PACIFIC EARTHQUAKE ENGINEERING RESEARCH CENTER

PEER 2016 Annual Report

Khalid M. Mosalam
Amarnath Kasalanati
Grace S. Kang

Pacific Earthquake Engineering Research Center
University of California, Berkeley

PEER Report No. 2017/01
Pacific Earthquake Engineering Research Center
Headquarters at the University of California, Berkeley

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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 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, multi-user 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.

CONTENTS

1 Mission, Vision, and Impact

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, several consulting companies, plus researchers at various State and Federal government agencies contribute to research programs focused on performance-based earthquake engineering in 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 in Berkeley Global Campus at Richmond Bay are operated under control of PEER.

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**. PEER's research defines appropriate performance targets, and develops 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 earthquake 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 earthquake issues.

1.2 VISION AND IMPACT


Director Khalid Mosalam

On January 1, 2016, Professor Khalid Mosalam became the new PEER Director as Professor Stephen Mahin completed his 6-year term. Director Mosalam outlined his vision for the PEER Center as follows: “I intend to work with the PEER community to maintain the Center’s focus and reputable work on performance-based earthquake engineering (PBEE) and the related enabling technologies. I am very excited to see the increased use of PBEE in engineering practice, and I am interested in further increasing the adoption of PBEE to the level of standard practice. I believe that the general methodology of performance based engineering (PBE) should be developed and utilized for achieving resilient designs and sustainable retrofits of infrastructure systems in urban areas that are exposed to multi-hazards. Therefore, I view as a top priority expanding the international footprint and collaborative research of PEER with domestic and worldwide centers of similar or complementary missions. Furthermore, I am keen on having more faculty and students from PEER core and affiliate institutes engage in Center activities. For all this to happen, it is important to strengthen ties with government agencies and to solidify support from our growing pool of Business and Industry Partnership (BIP) members."

The theme of the PEER Annual Meeting was "Decision-Making in the Face of Uncertainty." This meeting, held in January 2016, summarized the impact and vision of the Center by highlighting PEER's accomplishments and outlining the future direction of research for the Center. More details of the Annual Meeting are presented in Chapter 6. Emerging from the meeting are the key thrust areas for research consideration in coming years as summarized below. Some of these are already on-going projects at the Center and the rest will be initiated soon.

- Computational Modeling & Simulation
- Geo-hazards
- Interdependencies of Infrastructure Systems
- Resilient Infrastructure Systems
- Tsunami
- Transportation

PEER's Strategic Plan for the next 5 years is presented in Chapter 2. The impact of PEER's activities in these areas is summarized in Chapter 3, which demonstrates the Center's continued track record of multi-institutional research in these areas. Chapter 4 summarizes the key activities at the core institutions in the past year. Chapters 5 and 6 highlight PEER's research projects and outreach activities, respectively. Chapter 7 through Chapter 10 present PEER's tools, resources, facilities, funding information, and recognitions from professional organizations.

2 Strategic Plan

To achieve the broad goals of the organization, PEER has identified the following strategies:

1. Expand PEER's profile globally: PEER is well-known nationally and internationally among institutions that collaborate with the Center. Since PEER's research benefits all earthquake-prone areas around the world, there is a need to increase the awareness more broadly. To achieve this objective, PEER joined two international organizations in the past year and will continue its efforts in this direction.
2. Strengthen Industry Partnership: Actively engage industry partners in identifying research needs, participating in research, and setting the direction of new research and education activities at the Center. This will require strengthening the current Business Industry Partnership (BIP) program.
3. Improve the organizational structure: The Center's organizational structure was revised to include an Associate Director position who will focus on Strategic Initiatives. This focus will be to proactively pursue long-term strategies and work with the growing interest in the research community in multi-hazard mitigation.
4. Build on ideas from the PEER Annual Meeting: The PEER Annual Meeting identified several new thrust areas and provided a wealth of new ideas to pursue. PEER will issue Requests for Proposal (RFPs) in these thrust areas and will seek proposals from researchers.
5. Engage the PEER laboratories with our core institutions to serve the experimental research needs of PEER researchers: Some of the experimental research facilities of the PEER core institutions, such as UC Davis and UC San Diego, are part of NHERI (Natural Hazards Engineering Research Infrastructure) network. However, some of the other experimental facilities, e.g., UC Berkeley, are not. Therefore, these facilities can be put to the service of PEER researchers with a well-designed experimental facility coordination within PEER.

The Center's actions in pursuing these strategies are summarized in the following subsections.

2.1 EXPANDING GLOBAL PROFILE

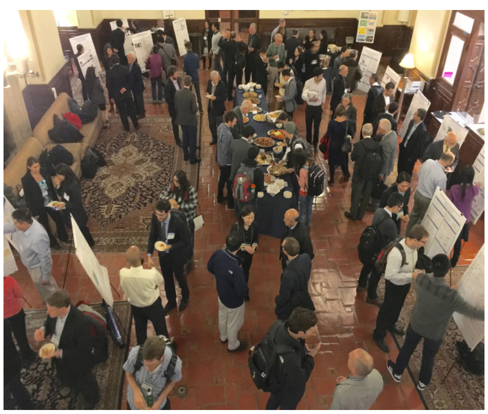
PEER is now an active board member of two important international organizations listed below. Furthermore, Memoranda of Understanding (MOU) have been signed with several institutions as described in Item 3 below. All these efforts extend PEER's outreach to global research collaborators and facilities, and gives PEER the opportunity to have input on research agendas.

1. ILEE "International Joint Research Laboratory of Earthquake Engineering" is headquartered at Tongji University, China. This relationship facilitates possibilities for PEER researchers to conduct future research at this outstanding testing facility.

