PACIFIC EARTHQUAKE ENGINEERING
RESEARCH CENTER

PEER Annual Report 2017–2018

Khalid M. Mosalam
Amarnath Kasalanati
Selim Günay

Pacific Earthquake Engineering Research Center
University of California, Berkeley

PEER Report No. 2018/01
Pacific Earthquake Engineering Research Center
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EXECUTIVE SUMMARY

The Pacific Earthquake Engineering Research Center (PEER) is a multi-institutional research and education center with headquarters at the University of California, Berkeley. PEER's mission is to (1) develop, validate, and disseminate performance-based engineering (PBE) technologies for buildings and infrastructure networks subjected to earthquakes and other natural hazards, with the goal of achieving community resilience; and (2) equip the earthquake engineering and other extreme-event communities with the 21st-century tools that define the current digital revolution. This reports presents the activities of the Center over the period of July 1, 2017 to June 30, 2018. PEER staff, in particular Grace Kang, Erika Donald, Claire Johnson, Christina Bodnar-Anderson, and Zulema Lara, helped in preparation of this report.

Key activities of the past academic year include the following:

- Continuation of major projects such as Tall Building Initiative (TBI) and Next Generation Attenuation (NGA) projects, and start of work on the major project funded by the California Earthquake Authority (CEA). The TBI was completed in 2017, and NGA projects are nearing completion soon.
- Addition of University of Nevada, Reno (UNR) as a core institution.
- Re-establishment of the PEER Research Committee.
- Issuing a Request for Proposal (RFP) from TSRP funds and funding 17 projects as a result of this RFP. Together with the ongoing projects, the total number of projects funded in 2017 is 24.
- Organization of several workshops focused on Liquefaction, Structural Health Monitoring (SHM), High-Performance Computing (HPC), Bridge Component Fragility Development, Physics-Based Ground Motions, Hybrid Simulation, and Research Needs for Resilient Buildings.
- Rollout of TBI seminars and HayWired activities as part of outreach.
- Conducting a blind prediction contest with robust participation and instructive findings on current modeling approaches.
- Organization of the PEER Annual Meeting with participation of 240 attendees.
- Continuing participation in board of directors of international organizations such as Global Alliance of Disaster Research Institutes (GADRI) and International Laboratory of Earthquake Engineering (ILEE).

Going forward, PEER aims to hold more focused workshops, form new committees, and draw on existing resources and experience on PBE to systematically move towards Resilient Design for Extreme Events (RDEE).

CONTENTS

1 Mission, Vision, and Organization

1.1 MISSION

The Pacific Earthquake Engineering Research Center (PEER) is a multi-institutional research and education center with headquarters at the University of California, Berkeley. Investigators from over 20 universities and several consulting companies, in addition to researchers at various State and Federal government agencies, contribute to research programs focused on performance-based earthquake engineering (PBEE) in various disciplines, including structural and geotechnical engineering, geology/seismology, lifelines, transportation, risk management, and public policy.

In addition, PEER is an Organized Research Unit (ORU) under the College of Engineering at the University of California, Berkeley, which provides space for PEER offices and largely covers the salaries of PEER staff. In addition, the National Information Service for Earthquake Engineering (NISEE) library and the earthquake simulator and structural research laboratories located at the U.C. Berkeley campus' Richmond Field Station are supported by PEER.

PEER's mission is to (1) develop, validate, and disseminate performance-based engineering technologies for buildings and infrastructure networks subjected to earthquakes and other natural hazards, with the goal of achieving community resilience; and (2) equip the earthquake engineering and other extreme event communities with the 21st-century tools that define the current digital revolution. A key goal of PEER's research efforts is to define appropriate performance targets, and develop engineering tools and criteria that can be used by practicing professionals to achieve those targets, such as safety, cost, and post-earthquake functionality. In addition, PEER actively disseminates its findings to professionals who are involved in the practice of earthquake engineering, through various mechanisms including workshops, conferences, and the PEER Report Series. PEER also conducts Education and Outreach programs to reach students, policy makers, practitioners, and others interested in public policy and research related to earthquakes and the built environment.

The core institutions, their researchers and facilities, and educational affiliates are crucial components for realizing the Center's mission and vision. The wide range of expertise among many researchers, unmatched capabilities of experimental facilities, and geographic spread of institutions make PEER a unique and impactful organization. Some of the most successful PEER projects have been multi-institution efforts with industry collaborations. In return, participating researchers benefit from the PEER infrastructure: access to well-maintained software and databases, dissemination of research through PEER reports, and regular communication efforts, and transparent opportunities and processes for research funding on regular basis with high rate of success.

1.2 VISION

Director Khalid Mosalam

During the PEER Annual Meeting held in January 2018, Professor Khalid Mosalam, PEER Director, presented the Center's vision for the coming 3–5 years. The Center aims to extend the current Performance-Based Earthquake Engineering (PBEE) to Resilient Design for Extreme Events. The new vision includes two natural extensions of the Center's past work: expansion from *earthquake engineering* to *extreme events* affecting the built environment, and extension of the *performance-based design* to *resilient design* that focuses on people, communities, and regions. PEER's vision is to be the thought leader in Resilient Design for Extreme Events affecting the built environment.

1.3 FUTURE GOALS

To move towards the goal of Resilient Design for Extreme Events, the Center has identified the following broad goals for the next few years:

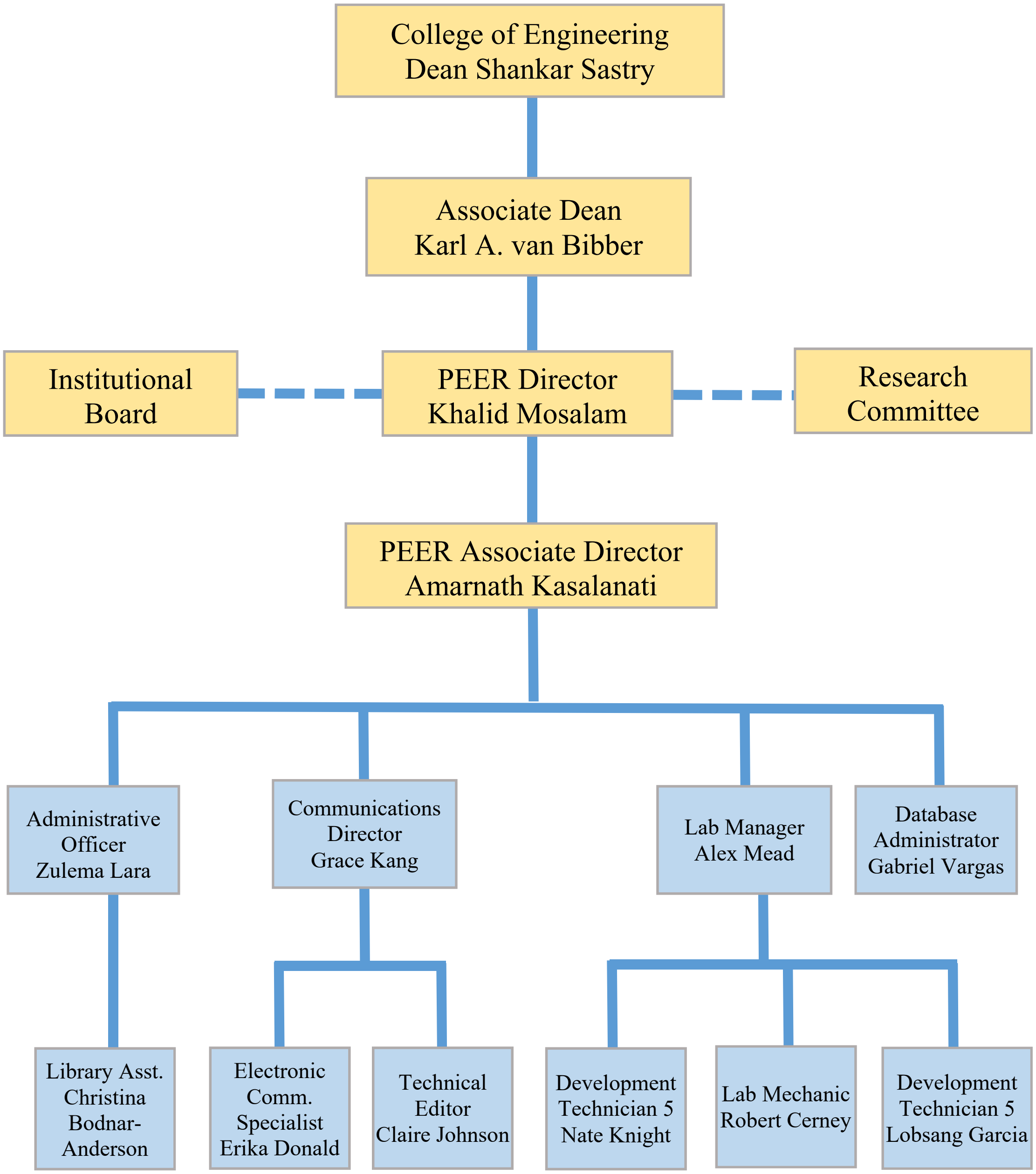
1. Continue the fundamental research in the field of earthquake engineering;
2. Adapt PBE research methodologies and tools to other domains of extreme events;
3. Develop the 21st century tools, such as High-Performance Computing (HPC), data science-related technologies, and Artificial-Intelligence (AI) tools for earthquake engineering and other extreme event domains;
4. Deploy resilient and sustainable design at community and regional levels;
5. Continue outreach activities and expand them to playing an advocacy role in shaping public policy; and
6. Identify and pursue new, large, and sustained funding sources to achieve these goals.

Focused workshops have been identified as an effective means of achieving the Center's goals. In the past year, the Center held workshops on a wide variety of research topics: Liquefaction, Structural Health Monitoring (SHM), High-Performance Computing (HPC), Bridge Component Fragility Development, Physics-Based Ground Motions, Hybrid Simulation, and Research Needs for Resilient Buildings. PEER Annual Meetings have been found to be an effective way to bring together stakeholders, researchers, and industry partners for developing an actionable research plan. The Center will form several committees and hold various workshops in the coming years to achieve the overall goal of RDEE.

1.4 ORGANIZATIONAL STRUCTURE

In addition to being a Multi-Institutional Research and Education Center, PEER is an Organized Research Unit (ORU) under the College of Engineering at University of California, Berkeley.

PEER has 12 full time staff members and several other Research Engineers, Project Scientists, and Graduate Student Researchers. An Institutional Board (IB), consisting of one representative from each of the core institutions, provides policy level guidance and oversight to the Center. The Research Committee (RC), consisting of industry and academic members, advises the Center in pursuing new research.



Organizational structure of PEER is shown here for the period of July 1, 2017 through June 30, 2018. More details of PEER's key personnel, IB members, RC members and PEER resources are presented in Section 6 of the report.

2 Major Research Projects

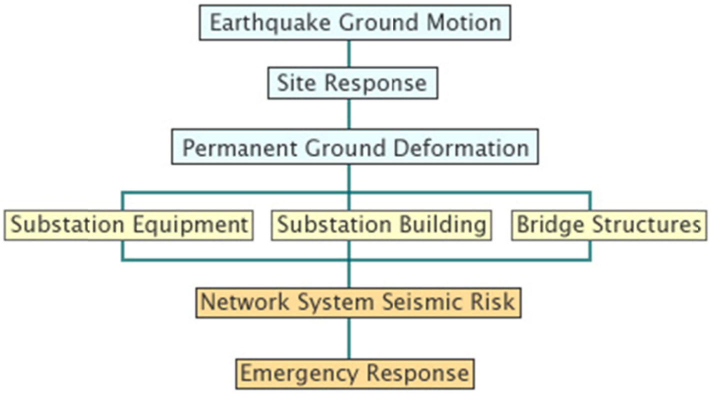
PEER manages several multi-year, multi-institutional projects. These projects explore key thrust areas and are broad in their scope and impact areas. Details of current major projects are provided in this chapter.

2.1 TRANSPORTATION SYSTEMS RESEARCH PROGRAM (TSRP)

PEER receives funding from the State of California to conduct research related to the seismic performance of transportation systems. The purpose of the TSRP is to reduce the negative impact of earthquakes on California's transportation systems, including highways and bridges, port facilities, high speed rail, and airports. The research utilizes and extends PEER's PBEE methodologies by integrating fundamental knowledge, enabling technologies, and systems. The research program also integrates seismological, geotechnical, structural, and socio-economical aspects of earthquake and tsunami engineering, and involves computational, experimental, and theoretical investigations.

PEER funded a total of 24 projects from the TSRP in 2017. Seven (7) projects were funded in the early part of the year. Through the RFP process with independent review by the research committee, six (6) seed proposals (less than $50,000) were funded in November 2017. Through the RFP process with independent review by the research committee, eleven (11) full proposals (less than $100,000) were funded in December 2017. Details of these projects are presented in Chapter 3 and at the TSRP website.

2.2 LIFELINES PROGRAM



Lifelines Research Topics

The goal of the PEER Lifelines program is to improve seismic safety and reliability of lifeline systems. The projects in this program are primarily user-driven research projects, with strong collaboration among sponsoring lifelines organizations and PEER researchers. These projects range from engineering characterization of ground motions, to local soil response, response of bridge structures, and performance of electric substation equipment. The lifelines research projects are organized into eight topics as shown in the accompanying diagram.

The Lifelines program brings together multidisciplinary teams of practicing engineers (geotechnical, structural); scientists (geologists, seismologists, social scientists); funding agencies (Federal, State of California, private industry); academicians, and end-users. An example of such successful multidisciplinary collaboration that was funded by the Lifelines Program is the NGA-West initiative, which resulted in major advances in characterization of seismic hazard, especially in the western U.S. Sources of funding for the Lifelines program and research projects are diverse and include the California Department of Transportation (Caltrans), and the Pacific Gas and Electric Company.

2.3 TSUNAMI RESEARCH PROGRAM

2004 Indian Ocean Tsunami Damage

There has been increasing public attention given to tsunamis since 2004 when the Indian Ocean Tsunami killed more than 230,000 people. Attention increased even further following the 2011 East Japan Tsunami, which killed more than 18,000 people and caused enormous economic damage, including a devastating nuclear disaster at the Fukushima Daiichi Nuclear Power Plant.

The U.S. Pacific Northwest (Washington, Oregon, and Northern California) is vulnerable to similar local tsunamis generated by a Cascadia subduction zone earthquake. In Southern California, there is a tsunami threat that could be triggered by a submarine landslide off the Santa Barbara or Los Angeles Basins. Based on the directivity characteristics of tsunami energy propagation, the entire U.S. west coast is vulnerable to distant tsunamis originating in the eastern end of the Aleutian (Alaska) and Philippine Main Islands. The extreme scenario would be strong, long-duration ground shaking associated with the subduction fault rupture, followed by large tsunami inundation. Such a scenario is not an exception; it is a common occurrence in the continental margin where major geologic subduction processes occur. Substantial structural damage caused by tsunamis in Japan underscores the urgency of re-examining the present engineering design practice for the multiple-hazard scenario.

PEER’s tsunami research program includes the development of an effective methodology for hazard, structural, damage, and loss analyses for critical structures and lifelines: e.g., nuclear and fossil power plants, liquefied natural gas and oil storage facilities, civilian and military ports, emergency tsunami shelters, transportation corridors including coastal bridges, and important public facilities (e.g., fire and police stations, hospitals, and schools). Failure of critical coastal structures and lifelines will likely lead to loss of life, delays in emergency response, and long-term economic impacts. This research focus is a crucial gap in tsunami research efforts currently being conducted elsewhere. PEER’s methodology development—called Performance-Based Tsunami Engineering (PBTE)—expands and extends the existing PBEE methodology.

2.4 SEISMIC PERFORMANCE OF RETROFITTED HOMES

The California Earthquake Authority (CEA), one of the world’s largest providers of residential earthquake insurance, awarded a $3.4 million, 3.5-year research contract to PEER. The research project, entitled “Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single Family Wood-frame Buildings,” will evaluate the seismic performance of residential homes, and will directly contribute to the improvement of seismic resiliency of California’s housing stock. The project is in progress and is in its second year. This multi-year project is conducted by a team of academic and practicing experts with unique and nationally recognized expertise in seismic design, analysis, testing, and earthquake-risk modeling. The team includes researchers from UC Berkeley, UC Irvine, UCLA, UC San Diego, and Stanford University, as well as experienced practicing engineers in California.

3 Research Highlights

PEER funded projects covered key thrust areas of geo-hazards, computational modeling and simulation, tsunami research, transportation, and infrastructure systems. Highlights of these funded projects and published PEER reports are presented in the following sections.

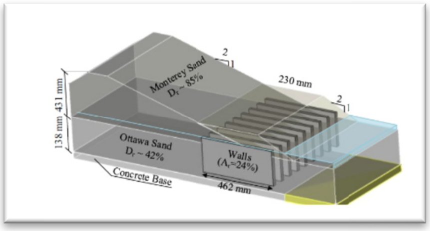
3.1 REMEDIATION OF LIQUEFACTION EFFECTS ON EMBANKMENTS USING SOIL–CEMENT REINFORCEMENTS

Ross W. Boulanger

Details of the PEER funded research project, "Remediation of Liquefaction Effects on Embankments Using Soil-Cement Reinforcements," are highlighted below. The project Principal Investigator (PI) is Ross W. Boulanger, Professor of Civil Engineering, UC Davis. The research team includes Mohammad Khosravi, Post-doc, UC Davis, Ali Khosravi, Visiting Scholar, Sharif University of Technology, Dan Wilson, Associate Director of CGM, UC Davis, W. Yunlong, Visiting Scholar, China Earthquake Administration, and A. Pulido, Undergraduate researchers, UC Davis

ABSTRACT

This research project facilitated performing two centrifuge tests on the 9-m radius centrifuge at UC Davis as part of a PEER-based collaborative effort to develop design procedures for use of soil–cement grid and panel reinforcements for mitigating liquefaction-induced ground deformations for embankments and other transportation infrastructure. The centrifuge tests provided the first available physical modeling data regarding how crack initiation and progression in soil–cement grids and panels during earthquake shaking affects their ability to mitigation potential ground deformations for embankment. The results of these tests filled a high-priority research need for developing and validating liquefaction remediation strategies. Although beyond the scope of this project, the archived data provide a basis for evaluating numerical modeling procedures. This collaborative research effort completed both experimental and numerical efforts by leveraging research efforts of individuals from the three involved institutions mentioned above.



Model Configuration with model dimensions in (mm)

RESEARCH IMPACT

Centrifuge tests and two-dimensional nonlinear dynamic analyses were performed for an embankment on a liquefiable foundation layer treated with soil–cement walls. The model corresponded to a 28-m-tall embankment underlain by a 9-m-thick saturated loose sand layer. Soil-cement walls were constructed through the loose sand layer over a 30-m-long section near the toe of the embankment with a replacement ratio of 24%. The model was shaken with scaled earthquake motions having peak horizontal base accelerations of 0.26*g* and 0.54*g*. The experimental data were archived as a lasting resource for validation of numerical modeling procedures. Nonlinear deformation analyses were performed using the platform FLAC with the user-defined constitutive model PM4Sand for the liquefiable materials and area-averaged properties for the treatment zone. The numerical simulations were in reasonable agreement with the recorded dynamic responses, including the triggering of liquefaction in the loose sand layer during both events. The simulations reasonably approximated the observed deformation magnitudes and patterns, and correctly predicted that the soil–cement walls would shear through their full length in the second event. The results of these comparisons provide support for use of these numerical modeling procedures, including the representation of the treatment zone with area-weighted properties, for analyses of embankments with soil–cement treatment of liquefiable soils in their foundations.

3.2 STOCHASTIC MODELING AND SIMULATION OF NEAR-FAULT GROUND MOTIONS FOR USE IN PBEE

Armen Der Kiureghian

Details of the PEER funded research project "Stochastic Modeling and Simulation of Near-Fault Ground Motions for use in PBEE" are highlighted below. The project Principal Investigator is Armen Der Kiureghian, President, American University of Armenia; Taisei Professor of Civil Engineering Emeritus, UC Berkeley. The co-Principal Investigator is Mayssa Dabaghi, Assistant Professor, Department of Civil and Environmental Engineering, American University of Beirut, Lebanon. The research team includes Yara Daoud, Graduate Research Assistant, American University of Beirut, Lebanon

ABSTRACT

This project is an extension of the research conducted under previous PEER funding on stochastic modeling and simulation of near-fault ground motions. We developed a site-based parameterized stochastic model of the near-fault ground motion in two orthogonal horizontal directions and presented a practical method of generating synthetic near-fault ground motions for specified earthquake source and site characteristics that are readily available to design engineers. As shown in the *Project Image*, this method accounts for the rupture directivity effect and produces pulse-like and non-pulse-like ground motions, in accordance with their observed proportions among recorded

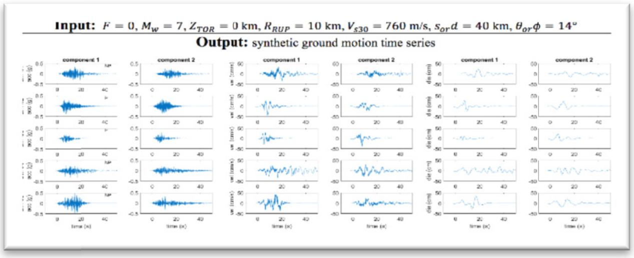


Illustration of Simulation Procedure

near-fault ground motions. The method accounts for temporal and spectral non-stationarity and for the variability inherent in real earthquake ground motions.

Given the small number of parameters and a limited dataset to which it was fitted, the current model is not able to capture all characteristics of recorded near-fault ground motions. Therefore, in this study, the existing model will be scrutinized and ways to improve its formulation investigated, with focus on those components that most influence structural response. The ground-motion characteristics that we seek to improve include correlations between spectral values at different periods and variability in spectral accelerations at long periods. The improved formulation will better characterize the level of ground shaking in seismic performance assessment and design of long-period structures, such as tall buildings and long-span bridges.

