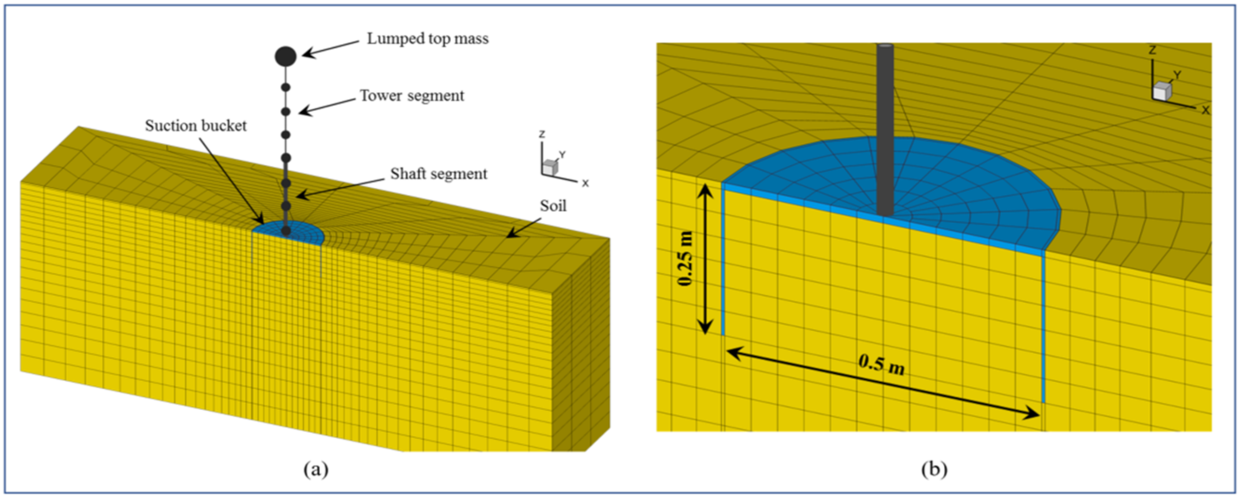


Figure 3: FE Model: a) 3D half-mesh of the bucket foundation wind turbine model b) enlarged view of bucket foundation mesh.

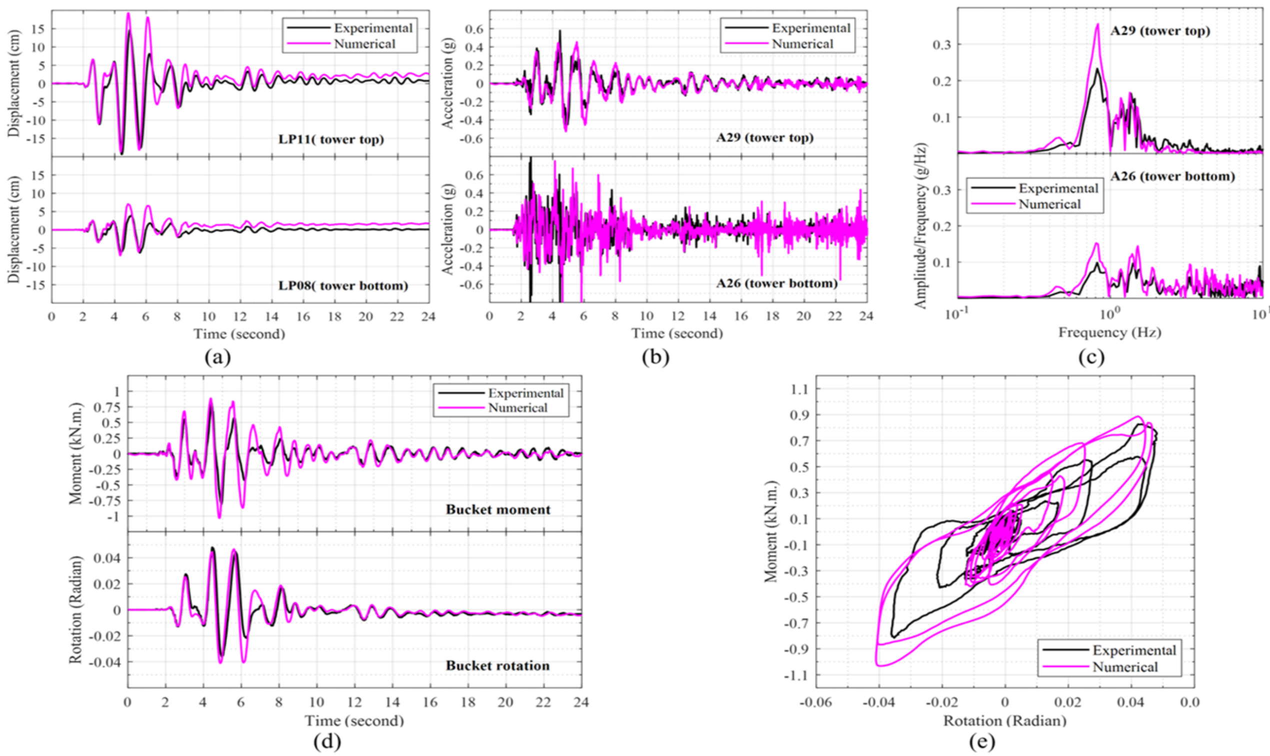


Figure 4: T3 shaking event experimental and numerical tower response: a) displacement b) acceleration c) frequency spectra d) bucket moment and rotation time histories e) bucket moment-rotation hysteresis.