2. GADRI "Global Alliance of Disaster Research Institutes" is headquartered at Kyoto University, Japan. This relationship gives PEER access to key institutions that conduct research in hazards related to and beyond earthquake engineering. In the upcoming years, PEER plans to coordinate with other emerging and leading earthquake engineering and multi-hazard institutions, such as the EUCENTRE in Europe and QuakeCoRE in New Zealand.

3. PEER signed Memoranda of Understanding (MOU) with four international institutions since January 2016: (i) McMaster Institute for Multi-Hazard Systemic Risk Studies (INTERFACE) and the NSERC-CREATE Network on Canadian Nuclear Energy Infrastructure Resilience under Seismic Systemic Risk (NSERC CaNRisk-CREATE); (ii) Institute of Engineering Mechanics, China Earthquake Administration; (iii) International Center of Integrated Protection Research of Engineering Structures (I-CIPRES), College of Civil Engineering, Nanjing Tech University, Nanjing, China; and (iv) Technical University of Civil Engineering of Bucharest (UTCB), Romania. These relationships are expected to facilitate more global collaborations among PEER and international researchers.

2.2 INDUSTRY PARTNERSHIP



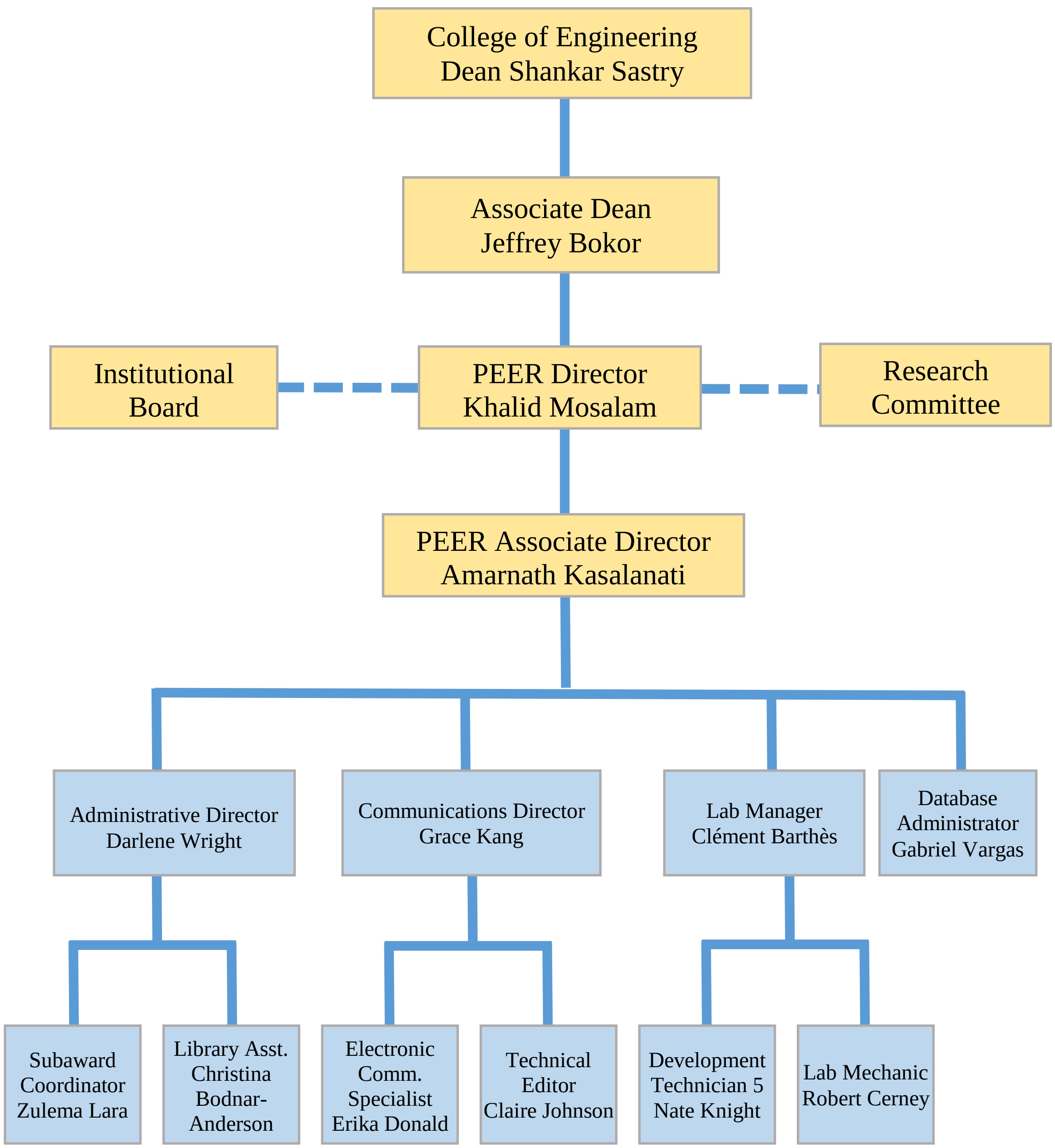
BIP – Information Exchange

Industry and government partners are an integral part of the research program at PEER. The PEER Business and Industry Partnership (BIP) Program engages industry members in PEER research and education programs, and provides access to PEER researchers, students, and products. Selected representatives of the Business and Industry Partnership plus representatives of key government agencies providing funding for PEER are the members of an Industry Advisory Board (IAB). This board advises PEER on its strategic plan, its research projects, implementation of research results, and new opportunities to explore. Chapter 9 provides more details of the BIP Program.

In the upcoming year, PEER plans to increase the membership of BIP program by inviting several national and international companies involved in extreme event hazard mitigation. The Associate Director will lead the efforts to strengthen the BIP program. PEER will continue to hold state-of-the-art and state-of-the-practice workshops on topics related to the PEER mission and will extend invitations to BIP members.

2.3 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. Moreover, a research committee, consisting of industry and academic members, advises the Center in pursuing new research. A new research committee is currently being formulated.