The research will also facilitate use of the simulation procedure for practicing engineers. The methods of computing the modulating function parameters will be improved; the size of the generated time series data will be reduced to make ensuing structural response calculations more tractable; and users will be given more flexibility in the specification of the input, e.g., by adding an option to generate ground motions for randomized hypocenter locations.

RESEARCH IMPACT

This project contributes to the first step of PEER's PBEE methodology, namely, characterization of the seismic hazard at a location of interest with a special focus on near-fault sites. Near-fault ground motions may possess distinct characteristics—including the rupture directivity effect—that should be taken into account in the seismic risk and performance assessment of structures located nearby active faults.

Probabilistic seismic hazard analysis (PSHA) can be conducted by combining the proposed ground-motion model and simulation procedure for seismic-source characterization. This first step of PBEE is crucial for the ensuing steps of computing structural responses for the given hazard, defining and computing relevant measures of damage to structural and non-structural components and equipment, and computing decision variables that relate to casualties, costs, and downtime. These decision variables drive performance-based design of structures, rendering careful characterization of ground motions essential. Thus, we believe the results of this project will fill an important gap in the practice of PBEE.

By improving the existing near-fault ground-motion model and simulation procedure, the research being conducted will facilitate the use of simulated ground motions in PBEE. Specifically, for any set of earthquake source and site characteristics, one can generate realistic simulated near-fault ground motions that have similar statistical characteristics as recorded motions in the NGA-West2 database. These simulated motions can be used in response history analysis and PBEE applications in place of or in addition to recorded ground motions, without any need for scaling (which is a questionable practice in many instances). For example, the outcome of this research can be used to characterize the level of ground shaking in the seismic performance assessment or design of long-period structures, such as tall buildings and long-span bridges in near-fault regions.

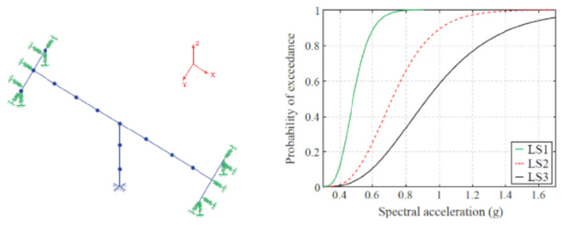
3.3 RESOLUTION OF NON-CONVERGENCE ISSUES IN SEISMIC RESPONSE ANALYSIS OF BRIDGES

Filip. C. Filippou

Details of the PEER funded research project “Resolution of Non-Convergence Issues in Seismic Response Analysis of Bridges” are highlighted below. The project Principal Investigator is Filip Filippou, Professor of Structural Engineering, UC Berkeley. The research team includes Thanh N. Do, Postdoctoral Researcher, UC Berkeley; Jade Cohen, Graduate Student Researcher, UC Berkeley; and Jiawei Chen, Graduate Student Researcher, UC Berkeley.

ABSTRACT

The project will develop guidelines for overcoming non-convergence issues under large displacements and corresponding deformations for bridge structures under extreme seismic excitations. Such guidelines will allow users to perform robust nonlinear dynamic analyses (NDAs) to assess the collapse risk of bridge structures in a fashion consistent with physical behavior and experimental observations.



(a) Analytical model of a typical bridge (b) Sample fragility curve of a bridge component

Analytical models for typical reinforced concrete bridges in California [refer to Project Image (a)] will be generated for study. After identifying the sources of numerical non-convergence in nonlinear bridge models, the following three critical aspects will be addressed simultaneously: (1) material models; (2) element models; and (3) solution strategies. Material models with robust convergence characteristics at large strains suitable for bridge analyses will be identified. Bridge piers will be represented with nonlinear elements to account for the complex interaction of axial, flexural, and shear forces without resorting to external zero-length spring or hinge elements, which introduce additional global degrees of freedom (DOF) leading to numerical sensitivities under the unbalanced dynamic forces at these DOFs. Adaptive solution strategies will be developed in the form of solution scripts with intelligent switching between suitable nonlinear solution schemes and integration methods in response to monitored local and global variables. Because of the interaction between the nested iterations between element, section, and material, it is important to coordinate the evaluation of the structural, element, and material response with the help of intelligent solution scripts.

An extensive set of NDAs under a large ensemble of ground motions will then be performed to develop guidelines for robust NDAs and the consistent collapse risk assessment of bridges. Collapse fragility curves [refer to Project Image (b)] will be used to correlate different Engineering Demand Parameters (EDPs) at relevant limit states in order to identify realistic criteria for describing physical collapse.

RESEARCH IMPACT

The PBEE concepts show great promise for improving design practice. The safety performance objective is defined in terms of an “acceptable” probability of collapse. Collapse shall be quantified as realistically as possible using NDA, which incorporates several suites of ground motions. A challenge with the proposed analysis procedure is that under high levels of loading, a significant percentage of nonlinear time history analyses fail to converge. Ignoring these runs completely may result in a substantial underestimation of the true collapse probability. Conversely, assuming all instances of non-convergence as representing physical collapse would result in an overestimation of the collapse probability.

A comprehensive set of guidelines will form the starting point for addressing the complexity inherent in nonlinear softening response under large displacements and deformations, and will contribute to the acceptance of nonlinear response studies in professional practice. The deployment of a new class of bridge pier models that account for localized phenomena such as shear and reinforcement pull-out in a consistent iterative element formulation will help minimize the non-convergence issues that arise with the large collection of zero length nonlinear spring and plastic hinge elements currently in use in nonlinear bridge response simulations. The development of intelligent nonlinear solution strategies that coordinate the structure, element, and material state determination will improve the state-of-the-art and practice of nonlinear dynamic analysis of structures for sophisticated structural elements by accounting for multi-axial interaction and several local phenomena. The standardized templates for element testing and NDAs of bridge structures will form the starting point for the collaborative growth of improved methods for nonlinear dynamic analysis of bridge models. It stands to reason that these tools will be useful for other types of structures.

3.4 TESTING AND HYBRID SIMULATION OF ENVIRONMENTALLY DAMAGED BRIDGE COLUMNS

Claudia Ostertag

Details of the PEER funded research project "Testing and Hybrid Simulation of Environmentally Damaged Bridge Columns" are highlighted below. The project Principal Investigator is Claudia P. Ostertag, T.Y. and Margaret Lin Professor in Civil Engineering, UC Berkeley. The research team includes Selim Günay, Project Scientist, UC Berkeley; Jacob F. Duncan, Graduate Student Researcher, UC Berkeley; and Ian D. Williams, Graduate Student Researcher, UC Berkeley.

ABSTRACT

Hybrid Simulation (HS) is utilized to investigate the seismic response of a corrosion-damaged reinforced-concrete (RC) bridge. Data regarding the seismic performance of corroded RC bridge columns is very limited, leading to inaccurate simulations of environmentally damaged bridge columns because of the complicated behavior of corrosion-damaged RC elements. Additionally, full-scale testing is complicated and expensive, and is thus virtually nonexistent. Hybrid Simulation provides a cost-effective, accurate method for testing corrosion-damaged bridge columns subjected to seismic demands. The purpose of this investigation is to evaluate the effect of corrosion damage in the plastic hinge of bridge columns on the seismic performance of bridge structures. The study considers a single-column, single-bent bridge with two spans, with the plastic hinge region of the column to be simulated as the experimental substructure; the remainder of the column and bridge will be simulated as the analytical substructure. Prior to HS testing, an impressed current will accelerate the propagation of corrosion damage in the

experimental substructure and induce vertical cracks matching those observed on existing bridge columns in the field. A set of three specimens will be tested: one non-corroded specimen as a control and two with varying levels of corrosion damage. The HS tests will be conducted using ground motions in two directions: one horizontal and one vertical. A three-actuator set-up is used to control three-degrees-of -freedom (DOF), two translational and one rotational, as shown in Figure 1. Results of these tests will then be used to assess the effects of corrosion-induced longitudinal cracking in the plastic hinge region on the seismic performance of bridge columns.

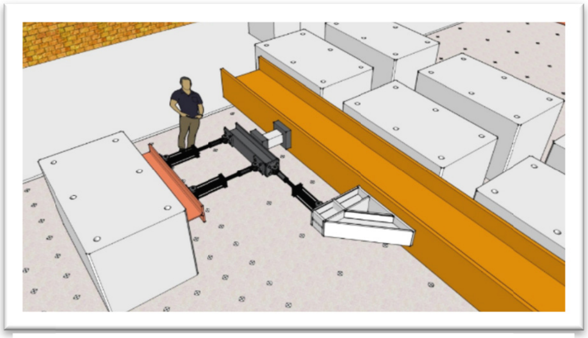


Figure 1: Experimental Set-Up

RESEARCH IMPACT

In 2016, the Federal Highway Administration reported that 5.6% of all RC bridges in the U.S. are structurally deficient. The deteriorated state of these bridges poses a serious risk, not only in day-to-day use, but especially in the case of a large seismic event. Following such an event, mobility of emergency and rescue crews is imperative for post-disaster response. Reinforced concrete bridges in seismically active regions are designed and tested thoroughly, with high confidence that such bridges will be operational immediately following a large earthquake. This assumes, however, that bridges are in a pristine, undamaged condition prior to the seismic event. The residual drift and load-carrying capacity of corroded bridges following a seismic event is unknown. This lack of data poses a large research gap, one that comes with potential threat to the safety of people living in seismically active areas. The research conducted in this project will help fill that gap in knowledge and obtain a better understanding of the seismic performance of environmentally deteriorated bridges.

3.5 TOWARDS MULTI-TIER MODELING OF LIQUEFACTION IMPACTS ON TRANSPORTATION INFRASTRUCTURE


Brett Maurer

Details of the PEER funded research project “Towards Multi-Tier Modeling of Liquefaction Impacts on Transportation Infrastructure” are highlighted below. The project Principal Investigator is Brett Maurer, Assistant Professor, University of Washington. The research team includes Mertcan Geyin, Graduate Student Researcher, University of Washington and Alex Baird, Graduate Student Researcher, University of Washington.

ABSTRACT

State-of-practice approaches for predicting soil liquefaction at the regional-scale (i.e., commensurate with distributed transportation infrastructure) have traditionally relied on (a) geology maps that are typically too general to be accurate at site-specific scales; and/or (b) *in situ* geotechnical tests that are typically too costly to be feasible over large areal extents. It thus remains a persistent challenge to assess regional liquefaction hazards in a manner that is both

accurate and inexpensive. By corollary, a still more difficult challenge is to predict the damage and loss incurred by transportation infrastructure as a result of liquefaction. Ultimately, infrastructure planners and owners must make decisions based on these downstream impacts, not on probabilities of liquefaction occurrence. Meanwhile, liquefaction-prediction models based on freely available geospatial data have recently been proposed. In contrast to conventional geotechnical methods, "geospatial" models can predict liquefaction rapidly and inexpensively at an infinite number of locations anywhere in the world. The research team has performed a preliminary test of liquefaction models based on geospatial versus geotechnical data utilizing ~10,000 case studies from the Canterbury, New Zealand, earthquakes. Two state-of-practice CPT-based geotechnical models were tested against the seminal geospatial model of Zhu et al. [2017]. Model efficacy was assessed via receiver-operating-characteristic (ROC) analysis, as shown in Figure 1(a), which measures the rates of true- and false-positive predictions. The area under a ROC curve (AUC) was used to quantify and compare model efficacy. As shown in Figure 1(b), the geospatial model performed remarkably well, especially considering its relative cost and simplicity. These provocative findings support the potential of this PEER Seed Project, which aims to extend geospatial modeling to predict damage and loss within PBEE frameworks. In particular, predictive tools may be developed for pavements, bridges, pipelines, and structures on shallow foundations. This is made possible, in part, by the unprecedented infrastructure-performance data resulting from the Canterbury earthquakes, which includes damage and loss-assessments for ~80,000 infrastructure assets.

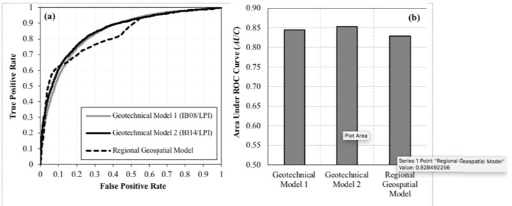


Figure 1. (a) Receiver operating characteristic (ROC) analysis of liquefaction prediction-models based on geospatial vs. geotechnical (CPT) data; and (b) summary of model performance, as quantified by the area under the ROC curve (*AUC*).

RESEARCH IMPACT

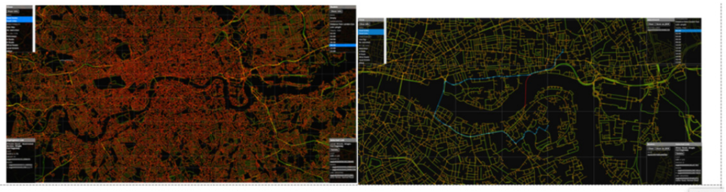
The PBEE-compatible tools resulting from this project will allow for the downstream impacts of soil liquefaction to be rapidly and probabilistically predicted at no cost. Potential applications include: (a) regional loss estimation and disaster simulation; (b) city planning and policy development; (c) emergency response; (d) post-event reconnaissance (e.g., to rapidly identify infrastructure with possible damage, thus maximizing the efficiency of field reconnaissance); and (e) areas that lack geotechnical testing. Beyond these immediate impacts, the research could ultimately inform an ensemble-modelling approach by which engineers can statistically coalesce data of diverse origins and scales to predict liquefaction impacts, thereby exploiting all available information to the fullest extent possible. In moving towards this long-term goal, a first-order approach is critical for complimenting methods that are more advanced but spatially-constrained by economics (e.g., methods based on *in situ* geotechnical tests or effective-stress numerical analyses). As part of this Seed Project, the PBEE application of the developed tools will be demonstrated for locations within PEER's geographic domain. Candidate locations include San Francisco, California; Santa Monica, California; Eureka, California; and Seattle, Washington, among others.

3.6 HIGH-PERFORMANCE COMPUTING-BASED DISTRIBUTED MULTI-LAYERED CITY-SCALE TRANSPORTATION NETWORK TOOL

Kenigi Soga

Details of the PEER funded research project “High-Performance Computing Based Distributed Multi-Layered City-Scale Transportation Network Tool” are highlighted below. The project Principal Investigator is Kenichi Soga, Chancellor’s Professor, UC Berkeley. The research team includes Joan Walker, UC Berkeley; Alexandre Bayen, UC Berkeley; and Jack Baker, Stanford University.

ABSTRACT



City-scale ABM tool – left-Browser-based visualization of journey times on a typical working day at 8AM in London, right-Micro-impact assessment of a bridge closure at mid-night in London

The goal of this project is to utilize a graph-parallel distributed agent-based model (ABM) to quantify the performance of transportation networks and water pipeline networks at the city scale under different ground motion scenarios. The objectives are to quantify the performance of these infrastructure networks using a high-fidelity microscale model and to develop a unified network model capable of simulating the interactions between the above two networks under different ground-motion scenarios. The developed graph-parallel distributed computing tool is capable of simulating city-scale infrastructure networks with hundred-thousand links and millions of agents traversing close to real time. The purpose of the ABM tool is to capture the complex city-scale response from individual agent behaviors. Macro-scale events such as earthquakes influence the weights of the edges on a graph network (e.g., reduced road capacity/road closures update the weights of the edges/ removal of an edge), which in turn affect the behavior of individual agents, thus changing the response of a city. In this project, pipeline damage scenarios by different ground-motion cases are supplied by EBMUD, and the effect on traffic network is examined. By doing so, the dynamic performance of water pipelines after an earthquake and the assessment and strategy of recovery of the water network is evaluated. This project links to the work of Stanford University, which aims to build and utilize a model that links individual bridges’ earthquake-damage-induced traffic capacity loss and restoration with network-level performance over time. The fragility curves and recovery time models for individual bridges subjected to earthquake shaking will be used as inputs to our HPC-based transportation network tool. A series of ABM simulations on traffic networks will be conducted to test scenarios when both bridges and water pipeline networks are affected by an earthquake event.

RESEARCH IMPACT

The loss of accessibility due to damages/closures of transportation network can greatly affect the rescue and recovery of a city after natural disasters. Transport asset managers need to know the route availability, traffic distribution, reduction in speed, and reconstruction resources required under disaster scenarios so as to evaluate the impacts and plan for disaster relief measures. The ultimate aim of this project is to provide a tool that enables city-scale resilience planning using

HPC for infrastructure planners in the Bay Area. The proposed tool can potentially be used for analysis in real time and enables probabilistic analysis through multiple runs for different recovery scenarios after an earthquake. Beyond this proposal, further research could be developed to include more sophisticated models and infrastructure types.

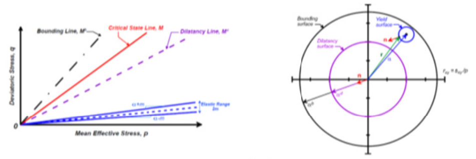
3.7 IMPLEMENTATION AND VALIDATION OF PM4SAND IN OPENSEES

Pedro Arduino

Details of the PEER funded research project “Implementation and Validation of PM4Sand in OpenSees” are highlighted below. The project Principal Investigator is Pedro Arduino, Professor, Department of Civil & Environmental Engineering, University of Washington. The research team includes Long Chen, PhD Graduate student, University of Washington.

ABSTRACT

Soil liquefaction is a major cause of damage during earthquakes. To predict the behavior of liquefiable soils, advanced constitutive models are necessary. Over the last decade several advanced models for liquefiable soils have been proposed. Among them, PM4Sand is a sand plasticity model for earthquake engineering applications recently proposed by Boulanger and Ziotopoulou [2015]. This 2D plane-strain model follows the plasticity framework proposed by Dafalias and Manzari [2004] and is based on bounding surface plasticity and critical state–soil mechanics concepts. The model has been calibrated at an element level to approximately simulate general trends observed in the field and empirical correlations commonly used in geotechnical earthquake engineering practice. By changing three primary input parameters, the user can achieve reasonable approximations of desired behavior, including pore pressure generation and dissipation, limiting strains, and cyclic mobility. Using secondary parameters (18 in total and optional), the user can further fine tune the response, although this is not necessary. Since its introduction, the PM4Sand model has drawn wide attention of geotechnical engineers and researchers due to its relatively easy calibration process and good agreement with field observations. The UW Computational Geomechanics group has implemented this model at the element level using a “container” constitutive driver specially designed to test constitutive models. Preliminary results using conventional stress paths are very promising. However, challenges related to model stability and efficiency and implementation into OpenSees require further work. The goal of this proposal is to implement PM4Sand in OpenSees and validate it using existing experimental results for 2D and 3D boundary-value problems.



$$f = \sqrt{(\boldsymbol{r}-\boldsymbol{\alpha}):(\boldsymbol{r}-\boldsymbol{\alpha})} - \sqrt{\tfrac{1}{2}}m = 0$$

PM4Sand model definition: bounding, dilatancy, and yield surfaces in (a) *qp* space and (b) deviatoric space.

RESEARCH IMPACT

Prediction of the behavior of liquefiable soils is important for design. Key to accomplishing this goal is to have an advanced model. Existing models usually require many input parameters and those parameters usually require a great effort to calibrate. The PM4Sand model was introduced to provide relatively good approximation and easy calibration process. An implemented PM4Sand model in OpenSees would provide a reliable and free tool to simulate behavior of liquefiable soils. This tool can be used by both researchers and engineers in practice.

3.8 MODELING BAY AREA TRANSPORTATION NETWORK RESILIENCE

Jack Baker

Details of the PEER funded research project "Modeling Bay Area Transportation Network Resilience" are highlighted below. The project Principal Investigator is Jack Baker, Associate Professor, Stanford University. The research team includes Rodrigo Silva, Graduate Student Researcher, Stanford University and Gitanjali Bhattacharjee, Graduate Student Researcher, Stanford University.

ABSTRACT

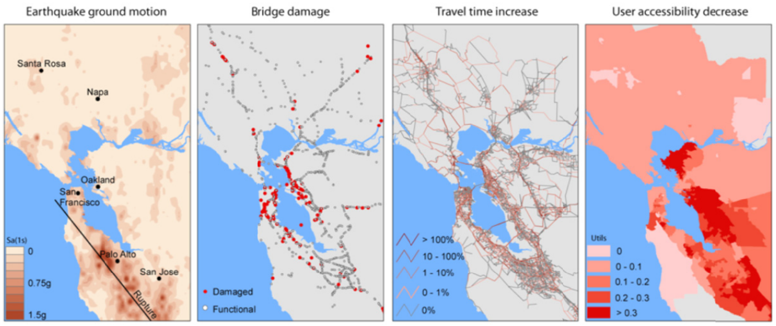


Figure 1 Illustration of the stages in transportation network risk analysis (from Miller and Baker [2014]).

The goal of this project is to build a model that links individual bridges' earthquake-damage-induced traffic capacity loss and restoration with network-level performance over time (e.g., additional travel time and loss of critical connections). The research objectives are to quantify how individual bridge performance contributes to network-level resilience, and to understand how resilience can be improved through mitigation actions at the individual-bridge level. We will build on our prior work to simulate regional-scale seismic hazards, bridge damage, and network disruption (Figure 1). To this we are adding models to characterize the restoration over time of bridge traffic capacity and network functionality. We plan to relate individual bridge risk to community resilience, and to efficiently quantify the impact of changing component performance (e.g., via retrofit) on that resilience assessment.

RESEARCH IMPACT

Community resilience is the focus of significant attention from a number of civic and research agencies. Common activities include the setting of resilience goals and the development of frameworks for describing resilience. This project aims to develop predictive models that relate individual bridge performance to those broader resilience goals. One aim of the project is thus to provide a link between PEER's work on enhanced bridge systems and the broader world's interest in enhanced disaster resilience. We also aim to identify key transportation network components and corridors whose functioning is deemed critical to regional resilience. By quantifying the benefits of improved bridge technology for community resilience, this project will help make the case for investing in higher-performance bridge systems (similar to the way that PEER's PBEE has helped make the case for investing in higher-performance building systems). By using performance metrics more closely aligned with those of relevance for resilience assessments, this project will also position PEER's research to more directly play a role in regional resilience planning efforts, such as SPUR's work with San Francisco and those of the region's Chief Resilience Officers.