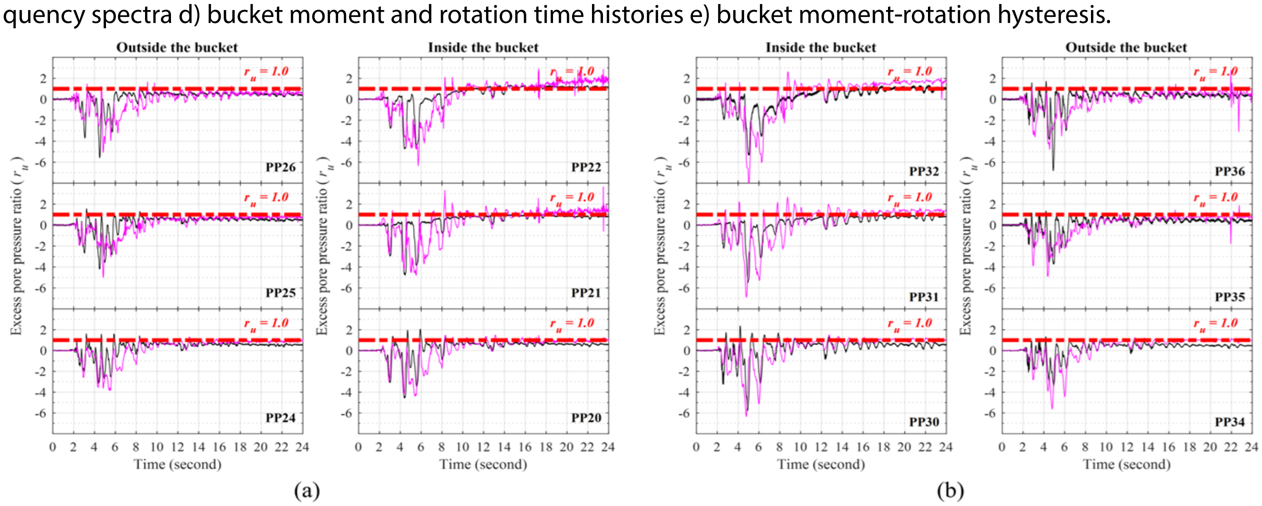
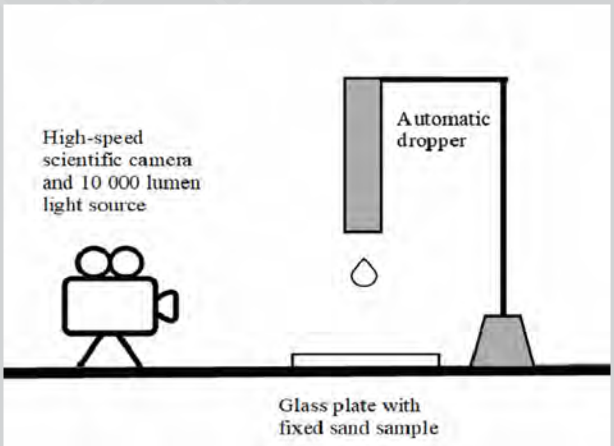


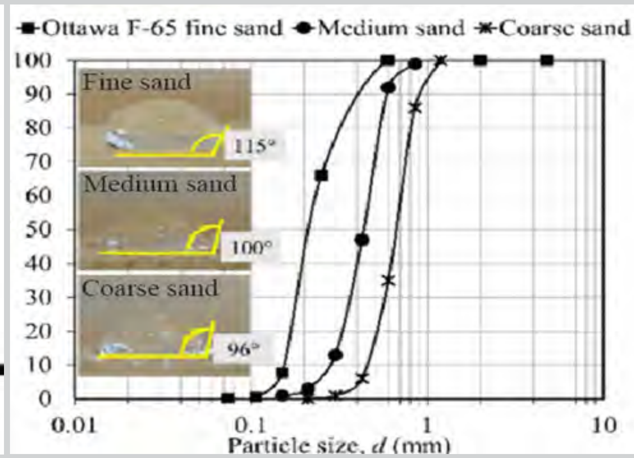
Figure 5. T3 shaking event time histories of excess pore pressure around bucket (Figure 1) for: a) north side and b) south side.