In the past year, PEER has been working on organizational structuring, which included securing the position of Associate Director for Operations and Strategic Initiatives, with support from the College of Engineering at UC Berkeley. PEER conducted a comprehensive search and appointed Dr. Amarnath Kasalanati as Associate Director of Operations and Strategic Initiatives.

Associate Director
Amarnath Kasalanati

Amarnath is a registered Professional Engineer in the state of California. Prior to joining PEER, Amarnath was with Dynamic Isolation Systems (DIS) for 19 years, serving as the Director of Engineering for most of his tenure. As a key member of the management team, he traveled widely to promote high-performance design and was responsible for overseas business development. He served as a member of ASCE 7-16 and AASHTO Code Committees for Seismic Isolation Design. He has been involved in collaborative research with several institutions, including UC Berkeley; University of Nevada, Reno; SUNY University at Buffalo; UC San Diego; NCREE MATS facility, Taiwan; and E-Defense Testing Facility, Japan.

The Associate Director's responsibilities include supporting the Director and the Center's operations: providing oversight to the activities of the PEER–UC Berkeley experimental testing facilities, the NISEE library, outreach activities and the BIP program, and financial and business management. Responsibilities also include proactively pursuing long-term strategies and work with the growing interest in the research community in multi-hazard mitigation.

2.4 NEW THRUST AREAS

The PEER Annual Meeting, held in January 2016, identified several key thrust areas and research ideas to pursue in coming years. This direction of research within PEER is indeed timely considering the February 2, 2016, White House Earthquake Resilience Summit and the new Executive Order (EO) [https://www.whitehouse.gov/the-press-office/2016/02/02/executive-order-establishing-federal-earthquake-risk-management-standard] about federal seismic standards signed by President Obama. The EO states that:

> *The Federal Government recognizes that building codes and standards primarily focus on ensuring minimum acceptable levels of earthquake safety for preserving the lives of building occupants. To achieve true resilience against earthquakes, however, new and existing buildings may need to exceed those codes and standards to ensure, for example, that the buildings can continue to perform their essential functions following future earthquakes. Agencies are thus encouraged to consider going beyond the codes and standards set out in this order to ensure that buildings are fully earthquake resilient. It is the policy of the United States to strengthen the security and resilience of the Nation against earthquakes, to promote public safety, economic strength, and national security. To that end, the Federal Government must continue to take proactive steps to enhance the resilience of buildings that are owned, leased, financed, or regulated by the Federal Government.*

Various presentations during the PEER Annual Meeting noted similar statements about the necessity in going beyond code objectives to achieve post-earthquake functionality and the public's misinterpretation of code objectives. With PEER's efforts in PBEE methodology and its extension to resilience, it is PEER's priority to do more towards fulfilling this public expectation of resiliency supported by governmental policies as indicated in the EO. Specifically, PEER intends to increase collaboration with ongoing efforts towards resilience; these efforts include:

- ATC-58's efforts in developing probabilistic performance-based design guidelines
- the U.S. Resiliency Council's building rating system
- NIST's Community Resilience Program
- the San Francisco Bay Area Planning and Urban Research's (SPUR) Resilient City approach
- research related to protective systems and modeling of community functioning following earthquakes.
- the practicing earthquake engineering community's efforts to reflect this resiliency extension on the design, assessment and retrofit applications as stated in the presidential EO.

In addition to the above initiatives, PEER will seek regular advice from the Institutional Board (IB) and the Industry Advisory Board (IAB) to identify new opportunities.

2.5 EXPERIMENTAL FACILITIES

Some of the experimental research facilities of the PEER core institutions, including UC Davis, UC San Diego and OSU, are part of the NHERI (Natural Hazards Engineering Research Infrastructure) network. However, some of the other experimental facilities, e.g., UC Berkeley, are not. Furthermore, there are several core PEER institutions with limited experimental facilities. PEER will focus its efforts for the coordination of these facilities for the use of PEER researchers, e.g. from Stanford University. These efforts will include advertising the labs, providing any required facility updates, and providing proposal preparation support for faculty who plan to make use of these facilities in their projects.

UC Davis Laboratory

OSU Tsunami Lab

UC San Diego Laboratory

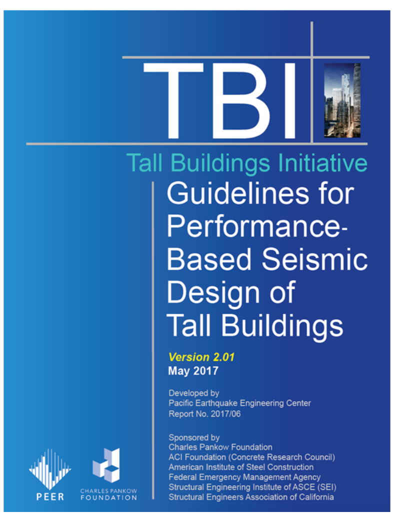
3 Mega Research Projects

PEER manages several multi-year, multi-institutional projects called Mega-Research Projects. These projects explore key thrust areas and are broad in their scope and impact on the subject. Details of current Mega projects are provided in this chapter.

3.1 TALL BUILDINGS INITIATIVE

Growing Cityscape

The design and construction of tall buildings surged in the Western U.S. from 2000 through 2008 and again in the period since 2011. Programmatic and economic demands resulted in significant innovation including use of structural systems beyond the range permitted by building code’s prescriptive provisions, as well as introduction of new structural technologies and methods of detailing. Recognizing the need to provide consistency among these approaches, as well as to facilitate the approval processes, PEER began the Tall Buildings Initiative (TBI). This initiative included research related to the unique seismic response characteristics of tall buildings, ground-motion characterization, analytical simulation of building behavior, societal needs, and costs associated with different design approaches.