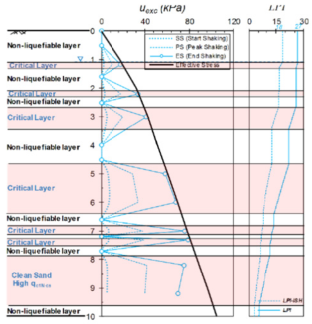
3.9 LIQUEFACTION TRIGGERING AND EFFECTS AT SILTY-SOIL SITES


Jonathan Bray

Details of the PEER funded research project "Liquefaction Triggering and Effects at Silty-Soil Sites" are highlighted below. The Principal Investigator is Jonathan D. Bray, Faculty Chair in Earthquake Engineering Excellence, Professor of Civil Engineering, UC Berkeley. The research team includes Daniel Hutabarat, Graduate Student Researcher, UC Berkeley.

ABSTRACT

Simplified liquefaction triggering procedures and post-liquefaction settlement procedures provide useful insights, but they cannot explain the different levels of liquefaction-induced structural damage during the 2010–2011 Canterbury earthquake sequence. It is extremely rare to have the opportunity to learn how the same ground and structures responded to several significant earthquakes that delivered different intensities and durations of strong shaking. The well-documented performance of land and structures in Christchurch, combined with the extensive suite of ground-motion recordings and the comprehensive subsurface investigation program, provide an exceptional opportunity to advance our understanding of the liquefaction of silty soil deposits.



(a) Gainsborough Site, New Zealand: Highly stratified deposit of silty soil with discontinuous, thin critical layers; high Liquefaction Potential Index (LPI) calculated, yet no manifestations of liquefaction observed after the 2011 Christchurch earthquake.

The primary research tasks are to investigate, characterize, and model the seismic performance of silty-soil sites. At the start of the project, we will investigate the geologic conditions of all 55 NGL-NZ sites. We will then focus on sites that conventional procedures indicate should have liquefied, but field observations indicate did not liquefy. It is hypothesized that a common set of discriminating geologic depositional environmental factors can be identified at sites that did not manifest liquefaction. It is also hypothesized that an assessment of the soil–water system response of stratified soil deposits is required to capture the observed cases of no liquefaction manifestation. *PM4Sand* has just recently been implemented in OpenSees. It will be employed to perform numerical simulations that capture the nonlinear, effective stress response of stratified silty-soil deposits to develop insights regarding key mechanisms and probable reasons for the lack of manifestations of liquefaction at sites that simplified procedures indicate should have liquefied. The *PM4Sand* soil model will be exercised extensively initially to ensure its

implementation in OpenSees is providing reliable results. It is hypothesized that the hydraulic response of the soil–water system will be a key issue to explore and to describe. Lastly, we will develop a set of design guidelines for evaluating liquefaction triggering and its consequences at silty-soil sites.

RESEARCH IMPACT

Learning from observations after design-level earthquakes is invaluable to advancing understanding in earthquake engineering. Investigating the occurrence or nonoccurrence of liquefaction of stratified deposits of silty and sandy soils and evaluating the effects of liquefaction on bridges and lifelines provide invaluable information that will serve as benchmarks to our understanding of soil liquefaction. The geologic data can be used to improve current empirical liquefaction triggering procedures and their consequential effects. Most of the liquefaction data currently available relates to sandy soils, so careful examination of silty-soil sites will assist greatly in broadening the applicability of design methods.

The over-prediction of liquefaction triggering by current procedures at silty-soil sites in Christchurch appears to be due to their inability to capture the seismic performance of stratified silty-soil deposits. The empirical database used to develop these procedures consists primarily of liquefaction triggering data from sand sites. Conservatism of the empirical liquefaction triggering procedures also contributes to the over-prediction of liquefaction. Engineers are currently faced with a dilemma: How can the prediction of liquefaction in these silty soils using established liquefaction triggering procedures be reconciled with the contradictory observations that surface manifestations of liquefaction were not observed after intense shaking from the Canterbury, New Zealand, earthquakes? This project will develop insights that will enable engineers to adjust state-of-the-art liquefaction procedures to address the discrepancy of their over-prediction of liquefaction triggering with the field observations that stratified silty sites of particular characteristics do not manifest liquefaction and damage bridge foundations.

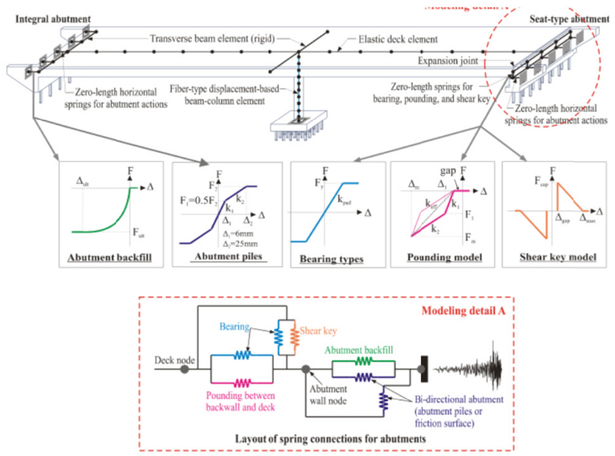
3.10 AFTERSHOCK SEISMIC VULNERABILITY AND TIME-DEPENDENT RISK ASSESSMENT OF BRIDGES


Henry V. Burton

Details of the PEER funded research project “Aftershock Seismic Vulnerability and Time-Dependent Risk Assessment of Bridges” are highlighted below. The project Principal Investigator is Henry V. Burton, Assistant Professor, Department of Civil and Environmental Engineering and Englekirk Presidential Endowed Chair in Structural Engineering, UCLA. The Co-Principal Investigator is Jonathan Stewart, Professor and Department Chair, Department of Civil and Environmental Engineering, UCLA. The research team includes Sujith Mangalathu, Postdoctoral Scholar, UCLA and Mehrdad Shokrabadi, PhD Candidate, UCLA.

ABSTRACT

Decisions about the structural integrity and functionality of earthquake-damaged bridges are a critical step in post-event response and recovery. Currently, the California Department of Transportation uses a set of bridge system-level damage states as the basis for classifying the post-earthquake operability of bridges. The damage states are based on the HAZUS classifications (minor, moderate, extensive, and complete), with each one assigned a "likely post-event traffic state." For example, a bridge that has been classified as having "moderate" damage is deemed "open to limited public traffic with speed, weight, and lane restrictions." Despite HAZUS being the primary tool used to inform post-earthquake decisions regarding the partial or complete closure of bridges, the extent to which knowledge of residual structural capacity and time-dependent aftershock hazard and risk inform these damage-traffic-state relationships is unclear. Moreover, while there has been significant research on the seismic vulnerability and risk to bridges posed by mainshocks, recognized research to quantify the vulnerability and time-dependent risk in the aftershock environment is still in its infancy. The proposed research will implement the PBEE framework to assess the aftershock vulnerability and time-dependent risk of earthquake-damaged bridges, with the goal of informing decisions regarding the appropriateness and timing of post-event closure (partial and complete).



Numerical modeling of bridge

RESEARCH IMPACT

Bridges are an essential part of the transportation system in California and other parts of the U.S. This is especially true during the period immediately following a major earthquake when the mobility of emergency responders is highly dependent on a functioning transportation network. As such, decisions regarding the structural integrity and functionality of earthquake-damaged bridges are a critical step in post-event response and recovery. The development of quantitative and comparable measures of aftershock bridge performance will ultimately lead to more informed post-earthquake decisions related to bridge closures, which has direct implications to the functionality and recovery of transportation networks.

3.11 POST-EARTHQUAKE FIRE PERFORMANCE OF INDUSTRIAL FACILITIES

Erica C. Fisher

Details of the PEER funded research project “Post-earthquake Fire Performance of Industrial Facilities” are highlighted below. The project Principal Investigator is Erica C. Fischer, Assistant Professor, Oregon State University.

ABSTRACT

This project is a seed project that will produce results necessary for a much larger scope project on performance-based earthquake and fire engineering. The scope of the project includes evaluation and investigation of the post-earthquake fire performance of industrial facilities. The investigation will use OpenSees. Previous researchers have demonstrated good results using OpenSees for multi-hazard evaluation of buildings. In some cases, post-earthquake fires tend to cause more damage than the earthquake itself. In the case of the 1906 San Francisco and the 1923 Tokyo earthquake, 80% of the damage was caused by post-earthquake fires. A variety of ground accelerations will be used and combined design fire scenarios developed using performance-based fire engineering approaches. The varying ground accelerations will cause varying degrees of damage to the building during the earthquake phase of the simulations. Varying ground accelerations will allow the researchers to quantify how much additional damage is caused by the fire versus the earthquake ground motion. This work will integrate seismological, multi-hazard, and socio-economical aspects of earthquake and fire engineering to improve emergency management and the resilience of communities. Cities on the west coast of the U.S. are quantifying the economic impact of post-earthquake fires on their communities. The proposed research project would work with practitioners to communicate the results and develop retrofit strategies that improve the performance of buildings in post-earthquake fires and are able to be implemented by contractors.

RESEARCH IMPACT

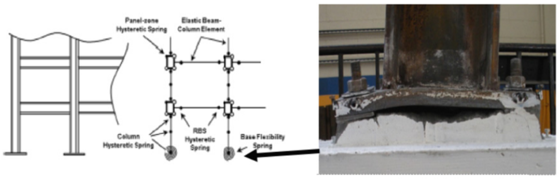
The losses from post-earthquake fires can be comparable to those experienced only from earthquakes. Typical building design allows for plastic deformation of the building and does not require fire suppression systems to be operable after an earthquake. This type of design approach leaves many structures vulnerable to post-earthquake fires without the capability of operational automatic fire suppression systems. In addition, if a building has already experienced plastic deformations, the structure is already weakened and potentially has residual deformations when the fire initiates. As both the earthquake- and fire-engineering fields move toward performance-based fire engineering approaches, more buildings can be designed to have operational fire suppression systems post-earthquake that accommodate the plastic deformation of the structural system; however, there are still many vulnerable existing buildings in high seismic regions that have not been designed with performance-based engineering practices in mind. This work has direct impact on the structural engineering and emergency management practice. Through evaluation of industrial facilities in post-earthquake fires, this project will identify the vulnerable components of these facilities and targeted improvements that can be made. The results of this research can provide important information regarding emergency management of cities and communities. By identifying types of structures vulnerable to collapse or partial collapse in post-earthquake fires, communities can realistically plan for their recovery after a disaster. The results of this research project would be the foundation for a much larger project that uses OpenSees to evaluate critical transportation infrastructure for post-earthquake fires. The results of the research would contribute to both the performance-based earthquake engineering and performance-based fire engineering design methodologies.

3.12 DISSIPATIVE BASE CONNECTIONS FOR MOMENT-FRAME STRUCTURES IN AIRPORTS AND OTHER TRANSPORTATION SYSTEMS


Amit M. Kanvinde

Details of the PEER funded research project “Dissipative Base Connections for Moment Frame Structures in Airports and Other Transportation Systems” are highlighted below. The project Principal Investigator is Amit M. Kanvinde, Professor, UC Davis. The research team includes Vincente Pericoli, Post-doctoral Researcher, UC Davis; Yazhi Zhu, Post-doctoral Researcher, UC Davis; Mason Walters, Forell Elsesser, PEER BIP; Geoff Bomba, Forell Elsesser, PEER BIP; and Ali Roufegarinejad, Forell Elsesser, PEER BIP.

ABSTRACT



(a) Computational model of frames with dissipative/yielding bases

(b) Test setup for experimental component of the study

Steel column to concrete footing connections are critical components of numerous structures within the transportation infrastructure. These primarily include moment frames in airports (a large majority of airports in California utilize these to achieve unobstructed bays), and in numerous pre-1990 bridges and freeway overpasses. The current practice for designing base connections is inhibited by knowledge gaps in several areas, with serious implications for the performance and economy of critical infrastructure. First, structural systems do not allow ductile/dissipative response in the base connections, requiring designers to design them as elastic and fixed. This results in extremely expensive base connections. Recent experimental research shows that the base connections may be highly ductile, whereas the columns have limited rotation capacity (due to local or lateral torsional buckling). Against this backdrop, this study develops a design paradigm that allows for dissipation/inelastic deformation in the base connections, while providing acceptable frame performance. This is achieved through a coordinated plan of testing and simulation; tests (supported independently of the PEER project) are required to develop resilient (i.e., reliably ductile and repairable) base connections, whereas simulations are required to examine interactions between these connections and the system, to establish acceptance/demand criteria for the components themselves while developing guidelines for structural design such that it

achieves acceptable performance (e.g., collapse probabilities, deformations etc.), as determined within a PBEE framework.

RESEARCH IMPACT

Column base connections are an essential component of a huge number of transportation structures. Moreover, they are possibly the most important connections in these structures because they carry the largest forces and interact with the frame affecting its response. Current design/construction practices for base connections as well as the structures that utilize them have major conservatisms in material requirements (e.g., deeper embedment or large anchor rods) and inefficiencies (e.g., multiple concrete pours, coordination between steel and concrete trades) that may be eliminated by more research on embedded base connections. These outcomes (mitigation of conservatisms and inefficiencies) will be particularly impactful for two reasons:

- They will affect all structures that employ steel–concrete footing connections. These impacts are not limited to one connection detail or issue, and have a broad impact affecting possibly thousands of transportation structures.
- Research on base connections is much less developed compared to other connections (beam–column connections). As a result, we are on the steep part of the learning curve, such that major (rather than incremental) advances in our understanding of these connections are expected.

These impacts will be pursued through early and sustained engagement with key code/standard committees, including the American Institute of Steel Construction.

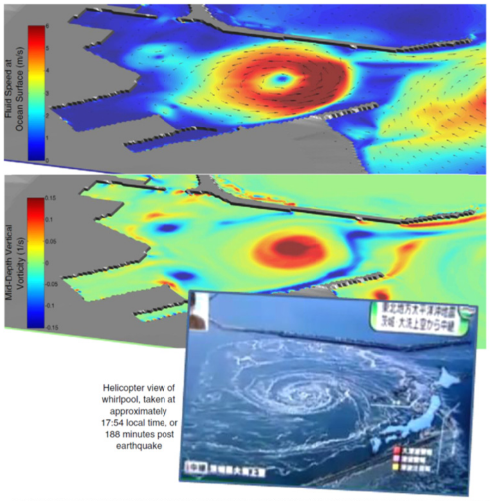
3.13 TSUNAMI DEBRIS: SIMULATING HAZARD AND LOADS


Patrick Lynett

Details of the PEER funded research project "Tsunami Debris: Simulating Hazard and Loads" are highlighted below. The project Principal Investigator is Patrick J. Lynett, Professor of Civil Engineering, USC. The research team includes Aykut Ayca, Graduate Student Researcher, USC.

ABSTRACT

Port facilities are among the most vulnerable to tsunami hazards. Even a relatively small tsunami causing limited or no inundation locally could greatly impact port operations through strong currents. Large vessels, when pulled from their berths by the tsunami currents, become "extraordinary debris," causing severe damage to any structure they might impact. With a reasonable handle on tsunami-induced current modeling in ports, it becomes feasible to accurately predict both the generation and transport of debris. It is the main goal of this proposed project to develop, validate, and apply transport models for various types of debris inside ports, such that both the probability of debris impact as well as the magnitude of debris loading can be quantified. For this research area, we divide the debris transport modeling studies into two categories: (1) detailed 3D simulation of the flow around a single large object; and (2) two-horizontal-dimension (2HD) simulation of a large volume of debris through port-sized domains. These two approaches represent a means to answer research questions on two different scales. The 3D simulation permits the quantification of the detailed pressure distribution around an object or structure, which then allows for a proper design in response to these loads. In the 2HD study, we aim to understand the combined and coupled dynamics of a tsunami churning through a port with a temporally increasing debris field. The debris field includes objects with length scales typical of cargo shipping containers, small boats, and vehicles to understand the impact of the debris on the flow field and the potential to impart loads on structures.



Numerical model results of the Tohoku tsunami in the Port of Oarai. Snapshots are from 188 minutes after the arthquake: (top) fluid speed, (middle) vertical vorticity at mid-depth, and (bottom) aerial image of the rotational feature at approximately the same time

RESEARCH IMPACT

Advances in this area are greatly in need, as existing approaches for debris loading (e.g. Chapter 6 of ASCE7-16) are shockingly crude and often highly conservative. Indeed, as the ASCE7 tsunami subcommittee begins to organize for ASCE7-22 revisions, early discussions indicate that the debris loading section will undergo significant revision. The research proposed here would likely be the main guide for determining how to change the section. In the short term, the ability to predict debris transport in ports, and the detachment and drifting of large vessels has immediate application. Scenario simulations will be performed at major ports along the U.S. West Coast (i.e., San Diego, LA/LB, Oakland/Richmond, and Seattle/Tacoma) to both visualize and quantify debris effects. Finally, a workshop will be organized to demonstrate the need to recognize the tsunami debris hazard, and to show stakeholders how to use the developed tools to estimate local impacts. Industry in the energy and cargo sectors, as well as the Navy, Coast Guard, and port/harbor commissions will be brought together in the workshop and will be shown the potential of these hazards in their local ports.

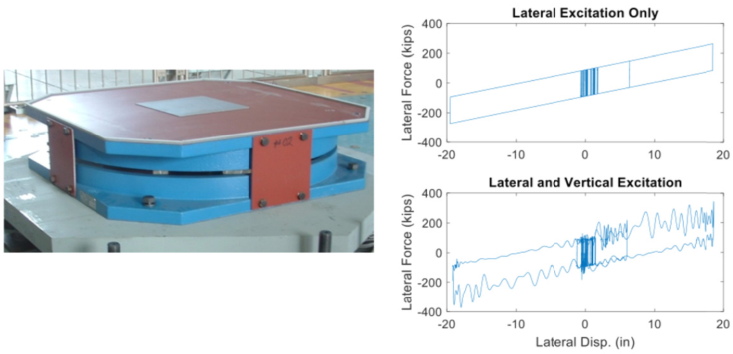
3.14 INFLUENCE OF VERTICAL GROUND SHAKING ON DESIGN OF BRIDGES ISOLATED WITH FRICTION PENDULUM BEARINGS


Keri Ryan

Details of the PEER funded research project "Influence of Vertical Ground Shaking on Design of Bridges Isolated with Friction Pendulum Bearings" are highlighted below. The project Principal Investigator is Keri L. Ryan, Associate Professor of Civil Engineering, University of Nevada, Reno. The research team includes Rushil Mojidra, Graduate Student Researcher, University of Nevada, Reno.

ABSTRACT

The objective of this seed project is to answer the question: "Should vertical ground shaking be explicitly considered in the design of bridges with friction pendulum bearings?" The project builds on prior NEES/E-Defense testing that demonstrated both experimentally and numerically that vertical shaking can increase both the base shear and the story accelerations in buildings isolated with triple pendulum bearings. Vertical shaking introduces a high-frequency variation in bearing axial force that is transmitted to the base shear and can excite higher structural modes. More complete understanding is needed to develop sensible guidelines for including this effect in design. Application to bridges, due to their relative simplicity, is an ideal starting point to develop a holistic understanding of the influence of vertical shaking on relevant response quantities.



Triple pendulum bearing (left), and representative isolator force versus displacement for a single degree-of-freedom system with friction pendulum bearing, with and without (strong) vertical shaking (right)

A simplified bridge model will be developed and computational simulations performed to understand the influence of vertical ground shaking on bridge response as a function of key system parameters. The model will capture the vertical vibration of the superstructure spans, which is accomplished through element discretization and distributed mass. A parametric study will be conducted to understand how the base shear varies with increasing vertical shaking intensity. The bridge seismic response will be evaluated by response history analysis using OpenSees under a suite of ground motions that best represents high vertical seismicity (V/H ratio of 1.2). Isolation bearings will be modeled using single friction pendulum bearing or triple

friction pendulum elements, which use friction models to simulate the interaction of bearing axial force and lateral force. Increase in base shear and other effects for 3D shaking relative to 2D shaking will be evaluated, focusing on systematic trends that can be justified by fundamental engineering principles. A small project Advisory Board will be assembled to provide input in the design of the parametric study.

RESEARCH IMPACT

Performance-based design techniques are used for critical infrastructure that have seismic performance objectives beyond minimum code requirements. Highway bridges are a critical component of resilient transportation systems that support post-earthquake response and recovery. Seismic isolation techniques are recognized as an effective option to reliably achieve high post-earthquake performance objectives such as continuous operation. The influence of vertical shaking on the lateral response of systems with friction pendulum bearings has been identified as a potential shortcoming that may prevent achievement of envisioned performance objectives targeted through PEER performance-based earthquake engineering methodology. However, prior research has shown that the influence of vertical shaking can be reliably predicted through properly constructed models and analysis techniques. In this project, a thorough parametric study will lead to more complete understanding of the significance of vertical shaking on isolated bridges with a variety of response characteristics, and may ultimately lead to recommended changes in the design of bridges isolated with triple pendulum bearings. If it is concluded that vertical shaking should be considered, then follow-up work is anticipated to determine the specifics of design guidelines for seismically isolated bridges. Efforts to determine specifics should be driven by interaction and feedback with code committees, such as AASHTO or Caltrans.

3.15 DEVELOPMENT OF A DATABASE AND A TOOLBOX FOR REGIONAL SEISMIC RISK ASSESSMENT OF CALIFORNIA'S HIGHWAY BRIDGES

Ertugrul Taciroglu

Details of the PEER funded research project "Development of a Database and a Toolbox for Regional Seismic Risk Assessment of California's Highway Bridges" are highlighted below. The project Principal Investigator is Ertugrul Taciroglu, Professor, UCLA. The research team includes Barbaros Cetiner, Graduate Student Researcher, UCLA and Peng-Yu Chen, Graduate Student Researcher, UCLA.