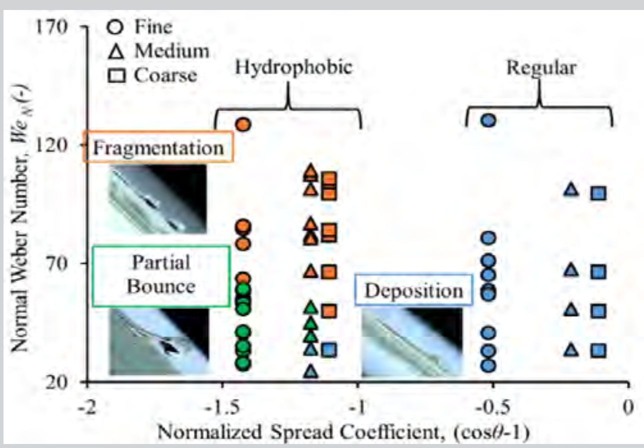
HYDROPHOBICITY MODIFICATION OF PARTICULATE MATTER

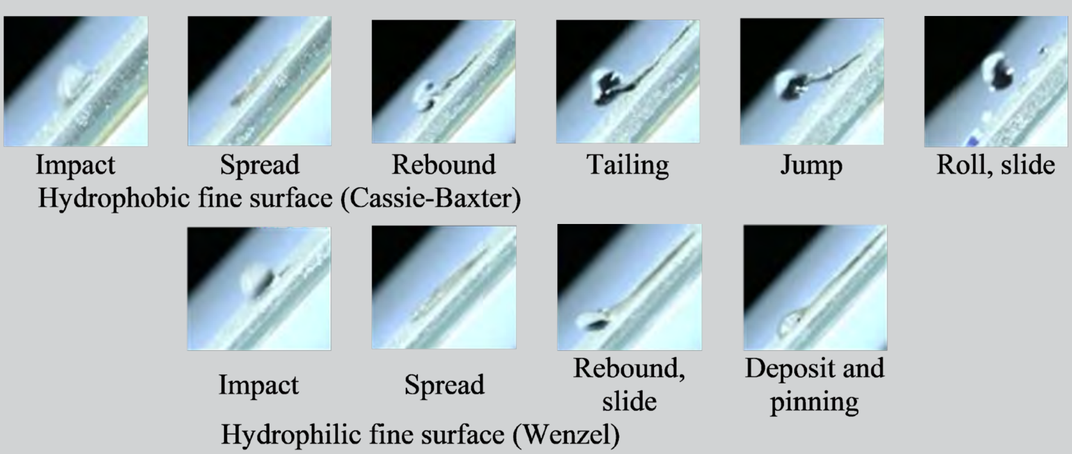
ASSISTANT PROFESSOR INGRID TOMAC

This is an experimental and theoretical investigation of the effects of sand particle size and hydrophobicity of a water drop impacting horizontal and inclined surfaces within a context of post-wildfire mudflow precursors. Although previous research established that wildfires often turn hillslope surficial soil hydrophobic, little research shows how wildfire-altered soil surfaces affect raindrops' impact behavior. Specific findings point to a significant effect of sand type on the drop impact dynamics. After spreading, the drop gathers back more on finer than coarser hydrophobic sands due to the substrate air-entrapped grooves, as in the Cassie-Baxter model, leading to drop retraction, rebound, splash, and fragmentation into droplets. The results indicate that if the hillslope dominant median grain size is fine, alteration to hydrophobicity would multifold enhance drop downhill mobility. In contrast, coarse sand surfaces exhibit minimal effects on drop mobility after hydrophobization. In addition, this paper proposes a modified Tang et al. model for the maximum spread factor as a function of the median grain size and hydrophobicity. This research offers essential findings from the perspective of the previous limiting understanding that only drop infiltration prevents erosion in hydrophilic slopes (Movasat and Tomac, 2023).





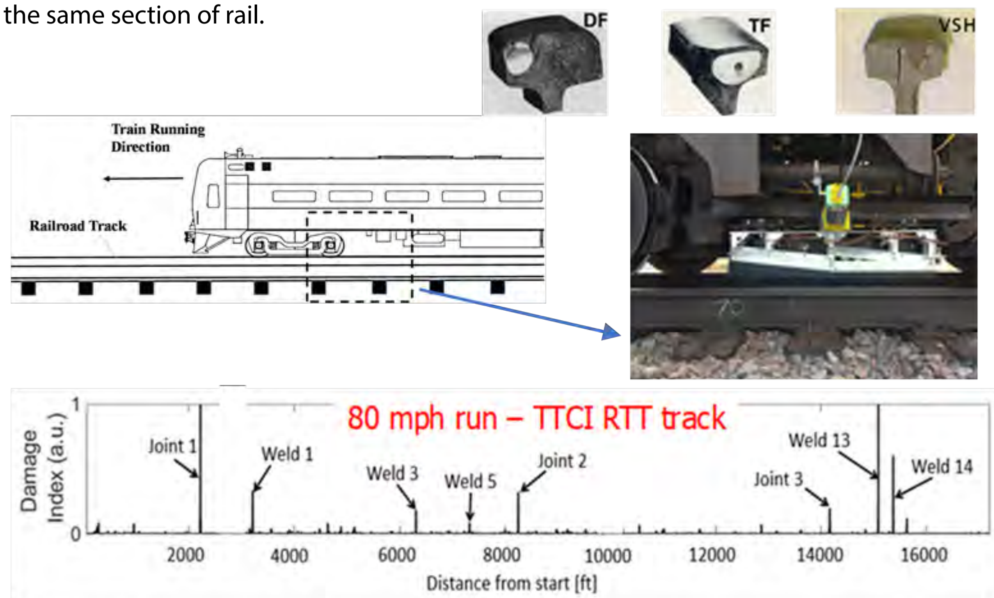




HIGH-SPEED RAIL INSPECTION

PROFESSOR FRANCESCO LANZA DI SCALEA

According to the Federal Railroad Administration's Safety Statistics data, in the past five years (2018-2022) internal rail flaws such as "Detail Fractures" (DF), "Transverse/Compound Fissures" (TF), and "Vertical Split Head" (VSH) defects caused as many as 80 derailments per year and $25 million in damage costs per year. UC San Diego is working on technologies to detect these defects effectively and at a high speed. Specifically, an "output only" technique is being applied to extract the ultrasonic Green's function between two points of the rail to enable inspections at regular train speed (e.g. revenue speed of 60 miles per hour). If fully developed, this technique can be implemented in "smart trains" that can perform rail inspections during regular traffic. This capability would increase the probability of detection and decrease the rate of false alarms by exploiting the redundancy afforded by the multiple train passes over the same section of rail.

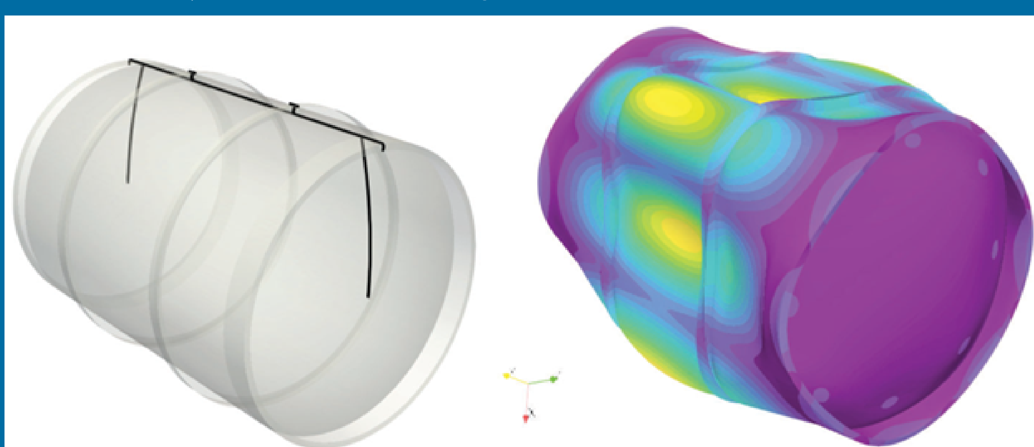


UCSD high-speed rail inspection prototype and a test run at 80 mph at TTCI (RTT track)