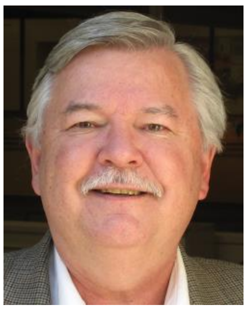


The TBI brought together a broad array of researchers, practitioners, and stakeholders to explore performance objectives, conduct research on building response and performance characteristics, and develop the TBI “Guidelines for Performance-Based Seismic Design of Tall Buildings” (PEER Report 2010/05). Additionally, practical guidance for analysis and acceptance criteria was developed in conjunction and co-published with ATC as “Modeling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings” (ATC-72). The TBI Guidelines and supporting documents, developed by the project team led by Jack Moehle and Ron Hamburger, are widely used today in the performance-based design of tall buildings in California and worldwide.

Jack Moehle

In December 2015, PEER and the Los Angeles Tall Buildings Structural Design Council were joint awardees for the ATC-SEI 2015 Champions of Earthquake Resilience Awards Program for an "Exceptional Public-and-Private Sector Research Development (R&D) Program" for "Tall Building Seismic Design Guidelines." Refer to Chapter 10 for additional information.

In 2016, an update to the "Guidelines for Performance-Based Seismic Design of Tall Buildings" was developed and released as PEER Report 2017/06, May 2017. The project team, led by co-chairs Ron Hamburger and Jack Moehle, included Jack Baker, Jonathan Bray, CB Crouse, Gregory Deierlein, John Hooper, Marshall Lew, Joe Maffei, Steve Mahin, James O. Malley, Farzad Naeim, Jonathan P. Stewart, and John Wallace.

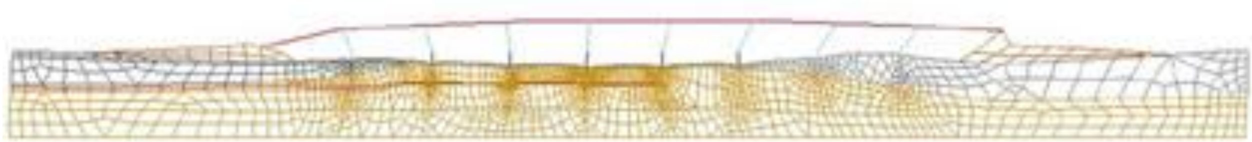


Stephen Mahin

Recently the Tall Buildings Initiative was expanded with research by Steve Mahin to include assessment of the seismic performance of *existing tall buildings*. The specific objectives of the expanded program are to improve understanding of the seismic behavior of existing tall buildings designed and constructed before the advent of modern design codes and analysis tools, to assess the applicability of available guidelines for the evaluation of existing structures to tall buildings, and explore efficient and economical retrofit strategies for improving seismic performance. The research covers existing tall buildings that are 20 stories or more in height, and that were designed and constructed from 1960–1990 on the west coast of the U.S. Tasks incorporated in the new program include identifying case study buildings, developing their numerical models, conducting consequent analyses, and identifying retrofit strategies.

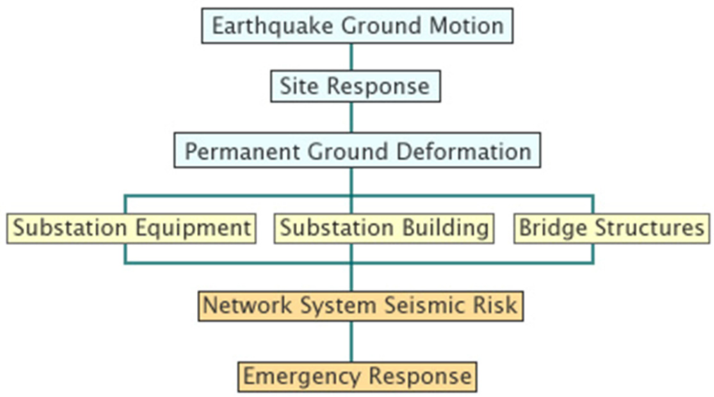
3.2 TRANSPORTATION SYSTEMS RESEARCH PROGRAM (TSRP)

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 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 performance-based earthquake engineering methodologies by integrating fundamental knowledge, enabling technologies, and systems. The research program also integrates seismological, geotechnical, structural, and socio-economical aspects of earthquake engineering, and involves computational, experimental, and theoretical investigations.



3.3 LIFELINES PROGRAM

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.



Lifelines Research Topics

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 Program that has 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.

3.4 TSUNAMI

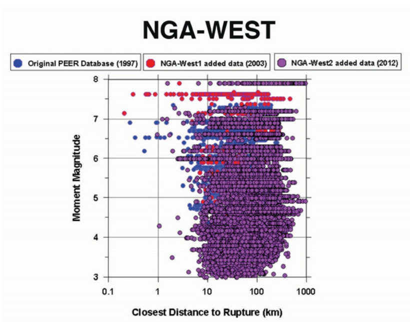
2004 Indian Ocean Tsunami Damage

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 Basin. Based on the directivity characteristics of tsunami energy propagation, the entire U.S. west coast is vulnerable to distant tsunamis originated in the eastern end of the Aleutian (Alaska) and also Philippine Main. The extreme scenario would be strong, long-duration earthquake ground shaking associated with the subduction fault rupture, followed by large tsunami inundation. Such a scenario is not an exception but 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 (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)–will ultimately expand and extend the existing Performance-Based Earthquake Engineering (PBEE) methodology.