ABSTRACT

The first objective of this proposed project is to develop a database of California's bridges. This database will provide various data and metadata that can be used by experts from multiple domains, including bridge engineers, city planners, emergency responders, and insurance researchers. The database will be launched with content that is harvested by the project team from several sources, and it will be editable by direct input from users—through a crowd-sourcing model like Wikipedia—and by automated continuous updating scripts developed by the project team. The second-year objective of the project will be to synthesize a computational seismic "app"—*BridgeR*—that will interact with the database and produce continuous performance-based seismic assessments of California's highway transportation network. *BridgeR* will produce quantitative results in the form of site- and facility-specific seismic bridge fragilities, which will ultimately enable regional economic loss studies. *BridgeR* will incidentally form the blueprint for future apps that will be developed by experts from other domains (e.g., first responders). Through the present project, we aim to develop the backbone of *BridgeR*, verify it, and apply it to a set of testbed bridges in Los Angeles.

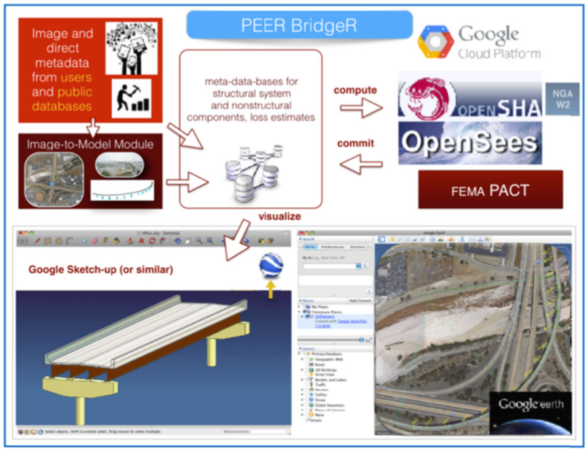


Figure 1 Graphical illustration of *BridgeR* components.

RESEARCH IMPACT

Once publicly launched, the database and its seismic app *BridgeR* will have the potential to grow and evolve with contributions from many users due to its open-access architecture and open-source building blocks. The resulting bridge-specific seismic safety/loss information can be used by decision makers who play integral roles in managing seismic risks. That is, government policymakers can better prioritize critical bridges for retrofits; and emergency first-responders can better prepare, plan, and react to a powerful earthquake if they know where the greatest structural damage is most likely to occur.

3.16 ACCOUNTING FOR EARTHQUAKE DURATION IN PERFORMANCE-BASED EVALUATION AND DESIGN OF BRIDGES (UNR-STANFORD COLLABORATION)


David Sanders


Greg Deierlein

Details of the PEER funded research project "Accounting for Earthquake Duration in Performance-Based Evaluation and Design of Bridges (UNR-Stanford Collaboration)" are highlighted below. The project Principal Investigator is David H. Sanders, University of Nevada, Reno. The research team includes John Anderson, University of Nevada, Reno; Greg Deierlein, Stanford University; and Mohammed Saeed Mohammed, Dynamic Isolation Services.

ABSTRACT

Previous studies have shown that earthquake duration can have a significant effect on structural performance, decreasing displacement capacity on the order of 25% and increasing the risk of structural collapse compared to shorter-duration motions upon which most design models and criteria are based. In addition to concerns related to long-duration motions from large magnitude (**M**8 and **M**9) earthquakes, duration effects are also important for evaluating structural performance under aftershocks and multiple earthquake events.

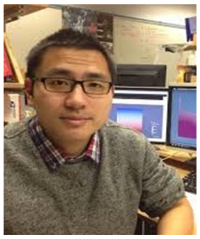
The overall goal of this project is to develop models and recommendations for considering earthquake duration in the performance assessment and design of bridges. Related objectives are as follows: (1) to develop improved design details to mitigate the effect of duration on reinforced concrete bridge piers; and (2) to leverage research on cyclic deterioration to help qualify the use of high-strength reinforcement in the seismic design of bridges. Four shake table column experiments will be conducted at the University of Nevada, Reno, that will be extended through the use of analytical modelling. The test results and analyses will be integrated through the PEER performance-based framework to consider the combined effects of ground-motion intensity, spectral shape, and duration on structural response. The framework will be applied to develop and calibrate performance-based design requirements that account for earthquake duration. The proposed research will be conducted through two companion projects at the University of Nevada, Reno and Stanford University.


(a) Shake table experiments

RESEARCH IMPACT

This project will develop seismic design provisions that account for earthquake duration effects, which are especially important for Northern California, Oregon, and Washington where large subduction earthquakes are expected to occur. The project will also contribute to the reliable use of high-strength reinforcement for bridges in high seismic regions and develop details for mitigating duration impact. The PIs will work with Caltrans, AASHTO, ACI, and other organizations to implement the research findings into design standards.

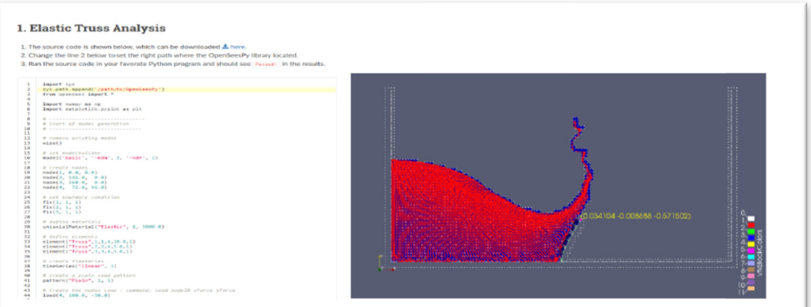
3.17 FLUID–STRUCTURE INTERACTION AND PYTHON SCRIPTING CAPABILITIES IN OPENSEES


Minjie Zhu

Details of the PEER funded research project “Fluid-Structure Interaction and Python Scripting Capabilities in OpenSees” are highlighted below. The project Principal Investigator is Minjie Zhu, Oregon State University. The research team includes Michael H. Scott, Co-PI, Oregon State University.

ABSTRACT

Building upon recent advances in OpenSees, the goals of this project are to expand the framework’s Python scripting capabilities and to further develop its fluid–structure interaction (FSI) simulation capabilities, which are based on the particle finite-element method (PFEM). From the start of their development, the FSI modules in OpenSees have been based on Python scripting, and to accomplish FSI simulations in OpenSees, Python commands have been added for a limited number of pre-existing element and material commands available in OpenSees, e.g., linear-elastic triangle elements and beam–column elements with *Concrete01*/*Steel01* fiber sections. However, hundreds of constitutive models and element formulations remain to be incorporated under the Python umbrella for FSI and general OpenSees use. The original scripting language, Tcl, in OpenSees is string-based, powerful, and easy to learn; however, it is not suited for mathematical computations. Recent trends in scripting languages for engineering applications have embraced more general, scientific languages such as Python, which has evolved to a large community with numerous libraries for numerical computing, data analysis, scientific visualization, and web development. Extending OpenSees to Python will help OpenSees keep pace with new scripting developments from the scientific computing community and make the framework more accessible to graduate students who likely have learned Python as undergraduates.


1. Elastic Truss Analysis

1. The source code is shown below, which can be downloaded here.
2. Change the line 2 below to set the right path where the OpenSeesPy library located.
3. Run the source code in your favorate Python program and should see `Passed!` in the results.

```
1   import sys
2   sys.path.append('/path/to/OpenSeesPy')
3   from opensees import *
4
5   import numpy as np
6   import matplotlib.pyplot as plt
7
8   # ------------------------------
9   # Start of model generation
10  # -----------------------------
11
12  # remove existing model
13  wipe()
14
15  # set modelbuilder
16  model('basic', '-ndm', 2, '-ndf', 2)
17
18  # create nodes
19  node(1, 0.0, 0.0)
20  node(2, 144.0,  0.0)
21  node(3, 168.0,  0.0)
22  node(4,  72.0, 96.0)
23
24  # set boundary condition
25  fix(1, 1, 1)
26  fix(2, 1, 1)
27  fix(3, 1, 1)
28
29  # define materials
30  uniaxialMaterial("Elastic", 1, 3000.0)
31
32  # define elements
33  element("Truss",1,1,4,10.0,1)
34  element("Truss",2,2,4,5.0,1)
35  element("Truss",3,3,4,5.0,1)
36
37  # create TimeSeries
38  timeSeries("Linear", 1)
39
40  # create a plain load pattern
41  pattern("Plain", 1, 1)
42
43  # Create the nodal load - command: load nodeID xForce yForce
44  load(4, 100.0, -50.0)
```

(a) OpenSeesPy webpage for a simple elastic truss analysis in Python and (b) screenshot of Fluid-Structure Interaction simulation using OpenSeesPy.

RESEARCH IMPACT

This project will increase the user base of OpenSees with the popular Python interpreter and improve the user experience of OpenSees with a friendlier user interface. The wide array of libraries available in Python, e.g., numpy, pandas, etc., will allow OpenSees to be used in a variety of Python-based applications. The continued development of OpenSees for FSI via the PFEM will support the development of fragility curves and other structural engineering applications using the nonlinear structural models with which current OpenSees users feel most comfortable.

3.18 PEER REPORTS 2017

PEER 2017/01 *2016 PEER Annual Report*. Khalid M. Mosalam, Amarnath Kasalanati, and Grace Kang. March 2017.

The Pacific Earthquake Engineering Research Center (PEER) is a multi-institutional research and education center with headquarters at the University of California, Berkeley. PEER's mission is to develop, validate, and disseminate performance-based seismic design technologies for buildings and infrastructure to meet the diverse economic and safety needs of owners and society.

The year 2016 began with a change of leadership at PEER. On January 1, Professor Khalid Mosalam became the new PEER Director as Professor Stephen Mahin completed his 6- year term. Also in early 2016, Dr. Yousef Bozorgnia stepped down from the position of Executive Director, after serving as a key member of PEER's management team for over 12 years. Several accomplishments of the Center during the leadership of Director Mahin were recounted during the PEER Annual Meeting on January 28–29, 2016. This meeting also set the course of the Center with several new thrust areas identified for future research.

During the past year, PEER has continued its track record of multi-institutional research with several multi-year Mega-Projects. The PEER Tall Buildings Initiative (TBI) was recently expanded to include assessment of the seismic performance of existing tall buildings. The California Earthquake Authority (CEA) awarded a $3.4 million, 3.5-year research contract to PEER to investigate the seismic performance of wood-frame homes with cripple walls. The project will directly contribute to the improvement of seismic resiliency of California's housing stock. Former Director Mahin will lead a broad effort for computational modeling and simulation (SimCenter) of the effects of natural hazards on the built environment. Supported by a 5-year, $10.9-million grant from the National Science Foundation (NSF), the SimCenter is part of the Natural Hazards Engineering Research Infrastructure (NHERI) initiative, a distributed, multiuser national facility that will provide natural hazards engineers with access to research infrastructure (earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and simulation tools, and research data), coupled with education and community outreach activities.

In addition to the Mega Projects, PEER researchers were involved in a wide range of research activities in the areas of geohazards, tsunami, and the built environment focusing on the earthquake performance of old and new reinforced concrete and steel structures, tall buildings, and bridges including rapid bridge construction. As part of its mission, PEER participated in a wide range of education and outreach activities, including a summer internship program, seminars, OpenSees days, and participation in several national and international conferences. The Center became an active board member of two prominent international organizations, namely GADRI (Global Alliance of Disaster Research Institutes) and ILEE (International Laboratory of Earthquake Engineering). PEER researchers and projects were recognized with awards from several organizations.

Going forward, PEER aims to improve the profile and external exposure of the Center globally, strengthen the Business-Industry-Partnership (BIP) program, engage the Institutional Board (IB) and the Industry Advisory Board (IAB) to identify new areas of research, and explore new funding opportunities.

PEER 2017/02 *U.S.–New Zealand–Japan Workshop: Liquefaction-Induced Ground Movements Effects, University of California, Berkeley, California, 2–4 November 2016.* Jonathan D. Bray, Ross W. Boulanger, Misko Cubrinovski, Kohji Tokimatsu, Steven L. Kramer, Thomas O'Rourke, Ellen Rathje, Russell A. Green, Peter K. Robinson, and Christine Z. Beyzaei. March 2017.

There is much to learn from the recent New Zealand and Japan earthquakes. These earthquakes produced differing levels of liquefaction-induced ground movements that damaged buildings, bridges, and buried utilities. Along with the often spectacular observations of infrastructure damage, there were many cases where well-built facilities located in areas of liquefaction-induced ground failure were not damaged. Researchers are working on characterizing and learning from these observations of both poor and good performance.

The "Liquefaction-Induced Ground Movements Effects" workshop provided an opportunity to take advantage of recent research investments following these earthquake events to develop a path forward for an integrated understanding of how infrastructure performs with various levels of liquefaction. Fifty-five researchers in the field, two-thirds from the U.S. and one-third from New Zealand and Japan, convened in Berkeley, California, in November 2016. The objective of the workshop was to identify research thrusts offering the greatest potential for advancing our capabilities for understanding, evaluating, and mitigating the effects of liquefaction-induced ground movements on structures and lifelines. The workshop also advanced the development of younger researchers by identifying promising research opportunities and approaches, and promoting future collaborations among participants.

During the workshop, participants identified five cross-cutting research priorities that need to be addressed to advance our scientific understanding of and engineering procedures for soil liquefaction effects during earthquakes. Accordingly, this report was organized to address five research themes: (1) case history data; (2) integrated site characterization; (3) numerical analysis; (4) challenging soils; and (5) effects and mitigation of liquefaction in the built environment and communities. These research themes provide an integrated approach toward transformative advances in addressing liquefaction hazards worldwide.

The archival documentation of liquefaction case history datasets in electronic data repositories for use by the broader research community is critical to accelerating advances in liquefaction research. Many of the available liquefaction case history datasets are not fully documented, published, or shared. Developing and sharing well-documented liquefaction datasets reflect significant research efforts. Therefore, datasets should be published with a permanent DOI, with appropriate citation language for proper acknowledgment in publications that use the data.

Integrated site characterization procedures that incorporate qualitative geologic information about the soil deposits at a site and the quantitative information from in situ and laboratory engineering tests of these soils are essential for quantifying and minimizing the uncertainties associated site characterization. Such information is vitally important to help identify potential failure modes and guide in situ testing. At the site scale, one potential way to do this is to use proxies for depositional environments. At the fabric and microstructure scale, the use of multiple in situ tests that induce different levels of strain should be used to characterize soil properties.

The development of new *in situ* testing tools and methods that are more sensitive to soil fabric and microstructure should be continued. The development of robust, validated analytical procedures for evaluating the effects of liquefaction on civil infrastructure persists as a critical research topic. Robust validated analytical procedures would translate into more reliable evaluations of critical civil infrastructure iv performance, support the development of mechanics-based, practice-oriented engineering models, help eliminate suspected biases in our current engineering practices, and facilitate greater integration with structural, hydraulic, and wind engineering analysis capabilities for addressing multi-hazard problems. Effective collaboration across countries and disciplines is essential for developing analytical procedures that are robust across the full spectrum of geologic, infrastructure, and natural hazard loading conditions encountered in practice.

There are soils that are challenging to characterize, to model, and to evaluate, because their responses differ significantly from those of clean sands: they cannot be sampled and tested effectively using existing procedures, their properties cannot be estimated confidently using existing *in situ* testing methods, or constitutive models to describe their responses have not yet been developed or validated. Challenging soils include but are not limited to: interbedded soil deposits, intermediate (silty) soils, mine tailings, gravelly soils, crushable soils, aged soils, and cemented soils. New field and laboratory test procedures are required to characterize the responses of these materials to earthquake loadings, physical experiments are required to explore mechanisms, and new soil constitutive models tailored to describe the behavior of such soils are required. Well-documented case histories involving challenging soils where both the poor and good performance of engineered systems are documented are also of high priority.

Characterizing and mitigating the effects of liquefaction on the built environment requires understanding its components and interactions as a system, including residential housing, commercial and industrial buildings, public buildings and facilities, and spatially distributed infrastructure, such as electric power, gas and liquid fuel, telecommunication, transportation, water supply, wastewater conveyance/treatment, and flood protection systems. Research to improve the characterization and mitigation of liquefaction effects on the built environment is essential for achieving resiliency. For example, the complex mechanisms of ground deformation caused by liquefaction and building response need to be clarified and the potential bias and dispersion in practice-oriented procedures for quantifying building response to liquefaction need to be quantified. Component-focused and system performance research on lifeline response to liquefaction is required. Research on component behavior can be advanced by numerical simulations in combination with centrifuge and large-scale soil–structure interaction testing. System response requires advanced network analysis that accounts for the propagation of uncertainty in assessing the effects of liquefaction on large, geographically distributed systems. Lastly, research on liquefaction mitigation strategies, including aspects of ground improvement, structural modification, system health monitoring, and rapid recovery planning, is needed to identify the most effective, cost efficient, and sustainable measures to improve the response and resiliency of the built environment.

PEER 2017/03 *NGA-East Ground-Motion Models for the U.S. Geological Survey National Seismic Hazard Maps*. Christine A. Goulet, Yousef Bozorgnia, Nicolas Kuehn, Linda Al Atik, Robert R. Youngs, Robert W. Graves, and Gail M. Atkinson. March 2017.

The purpose of this report is to provide a set of ground motion models (GMMs) to be considered by the U.S. Geological Survey (USGS) for their National Seismic Hazard Maps (NSHMs) for the Central and Eastern U.S. (CEUS). These interim GMMs are adjusted and modified from a set of preliminary models developed as part of the Next Generation Attenuation for Central and Eastern North-America (CENA) project (NGA-East). The NGA-East objective was to develop a new ground-motion characterization (GMC) model for the CENA region. The GMC model consists of a set of GMMs for median and standard deviation of ground motions and their associated weights in the logic-tree for use in probabilistic seismic hazard analysis (PSHA).

NGA-East is a large multidisciplinary project coordinated by the Pacific Earthquake Engineering Research Center (PEER), at the University of California, Berkeley. The project has two components: (1) a set of scientific research tasks, and (2) a model-building component following the framework of the "Seismic Senior Hazard Analysis Committee (SSHAC) Level 3" [Budnitz et al. 1997; NRC 2012]. Component (2) is built on the scientific results of component (1) of the NGA-East Project. This report does not document the final NGA-East model under (2), but instead presents interim GMMs for use in the U.S. Geological Survey (USGS) National Seismic Hazard Maps.

Under component (1) of NGA-East, several scientific issues were addressed, including: (a) development of a new database of empirical data recorded in CENA; (b) development of a regionalized ground-motion map for CENA, (c) definition of the reference site condition; (d) simulations of ground motions based on different methodologies, (e) development of numerous GMMs for CENA, and (f) the development of the current report. The scientific tasks of NGA-East were all documented as a series of PEER reports.

This report documents the GMMs recommended by the authors for consideration by the USGS for their NSHM. The report documents the key elements involved in the development of the proposed GMMs and summarizes the median and aleatory models for ground motions along with their recommended weights. The models presented here build on the work from the authors and aim to globally represent the epistemic uncertainty in ground motions for CENA.

The NGA-East models for the USGS NSHMs includes a set of 13 GMMs defined for 25 ground-motion intensity measures, applicable to CENA in the moment magnitude range of 4.0 to 8.2 and covering distances up to 1500 km. Standard deviation models are also provided for general PSHA applications (ergodic standard deviation). Adjustment factors are provided for hazard computations involving the Gulf Coast region.

PEER 2017/04 *Expert Panel Recommendations for Ergodic Site Amplification in Central and Eastern North America*. Jonathan P. Stewart, Grace A Parker, Joseph P. Harmon, Gail M. Atkinson, David M. Boore, Robert B. Darragh, Walter J. Silva, and Youssef M.A. Hashash. March 2017.

The U.S. Geological Survey (USGS) national seismic hazard maps have historically been produced for a reference site condition of V_{S30} = 760 m/sec (where V_{S30} is time averaged shear wave velocity in the upper 30 m of the site). The resulting ground motions are modified for five site classes (A-E) using site amplification factors for peak acceleration and ranges of short- and long-oscillator periods. As a result of Project 17 recommendations, this practice is being revised: (1) maps will be produced for a range of site conditions (as represented by V_{S30}) instead of a single reference condition; and (2) the use of site factors for period ranges is being replaced with period-specific factors over the period range of interest (approximately 0.1 to 10 sec). Since the development of the current framework for site amplification factors in 1992, the technical basis for the site factors used in conjunction with the USGS hazard maps has remained essentially unchanged, with only one modification (in 2014). The approach has been to constrain site amplification for low-to-moderate levels of ground shaking using inference from observed ground motions (approximately linear site response), and to use ground response simulations (recently combined with observations) to constrain nonlinear site response. Both the linear and nonlinear site response has been based on data and geologic conditions in the western U.S. (an active tectonic region). This project and a large amount of previous and contemporaneous related research (e.g., NGA-East Geotechnical Working Group for site response) has sought to provide an improved basis for the evaluation of ergodic site amplification in central and eastern North America (CENA). The term ‘ergodic’ in this context refers to regionally-appropriate, but not site-specific, site amplification models (i.e., models are appropriate for CENA generally, but would be expected to have bias for any particular site). The specific scope of this project was to review and synthesize relevant research results so as to provide recommendations to the USGS for the modeling of ergodic site amplification in CENA for application in the next version of USGS maps.

The panel assembled for this project recommends a model provided as three terms that are additive in natural logarithmic units. Two describe linear site amplification. One of these describes V_{S30}-scaling relative to a 760 m/sec reference, is largely empirical, and has several distinct attributes relative to models for active tectonic regions. The second linear term adjusts site amplification from the 760 m/sec reference to the CENA reference condition (used with NGA-East ground motion models) of V_S =3000 m/sec; this second term is simulation-based. The panel is also recommending a nonlinear model, which is described in a companion report [Hashash et al. 2017a]. All median model components are accompanied by models for epistemic uncertainty.

The models provided in this report are recommended for application by the USGS and other entities. The models are considered applicable for V_{S30} = 200–2000 m/sec site conditions and oscillator periods of 0.08–5 sec. Finally, it should be understood that as ergodic models, they lack attributes that may be important for specific sites, such as resonances at site periods. Sites-specific analyses are recommended to capture such effects for significant projects and for any site condition with V_{S30} < 200 m/sec. We recommend that future site response models for hazard applications consider a two-parameter formulation that includes a measure of site period in addition to site stiffness.