ROBUST SIMULATION OF THE STATICS AND DYNAMICS OF SHELL STRUCTURES

PROFESSOR PETR KRYSL

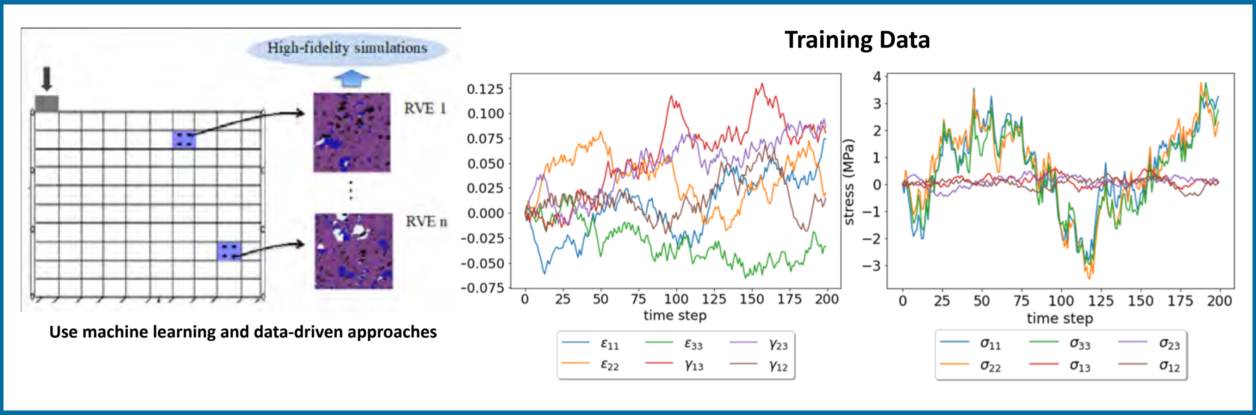
A flat facet finite element with three nodes and six degrees of freedom per node for linear static and dynamic analysis of thick and thin shells was developed. The element was shown to be robust for extremely thin shells, applicable to homogeneous or composite shells, and very computationally efficient. Performance was illustrated with static and dynamic examples including branched and folded shell structures.

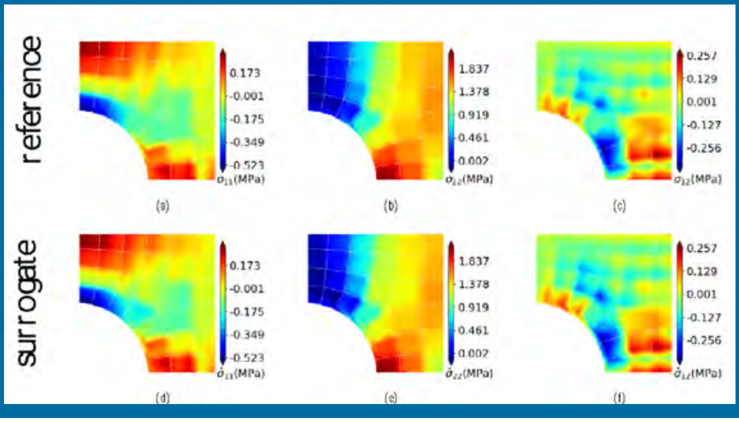


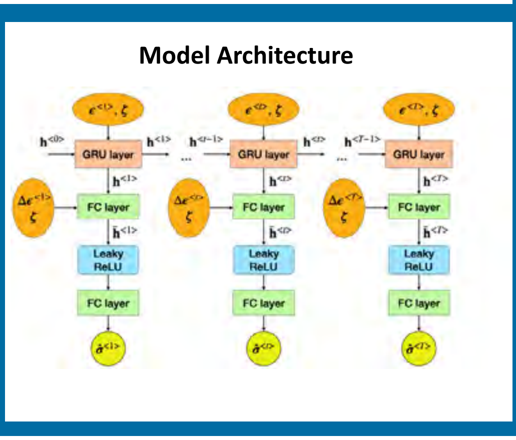
MACHINE LEARNING ENHANCED MULTI-SCALE MODELING

ASSISTANT PROFESSOR SHABNAM SEMNANI

Many natural and synthetic materials are multi-scale in nature and demonstrate a nonlinear and path-dependent behavior, which is determined by the microscopic heterogeneities as well as properties, shape, and distribution of the constituents. One of the major challenges associated with multi-scale modeling of complex systems includes computational costs of high-fidelity simulations and transferring the information across different length scales. Consequently, design and analysis of these systems often involves phenomenological continuum-scale constitutive models that are implemented in a computational framework such as the Finite Element Method (FEM). We have developed advanced machine learning-enhanced modeling frameworks for path-dependent and multi-physics behavior of materials and their applications in solving boundary value problems. For this purpose, we have developed new model architectures and random walk-based training data generation methods to address the challenges associated with multi-scale multi-physics simulations of complex systems.