3.5 NGA-WEST2



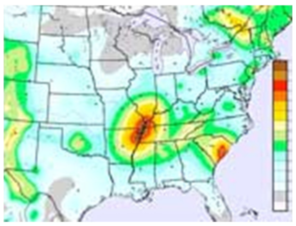
To better quantify earthquake related hazards for use in PBEE and design practice, PEER initiated its Next Generation Attenuation (NGA) program. The initial effort focused on shallow crustal earthquakes, such as those that occur in California. PEER developed and coordinated the Next Generation Attenuation-West (NGA-West) Project in two phases: NGA-West1 (2003–2008), and NGA-West2 (2010–2014). In this project, the multi-disciplinary PEER community developed the world’s largest uniformly processed earthquake ground-motion database and a set of ground motion attenuation models for applications in seismic analysis, design, evaluation, and loss estimation.

The NGA-West Project provides a database of over 60,000 recorded earthquake ground motions in shallow crustal active tectonic regions, such as California. It also provides NGA models, also known as ground -motion prediction equations (GMPEs), which provide a means of predicting the level of ground shaking and its associated uncertainty at any location susceptible to shallow crustal earthquakes. The NGA-West project included the following sub-projects: directivity and directionality, database and models for vertical ground motion, scaling ground motions for different levels of damping, and improved soil amplification factors.

The NGA-West GMPEs are exclusively used to characterize earthquake ground motions for all west coast performance-based design and evaluation projects requiring project-specific seismic hazard analysis. The PEER NGA database of recorded earthquake ground motions is regularly used as the primary source of ground-motion time histories used by the global community of design engineers, building officials, peer reviewers, and researchers in the seismic design and review of civil engineering structures ranging from buildings, bridges, dams, and power plants. Additionally, the improved database and ground-motion attenuation models provide the best available science for the estimation of seismic financial loss estimates, and they are used as a basis to set earthquake insurance premiums.

PEER has extended the NGA program to improve characterization of seismic hazards for the central and eastern U.S. (NGA-East), subduction zone events (NGA-Sub), and globally (global GMPE).

3.6 NGA-EAST



CENA Region

NGA-East is a multi-disciplinary research project that engages a large number of participating researchers from various organizations in academia, industry, and government. The project is jointly sponsored by the U.S. Nuclear Regulatory Commission (NRC), the U.S. Department of Energy (DOE), the Electric Power Research Institute (EPRI) and the U.S. Geological Survey (USGS).

The objective of NGA-East is to develop a new ground motion characterization (GMC) model for the Central and Eastern North-American (CENA) region. The GMC model consists of a set of GMPEs for median and standard deviation of ground motions (GMs) and their associated weights in the logic-trees for use in probabilistic seismic hazard analyses (PSHA).

NGA-East was originally developed as a science-based research project originally designed as a follow-up to the previous NGA project (referred to as NGA-West for clarity) that focused on the development of GMPEs for shallow crustal earthquakes in active tectonic regions. NGA-East evolved to a SSHAC (Senior Seismic Hazard Analysis Committee) Level 3 in early 2010 so that it would be consistent with the CEUS SSC (Central and Eastern United States Seismic Source Characterization) project and to allow the products of these projects to be combined for use in Level 3 site-specific studies. As a result, the scope of work and the level of complexity of the project have increased considerably. Additional objectives include a close collaboration and integration activities with the following:

- CEUS Seismic Source Characterization Project
- USGS National Seismic Hazard Mapping Program
- NGA-West 2 Project

3.7 SEISMIC PERFORMANCE OF RETROFITTED HOMES

Yousef Bozorgnia

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, titled "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. 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.

"The project will include comprehensive experimental and simulation studies to investigate the potential of damage to retrofitted and un-retrofitted residential homes in California," said Professor Yousef Bozorgnia, Principal Investigator. "The results and findings of the project will quantify the benefits of seismic upgrade for earthquake insurance in California," said Professor Steve Mahin. "I commend the dedication of the research team and congratulate them on this important research project," said PEER Director Khalid Mosalam.

4 Activities of Core Institutions

PEER is a consortium of participating institutions, including ten Core Institutions that are mainly involved in the activities of PEER. Reports of research activities from the core institutions are presented in the following subsections. Information for each institution was provided by the respective Institutional Board member, who is identified with the first photograph of each section. These Core Institutions are:

University of California: **Lead Institution**	California Institute of Technology
Oregon State University	Stanford University
University of California, Davis	University of California, Irvine
Univeristy of California, Los Angeles	University of Califiornia, San Diego
University of Southern California	University of Washington

PEER also engages Educational Affiliates who participate in education activities. These are:

- California Polytechnic State University, San Luis Obispo
- California State University, Los Angeles
- California State University, Northridge
- San Jose University
- University of Hawaii
- Johns Hopkins University

4.1 ACTIVITIES AT UNIVERSITY OF CALIFORNIA, BERKELEY: LEAD INSTITUTION

Professor Jack Moehle is the PEER institutional board member representing the University of California, Berkeley.

4.1.1 Tall Buildings Initiative – Updated Seismic Design Guidelines

Jack Moehle

In 2016, an update to the "Guidelines for Performance-Based Seismic Design of Tall Buildings" was developed. The project team, led by co-chairs Ron Hamburger and Jack Moehle (UC Berkeley), include Jack Baker, Jonathan Bray (UC Berkeley), CB Crouse, Gregory Deierlein, John Hooper, Marshall Lew, Joe Maffei, Steve Mahin (UC Berkeley), James O. Malley, Farzad Naeim, Jonathan P. Stewart, and John Wallace. More details of this project are provided in Section 3.1.