PEER 2017/05 *Recommendations for Ergodic Nonlinear Site Amplification in Central and Eastern North America*. Youssef M.A. Hashash, Joseph A. Harmon, Okan Ilhan, Grace A. Parker, and Jonathan P. Stewart. March 2017.

This document is a companion report to Expert Panel Recommendation for Ergodic Linear Site Amplification Models in central and eastern North America (PEER Report No. 2017/04, Stewart et al. 2017). This report describes the panel recommendations for ergodic median nonlinear site amplification models, which are meant to accompany linear models in the companion report. Nonlinear models for site amplification must represent the strength of the input ground motion in some manner, and peak acceleration for a reference condition (PGAr) is often used. The use of PGAr (and similar parameters) requires specification of a reference condition in the development of nonlinear models, and those provided here consider reference conditions of V_S = 3000 m/sec and V_{S30} = 760 m/sec. One of the proposed models (the GWG-S nonlinear amplification model) is derived for a reference condition of V_S = 3000 m/sec. A second is identical to the first except that PGAr is adjusted to a V_{S30} = 760 m/sec reference condition. Nonlinear amplification models in this report are produced as functions of V_{S30} and (PGAr). Other models evaluated in this report are the PEA nonlinear amplification model and the GWG-S model with an alternative approach to convert GWG-S nonlinear amplification model estimations to a V_{S30} = 760 m/sec reference condition. A recommended epistemic uncertainty model on the GWG-S recommended median nonlinear amplification models is provided in piecewise functional form to generate reasonable variation of F_{nl} across the period and V_{S30} ranges of interest. Limitations on the recommended models are presented considering both the methodology of the recommended model derivation and limitations of nonlinear amplification models in general.

PEER 2017/06 *Guidelines for Performance-Based Seismic Design of Tall Buildings, Version 2.01.* Version 2.0, prepared by a TBI Working Group led by co-chairs Ron Hamburger and Jack Moehle: Jack Baker, Jonathan Bray, C.B. Crouse, Greg Deierlein, John Hooper, Marshall Lew, Joe Maffei, Stephen Mahin, James Malley, Farzad Naeim, Jonathan Stewart, and John Wallace. May 2017.

These Seismic Design Guidelines for Tall Buildings present a recommended alternative to the prescriptive procedures for seismic design of buildings contained in the ASCE 7 standard and the International Building Code (IBC). The intended audience includes structural engineers and building officials engaged in seismic design and review of tall buildings. Properly executed, these Guidelines are intended to result in buildings that are capable of reliably achieving the seismic performance objectives intended by ASCE 7, and in some aspects, and where specifically noted, somewhat superior performance to such objectives. Individual users may adapt and modify these Guidelines to serve as the basis for designs intended to achieve higher seismic performance objectives than specifically intended herein.

The Pacific Earthquake Engineering Research Center published a first edition of these Guidelines in 2010 in response to the growing use of alternative performance-based approaches for seismic design of tall buildings. Major innovations introduced in that volume included: use of Service-Level Earthquake (SLE) shaking to evaluate building response to frequent earthquakes coupled with a specific collapse-resistance evaluation for Maximum Considered Earthquake (MCER) shaking, use of nonlinear dynamic analysis; explicit evaluation of global, system-based performance criteria in addition to individual element or member-based criteria; introduction of the concept of critical and non-critical elements; and explicit evaluation of cladding adequacy for MCER demands.

In the time since the publication of the 2010 Guidelines, the profession has gained substantial experience in application of these techniques to design of buildings around the world, and, in particular, the western United States. Also, the ASCE 7 standard has been amended substantially, in no small part based on influence from the first edition of this document.

Additionally, significant advances have been made in nonlinear analytical capability and in defining ground motions for use in nonlinear seismic analysis. Initially, buildings designed using performance-based procedures were assigned to Risk Category II; these buildings were structurally regular and typically utilized concrete core wall systems for lateral resistance. Individual project development teams have extended the use of performance-based seismic design of tall buildings to encompass other structural systems, building complexes that include irregular structures and multiple towers on a single podium, and numerous structures assigned to higher Risk Categories. This second edition addresses lessons learned in application of the first edition on many projects and the conditions, knowledge, and state-of-practice that presently exist.

These Guidelines include the seismic design of structural elements normally assigned as part of the seismic-force-resisting system as well as structural elements whose primary function is to support gravity loads. Except for exterior cladding, design of nonstructural components is not specifically included within the scope of these Guidelines. Design for nonstructural systems should conform to the applicable requirements of the building code or other suitable alternatives that consider the unique response characteristics of tall buildings.

PEER 2017/07 *A Nonlinear Kinetic Model for Multi-Stage Friction Pendulum Systems. Paul L. Drazin and Sanjay Govindjee.* October 2017.

Multi-stage friction pendulum systems (MSFPs), or more specifically the triple friction pendulum (TFP), are currently being developed as seismic isolation devices for buildings and other large structures. However, all current models are inadequate in properly modeling all facets of these devices. Either the model can only handle uni-directional ground motions while incorporating the kinetics of the TFP system, or the model ignores the kinetics and only models bi-directional motion. And in all cases, the model is linearized to simplify the equations.

This paper presents an all-in-one model that incorporates the full nonlinear kinetics of the TFP system while allowing for bi-directional ground motion. In this way, the model presented here is the most complete single model currently available. The model is developed in such a way that allows for easy expansion to any standard type of MSFP, simply by following the procedure outlined in this report.

It was found that the nonlinear model can more accurately predict the experimental results for large displacements due to the nonlinear kinematics used to describe the system. It is also shown that the inertial effects of TFP system are negligible in normal operating regimes, however, in the event of uplift, the inertial effects may become significant. The model is also able to accurately predict the experimental results for complicated bi-directional ground motions.

PEER 2017/08 *Influence of Kinematic SSI on Foundation Input Motions for Bridges on Deep Foundations. Benjamin J. Turner, Scott J. Brandenberg, and Jonathan P. Stewart.* November 2017.

Seismic design of bridges and other pile-supported structures often utilizes a substructure method of dynamic analysis in which the foundation elements are not explicitly modeled but are replaced by springs and dashpots representing the foundation impedance. The ground motion appropriate for input to the free end of the springs, known as the “foundation input motion" (FIM), differs from the free-field motion (FFM) due to the difference in stiffness and deformation characteristics between the pile(s) and soil, which is typically overlooked in practice. Results of a parametric study of the influence of kinematic pile–soil interaction on FIM are presented. One dimensional nonlinear ground response analyses were used to define free-field motions, which were subsequently imposed on a beam-on-nonlinear-dynamic-Winkler-foundation pile model. The free-field ground surface motion and top-of-pile FIM computed from these results were then used to compute transfer functions and spectral ratios for use with the substructure method of seismic analysis. A total of 1920 parametric combinations of different pile sizes, soil profiles, and ground motions were analyzed.

Results of the study show that significant reductions of the FFM occur for stiff piles in soft soil, which could result in a favorable reduction in design demands for short-period structures. Group effects considering spatially-variable (incoherent) ground motions are found to be minor over the footprint of a typical bridge bent, resulting in an additional reduction of FFM by 10% or less compared to an equivalent single pile.

This study aims to overcome limitations of idealistic assumptions that have been employed in previous studies such as linear-elastic material behavior, drastically simplified stratigraphy, and harmonic oscillations in lieu of real ground motions. In order to capture the important influence of more realistic conditions such as material nonlinearity, subsurface heterogeneity, and variable frequency-content ground motions, a set of models for predicting transfer functions and spectral ratios has been developed through statistical regression of the results from this parametric study. These allow foundation engineers to predict kinematic pile–soil interaction effects without performing dynamic pile analyses.

While previously available elastic analytical models are shown to be capable of predicting the average results of this study, they do not adequately reflect the amount of variability in the results that arises from consideration of more realistic conditions. The new model is also used to re-examine available case history data that could not be explained by existing models.

PEER 2017/09 *"R" Package for Computation of Earthquake Ground-Motion Response Spectra* Pengfei Wang, Jonathan P. Stewart, Yousef Bozorgnia, David M. Boore, and Tadahiro Kishida. December 2017.

Earthquake ground motions are typically recorded with one vertical and two horizontal components. It has become standard practice to represent the horizontal component of ground shaking in a manner that recognizes a range of amplitudes with changing azimuths. These variable amplitudes can be generically denoted RotDxx, where xx indicates the percentile of the horizontal amplitude range. RotDxx representations of ground motion are used with amplitude parameters (peak acceleration and velocity) as well as response spectral ordinates for a range of oscillator periods. The use of RotDxx ground motions was introduced in the NGA-West2 project, and analysis procedures for their computation were originally developed in Fortran by the fourth author of this report. Here we describe the implementation of these analysis procedures in R, resulting in an "R" package referred to as Rotated Combination of Two-Component ground motions (RCTC). We describe related algorithms for recovering accurate peak quantities from digital data (i.e., Sinc-interpolation and subset selection), which are also implemented in RCTC. We verify the code outputs by comparing them with a prior Fortran code. RCTC takes as input two horizontal components of ground motion, their azimuths, and their time step, and returns various types of variables, including pseudo spectral acceleration for each horizontal component, RotDxx for xx=0, 50, 100% as well as earlier, orientation-independent, geometric mean parameter GMRotI50. Other period-independent variables are also computed and outputted. We document here the code verification and provide instructions for its use.

PEER 2017/10 *Development of Time Histories for IEEE693 Testing and Analysis (Including Seismically Isolated Equipment).* Shakhzod M. Takhirov, Eric Fujisaki, Leon Kempner, Michael Riley, and Brian Low. December 2017

This study was undertaken to address new developments in IEEE P693/D16 [IEEE693 WG 2017], account for the new strong-motion records from the recent major earthquakes, and assess their effects on the spectral demand. A large set of both crustal and subduction type records was investigated based on a number of parameters and intensity measures. The best candidates were selected as seed motions. The motions were matched to the IEEE693 spectrum in a time domain at 5% damping, which follows the guidance of IEEE P693/D16 [IEEE693 WG 2017]. In addition, three three-component synthetic time histories were generated. All modified and generated time histories were arranged into a suite of time histories proposed for use in IEEE693 seismic qualification analysis and testing. The suite consisted of four IEEE693-spectrum-compatible time histories modified from crustal records, one IEEE693-spectrum-compatible time history modified from a subduction record, and three IEEE693-spectrum-compatible synthetic time histories. The spectral matching was conducted with a tight tolerance to remain within a 15% strip above the IEEE693 spectra in a wide-frequency range. It was shown that the conservatism of the IEEE693 spectrum is different for crustal and subduction type records. Based on the results of the investigation, the study summarizes the basis for changes to the requirements for development of input time histories given in IEEE P693/D16, and considerations for input motion specifications for a future edition of the standard.

PEER 2017/11 *Preliminary Studies on the Dynamic Response of a Seismically Isolated Prototype Gen-IV Sodium-Cooled Fast Reactor (PGSFR*). Benshun Shao, Andreas H. Schellenberg, Matthew J. Schoettler, and Stephen A. Mahin, December 2017.

The KEPCO Engineering and Construction Company, Inc. (KEPCO E&C) is developing a Prototype Gen-IV Sodium-Cooled Fast Reactor (PGSFR). Preliminary evaluations of the behavior of the isolated PGSFR when subjected to seismic and aircraft impact loading conditions were conducted to support design efforts by KEPCO E&C. Results and key findings of these analyses are as follows: (i) because isolator deformations are typically quite small for the considered seismic excitation levels, the benefit of seismic isolation could be enhanced with revised isolator designs that reduce the apparent yield strength and permit greater displacement demands; (ii) the amplitudes of acceleration and displacement responses resulting from the impact of a large aircraft are similar to or exceed the demands imposed by a seismic event based on the NRC hazard with a peak ground acceleration of 0.3*g*, and (iii) as provided, the isolator initial stiffness is poorly conditioned since it leads to fundamental isolation frequencies that are not well separated from the plant's superstructure frequencies, and triggers some resonance that significantly increases floor acceleration response spectra.

PEER2017/12 *Experimental Investigation of the Behavior of Vintage and Retrofit Concentrically Braced Steel Frames under Cyclic Loading*. Barbara G. Simpson, Stephen A. Mahin, and Jiun-Wei Lai. December 2017.

The parallel evolution of seismic design provisions and braced-frame research has led to inconsistencies between the design and construction of braced frames and the development of modern seismic design codes and now-typical detailing requirements. Since literature on concentrically braced frames (CBFs) spans over several decades, existing older or *vintage* concentrically braced frames–especially those designed prior 1988–may be prone to a number of deficiencies that are now limited in new CBFs due to contemporary seismic design requirements.

The number and range of these deficiencies and their likely interdependence, makes assessing the likely behavior of vintage braced frame systems problematic. Recent research has focused on improving the seismic behavior of modern braced frame systems, such as the Special Concentrically Braced Frame (SCBF). In contrast, relatively little research has focused on existing braced frames, even though vintage CBFs may be characterized by distinctly different behavior from modern SCBFs. Component tests of non-compact braces and connections and documented failures during past earthquakes have shown that vintage CBFs may be vulnerable to a number of complex damage states, including limited deformability and energy-dissipation capacity of the braces, potentially brittle connection failures, beam yielding in V- or chevron configurations, etc.

To improve this situation, experiments of complete sub-assemblages of vintage braced frame systems are needed to improve understanding of seismic response, assess the feasibility and efficacy of possible retrofit strategies, and calibrate computational models for future parametric studies. This report presents results of experiments and related analyses performed on vintage CBF specimens. Cyclic quasi-static tests were performed on three full-scale CBF specimens. A common two-story, one-bay configuration was adopted. The first specimen was representative of a pre-1988 CBF incorporating hollow HSS braces. The second specimen was similar, but the HSS braces were filled with concrete. The third specimen incorporated a mast (or *strongback*) retrofit and other features intended to mitigate the weak-story behavior observed in the first two specimens.

The first test structure utilized square HSS braces placed in a "chevron" configuration with one column oriented in strong-axis bending and the other in weak-axis bending. The first specimen was designed according to the 1985 Uniform Building Code; as such, it did not satisfy many requirements of current seismic design codes. These inadequacies were typical of vintage construction and included high brace width-to-thickness ratios, weak gusset connections lacking adequate yield-lines, weak beams designed without consideration of an unbalanced load that may arise due to brace buckling, and no capacity design considerations in proportioning members or connections. This specimen formed a weak story in the second floor, while the rest of the frame experienced only minor yielding and little permanent damage. Both second-story braces buckled–exhibiting considerable local buckling at the brace midpoint–and then fractured within a few additional cycles. Since the imposed story drifts were modest, the frame was subsequently repaired. The fractured second-story braces and gussets were replaced with the same sections.

The new braces in the “second” test specimen were filled with low-strength concrete in an effort to postpone brace local buckling and fracture observed during the first experiment. Net section reinforcement was also added at all the brace-to-gusset connections. Testing of the second specimen also resulted in a weak-story mechanism but in the bottom story. Delayed local buckling and subsequent fracture was observed in one of the bottom-story braces. After fracture of this brace, the frame tended to behave like an eccentrically braced frame (EBF) with a long link beam. This beam provided a relatively weak and flexible energy-dissipating mechanism. Many different local failure mechanisms were observed during subsequent loading cycles, including nearly-complete fracture at one column-to-baseplate interface, significant local buckling, and multiple connection weld and base metal failures.

The third specimen utilized a “strongback” (SB) retrofit aimed at alleviating the weak-story behavior seen in both the first and second experimental tests. The SB system employs a steel truss “backbone” that is designed to remain essentially elastic. This truss enforces similar drift demands in adjacent stories to delay or prevent weak-story behavior. The retrofit design was composed of two halves: an “inelastic” truss utilizing a buckling-restrained brace (BRB) that dissipated seismic input energy and an “elastic” vertical truss designed to control weak-story behavior. The specimen was successful in imposing nearly uniform drifts over the full height of the frame throughout the duration of the test. These preliminary experimental results show that the SB system can be an effective means in limiting weak-story mechanisms.

A number of numerical simulations were calibrated to the experimental results. These analytical models are capable of predicting the observed behavior. The models developed adequately simulated the observed brace global buckling, braces fatigue, column-to-baseplate fracture, and the overall global response of the test specimens.

4 Events and Outreach Activities

PEER organized several events and was involved in numerous outreach activities in the past year. Seven (7) students participated in PEER summer internship program. Several experts presented their work in PEER seminar series. Highlights of the outreach activities are presented in the following sections.

4.1 PEER BIP PROGRAM

Industry and government partners are an integral part of the research program at PEER. For an annual donation, the PEER Business and Industry Partnership (BIP) Program involves members in PEER research and education programs, and provides access to PEER researchers and products. Researchers share individual research plans and findings with partners having similar interests. Business and Industry Partners are invited to present recent projects and technological needs at student-organized seminars, where they also have the opportunity to interact with PEER students and faculty.

Director Mosalam with BIP Members at a Recent Gathering

PEER holds frequent meetings to summarize research progress and seek input on the PEER research program. PEER also runs state-of-the-art and state-of-the-practice workshops on selected topics related to the PEER mission, and invites Business and Industry Partners to attend. Selected representatives of the Business and Industry Partnership plus representatives of key government agencies providing funding for PEER are members of an Industry Advisory Board (IAB), which advises PEER on its strategic plan, its research projects, implementation of research results, and new opportunities for funding.

As one of its strategic goals, PEER is focusing on increasing the depth and breadth of its BIP program, and developing extended ties with the structural firms and state and federal government agencies. The BIP program was revamped in 2017, and an international member (IHI) joined the program. Below is a listing of PEER's current Business & Industry Partners:

Sustaining Partners:

- California Department of Transportation (Caltrans)
- California Earthquake Authority (CEA)
- Pacific Gas & Electric Company (PG&E)

Annual Members:

- Arx-Pax
- Bechtel Corporation
- Degenkolb Engineers
- Exponent
- FM Global
- Forell/Elsesser Engineers, Inc.
- Holmes Structures
- IHI Corporation, Japan
- Micron Optics
- SAGE Engineers
- Skidmore, Owings & Merrill LLP
- Walter P Moore
- Wiss, Janney, Elstner Associates, Inc.

4.2 SUMMER 2017 INTERNSHIP PROGRAM

In the summer of 2017, the PEER Internship Program provided a unique opportunity for seven outstanding undergraduate students from the Universidad del Norte (UNINORTE) and American University of Beirut to participate in state-of-the-art research.

Internship participants were paired with a faculty advisor and a graduate student mentor. Students gained experience on learning how to conduct independent research and given the opportunity to participate as a member of a research team.

Some of the projects the interns participated in this summer included:

- Implementation of Hybrid Simulation with Online Modeling Updating
- Analytical Investigation of the Effect of Time Delay on Real-Time Hybrid Simulation
- Development of a Hydraulic Power Conversion Chain for Ocean Wave Energy Conversion

- Performance-based Evaluation of Infill Wall Effects on Code-designed Reinforced Concrete Frames
- Performance-based Earthquake Engineering Methodology for Informed Decision-Making on Highway Bridge Design and Retrofit
- Analytical Study of the Stability of Thin Walls in Colombian Buildings

4.3 UNR BECOMES A NEW PEER CORE INSTITUTION MEMBER

The University of Nevada, Reno (UNR) was added as a PEER Transitional Core Institution Member by the PEER Institutional Board. The transitional membership status has duration of three years, and at the end of that time, UNR may apply for full Core membership. During the three-year transitional period, the representative of UNR on the Institutional Board will have full voting rights, and UNR will be listed on the PEER website and other documents as one of PEER's Core Institutions.

Research testing facilities at UNR include two geotechnical labs and two structural labs. Research activities include accelerated bridge construction, anchor-zone performance, earthquake protective systems, fluid–structure interaction (FSI/tsunami inundation), innovative materials, non-structural systems, performance-based design, remote sensing, and soil–structure interaction. Faculty work closely with the Technical Committees of the Subcommittee on Bridges and Structures of the American Association of State Highway and Transportation Officials (AASHTO) in Washington DC.

4.4 PEER BRIDGE BENT BLIND PREDICTION CONTEST

In October 2017, PEER organized a blind prediction contest for a bridge bent that consisted of two self-centering resilient columns tested on the PEER UC Berkeley shaking table. Other unique features of the resilient columns were confinement provided by steel jackets, energy dissipation via unbonded rebar yielding, and column rocking allowed at the base.

Nineteen teams participated in the competition, where the numbers of teams in the "Research & Academic" and "Practicing Engineers" categories were 10 and 9, respectively. Information provided to the contestants included structural drawings of the specimen and test set-up; tested material properties for reinforcing (mild and prestressing) steel, concrete, steel shell, and the grout; construction sequence including photographs; properties of the mass blocks; and measured accelerations on the table for each test. The Blind Prediction testing experiment was conducted by a team that consisted of Arpit Nema and Jose Restrepo of UC San Diego and Yingjie Wu, Selim Günay, and Khalid Mosalam of UC Berkeley.

Participating teams were asked to predict 13 response quantities for each of the applied 9 ground motions, which led to a total of 117 quantities. For each predicted quantity, the teams were ranked in the order of increasing error; the 1st, 2nd, 3rd, and 4th teams received 8, 5, 3, and 1 points, respectively. Scores for all quantities were summed for each team, and the teams with the highest score in each category were declared the winners. The winners were announced at the PEER Annual Meeting held at UC Berkeley in January 18–19, 2018.

In addition to the predictions, the contestants were asked to provide a range that they thought the measured response would be within with 80% probability. Statistical evaluation of the competition results is in progress and will be published in the form of scholarly papers and a PEER report soon.

More information about the competition can be accessed from: http://peer.berkeley.edu/prediction_contest/. The experimental results are posted on the contest website, and contestants are encouraged to compare their predictions with these results, update their models according to the test results, and provide any feedback to PEER on improved modeling. Although the competition is completed, information required to develop analytical models and the corresponding experimental results are still available on the website; therefore, members of the earthquake engineering community are welcome to use these data and information to continue developing analytical models.