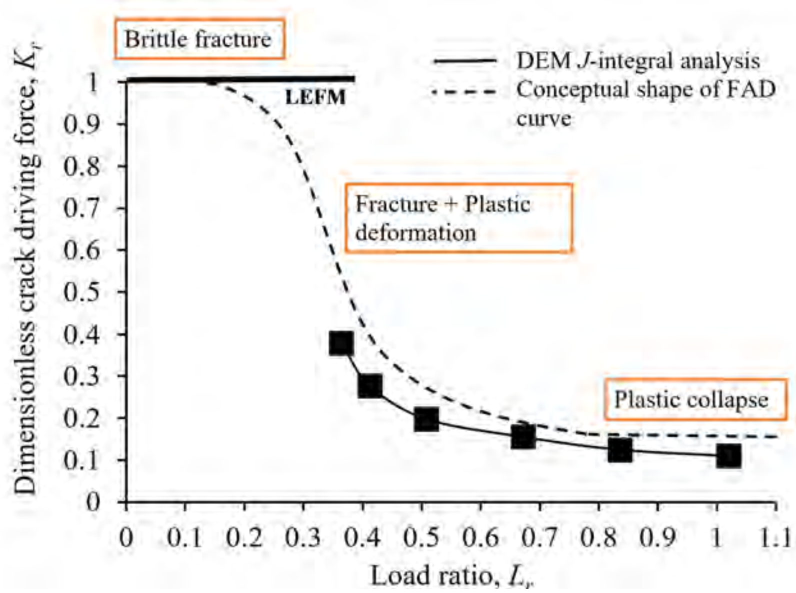




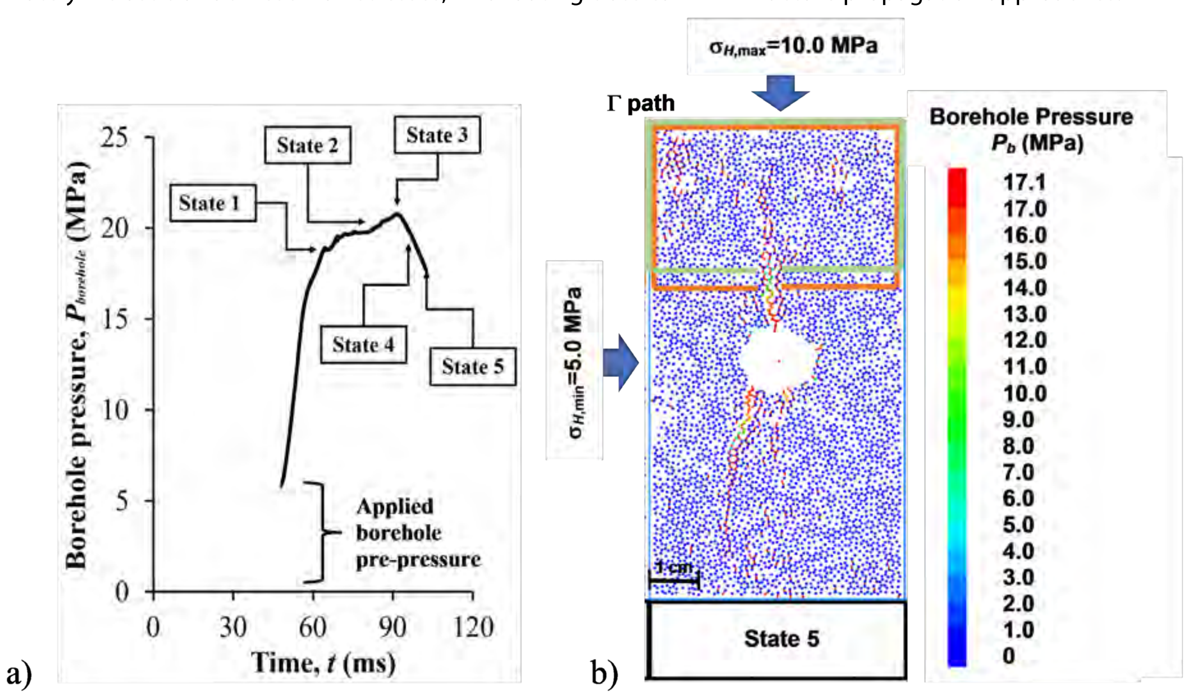
GEOTHERMAL ENERGY AND COUPLED PROCESSES IN ROCK MASS

ASSISTANT PROFESSOR INGRID TOMAC

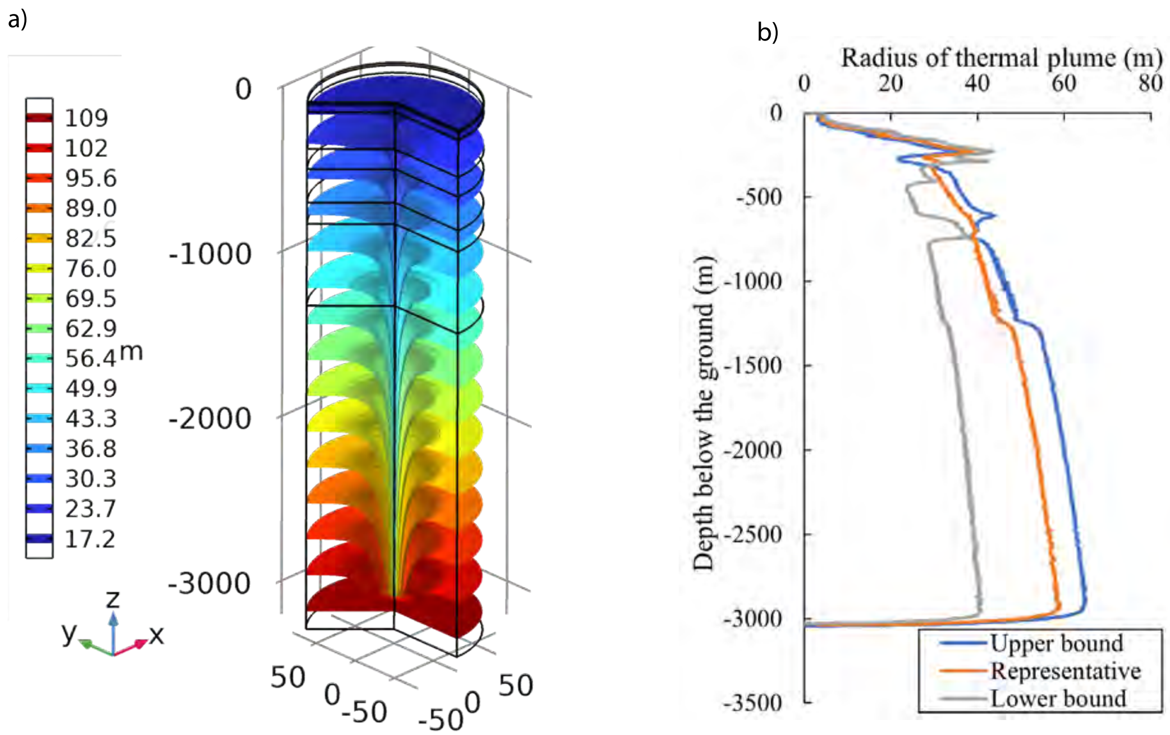
Exploration of geothermal energy from deep hot rock mass is a promising renewable energy approach. This research addresses Enhanced Geothermal Systems (EGS) and Deep Borehole Heat Exchanger (DBHE) technological challenges and carves pathways towards a better understanding of underlying fundamental processes. For example, inelasticity in hydraulic fracture propagation in weak sandstone is studied by using models obtained by the Discrete Element Method (DEM) as a basis for quantifying the Failure Assessment Diagram (FAD) and J-integral. Although current engineering models use Linear Elastic Fracture Mechanics (LEFM), including improvements like the fracture tip damage zone where fracture tip plasticity is small enough to fit into the near-field stress zone, this paper hypothesizes that hydraulic fracture propagates in an inelastic regime in certain conditions typically for underground rock reservoirs. Discrepancies within field or laboratory data, including microcrack clouds identified as acoustic emissions that induce plastic deformations, motivate the investigation of inelasticity and implementation of elastoplastic fracture propagation theories. The Discrete Element Method (DEM) has been widely used to approach rock failure problems from the micromechanical level, where explicit modeling of local particle-bond breakage enables insights into propagating fracture branching, damage, microcrack coalescence, stress-strain re-distribution, irreversible deformation, and fracture arrest. Results show that inelastic J-integral increases dramatically with rock confinement, especially its non-elastic portion, and the elastic portion