4.1.2 Seismic Evaluation and Retrofit of Existing Tall Buildings

Stephen Mahin

The PEER Tall Buildings Initiative (TBI) was expanded with research by Steve Mahin to include assessment of the seismic performance of existing tall buildings. The specific objectives of the expanded program are to (1) improve understanding of the seismic behavior of existing tall buildings designed and constructed before the advent of modern design codes and analysis tools; (2) to assess the applicability of available guidelines for the evaluation of existing structures to tall buildings; and (3) and explore efficient and economical retrofit strategies for improving seismic performance. The research covers existing tall buildings that are 20 stories or more in height, and that were designed and constructed on the west coast of the U.S. from 1960–1990. Tasks incorporated in the new program included: (1) developing and inventory of tall buildings in California; (2) identifying case study buildings for further study; (3) developing numerical models for the case study buildings based on various guidelines and first principles; (4) selecting from the NGA West2 database suites of ground motions appropriate for the sites of the case study buildings considering several seismic hazard levels; (5) analyzing the case study buildings in accordance with modeling and evaluating procedures outlined in ASCE 41, FEMA 352, FEMA P-58 and other evaluation guidelines; (6) identifying and evaluating various retrofit strategies to assess the technical and economic feasibility of improving performance where deficiencies are detected; and (7) as necessary and in conjunction with the professional design community, suggested improved guidelines for the seismic evaluation and retrofit of existing tall buildings.

RECENT ACTIVITIES

Second ATC/SEI Conference on Improving the Seismic Performance of Existing Building

PEER organized a special session at this national conference in December 2015 that highlighted work by the PEER team, as well as work performed by several engineering firms (Holmes Engineering, Forell/Elsesser Engineers, Tipping Engineers) that had conducted seismic evaluations of existing tall buildings.

PEER Existing Tall Building Workshops

The Second PEER workshop on "Evaluation and Upgrading Issues Related to Existing Tall Buildings" was held in June 2016 at the San Francisco office of Simpson Gumpertz and Heger. More than 50 engineers and academics from Northern and Southern California participated in the day-long meeting. PEER's Existing Tall Buildings (TBI-2) team members presented their research findings, followed by several talks from engineers and researchers who are involved with actual evaluation and retrofit projects. Participants discussed re-occurring and common technical problems and performance issues associated with existing tall buildings, and identified actions to move forward in addressing these issues.

TECHNICAL PRESENTATIONS

Findings of the TBI-2 project were presented at a variety of conferences and technical meetings during 2016, including: (a) 3rd US-China Tall Building Symposium, (b) EERI 68th annual meeting, (c) SEAOC convention, and (d) SEAONC Seismology Committee.

AWARDS

PEER received the ***2016 Excellence in Structural Engineering Award of Merit for Research*** from the Structural Engineers Association of California for this work at its October 2016 Annual Convention.

PUBLICATIONS

Lai, J-W., Wang, S., Schoettler, M.J. and Mahin, S. (2016). "Seismic evaluation and retrofit of existing tall Buildings in California: case study of a 35-story Steel moment-resisting frame building in San Francisco." *PEER Report No. 2015/14*.

Wang, S., Lai, J.-W., Schoettler, J.M. and Mahin S. (2017). Seismic assessment of existing tall buildings: a case study of a 35-stoy steel building with Pre-Northridge connections. *Eng. Struct*. DOI: 10.1016/j.engstruct.2017.03.047.

Wang, S., and Mahin, S. (2017). Seismic retrofit of a high-rise steel moment-resisting frame using fluid viscous dampers. *Struct Design Tall Spec. Build.* 2017; e1367. https://doi.og/10.1002/ta;.1367.

PARTICIPANTS

During 2016, the PEER TBI-2 research team consisted of Shanshan Wang, Matt Schoettler and Stephen Mahin (PI). Many other researchers and engineers provided technical advice and shared their expertise and experience. These individuals are greatly acknowledged for their support:

- Frank McKenna, Andreas Schellenberg – PEER;
- Kasai Kazuhito – Tokyo Institute of Technology;
- Amarnath Kasalanati – PEER, formerly DIS;
- Vesna Terzic – California State University, Long Beach;
- Rob Smith, Ibrahim Almufti – Arup;
- Jim Malley – Degenkolb Engineers;
- Kit Miyamoto, Amir Gilani — Miyamoto International;
- Joe Maffei, Lawrence Burkett – Maffei Structures;
- John Hooper – Magnusson Klemencic Associates;
- More than 40 others who participated in workshops and meetings.

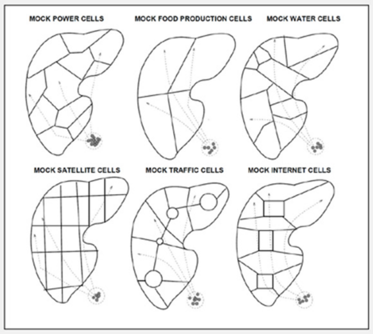
ACKNOWLEDGEMENTS

This project was funded by the California Office of Emergency Services (CalOES) under Contract No. DR-1884: *Seismic Performance of Existing Tall Buildings and Development of Pilot Internet Database for Post-Earthquake Applications*. Additional funding was provided by PEER as part of the Tall Buildings Initiative and Next-Generation Attenuation Relation programs. Supplemental funding was provided by the Byron and Elvira Nishkian Endowed Chair in Structural Engineering.

2017 AND BEYOND

Four areas of needed work have been identified. The first of these is to carryout detailed investigations of other existing tall buildings. In this way, similarities and differences can be identified, and results can be used to develop more general guidelines for the evaluation and retrofit of vintage tall buildings. Several buildings in Northern and Southern California have been identified as candidates. Second, several major structural deficiencies have been identified in the investigated building that have yet to find satisfactory resolution. For example, the column compression demands were extremely large, and many practical issues arose in trying to attach strong retrofit system components to the existing fragile structure. Third, it appears that the disruption and cost of retrofit of tall buildings will be considerable, as would be any post-earthquake repair or demolition/replacement of the building. As such, more work is needed to study the logistics and costs of retrofit or repair, and the business impacts of these interruptions. Lastly, on-going work at UC Berkeley is focusing on using high-performance computing to streamline and optimize the process of identifying cost-effective retrofit strategies.