4.5 PEER-TSRP FUNDS 6 SEED AND 11 FULL PROPOSALS

PEER has continuing funding from the State of California related to the seismic performance of transportation systems. This funding supports the Transportation Systems Research Program (TSRP), the purpose of which is to lessen the impacts of earthquakes on the transportation systems of California, including highways and bridges, port facilities, high-speed rail, and airports. In September 2017, PEER issued a request for proposals, "Solicitation PEER TSRP 17-01" for one- and two-year projects aligned with the current TSRP research priorities and vision.

In response to "Solicitation PEER TSRP 17-01," 47 outstanding proposals were received, covering 16 different issues in the broad domains of: Geotechnical Engineering (G), PBEE of Bridges and Other Transportation Systems (S), PBEE Methodology (M), PBEE Tools (T), and Areas of Application (A). All proposals were grouped into two categories: 13 seed proposals of $50,000 total budget or less and 34 full proposals of more than $50,000 total budget. Each proposal received three independent reviews from members of the PEER Research Committee. Based on the priorities of the pre-set strategic plan, pre-defined evaluation criteria that was specified in the RFP, and factors such as the PI qualifications and level of engagement of as many of the PEER core institutes as possible, 17 new projects were approved: 6 seed projects and 11 full projects, comprising a total of 17 projects funded for over $1 million.

Two of the 11 full projects involve collaborations of PEER core campuses. One project is a collaboration between PEER core campuses Stanford University and UNR, and another project is a collaboration between a PEER core campus, UC Davis and Forell/Elsesser Engineers, a member of PEER Business and Industry Partnership (BIP) program, Awarded projects are listed on the PEER-TSRP website at http://peer.berkeley.edu/transportation/projects/. Details of these projects can be found in Chapter 3, where it can be observed that each project provided a major contribution to the PEER mission individually and holistically.

4.6 PEER-USGS WORKSHOP: HAYWIRED AND BUILDING CODES

On January 17, 2018, PEER partnered with the United States Geological Survey (USGS) to co-host a workshop to identify research needs and opportunities arising from the USGS HayWired Scenario's examination of outcomes of current building code requirements. The HayWired scenario asks, "What if a Magnitude 7.0 earthquake happens on the Hayward Fault starting under Oakland, California, on 4/18/18 at 4:18PM?" In this workshop, participants discussed how scenarios like HayWired can inform a research agenda for the earthquake resilience of new buildings. Experts from many disciplines estimated earth-science hazards, engineering impacts, and socioeconomic consequences of a large earthquake on the country's most urbanized and active fault. Among other products, HayWired estimates the outcome if every Bay Area building met current code requirements before the earthquake occurred, providing a lens through which to view code objectives and options for a more resilient building stock in the future.

4.7 2018 PEER ANNUAL MEETING

The 2018 PEER Annual Meeting was held on January 18–19, 2018, at the International House on the UC Berkeley campus: PEER at 21: The Practice of Performance-Based Engineering for Natural Hazards. This year's meeting featured the role of multi-disciplinary performance-based engineering with seismic and related natural hazards to achieve community resiliency. The meeting opened on Thursday, January 18, with plenary sessions highlighting the role of PEER research in the fields of performance-based engineering and resilience, and the need to identify areas where research and development of technology and tools should be developed for effective decision-making. Plenary sessions included presentations on the following topics:

- • Earthquake Hazard Characterization
- • Performance-Based Engineering: Applications
- • Performance-Based Engineering: Research
- • Engineering and Public Policy for Earthquake Resilient Communities

The first day concluded with the announcement and recognition of two winning teams in the 2017 Blind Prediction Contest, followed by the evening Poster Session & Reception that featured emerging research. An invitation-only dinner for PEER's Business and Industry Partnership (BIP) program participants ended the evening.

On Friday, January 19, concurrent breakout sessions were formatted for more detailed discussion and engagement of PEER-funded researchers and projects, with the goal of creating a synergy of resources and information. Concurrent discussion topics included:

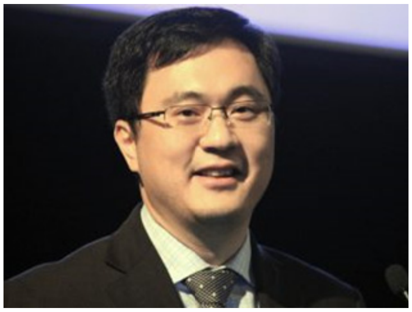
- Buildings
- Characterization of Geohazards
- Bridges
- Designing for Geohazards

The day concluded with a plenary session, "Computational Simulation," followed by reports from the concurrent sessions and final remarks from Director Mosalam.

Both days of the Annual Meeting featured the following Special Presentations:

- PEER – The First Decade – Jack Moehle, UC Berkeley
- Extreme Events Reconnaissance: The Promise and Possibility of Collaborative Social Science and Engineering Research – Lori Peek, Natural Hazards Center
- Learning with Confidence: Theory and Practice of Information Geometric Learning from High-Dimensional Sensory Data – Lin Zhang, Tsinghua-Berkeley Shenzhen Institute

Over 240 attendees at the meeting included researchers, industry stakeholders, practitioners, and students. Presentations and posters can be found on the 2018 PEER Annual Meeting website.



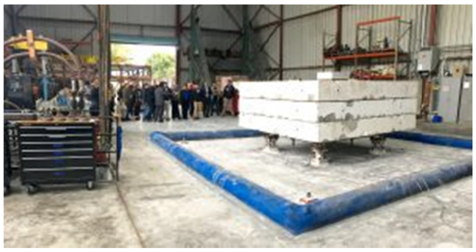
4.8 GADRI MEETING, MARCH 2018, PEER PARTICIPATION

PEER participated in the Global Alliance of Disaster Research Institutes (GADRI) meeting on March 14–15, 2018, held at the Disaster Prevention Research Institute (DPRI) in Uji Campus, Kyoto University, Kyoto, Japan. The first day was devoted to meetings of the Board of Directors, and it included the formation of the GADRI Advisory Board. PEER has transitioned from the Board of Directors to the Advisory Board. The second day was dedicated to an Open Discussion Forum with the following agenda: (1) Outlining GADRI activities and introducing the members of the Board of Directors and Advisory Board; and (2) Facilitating discussion between GADRI members and important stakeholders in disaster risk reduction, including universities, networks, and organizations in collaboration with UN agencies such as UNISDR, UNESCO, and others. Currently, GADRI membership includes 150 institutes from 40 countries. For more details, refer to http://gadri.net/.

Discussing future directions and how to proceed in the next few years, PEER Director Khalid Mosalam gave a talk entitled, *PEER at 21: The Practice of Performance-Based Engineering for Natural Hazards*, where he outlined examples of future PEER initiatives. PEER visiting scholar Dr. Charles Scawthorn introduced the new initiative for GADRI Regional Alliances for North America.

GADRI is a collaborative platform for discussion, sharing knowledge, and promoting networks on topics related to disaster risk reduction and resilience to disasters based on the Sendai Framework for Disaster Risk Reduction 2015–2030. PEER has been an active participant in GADRI and has been on the Board of Directors since GADRI's inauguration in March 2015.

4.9 HYBRID SIMULATION WORKSHOP HOSTED BY PEER AND MTS


MTS Attendees View PEER Shaking Table

PEER, in collaboration with MTS's Lab Expert Seminar Series, held a two-day workshop on March 20–21, 2018, focusing on a comprehensive exploration of hybrid simulation technologies and methods. The event was held at the UC Berkeley Richmond Field Station and had a great turnout, with active participation of 45 attendees.

The first day of the workshop focused on quasi-static (slow) hybrid simulation. The morning session was devoted to lectures that described an overview of the methodology and fundamentals. Presentations in this session included past and future of the methodology, introduction to mechanical hybrid simulation, and description of hybrid simulation techniques. Furthermore, presentations focused on core aspects of the methodology, including substructuring, integration methods, simulation errors and geographically distributed hybrid simulation, and the implementation frameworks OpenFresco and OpenFresco Express. The workshop continued with a lunch presentation describing the current and future states of PEER activities.

After the overview of the methodology and fundamentals in the morning session, afternoon session included quasi-static hybrid simulation applications and demonstrations. Four applications were presented, covering a wide range between a small-component hybrid simulation and a large-scale multi-directional hybrid simulation. Demonstrations started with a description of the control room and the PEER hybrid simulation system, and continued with live tests of a variety of interesting quasi-static hybrid simulation cases, including free-vibration hybrid simulation, geographically distributed hybrid simulation, and local hybrid simulation conduced near collapse.

The second day of the workshop focused on real-time hybrid simulation and hybrid simulation in other industries. Presentations in the morning session included an overview of the theory, development and applications of real-time hybrid simulation in actuator and shaking table configurations, and seismic testing system modeling and control techniques for real-time hybrid simulation. In honor of Professor Steve Mahin, the lunch-time presentation included talks of some of the workshop speakers and attendees that reflect Professor Mahin's valuable contributions to hybrid simulation and to earthquake engineering, academia, and life in general. The afternoon session started with a live demonstration of the real-time hybrid simulation of a tuned mass damper on the PEER 6-DOF shaking table and continued with hybrid simulation applications in other domains, including energy generation from ocean waves, daylighting systems and adaptive façades, and fire hybrid simulation.

The workshop concluded with a one-hour Q&A session, where a panel of seven hybrid simulation experts addressed questions from the audience and discussed the future of hybrid simulation. The panel members were Dr. Shawn Gao (MTS), Dr. Selim Günay (PEER), Mr. Martin LeClerc (Polytechnique Montreal), Professor Khalid Mosalam (PEER), Dr. Andreas Schellenberg (Maffei Structural Engineering), Dr. Shakhzod Takhirov (UC Berkeley), and Dr. Shawn You (MTS). Discussed aspects were the challenges in the current state of hybrid simulation and ways to overcome them, and how to make hybrid simulation easily accessible to the broad engineering community including industry and academia.

PEER and MTS are planning on holding similar workshops in the future. The workshop presentations and demonstrations are posted in the event website and will be compiled in a PEER report.

4.10 FRENCH DELEGATION VISITS PEER

A French delegation of 14 people visited PEER headquarters in Berkeley, California, on February 14, 2018, to learn about PEER activities and global seismic risk. The California-based part of the delegation included Mr. Emmanuel Lebrun-Damiens (French Consul General in San Francisco), Mr. Christophe Lemoine (French Consul General in Los Angeles) and their staff. The international team traveled from Paris and included representatives from the communications and response units of the French Emergency Management Center for French Nationals Abroad.

The delegation was keen to learn how to be better prepared to assist the French communities abroad when there is an earthquake. The Haitian earthquake in 2010 destroyed the French Embassy along with the French Residence, which was the home of the ambassador and diplomatic visitors. Therefore, mitigating the risks for the French population, along with the embassies and consulates, in earthquake-prone areas was of great interest to the delegation.

PEER Director Khalid Mosalam discussed the Center's activities, details of seismic activity around the world, how risk is evaluated, PEER's PBEE methodology, and early warning systems. Director Mosalam also emphasized PEER's ties with the France–Berkeley Fund, as well as the work that was done with sensors as a result of this collaboration. Additionally, Heidi Tremayne, Executive Director of EERI, talked about EERI's efforts in reducing earthquake risks around the world.

Following the presentations, delegates from the international team asked questions about mitigating seismic risk: where to begin, what to do, and how to do it. Questions also arose about sensors and early warning systems. Mr. Philippe Perez, the Attaché for Science and Technology in San Francisco, enquired about the ways they can actively engage with the earthquake engineering community to stay abreast of latest developments. PEER and EERI recommended participation in the upcoming 11NCEE as a way to start participation. PEER will follow up with Mr. Perez in June 2018 about participation in the conference and other related activities.

4.11 PEER HUB IMAGENET (PHI) CHALLENGE

The Pacific Earthquake Engineering Research Center (PEER) organized the first image-based structural damage identification competition: the PEER Hub ImageNet (PHI) Challenge to be announced in the mid-summer of 2018.

In this challenge, two sets of images will be provided to the contestants, one for training and the other for testing. The first set consists of about 20,000 labeled images for different categories, examples of which are structural component type, damage level, and damage type. Each competing team is expected to use/develop algorithms to train their recognition models based on these well-labeled images. The second set consists of 5000 unlabeled images to be labeled by the teams using their trained algorithms. Labels predicted for the test set will be compared against reference labels, and teams with the highest accuracy will be declared the winners of the challenge. Reference labels will be provided by a team of structural experts determined by the competition organization committee. Scoring and other rules will be provided during the formal challenge announcement.

This effort is part of PEER's strategic plan of equipping the earthquake engineering community with tools of the current Digital Revolution Era of Machine Learning, Deep Learning, Artificial Intelligence, and High-Performance Computing. The objective of this challenge is to fully engage the earthquake engineering and other members of the extreme events community at all stages, including preparation of the datasets, execution of the computations, and processing and interpretation of the results. In the datasets preparation stage, members of the community are expected to contribute by uploading images that can be used in the challenge and by labeling these images. To encourage participation to the datasets presentation, PEER hosted a Boot Camp of Machine Learning in Vision-based Structural Health Monitoring, http://apps.peer.berkeley.edu/phichallenge, between May 29th and June 15th, 2018, where around 20 students attended this Boot Camp.

4.12 HAYWIRED SCENARIO ROLLOUT: APRIL 18, 2018


Khalid Mosalam

The HayWired earthquake scenario, led by the U.S. Geological Survey, anticipates the impacts of a hypothetical **M**7 earthquake on the Hayward Fault, with its epicenter in Oakland. The fault is considered the most active and dangerous in the U.S. because it runs through a densely urbanized and interconnected region. The scenario methodology is very similar to PEER's performance-based framework: a hazard is postulated and defined, engineering is applied to determine consequences to buildings, and lifeline networks and social impacts are explored.

The event started with a media tour in Fremont at the Science Center that featured a concrete slab located on top of the Hayward fault to show the displacement of the fault. Later that morning, another media tour was held at UC Berkeley, which highlighted seismic retrofit schemes of two unique and monumental structures: the Hearst Memorial Mining Building, located yards away from the Hayward Fault, and the California Memorial Stadium, which lies on top of the fault. In the afternoon, a press conference was held at the University Club located at the top of Memorial Stadium. HayWired researchers gave an overview of the scenario, followed by a series of responses from leaders, partners, and sponsors. The evening concluded with the Lawson Lecture where the HayWired researchers provided the overview of the scenario to the general public, followed by a question and answer session.


HayWired Attendees, University Club, Memorial Stadium

The HayWired scenario team is building on the engineering analyses to further explore the societal consequences of the **M**7.0 earthquake, and the results are anticipated in October 2018. These issues include impacts on information and communications technology, risks to infrastructure and lifeline networks, community recovery including population displacement and social vulnerability, effects on jobs and the regional economy, and earthquake early warning systems.

PEER looks forward to additional HayWired results to be released in October and will continue to engage the academic, research, and practitioner community with the statewide initiative. Among the documents published to date, the USGS Fact Sheet can be found in https://doi.org/10.3133/fs20183016 and the HayWired Earthquake Scenario reports published so far (Volume I: Earthquake Hazards and Volume II: Engineering Implications) can be found in https://doi.org/10.3133/sir20175013.

4.13 PEER PARTICIPATION AT THE 11NCEE, JUNE, 2018

11NCEE
LA2018
11th National Conference
on Earthquake Engineering
integrating science, engineering, & policy
June 25–29, 2018

Many PEER-affiliated researchers participated at the 11th National Conference on Earthquake Engineering held in Los Angeles, California, on June 2 –29, 2018. Over a dozen faculty, post-docs, and students presented their work on PEER-funded research. Additionally, over 70 PEER-affiliated researchers from PEER core institutions as well as other institutions throughout the world presented and shared posters during the conference.

The PEER exhibit booth was well attended, with scheduled “Meet the Expert” sessions held during the morning and afternoon breaks, as well as impromptu gatherings with researchers and practitioners. Scheduled experts included Dimitrios Lignos, Jack Baker, Jonathan Stewart, I. M. Idriss, Vesna Terzic, Erica Fisher, Barbara Simpson, Tali Feinstein, Hong-Kie Thio, and Selim Günay.

A special session titled, “Steve Mahin Retrospective,” was held Thursday morning, in honor of former PEER Director Mahin. The session was moderated by Jim Malley (Degenkolb Engineers) and Jack Moehle (UC Berkeley, former PEER Director). Speakers included Mahin’s first Ph.D. student as well as his most recent Ph.D. students. Members of the audience were also invited to share their memories of Steve.

Norm Abrahamson, UC Berkeley, delivered Wednesday’s Plenary Session Presentation, “What Changes to Expect in Seismic Hazard Analyses in the Next 5 Years.” Maryann Phipps, Estructure, delivered Thursday’s Plenary Session Presentation, “Seismic Risk: Towards Performance-Based Construction—Better Buildings by Design,” and mentioned the broad range of analysis results recently illustrated by submittals to the 2017 PEER Blind Prediction Contest. Selim Günay, PEER, presented “Deep Residual Network with Transfer Learning for Image-based Structural Damage Recognition,” and introduced the PEER PHI Challenge that will have more details announced on July 15, 2018.

4.14 PEER SEMINARS

4.14.1 Structural Health Monitoring of Composite Structures: Application to Aeronautic Nacelles

Nazih Mechbal

Nazih Mechbal presented this seminar on May 19, 2017, and he focused on Structural Health Monitoring (SHM) systems for complex composite structures with an application to elements of aeronautical nacelles. The ability to monitor autonomously the health of complex structures such as aeronautic or civil engineering structures in real time is becoming increasingly important. This process relies on onboard platforms comprising sensors, actuators, computational units, and communication resources. The SHM process is typically divided into four steps: damage detection, damage localization, damage classification, and damage quantification.

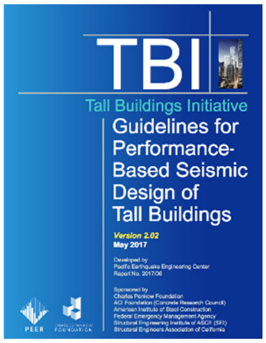
The main parts of the nacelle concerned with the proposed approach are the fan cowl (composite monolithic) and the inner fixed structure (IFS, sandwich structure with honeycomb core) of the thrust reverser. These structures—made from composite materials—are subjected to many types of damage, which can reduce the useful life of a nacelle (fiber breakage, delamination, crack, etc.). Furthermore, these structures are exposed to many environmental constraints such as changing thermal variations (from -55°C to +120°C). The challenge addressed in this talk was to develop and validate a SHM system able to detect and localize damage before the degradation of the whole structure occurs, independently of the ambient temperature.

4.14.2 Probabilistic Risk Assessment of Petrochemical Plants under Seismic Loading

Fabrizio Paolacci

Fabrizio Paolacci in this seminar on July 24, 2017, discussed the vulnerability of the urbanized territory against Na-Tech events, which represents a strategic issue because of the general unpreparedness of the countries in predicting effects and consequences in the aftermath of a disaster. Despite the continuous evolution of knowledge on this matter, there is lack information about possible procedures to predict damage propagation within a processing plant and in the surrounding areas, and the quantification of the risk under Na-Tech events. The effects of earthquakes on chemical plants is important, as demonstrated by the recent 2011 Tohoku Earthquake, where many industrial plants suffered losses from damage. It is known that the classical Quantitative Risk Assessment (QRA) methods cannot be applied to evaluate consequences in case of earthquakes because of the presence of multi-damage conditions in multiple equipment, and the generation of multiple-chains of events and consequences. In literature, several attempts to modify the classic QRA approach have been formalized but without converging toward a unified approach. This seminar presents a new tool for the probabilistic risk assessment methodology for petrochemical plants under seismic loading, which is based on Monte Carlo simulations. Specifically, starting from the seismic hazard curve of the site, a multi-level approach is proposed in which the first level is represented by the components seismically damaged, and the following levels are treated through a classical consequence analysis that includes propagation of multiple simultaneous and interacting chains of accidents. The procedure has been implemented in PRIAMUS software, which assumes that the accident may be represented by a sequence of propagation “levels.” With a series of automatically generated samples of damage propagation scenarios, the risk of the plant can be easily quantified. The application of this method to a petrochemical plant shows the potential of the method and envisages possible further evolutions.

4.15 PEER SEMINAR: TBI GUIDELIINES FOR PERFORMANCE-BASED SEISMIC DESIGN OF TALL BUILDINGS VERSION 2.03


TBI
Tall Buildings Initiative
Guidelines for Performance-Based Seismic Design of Tall Buildings
Version 2.02
May 2017
Developed by
Pacific Earthquake Engineering Center
Report No. 2017/06
Sponsored by
Charles Pankow Foundation
ACI Foundation (Concrete Research Council)
American Institute of Steel Construction
Federal Emergency Management Agency
Structural Engineering Institute of ASCE (SEI)
Structural Engineers Association of California
PEER
CHARLES PANKOW FOUNDATION

PEER partnered with the Structural Engineers Association of California (SEAOC) Foundation and the Structural Engineers Association of Washington (SEAW) to co-host seminars to introduce the PEER-managed Tall Buildings Initiative project “TBI Guidelines for Performance-Based Seismic Design of Tall Buildings, Version 2.03.”

This seminar highlighted revisions incorporated into the just published Pacific Earthquake Engineering Research (PEER) *Report No. 2017/06*: “Guidelines for Performance-Based Seismic Design of Tall Buildings, Version 2.03,” prepared by a TBI Working Group led by co-chairs Ron Hamburger and Jack Moehle, with contributions from Jack Baker, Jonathan Bray, C.B. Crouse, Greg Deierlein, John Hooper, Marshall Lew, Joe Maffei, Stephen Mahin, James Malley, Farzad Naeim, Jonathan Stewart, and John Wallace.

These guidelines present a recommended alternative to the prescriptive procedures for seismic design of buildings contained in the ASCE 7 standard and the International Building Code (IBC). Properly executed, these Guidelines are intended to result in buildings that are capable of reliably achieving or exceeding the seismic performance objectives intended by ASCE 7, and in some aspects where specifically noted for Risk Categories II, III, and IV. The Pacific Earthquake Engineering Research Center published a first edition of these Guidelines in 2010 in response to the growing use of alternative performance-based approaches for seismic design of tall buildings. Newly released Version 2.03 addresses new knowledge including lessons learned in application of the first edition on many projects.