of the total J-integral remains a relatively small part. Higher confinement stresses and higher confinement stress contrast enhance the inelastic fracture propagation. Additionally, shorter fracture lengths and smaller dry tip zones characterize inelasticity. Rock stiffness increase leads to total J-integral increase and decrease of J-elastic, leading to pronounced inelasticity. Therefore, results indicate that LEFM is rarely applicable for describing fracture propagation through rocks at higher confinement stresses and stiffness.



Results of DEM simulation of hydraulic fracture propagation show that fracture propagation regime is predominately inelastic under reservoir stresses, invalidating classical LEFM fracture propagation approaches.



a) Borehole pressure evolution and states for calculations 1-5 b) Snapshot of the fracture at State 5 with tensile microcracks (red lines) and pressures in fluid flow reservoirs.

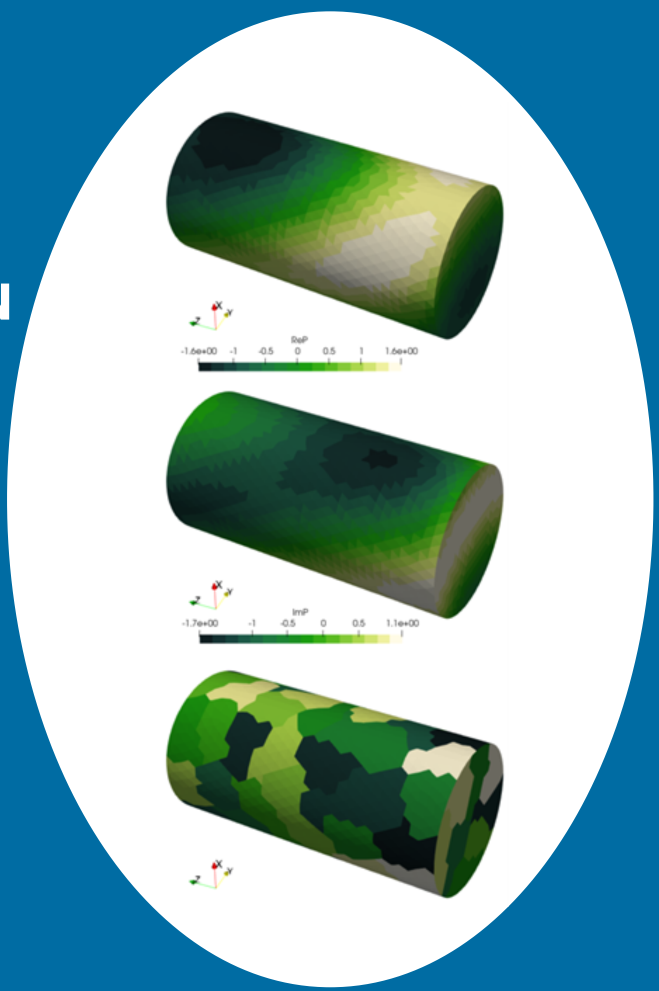


Thermal plume of DBHE after operation of 20 years: (a) 3D thermal plume under representative formation properties (b) thermal plume boundary.

FINITE ELEMENT-BOUNDARY ELEMENT ACOUSTIC BACKSCATTERING WITH MODEL REDUCTION OF SURFACE PRESSURE BASED ON COHERENT CLUSTERS

Ahmad T Abawi, Heat, Light, and Sound, Inc., Professor Petr Krysl

Computing backscattering of harmonic acoustic waves from underwater elastic targets of arbitrary shapes is a challenging problem of considerable practical significance – searching for munitions, shipwrecks, archeological deposits, and so on. The models tend to be quite expensive, and making the computations less resources hungry is highly desirable. In this work we could achieve order of magnitude speed-ups by incorporating the coherence of acoustic pressures on the surface, effectively employing a model-order-reduction as an intermediate step.