4.1.3 Swarm-Enabled Infrastructure Mapping for Rapid Damage Assessment following Earthquakes



Different coexisting infrastructures requiring different mapping strategies and path planning

A PEER funded research project, "Swarm-Enabled Infrastructure-Mapping for Rapid Damage Assessment Following Earthquakes," is led by Principal Investigator (PI) Tarek Zohdi, Will C. Hall Family Endowed Chair in Engineering, UC Berkeley. The research team includes Khalid Mosalam, Taisei Professor of Civil Engineering, UC Berkeley, and Yuqing Gao, Graduate Student Researcher, UC Berkeley. This study is expected to complement several ongoing PEER projects based on developing databases for different infrastructure systems and their earthquake performance. More details of this project are presented in Chapter 5.

4.1.4 NSF Funded US-Japan-New Zealand Workshop on Liquefaction


Liquefaction Workshop Attendees

The "Liquefaction-Induced Ground Movements Effects" workshop was a PEER-organized, NSF-funded workshop with UC Berkeley Professor Jon Bray as PI, held at UC Berkeley on November 2-4, 2016. The workshop provided an opportunity to make use of recent research investments following recent 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. Details of the event are presented in Chapter 6.

4.1.5 PEER Former Director Mahin Leads Center for Computational Modeling and Simulation of the Effects of Natural Hazards on the Built Environment (SimCenter)

PROJECT OVERVIEW

With the support of a five-year, $10.9-million grant from the NSF, a new center for computational modeling and simulation of the effects of natural hazards on the built environment (SimCenter) was established at UC Berkeley in October 2016. The SimCenter is part of the NSF's Natural Hazards Engineering Research Infrastructure (NHERI) program, a distributed, multi-user national facility that will provide natural hazards engineers with access to research infrastructure (earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and


Natural Hazards

simulation tools, and research data), coupled with education and community outreach activities. In addition to the SimCenter, NHERI includes a Network Coordination Office (NCO), Cyberinfrastructure facility (CI), and Experimental Facilities for earthquake and wind hazards engineering research, including a post-disaster, rapid response research (RAPID) facility. NHERI has the broad goal of supporting research that will improve the resilience and sustainability of civil infrastructure, such as buildings and other structures, underground structures, levees, and critical lifelines, against the natural hazards of earthquakes, tsunami, and windstorms in order to minimize loss of life, damage, and economic loss.

The goal of the SimCenter is to provide the natural hazards engineering research and education community with access to next-generation computational modeling and simulation software tools, user support, and educational materials needed to advance the nation's capability to simulate the impact of natural hazards on structures, lifelines, and communities. In addition, the new center will enable leaders to make more informed decisions about the need for and effectiveness of potential mitigation strategies.

The SimCenter will provide modeling and simulation tools using a new open-source framework that: (1) addresses various natural hazards, such as windstorms, storm surge, tsunami, and earthquakes; (2) tackles complex, scientific questions of concern to disciplines involved in natural hazards research, including earth sciences, geotechnical and structural engineering, architecture, urban planning, risk management, social sciences, public policy, and finance; (3) utilizes machine learning to facilitate and improve modeling and simulation using data obtained from experimental tests, field investigations, and previous simulations; (4) quantifies uncertainties associated with the simulation results obtained; (5) utilizes high-performance parallel computing, data assimilation, and related capabilities to easily combine software applications into workflows of unprecedented sophistication and complexity; (6) extends and refines software tools for carrying out performance-based engineering evaluations and supporting decisions that enhance the resilience of communities susceptible to multiple natural hazards; and (7) utilizes existing applications that already provide many of the components required for the complex computational workflows.

As such, the new NHERI SimCenter will provide a cloud-based ecosystem for diverse multidisciplinary groups to work collaboratively on solutions to complex problems in natural hazard engineering irrespective of their local resources and geographic proximity. In tandem with the framework and applications being developed, online educational programs will be created within a new Virtual Community of Practice to provide an online meeting place for researchers and practitioners to exchange ideas, provide feedback, and share best practices, insights, and innovations for modeling and simulation of natural hazards engineering. The SimCenter will also offer workshops and a graduate student research training program, and will host students as part of the NHERI NCO's Research Experiences for Undergraduates program.

The SimCenter welcomes the contributions and participation of all those interested in the application of computational simulation to improving the resilience of structures and communities to natural hazards.

PARTICIPANTS

The SimCenter is an independent center, formed at the request of the PEER Institutional Board. The SimCenter builds on the institutional support of UC Berkeley, especially the Center for Information Technology Research in the Interests of Society (CITRIS), the Lawrence Hall of Science, and PEER.

Stephen Mahin

The Center's Principal Investigator is Stephen Mahin. He is joined by co-PIs from Stanford University (Greg Deierlein), University of Washington (Laura Lowes), University of Notre Dame (Ahsan Kareem), and UC Berkeley/CITRIS and the Banatao Institute (Camille Crittenden). Prof. Sanjay Govindjee, Dr. Frank McKenna (Chief Technology Officer) and Dr. Matthew Schoettler (Associate Director for Operations), all from UC Berkeley and who also serve on the leadership team. More than 35 other affiliated faculty, staff, postdocs, and students from more than 12 major research universities and institutes from around the U.S. actively contribute to the SimCenter's activities.

RECENT ACTIVITIES

The SimCenter is still in the start-up phase, but the center's team of programmers is being assembled, and several applications are under development. In addition, several talks discussing the SimCenter's vision and work plans have already been made, including presentations at the 2016 Structural Engineering Association of California Annual Convention, the 16th World Conference on Earthquake Engineering, and the 13th Americas Conference on Wind Engineering.

In conjunction with DesignSafe-ci, the SimCenter has initiated a number of web-based educational programs, including a **Young Researcher Forum,** where research students and post-docs regularly present and discuss research based on high performance computing, **Natural Hazards Engineering Seminars,** where experienced academic and professional engineers cover the basic principles of natural hazards risk assessment, analysis, design and testing, and a **Simulation-Based Research Colloquium,** where experts in computational modeling and simulation present and discuss their latest work. The SimCenter is also developing a series of on-line courses focusing on various topics related to computational modeling and simulation, as well as on the use of SimCenter tools. To better enable users to incorporate their software, and to modify and extend the capabilities of the SimCenter Framework, the SimCenter will be offering an annual advanced **Programming Bootcamp**.