The seminars were held on October 24 (San Francisco with webcasts in San Diego and Sacramento), November 2 (Seattle), and November 28, 2017 (Los Angeles). Over 200 seminar participants included structural engineers and building officials engaged in seismic design and review of tall buildings. Attendees received a copy of the presentations, a hardcopy of the updated Guidelines, and 4 PDHs.

5 Technology Tools and Resources

5.1 OPENSEES

The Open System for Earthquake Engineering Simulation (OpenSees) is a software framework for simulating the seismic response of structural and geotechnical systems. OpenSees has been developed as the computational platform for research in performance-based earthquake engineering at PEER. The goal of the OpenSees development is to improve modeling and computational simulation in earthquake engineering through open-source development.

OpenSees has advanced capabilities for modeling and analyzing the nonlinear response of systems using a wide range of material models, elements, and solution algorithms. The software is designed for parallel computing to allow scalable simulations on high-end computers or for parametric studies.

OpenSees provides beam–column elements and continuum elements for structural and geotechnical models. A wide range of uniaxial materials and section models are available for beam/columns. Nonlinear analysis requires a wide range of algorithms and solution methods, and OpenSees provides a large variety of nonlinear static and dynamic methods, equation solvers, and methods for handling constraints.

As an open-source framework, OpenSees provides a computational environment for researchers from different disciplines and different parts of the world to work together, helping bind the PEER earthquake engineering community together. It is under continual development, so users and developers should expect changes and updates on a regular basis. In this sense, all users are developers so it is important to register. The OpenSees website provides information about the software architecture, access to the source code, the development process, detailed explanations of the included materials, elements, solution algorithms, etc., along with a large variety of basic and advanced examples. OpenSees fosters development of community-based modeling and simulation methods that have advanced simulation capabilities and integrated structural and geotechnical engineering disciplines. PEER provides support to users through the OpenSees Days workshops and via OpenSees Community message board.

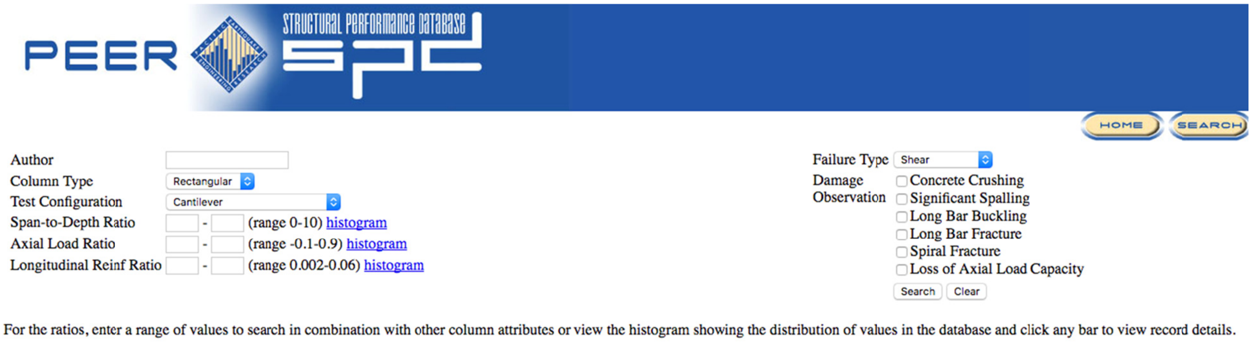
New Functionality to OpenSees

OpenSees continued to grow in the past year with many additions from the community. A full list of contributions can be found at: http://opensees.berkeley.edu/OpenSees/changeLog.php. A few examples are indicated below.

- Element Modeling: MVLEM, SFI_MVLEM multiple vertical line element models to model shear walls, *ComponentElement2D* to combine *zeroLength* hinges at ends with an elastic element.
- UniaxialMaterial: *ConcreteD, ConcreteCM, SteelMPF*, and *BilinearOilDamper*
- Solvers: New GPU solvers, CulaS4 and CulaS5, SimpsonsTimeSeriesIntegrator

5.2 DATABASES

5.2.1 Structural Performance Database



Author
Column Type: Rectangular
Test Configuration: Cantilever
Span-to-Depth Ratio ☐ - ☐ (range 0-10) histogram
Axial Load Ratio ☐ - ☐ (range -0.1-0.9) histogram
Longitudinal Reinf Ratio ☐ - ☐ (range 0.002-0.06) histogram

Failure Type: Shear
Damage Observation
☐ Concrete Crushing
☐ Significant Spalling
☐ Long Bar Buckling
☐ Long Bar Fracture
☐ Spiral Fracture
☐ Loss of Axial Load Capacity

For the ratios, enter a range of values to search in combination with other column attributes or view the histogram showing the distribution of values in the database and click any bar to view record details.

This site (nisee.berkeley.edu/spd) provides the results of over 400 cyclic, lateral-load tests of reinforced-concrete columns. The database describes tests of:

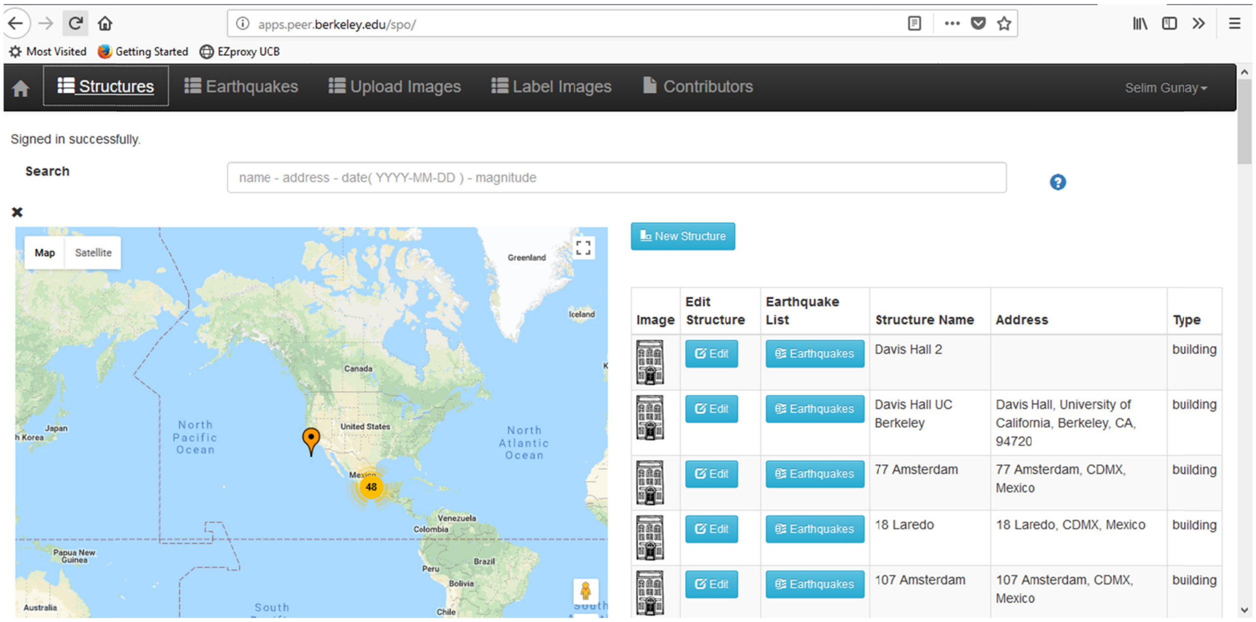
- spiral or circular hoop-reinforced columns (with circular, octagonal, or rectangular cross sections)
- rectangular reinforced columns
- columns with or without splices

5.2.2 Seismic Performance Observatory (SPO)

SPO is an application for storing and searching post-earthquake damage information. The objective of SPO is to

- have a centralized, accessible and scalable database
- have information of post-earthquake damage like videos, pictures, data, etc., of structures
- provide data obtained from earthquakes at magnitudes of 5.5 and up that have occurred since 1900 and linked to structures
- provide pre-earthquake data for comparison purposes
- unify the post-earthquake data collection efforts

SPO has been effectively used in the field by several reconnaissance teams after the 2017 Mw7.1 Puebla, Mexico Earthquake.



Signed in successfully.

Image	Edit Structure	Earthquake List	Structure Name	Address	Type
	Edit	Earthquakes	Davis Hall 2		building
	Edit	Earthquakes	Davis Hall UC Berkeley	Davis Hall, University of California, Berkeley, CA, 94720	building
	Edit	Earthquakes	77 Amsterdam	77 Amsterdam, CDMX, Mexico	building
	Edit	Earthquakes	18 Laredo	18 Laredo, CDMX, Mexico	building
	Edit	Earthquakes	107 Amsterdam	107 Amsterdam, CDMX, Mexico	building

5.3 NISEE / PEER LIBRARY

The National Information Service for Earthquake Engineering (NISEE) /PEER library is an affiliated library of UC Berkeley, specializing in structural engineering, geotechnical engineering, structural dynamics, engineering seismology, and earthquake public safety. In 1971, the NISEE-PEER Library opened its doors at the Richmond Field Station and began its mission of serving the information needs of the earthquake engineering community. The NISEE-PEER Library houses a large, specialized physical collection of library materials in addition to the NISEE-PEER Online Archive. Researchers worldwide can access this vast database ($25 annual membership) of earthquake, structural, seismology, geotechnical and public policy engineering research literature, as well as research software, images, and video recordings.

The NISEE–PEER Library originally began in 1971 as a public service project, the National Information Service for Earthquake Engineering (NISEE), with two facilities: one at the Earthquake Engineering Research Center (EERC), University of California, Berkeley, at the Richmond Field Station and another at the Earthquake Engineering Research Laboratory of the California Institute of Technology, Pasadena, California. The physical collection of the library began with the generous contributions of UC Berkeley Professors Ray W. Clough and Joseph Penzien, followed by numerous donations through the years.

Woodcut showing effects of earthquakes Jan Kozak Collection

In 2008, EERC merged with the Pacific Earthquake Engineering Research Center (PEER) becoming the NISEE–PEER Library. Particularly unique to this collection are numerous images donated by UC Berkeley Professors Karl Steinbrugge and Bill Godden, and Geophysicist Jan Kozak, which have been digitized by library staff. Many other image collections have been donated to the library from students, professors, engineers in the community, and Caltrans.

Professor Vitelmo Bertero's tutorial, *An Introduction to Earthquake Engineering*, is also available through the archive, as well as EERC, SEMM, PEER, and UC Berkeley Geotech reports, which include seminal research in earthquake, structural and geotechnical engineering done at UC Berkeley since 1967. Research reports are also available digitally. More information can be found online at https://nisee.berkeley.edu/elibrary.

6 Facilities and Resources

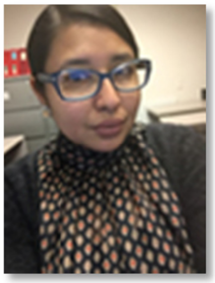
6.1 KEY PERSONNEL (HEADQUARTERS)

Khalid Mosalam
Director

Amarnath Kasalanati
Associate Director for Operations & Strategic Initiatives

Darlene Wright
Administrative Director
(Retired in Jan 2018)

Grace Kang
Communications Director



Zulema Lara
Financial Analyst and Subaward Coordinator

Erika Donald
Electronic Communications & Web Specialist

Selim Günay
Project Scientist

Frank McKenna
Chief Information Officer/Manager

Gabriel Vargas
Database Specialist

Christina Bodnar-Anderson
Library & Information Services

Claire Johnson
Technical Editor

Alex Mead
Lab Manager

Robert Cerney
Laboratory Mechanician

Lobsang Garcia
Laboratory Mechanician

Nathaniel Knight
Development Technician

6.2 PEER STAFF RESEARCH ENGINEERS AND PROJECT SCIENTISTS

Tadahiro Kishida
Assistant Project Scientist

Laurie Johnson
Visiting Project Scientist

Nicolas Kuehn
Assistant Project Scientist

Silvia Mazzoni
Visiting Assistant Researcher

Sifat Sharmeen Muin
Research Engineer

Martin Nuenschwander
Visiting Post-doctoral Fellow

Sharyl Rabinovici
Visiting Researcher

Charles Scawthorn
Visiting Research Engineer

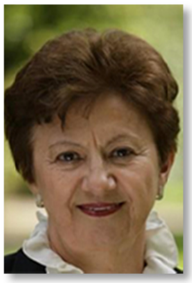
Andreas Schellenberg
Research Engineer

Matthew Schoettler
Research Engineer

Tsubasa Tani
Visiting Scholar

6.3 INSTITUTIONAL BOARD

The Institutional Board members, listed in the following page, are appointed by the Dean of the College of Engineering or an appropriate Department Chair at the respective core institution and represent PEER researchers at their institution. General duties of the Institutional Board are to provide policy level guidance and oversight for the Center with a goal to help PEER fulfill its mission.



Anne Kiremidjian
Chair, Institutional Board
Stanford University

Dominiki Asimaki
California Institute of Technology

Ian Buckle
University of Nevada,
Reno

Joel P. Conte
University of California, San Diego

Rakesh Goel
Educational Affiliate Representative
CalPoly

Erik A. Johnson
University of Southern California

Sashi Kunnath
University of California, Davis

Dawn Lehman
University of Washington

Jack Moehle
University of California, Berkeley

Michael Scott
Oregon State University

John Wallace
University of California, Los Angeles

Farzin Zareian
University of California, Irvine

6.4 RESEARCH COMMITTEE

The Pacific Earthquake Engineering Research Center (PEER) is a multi-campus research center that has continuing funding from the State of California related to the seismic performance of transportation systems. This funding supports the Transportation Systems Research Program (TSRP), the purpose of which is to lessen the impacts of earthquakes on the transportation systems of California, including highways and bridges, port facilities, high-speed rail, and airports. Funding from the TSRP supports transportation-related research that uses and extends PEER's performance-based earthquake engineering (PBEE) methodologies, and integrates fundamental knowledge, enabling technologies and systems. The program also aims to integrate seismological, geotechnical, structural, hydrodynamic and socio-economical aspects of earthquake and tsunami engineering, and involve theoretical, computational, experimental, and field investigations. The program also encourages vigorous interactions between practitioners and researchers.

The PEER TSRP is coordinated by a Research Committee (PEER-RC) consisting of Pedro Arduino (University of Washington), Jack Baker (Stanford University), Judy Liu (Oregon State University), Khalid Mosalam (ex-officio, University of California, Berkeley), Gilberto Mosqueda (University of California, San Diego), and Tom Shantz (ex-officio, Caltrans). In addition, Amarnath Kasalanati and Selim Günay of PEER helped the committee with organization of proposals, assignment and compilation of the reviews.

Pedro Arduino
University of Washington

Jack Baker
Stanford University

Judy Liu
Oregon State University

Gilberto Mosqueda
University of California, San Diego

Tom Shantz
Ex-Officio Member
Caltrans

Khalid Mosalam
Ex-Officio Member
University of California, Berkeley

Amarnath Kasalanati
Assigning and Compilation of Reviews
PEER/UC Berkeley

Selim Günay
Compilation of Reviews
PEER/UC Berkeley

6.5 PEER LABORATORIES AT UC BERKELEY

As an Organized Research Unit (ORU) under the College of Engineering at University of California, Berkeley, PEER operates the following laboratories.

6.5.1 Earthquake Simulator Laboratory

The signature piece of testing equipment at the PEER–UC Berkeley Lab is the six degree-of-freedom shaking table, the largest in the U.S., and one of the largest in the world. The PEER-UC Berkeley Lab also houses a large-scale structures lab consisting of a 20 ft × 60 ft strong floor with an integrated, reconfigurable, modular reaction wall. A comprehensive inventory of both static and dynamic hydraulic actuators, ranging from 5 kips to 2000 kips, along with an inventory of other test hardware and components are available to accommodate both simple single-degree-of-freedom test set-ups as well as multi-axis custom test configurations. In addition, the PEER–UC Berkeley Lab houses large and small damper test machines, a 200-kip and a 4000-kip uniaxial load frame, along with all of the associated control, measurement, and data acquisition equipment required to operate the lab's various test machines. The PEER facility also houses a micro lab for smaller-scale experiments in self-equilibrating testing frames. The PEER–UC Berkeley Lab is at the forefront in the development of both the hybrid simulation test method and digital image processing for the measurement of continuous strain fields.

The PEER–UC Berkeley Lab demonstrates best-practice protocol in its general lab operation and maintains an IAS accreditation, related to the shaking table testing of both AC-156 and IEEE-693 test protocols. The PEER–UC Berkeley Lab has a long history of successfully providing the engineering community testing facilities, the staffing expertise to execute a given project in a timely manner, and the academic background to provide appropriate data analysis, design input, and overall project management. The PEER–UC Berkeley Lab is available to write both academic style reports, along with AC156 and IEEE-693 reports submitted to regulatory agencies, refer to the "Service to Industry" web page for more information. A welding shop, machine shop and electronics shop, along with dedicated control rooms, conference rooms, and a suite of offices are also located at the PEER–UC Berkeley Lab facility.

The PEER-UC Berkeley Labs are available to both the research community and to private industry that may require large-capacity testing services. Published recharge rates are utilized in the development of project budgets. Priority in scheduling a given test always favors the research community, and time is made available to commercial clients on a time-available basis.

6.5.2 Service-to-Industry

In addition to regular research work (e.g., the resilient bridge bent used in the Blind Prediction Competition), PEER Labs at UC Berkeley partner with private industry and perform shaking table testing of critical equipment, e.g., emergency power generators, air handlers, and substation electrical equipment under varying earthquake excitations. The shaking table testing is performed to ensure compliance with seismic regulations and to confirm the effectiveness of seismic retrofit strategies with the goal of reducing damage and injury in the event of an earthquake.

The 6-DOF shaking table is accredited by International Accreditation Services (IAS) to perform the following test protocols:

(i) IEEE693, Recommended Practice for Seismic Design of Electrical Substations: these recommendations include discussion of qualification of each equipment type;

(ii) AC156, Seismic Certification by Shake-table Testing of Non-structural Components: This standard establishes criteria for a specific input motion, duration, and range of frequencies to which nonstructural components should be subjected;

(iii) Panel testing per ASTM E2126-11, Standard Test Methods for Cyclic (Reversed) Load Test for Shear Resistance of Vertical Elements of the Lateral Force Resisting Systems for Buildings; and

(iv) Beam–Column and Steel Frame Testing per ANSI/AISC 341-10, Chapter K, Pre-qualified Connections for Special and Intermediate Steel Moment Frames for Seismic Applications.

A select list of companies that have performed testing recently at the PEER laboratories includes the following:

- W.E. Gundy & Associates
- US Gypsum
- The VMC Group
- TRU Compliance
- Manwill Engineering LLC
- CW Iron, Inc.
- IEM (Industrial Electric Mfg)
- Tesla Motors
- CEL Consulting
- Dynamic Certifications Lab (DCL)
- Sonoma Cast Stone
- Tobolski Watkins Engineering

Disconnect Switch Testing

6.6 FACULTY PARTICIPANTS

6.6.1 Faculty Participants (Core Institutions)

University of California, Berkeley (Headquarters)

Norm Abrahamson
M. Reza Alam
Richard Allen
Abolhassan Astaneh-Asl
Alexander Bayen
Yousef Bozorgnia
Jonathan Bray
Anil Chopra
Mary Comerio
Armen Der Kiureghian
James Kelly
Shaofan Li
Stephen Mahin
Jack Moehle
Paulo J.M. Monteiro
Khalid Mosalam
Doug Dreger
Filip Filippou
Sanjay Govindjee
Peggy Hellweg
Roberto Horowitz
Dwight Jaffee
Mark Wilfried Mueller
Claudia Ostertag
Juan Pestana
Michael Riemer
Ray Seed
Nicholas Sitar
Kenichi Soga
David Sunding
Tarek Zohdi

California Institute of Technology

Jose Andrade
Domniki Asimaki
James Beck
John Hall
Thomas Heaton
Wilfred Iwan
Paul Jennings

Oregon State University

Scott Ashford
Andre Barbosa
Judy Liu
Ben Mason Michael Olson
Michael Scott
Harry Yeh
Solomon Yim

Stanford University

Jack Baker
Sarah Billington
Gregory Deierlein Anne
Kiremidjian
Kincho Law
Eduardo Miranda

University of California, Davis

Ross Boulanger
Rob Y.H. Chai
Jason deJong
I.M. Idriss
Boris Jeremíc
Amit Kanvinde
Sashi Kunnath
Bruce Kutter
Kenneth Loh
Brian Maroney

University of California, Irvine

Anne Lemnitzer
Ayman Mosallam
Farzad Naeim
Farzin Zareian

University of California, Los Angeles

Scott Brandenberg
Robert Kayen
Jonathan Stewart Ertugrul
Taciroglu
John Wallace
Jian Zhang

University of California, San Diego

Joel Conte
Ahmed Elgamal
Patrick Fox
Tara Hutchinson
J. E. Luco Gilberto Mosqueda
José Restrepo
Pui-Shum Shing
Chia-Ming Uang
Yael Van Den Einde

University of Southern California

Gregg Brandow
Roger Ghanem
Tom Jordan
Erik Johnson
Patrick Lynett
Sami Masri
James Moore
Costas Synolakis
Carter Wellford

University of Washington

Pedro Arduino
Jeffrey Berman
Paolo Calvi
Marc Eberhard
Michael Gomez
Steve Kramer
Dawn Lehman
Laura Lowes
Peter Mackenzie
Brett Maurer
Peter May
Mike Motley
Kamran Nemati
Dorothy Reed
Charles Roeder
John Stanton
Richard Wiebe

University of Nevada, Reno

Ian Buckle
Ahmed Itani
Ramin Motamed
Mohamed Moutafa
Gokhan Pekcan
David Sanders
Keri Ryan
Saiid Saidii

6.6.2 Faculty Participants (Affiliate Institutions and Outside Organizations)

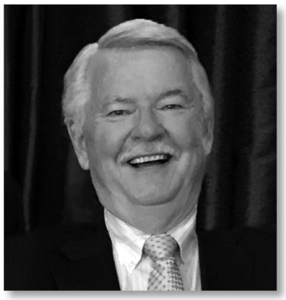
Boston College	John Ebel
Brigham Young University	Kyle Rollins
California State University, Chico	Curt Haselton
California State University, Long Beach	Lisa Star Vesna Terzic
Florida International University	Arindam Chowdhury
Johns Hopkins University	Judith Mitrani-Reiser (NIST)
McMaster University	Tracy Becker Dimitrios Konstantinidis
Sacramento State University	Benjamin Fell
San Diego State University	Steven Day
San Jose State University	Thalia Anagnos Kurt McMullin
University at Buffalo-SUNY	Michael Constantinou Andre Filiatrault Andrew Whittaker
University of California, Santa Barbara	Ralph Archuleta Jamison Steidl
University of Central Florida	Kevin Mackie Nicos Makris
University of Florida	Forrest Masters David Prevatt
University of Hawaii, Manoa	Ian Robertson
University of Illinois	Youssef Hashash
University of Memphis	Chris Cramer Shahram Pezeshk
University of Texas at Austin	Gregory Fenves Ellen Rathje Kenneth Stokoe
Virginia Tech University	Martin Chapman Adrian Rodriguez-Marek
Western University, Canada	Gail Atkinson

6.6.3 Industry Partners

AECOM (formerly URS Corporation)	Hong Kie Thio
AMEC Foster Wheeler	Brian Chiou Marshall Lew Robert Youngs
Bechtel	Alidad Hashemi James Marrone Farhang Ostadan
California Dept. of Transportation	Mark Mahan Tom Ostrom Tom Schantz Charles Sikorsky
California High-Speed Rail Authority	Kevin Thompson
California Seismic Safety Commission	Fred Turner
Canterbury Earthquake Recovery Authority (CERA)	Roger Sutton
Forell/Elsesser Engineers	Simin Nasseh Mason Walters
Image Cat	Bill Graf
Mar Structural Design	David Mar
NIST	Steve Cauffman Judith Mitrani-Reiser
Pacific Engineering & Analysis	Robert Darragh Walt Silva
Rutherford + Chekene	Bill Holmes Bret Lizundia
Simpson Gumpertz & Heger	Ron Hamburger Gayle S. Johnson Ron Mayes
Skidmore, Owings & Merrill	Peter Lee Mark Sarkisian
Tipping Structural Engineers	Leo Panian Steve Tipping
U.S. Geological Survey	Brad Aaagard Mehmet Celebi Dale Cox
U.S. Resiliency Council	Evan Reis

7 In Memoriam: Stephen A. Mahin (1946–2018)

PEER and the earthquake engineering community lost a legend this year, Stephen A. Mahin, former director of PEER.