LOW-ENERGY ADDITIVE MANUFACTURING (AM) AND DESIGN FOR AM OF HIGH-PERFORMANCE COMPOSITES

ASSISTANT PROFESSOR MEHRAN TEHRANI

The Tehrani Group is paving the way for the manufacturing of high-performance composites that are cost-effective, energy-efficient, and designed to meet the evolving needs of a broad range of industries including aerospace, e-mobility, and medical assistive technologies. Their mission is to expand the knowledge base in the field of high-performance composites. They are focused on studying three primary areas: additive manufacturing (AM) and design for AM of fiber-reinforced polymer composites, multifunctional graphene-based composites, and advanced electrical conductors.

Fiber reinforced polymer composites (FRP) have become integral to high-performance markets such as aerospace, energy, medical, and automotive industries where mass savings are critical. However, manufacturing these composite structures is a multi-step, energy-intensive, and laborious process that typically requires autoclaves. As such, AM has shown immense potential in retiring autoclaves, eliminating the need for molds, producing parts with higher geometric complexity, and providing optimized fiber placement and orientation for improved mechanical performance. The Tehrani Group is researching novel AM approaches to lower composite manufacturing costs and energy usage. The group has successfully demonstrated in-situ consolidation of aerospace quality composites through automated fiber placement (AFP) without any post-processing (Figure 1). Through a combination of experimental and numerical modeling techniques, they are exploring the connections among AFP processing parameters, interfacial phenomena, and the multi-scale mechanics of the resulting composite parts. The aim of this research is to provide optimal control of the AFP process. Additionally, the group is using AM design freedom for structural lightweighting by merging continuous carbon fibers with AM (Figure 2). This approach enables complex geometries with superior mechanical properties and reduced weight, which would otherwise not be possible.

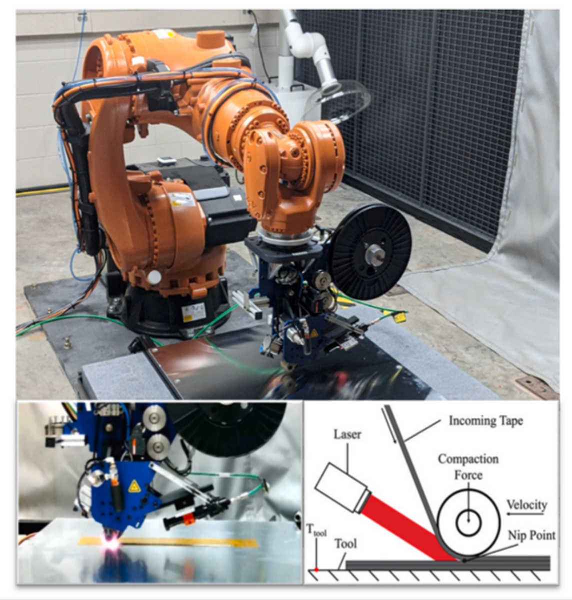


Fig 1. Laser-assisted AFP robot for in situ consolidation of high-performance thermoplastic composites.

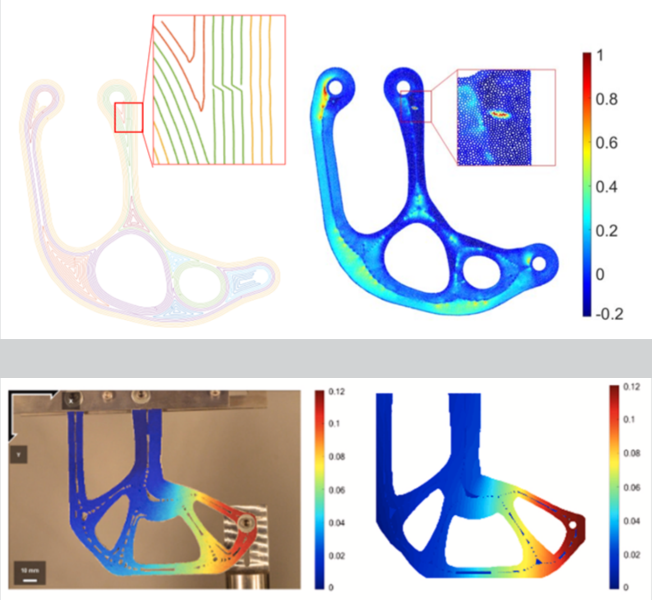
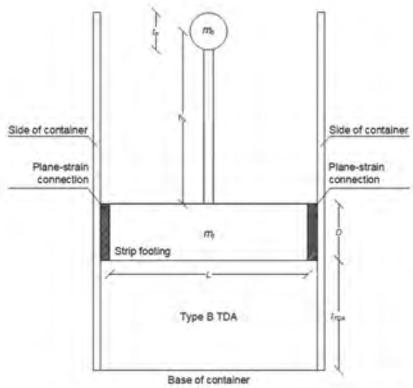


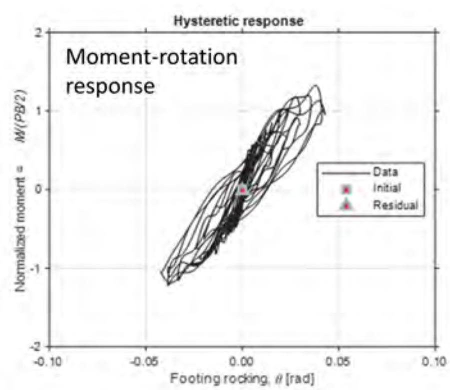
Fig 2. Top: Topology and fiber path design optimization of AM composites. Bottom: Experimental validation. Collaboration with Prof. Tamijani at ERAU.