Stephen A. Mahin

Stephen A. Mahin, the Byron L. and Elvira E. Nishkian Professor Emeritus of Structural Engineering in the Department of Civil and Environmental Engineering at the University of California, Berkeley, passed away on February 10, 2018.

He was a world-renowned expert in earthquake engineering, with wide-ranging teaching, research, and professional practice contributions in the characterization of earthquake strong ground motion; numerical modeling, computer simulation, and innovative structural testing methods for severe loading environments; inception and development of earthquake-protective systems; behavior and design of structural steel, reinforced concrete, and timber construction with applications in buildings, bridges, power plants, and offshore structures; and performance-based earthquake engineering.

Professor Mahin was born in Lodi, California, and attended school in Pacific Grove, California. He started undergraduate studies in Civil Engineering at the University of California (UC), Berkeley in 1964, earning his BS (Honors, 1968), MS (1970), and Ph.D. (1974). He worked as an Assistant Research Engineer at UC Berkeley from 1974–1977, then joined the faculty as Assistant Professor in 1977. At UC Berkeley, he served as the Chair of the Structural Engineering, Mechanics, and Materials (SEMM) Program (1990–1993), and was Director of PEER – the Pacific Earthquake Engineering Research Center (2009–2015).

In 2016, he became the founding Director of the Computational Modeling and Simulation Center (SimCenter) of the Natural Hazards Engineering Research Infrastructure, funded by the National Science Foundation. Under his visionary leadership, the SimCenter assembled a talented multi-university team of researchers to advance simulation methods to reduce effects of natural hazards on the built environment, with the ultimate aim to inform decision making to improve community resilience to earthquakes, storms, and other extreme hazards. The SimCenter is now under the co-directorship of Professor Greg Deierlein (Stanford University) and Professor Sanjay Govindjee (UC Berkeley), who are humbled by their new role, and who intend to carry out Steve's visionary efforts to transform research in natural hazards engineering.

Dr. Mahin's research focused on improving the understanding of seismic behavior of systems by integrating high-performance numerical and experimental simulation methods. He pioneered the development of hybrid simulation theories and methods that integrated large-scale physical tests with computer simulations, thereby enabling study of complete structural systems under realistic loading.

He recognized the value of seismic isolation and protective systems, and conceived and developed these technologies with the goal of reducing costs and enhancing seismic performance. He was active in adapting supplemental viscous damping, added mass damping, and seismic isolation systems to the needs of actual building projects.

Professor Mahin published hundreds of journal articles, papers, and reports, and the range of topics reflects the comprehensive and broad expanse of his research engagement.

In 1983 he was awarded the ASCE Walter Huber Civil Engineering Research Prize for his practical application of rigorous theory to complex engineering problems. In 1987 he was awarded the Norman Medal by ASCE for his seminal work on the seismic behavior of offshore platforms, and in 2012 he was inducted into the ASCE/OTC Hall of Fame. His pioneering work on self-centering bridges earned him the FHWA James Cooper Best Paper Award in 2007.

The American Institute of Steel Construction (AISC) honored him with its Special Educator Achievement Award in 2001 for leadership in improving steel structures subjected to earthquakes, and its Lifetime Achievement Award in 2013 for sustained contributions to the profession, industry, and academia. He was recognized for innovative research related to the seismic behavior of conventional and buckling restrained braced frames as well as moment-frame structures. He served as program manager for the six-year FEMA-sponsored SAC Steel Project that developed guidelines for the design of steel moment-frame structures following the 1994 Northridge earthquake. The SAC guidelines and supporting documents led directly to major changes to the AISC seismic design standards that are used in the United States and worldwide, and that will greatly improve the performance of steel buildings in future earthquakes.

Dr. Mahin served as President of CUREe (1994–1997), Vice-President of the Association for Steel-Concrete Composite Structures (1997–2000), and recently served as Vice President of the International Association for Experimental Structural Engineering. He served as a Director of the Structural Engineers Association of Northern California (SEAONC), and was awarded SEAONC's Helmut Krawinkler Award (2017) for outstanding leadership in implementing state-of-the-art research into structural engineering practice. The Northern California Chapter of the Earthquake Engineering Research Institute (EERI) recognized Steve as its 2017 Individual Awardee for Leadership, Innovation, and Outstanding Accomplishments in Earthquake Risk Reduction for decades of visionary work in engineering research and teaching.

Dr. Mahin chaired the NEHRP Northridge Earthquake Engineering Research Coordination Program (1995–1997). He worked tirelessly on behalf of the US–Japan cooperative programs, opening the door for US participation in landmark experiments at Japan's E-Defense facility, resulting in the NEES/E-Defense collaboration. He chaired the NSF US–Japan Cooperative Earthquake Research Program on Composite and Hybrid Structures (1995–1999), and NEES/E-Defense Collaborative Research Program since 2004.

He had a deep interest and unique talent to interact and make friends with fellow researchers throughout the world. Many international research collaborations with Asia, including China, Japan, Korea, Singapore, and Taiwan, among others, were initiated and nurtured by his leadership. Over three decades he enlightened, guided, and led multiple phases of US–Japan research collaboration on earthquake engineering using large-scale test facilities operated by the two countries.

Dr. Mahin was named a Master Academician (2014) by Tongji University of Shanghai, China. The title is given to the top 100 professors internationally in all fields of the National Natural Science Foundation of China (NSFC). He was Director of ILEE–International Joint Research Laboratory of Earthquake Engineering, located at Tongji University.

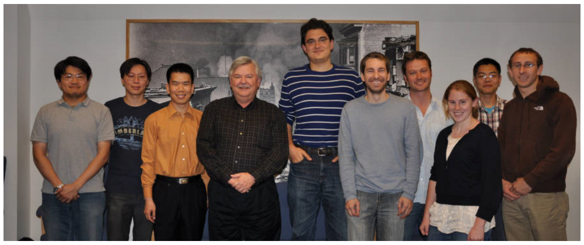
Dr. Mahin was invited to give keynote addresses at several national and international conferences. Notable among his recent addresses was the opening keynote lecture at 16WCEE in Santiago, Chile (January 2017), on "Resilience by Design: A Structural Engineering Perspective." The lecture reflected his unique perspective, which included disciplines beyond structural engineering.

He delivered the opening keynote lecture at the Structural Engineering Frontiers Conference (SEFC17) at the Tokyo Institute of Technology on March 2017, on recent advances in the use of computer-enabled optimization to enhance the seismic performance of existing tall buildings using fluid viscous dampers. The conference brought together more than 200 academic and professional engineering experts from Japan and abroad to discuss emerging trends in structural engineering.

Professor Mahin gave a keynote address at National Center for Research in Earthquake Engineering (NCREE) in Taiwan (August 2017), at the opening of their new earthquake simulation laboratory. Mahin discussed lessons from recent disastrous earthquakes, and their implications for research over the next several decades. He also highlighted recent work by his research group on hybrid simulation using large scale test machines and shaking tables, like those in the new NCREE laboratory.

Steve Mahin’s life includes many achievements, and the list would not be complete without mentioning his sons, Jeff and Colin, two fine men prominent in Steve’s life and heart, and of whom he was very proud.

Professor Mahin was an engaging mentor of numerous students over his long career. His students recall that he taught them to see problems with ten solutions instead of one solution, to always think outside of the box, and to never shrink from sharing new and thought-provoking ideas. A meeting or casual encounter with Professor Mahin could generate ideas leading to decades of research. National and international travel to engage the broad earthquake community were a regular part of graduate student training with Professor Mahin.



During his nearly 50-year career at Berkeley and with international activities, Professor Mahin taught, advised, and mentored generations of students, postdoctoral fellows, research associates and colleagues, and practicing engineers. His broad range of interests also engaged social scientists and stakeholders. His creative approach, collaborative spirit, and enthusiastic generosity in sharing his prolific ideas have inspired everyone who has spent time with him, and he will leave his mark on the profession for years to come.

Appendix A List of Sub-Award Projects (Prior 5 Years)

Fund Source	PI	Institution	Project Title
TSRP	Jose Andrade	Cal Tech	Micro-Inspired Continuum Modeling Using Virtual Experiments
TSRP	Brett Maurer	University of Washington	Towards Multi-Tier Modeling of Liquefaction Impacts on Transportation Infrastructure
TSRP	Pedro Arduino	University of Washington	Implementation and Validation of PM4Sand in OpenSees
TSRP	Keri Ryan	University of Nevada, Reno	Influence of Vertical Ground Shaking on Design of Bridges Isolated with Friction Pendulum Bearings
TSRP	Minjie Zhu	Oregon State University	Fluid–Structure Interaction and Python Scripting Capabilities in OpenSees
TSRP	Kenichi Soga	UC Berkeley	High-Performance Computing-Based Distributed Multi-Layered City-Scale Transportation Network Tool
TSRP	Jack Baker	Stanford	Modeling Bay Area Transportation Network Resilience
TSRP	Henry Burton	UCLA	Aftershock Seismic Vulnerability and Time-Dependent Risk Assessment of Bridges
TSRP	Ahmed Elgamal	UCSD	A Systematic Computational Framework for Multi-Span Bridge PBEE Applications
TSRP	Erica Fischer	OSU	Post-Earthquake Fire Performance of Industrial Facilities
TSRP	Patrick Lynett	USC	Tsunami Debris: Simulating Hazard and Loads
TSRP	Amit Kanvinde	UCD	Dissipative Base Connections for Moment Frame Structures in Airports and Other Transportation Systems
TSRP	Gregory Deierlein	Stanford	UNR-Stanford Collaboration: Stanford - Accounting for Earthquake Duration in Performance-Based Evaluation and Design of Bridges
TSRP	David Sanders	UNR	Project Title: UNR-Stanford Collaboration: UNR - Accounting for Earthquake Duration in Performance-Based Evaluation and Design of Bridges

Fund Source	PI	Institution	Project Title
TSRP	Anne Lemnitzer	UCI	Towards Next Generation P-Y Formulations - Part 2: Statistical Assessment of Uncertainties in Key Components of Soil Resistance Functions
TSRP	Ertugrul Taciroglu	UCLA	Development of a Database and a Toolbox for Regional Seismic Risk Assessment of California's Highway Bridges
TSRP	Jonathan Bray	UCB	Liquefaction Triggering and Effects at Silty Soil Sites
TSRP	Steven L. Kramer	UW	Next Generation Liquefaction: Japan Data Collection
TSRP	Jonathan P. Stewart	UCLA	Next Generation Liquefaction: Japan Data Collection (Task #3k01-Tsrp, Year 2)
TSRP	Jose I. Restrepo	UCSD	Earthquake Resilient Bridge Columns
TSRP	Patrick Lynett	USC	Tsunami Design Guide Specifications for Bridges: Local Tsunami Hazard Assessment
TSRP	Harry Yeh	Oregon State University	Tsunami Engineering: Performance Based Tsunami Engineering
TSRP	Hong Kie Thio	AECOM	Tsunami Engineering: Performance Based Tsunami Engineering
TSRP	Anne Lemnitzer	UCI	Towards Next Generation P-Y Curves - Part 1: Evaluation of the State of the Art and Identification of Recent Research Developments
TSRP	Vesna Terzic	CSU Long Beach	Recovery Model for Commercial Low-Rise Buildings
TSRP	Armen Der Kiureghian	American University of Armenia	Stochastic Modeling and Simulation of Near-Fault Ground Motions for Use in PBEE
TSRP	Kamran M. Nemati	UW	How Water/Biner Ratio and Voids Affect The Performance of Hardened Concrete Subjected to Fire
TSRP	Sanjay Govindjee	UCB	Geometrically Exact Nonlinear Modeling of Multi-Storage Friction
TSRP	Tarek I. Zohdi	UCB	Swarm-Enabled Infrastructure-Mapping for Rapid Damage Assessment following Earthquakes

Fund Source	PI	Institution	Project Title
TSRP	Claudia Ostertag	UCB	Conventional Testing and Hybrid Simulations of Environmentally Damaged Bridge Columns
TSRP	Steve Mahin	UCB	3 Axis Testing of Four PEER Columns (Six Weeks Maximum Shaking Table Occupation and Testing Time)
TSRP	Steve Mahin	UCB	Bridge Column Testing
TSRP	Jonathan D. Bray	UCB	Liquefaction-Induced SFSI Damage Due To the 2010 Chile Earthquake
TSRP	Gregory Deierlein	Stanford University	Effects of Long-Duration Ground Motions on Structural Performance
TSRP	Jose L. Restrepo	UCSD	Advanced Precast Concrete Dual-Shell Steel Columns
TSRP	Joel P. Conte	UCSD	Probabilistic Performance-Based Optimal Seismic Design of Isolated Bridge Structures
TSRP	Claudia P. Ostertag	UCB	Shaking Table Test of Pre-Cast Post-Tensioned Hyfrc Bridge Column
TSRP	Kyle Rollins	Brigham Young University	Supplemental Field Testing of Pile Down Drag Due to Liquefaction
TSRP	Steven L. Kramer	UW	Next Generation Liquefaction: Japan Data Collection
TSRP (Tsunami)	Hong Kie Thio	URS Corporation	Performance Based Tsunami Engineering Methodology (Tsunami Research Program)
TSRP (Tsunami)	Patrick Lynett	USC	Simulation Confidence in Tsunami-Driven Overland Flow (Tsunami Research Program)
TSRP (Tsunami)	Harry Yeh	Oregon State University	Performance Based Tsunami Engineering Methodology (Tsunami Research Program)
TSRP	John W. Wallace	UCLA	Shear-Flexure Interaction Modeling for Reinforced Concrete Structural Walls and Columns Under Cycling Loading
TSRP	Jack Baker	Stanford University	Ground Motions and Selection Tools for PEER Research Program
TSRP	Jonathan P. Stewart	UCLA	Next Generation Liquefaction: Japan Data Collection (Task #3K01-TSRP, Year 2)
TSRP & Validus	Vesna Terzic	CSU Long Beach	Towards Resilient Structures

Fund Source	PI	Institution	Project Title
TSRP	Scott J. Brandenberg	UCLA	Influence of Kinematic SSI on Foundation Input Motions for Bridges on Deep Foundations
TSRP	Ross W. Boulanger	UC Davis	Mitigation of Ground Deformations in Soft Ground
TSRP	Jose I Restrepo	UCSD	Earthquake Resilient Bridge Columns
TSRP	Jonathan D. Bray	UC Berkeley	Next Generation Liquefaction: New Zealand Data Collection
Lifelines	Jonathan P. Stewart	UCLA	NGL: Next Generation Liquefaction Database Development and Implications for Engineering Models
Lifelines	Steven L Kramer	UW	NGL: Next Generation Liquefaction Database Development and Liquefaction Triggering Evaluation
Lifelines	Filip C. Filippou	UCB	PEER-Lifelines Proposal - Non Convergence
Lifelines	Sashi Kunnath	UCD	Caltrans-PEER Workshop on Characterizing Uncertainty in Bridge-Component Capacity Limit-States
NC1T01	Steven Day	UCSD	Vertical-Component Basin Amplification Model
NC2Q03	Jason DeJong	UCD	In-Situ Identification and Characterization of Intermediate Soils
NC2S01	Jonathan P. Stewart	UCLA	In-Situ Identification and Characterization of Intermediate Soils
NC2L01	Robert Bachman	Cosmos	Archiving and Web Dissemination of Geotechnical Data, Phase 4a: Production GVDC Using DIGGS Standard
NC1E09	Robert Darragh	Pacific Engineering and Analysis	NGA Processing Update 2
NC10A2	Hong Kie Thio	URS Corporation	Tsunami Hazard Analysis Phase2
NC9K02	Farzin Zareian	UCI	Quantification of Variability in Performance Measures of Ordinary Bridges to Uncertainty in Seismic Loading Directionality and Its Implication in Engineering Practice

Fund Source	PI	Institution	Project Title
NC10B1	Michael H. Scott	Oregon State University	Validation of OpenSees for Tsunami Effects on Bridge Superstructures
NC9M01	Pedro Arduino	UW	Estimation of Shear Demands on Rock-Socketed Drilled Shafts subjected to Lateral Loading
NC4E01	Scott J. Brandenberg	UCLA	Evaluation of Collapse and Non-Collapse of Parallel Bridges Affected by Liquefaction and Lateral Spreading
NC3J01	Steve Kramer	UW	Effects of Liquefaction on Surface Response Spectra
NC2U01	Jonathan P. Stewart	UCLA	Guidelines for Performing Hazard-Consistent 1-D Ground Response Analysis for Ground Motion Prediction
NCBC01	Armen Der Kiureghian	UCB	Synthetic Near-Fault Ground Motion Arrays for PBEE Analysis
NC9N01	Marios Panagiotou	UCB	Three Dimensional Seismic Demand Model for Bridge Piers Supported on Rocking Shallow Foundations
NC3KL1	Jonathan P. Stewart	UCLA	Next Generation Liquefaction: Japan Data Collection
NC2T01	Scott J. Brandenberg	UCLA	Influence of Kinematic SSI on Foundation Input Motions for Bridges on Deep Foundations
DOE	Robert R. Youngs	AMEC Environment & Infrastructure	NGA-East: SSHAC and TI Seismic Research Review
NRC	Walter J. Silva	Pacific Engineering and Analysis	NGA-East: GMPE Implementation
NRC	Robert R. Youngs	AMEC Environment & Infrastructure	NGA-East: SSHAC and TI Seismic Research Review
DOE	Walter J. Silva	Pacific Engineering and Analysis	Development of Vertical Amplification Factors

Fund Source	PI	Institution	Project Title
DOE	Robert R. Youngs	AMEC Environment & Infrastructure	NGA-East: SSHAC, PPRP and TRC Seismic Research Review
NRC	Martin Chapman	Virginia Tech	NGA-East Path/Source Working Group Tasks
DOE	Martin Chapman	Virginia Polytechnic Institute and State University	NGA-East Path Working Group Tasks
NRC (24669)	Thomas Jordan	USC	Support of the SCEC Broadband Platform for NGA-East Simulations
DOE	Youssef Hashash	University of Illinois at Urbana-Champaign	Geotechnical Working Group Integration Project
CEA	Paul Somerville	URS Corporation	Directivity Corrections for NGA-West GMPE's
CEA	Mark Petersen	USGS	PEER-USGS Collaboration on NGA-WEST 2
CEA	Stanford	Stanford	Directionality Model for NGA West 2
CEA	Jonathan P. Stewart	UCLA	Further Development of Site Responses in NGA Models
CEA	Paul Spudich	USGS	Update of the Spudich and Chiou 2008 Directivity Model for Improved Prediction and Directivity and Directionality
CEA	Robert R. Youngs	AMEC Geomatrix	GMPE Development and Assessment of Epistemic Uncertainty
CEA	Walter J. Silva	Pacific Engineering and Analysis	Update NGA-W Strong Motion Database and Develop Vertical Amplification Factors
FM Global	Walter J. Silva	Pacific Engineering and Analysis	NGA-Subduction Strong Ground Motion
USDI	Jonathan Stewart	UCLA	NGA-Subduction Analysis of Maule Chile and Tohoku Japan Ground Motion Data

Fund Source	PI	Institution	Project Title
TSRP	Steven L. Kramer	UW	Next Generation Liquefaction: Japan Data Collection
TSRP	Jonathan P. Stewart	UCLA	Next Generation Liquefaction: Japan Data Collection (Task #3K01-TSRP, Year 2)

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