GEOTECHNICAL SEISMIC ISOLATION WITH TIRE-DERIVED AGGREGATES

AXEL YARAHUAMAN, PROFESSOR JOHN MCCARTNEY

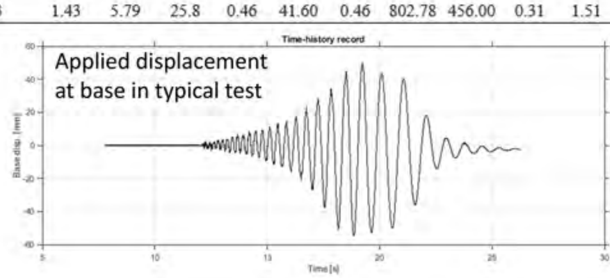
The United States has experienced an exponential increase in the number of end-of-life waste tires, with California being one of the largest generators of waste tires in the U.S. To avoid the environmental impacts of incineration, waste tires can be recycled in civil engineering projects in the form of tire-derived aggregate (TDA). TDA has a unit weight that is half that of most granular backfill soils while having similar shear strength, making it an excellent lightweight backfill material for embankments or retaining walls. The geotechnical group at UC San Diego has gained significant experience in characterizing the quasi-static and dynamic response of TDA with large particle sizes, along with understanding the interaction between foundations and TDA. TDA has favorable dynamic properties that can be exploited in developing novel low-cost geotechnical seismic isolation systems for buildings, including a ductile stress-strain curve, a long elastic range during cyclic shearing, and a high damping ratio. Recent shaking table tests performed at UC San Diego on footings embedded in TDA layers confirm that TDA can be used to form a flexible layer with high energy dissipation, acceptably small settlements, and excellent recentering. Research is underway to explore the use of TDA in providing energy dissipation by promoting footing rocking to delay formation of a plastic hinge in columns during earthquake shaking, providing a seismic isolation effect, reducing potential seismic lateral earth pressures on foundations or retaining walls, reducing lateral stresses on piles due to lateral spreading effects, and reducing possible impact forces of bridge decks on bridge abutments.

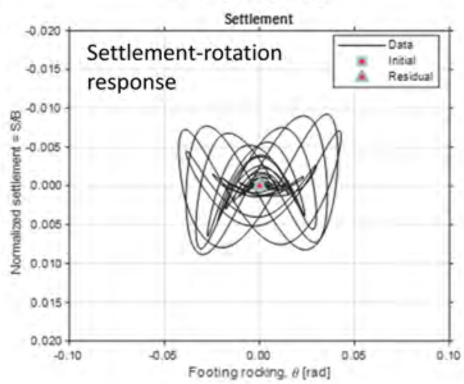




Details of Shake Table Tests on Strip Footings Embedded in TDA Layers

Specimen No	t_{TDA} [m]	γ_{TDA} [kN/m]	A/Ac	B [m]	L [m]	D [m]	m_f [kg]	m_s [kg]	t_w [m]	h_s [m]	k_s [kN/m]
1	0.69	5.85	> 100	0.46	41.60	0.46	802.78	114.00	0.29	1.48	187.25
2	0.93	6.29	25.8	0.46	41.60	0.46	802.78	456.00	0.31	1.51	187.25
3	1.43	5.79	25.8	0.46	41.60	0.46	802.78	456.00	0.31	1.51	187.25





NEWS

NSF DIRECTOR INAUGURATES NEWLY UPGRADED EARTHQUAKE SHAKE TABLE

National Science Foundation (NSF) Director Sethuraman Panchanathan attended the grand reopening of UC San Diego's earthquake simulator, an esteemed facility boasting the largest outdoor shake table in the world. Led by structural engineering Professor Joel Conte, the facility underwent a notable upgrade, made possible by a $16.9 million grant from the NSF. The renovation expanded the shake table's capabilities, elevating it from one degree of freedom to an impressive six degrees of freedom. This groundbreaking enhancement enables the facility to conduct tests on structures with unparalleled accuracy, closely mimicking real earthquake ground motions.

One of the first structures to be tested on the upgraded shake table is a 10-story wood frame building as part of the TallWood project, which is sponsored by the NSF. The objective of this undertaking is to demonstrate that tall wooden structures can be designed to exhibit resilience in the face of seismic activity. The shake table is located at the Englekirk Structural Engineering Center in San Diego.

Credit: UC San Diego

EXPERIMENTING IN SPACE TO PREVENT MUDSLIDES ON EARTH

An automated experiment designed by Assistant Professor Ingrid Tomac has been launched to the International Space Station to improve our ability to prevent mudslides after a fire on Earth by studying the hydrodynamics of mudslides. Results could lead to improved mudflow models, new critical infrastructure, and the development of early-warning systems. This investigation could help researchers create better models to predict mudflow.
Credit: UC San Diego Today

PROPOSED UPDATES TO STEEL BUILDING STANDARD COULD ENHANCE EARTHQUAKE RESILIENCE

Researchers at the National Institute of Standards and Technology (NIST) and UC San Diego identified deficiencies in the performance of a type of steel column, including premature buckling. Based on the results of experiments at a UC San Diego shake table and a detailed data analysis, the researchers devised new limits for column slenderness. The American Institute of Steel Construction (AISC) has adopted the proposed limits in a draft for public feedback in the 2022 edition of AISC 341.

Credit: UC San Diego Today

ALUMNI-LED START-UP MAKES PROSTHESES AFFORDABLE, ACCESSIBLE

Alumni from the lab of structural engineering Professor Falko Kuester formed LIMBER Prosthetics to bring affordable prosthetics to individuals who might need them. Using their unique combination of personalized scans and digital designs, the 3D-printing may reduce the cost of a prosthesis from 50% to 90%.

Credit: UC San Diego Today

UC SAN DIEGO HOSTS ASCE PACIFIC SOUTHWEST SYMPOSIUM

The UC San Diego chapter of the Society for Civil and Structural Engineers hosted the ASCE Pacific Southwest Symposium in 2022, drawing 850 students from 14 universities for challenges including the Concrete Canoe and Steel Bridge competitions. The UC San Diego Steel Bridge team won first place.

Credit: UC San Diego Today

Photo courtesy of UC San Diego Jacobs School of Engineering

DEPARTMENT OF STRUCTURAL ENGINEERING
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Photos courtesy of UC San Diego