ACKNOWLEDGEMENTS

The NHERI SimCenter is supported by NSF under its Natural Hazards Engineering Research Infrastructure program through cooperative agreement CMMI-1612843. The assistance of Dr. Joy Pauschke, NSF Project Manager, is greatly appreciated. Any statements in this summary are those of the authors and do not necessary represent the views of the NSF.

2017 AND BEYOND

The activities of the SimCenter are just beginning. The SimCenter team looks forward to working with the Natural Hazards Engineering community to develop new computational tools that can be linked through innovative workflows to facilitate the collaboration and simulations needed to solve critical natural hazards engineering challenges.

4.2 ACTIVITIES AT CALIFORNIA INSTITUTE OF TECHNOLOGY

Domniki Asimaki

Professor Domniki Asimaki is the PEER institutional board member representing the California Institute of Technology. Caltech had no activities or news to report that are associated with or have been facilitated by PEER. In the past year, Caltech faculty have been awarded a planning grant for an I/U Cooperative Research Center on Geomaterials and Geomechanics by NSF.

4.3 ACTIVITIES AT OREGON STATE UNIVERSITY

Michael Scott

Professor Michael Scott is the PEER institutional board member representing the Oregon State University. Under the leadership of Scott Ashford, Dean of the College of Engineering, and Jason Weiss, Head of the School of Civil and Construction Engineering, Oregon State University (OSU) continued its efforts in 2016 to be a leader in national resilience efforts and other PEER-related activities. Michael Scott, Associate Professor, is a working group leader on a DOT-pooled fund project managed by PEER for the development of bridge design guidelines for tsunami hazards. The project involves all five state DOTs along the Pacific Rim (California, Oregon, Washington, Alaska, and Hawaii) and collaborators from USC, UW, and AECOM. Professor Harry Yeh is PI on a PEER-funded project for the development of a performance-based tsunami engineering (PBTE) framework. The project focuses on characterizing the uncertainty of tsunami flow height and velocity at locations along the Pacific coast and utilizes source-to-site physics-based models of open ocean flow and on-shore run-up. Professors Scott and Yeh also helped organize and led sessions on tsunami modeling at the 2016 PEER Annual Meeting.

New developments in OpenSees emanated from OSU in 2016. Professors Scott and Dr. Minjie Zhu added new modules for fluid-structure interaction based on the particle finite element method (PFEM) as well as a general Python-based interpreter. With the PFEM, researchers are able to simulate tsunami loading on structures and to examine the effect of multi-hazard earthquake and tsunami hazards on structural response. The Python-based interpreter makes OpenSees more accessible to a new generation of graduate student researchers that learned Python as undergraduates and also allows developers and users of OpenSees to utilize the wide range of scientific computing libraries built for Python. As a core developer of OpenSees, Professor Scott continues to maintain large segments of code in collaboration with Dr. Frank McKenna at UC Berkeley.

Nepal Reconnaissance Team

OSU faculty were actively involved in international earthquake reconnaissance efforts in 2016. Ben Mason, Assistant Professor, made multiple visits to Nepal, surveying geotechnical failures and conducting workshops for local engineers with the support of USAID and in collaboration with researchers from USGS and Cal Tech. Michael Olsen, Associate Professor, led LIDAR-based structural damage surveys in Christchurch, New Zealand. Professor Olsen is also co-PI on the NHERI Post-Disaster Rapid Response Research Facility awarded to UW by NSF in 2016. The Large Wave Flume and Directional Wave Basin at the O.H. Hinsdale Wave Research Lab at OSU received support from NSF as a NHERI Experimental Facility (EF) in 2016. The EF is led by Professor Dan Cox (PI), Professor Chris Higgins (co-PI), and HWRL Director, Dr. Pedro Lomanaco (co-PI).

Reconnaissance Surveying

In 2016, Dan Cox, Andre Barbosa, and Michael Scott continued their efforts with the NIST-funded Center for Risk-Based Community Resilience Planning. Their work is focused on the development of physics-based fragility functions for tsunami, earthquake, and flood hazards and the development of the IN-CORE computational environment for comprehensive modeling of community-level disaster planning, response, and recovery. Professor Barbosa also worked with the city of Portland on the development of fragility functions for masonry structures and is actively involved in research on the seismic performance of structures with cross-laminated timber (CLT) members.

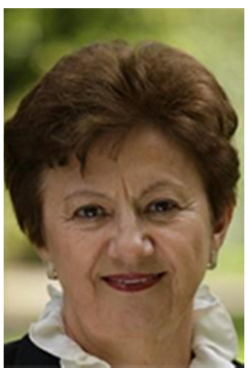
Wave Research Lab

OSU's Cascadia Lifelines Program (CLiP), under the leadership of Dan Cox and in collaboration with PEER, sponsored research on the resilience of transportation and utility networks, including electric, gas, water, and wastewater, to long duration subduction earthquakes along the Cascadia subduction zone (CSZ). Many of these networks were designed for the short-duration earthquakes typically experienced in California, and are thus in a precarious position with limited resources available to address the hazards posed by a CSZ event. In addition to utility providers, the Oregon DOT and Port of Portland are members of the CLiP consortium.

SURF participants

With a wealth of active research projects on resilience, the OSU School of CCE conducted a summer undergraduate research fellowship (SURF) program in 2016. The SURF program gave ten OSU undergraduate students research experience, with faculty and graduate student mentors, on infrastructure and community resilience with respect to earthquake and tsunami hazards in the Pacific Northwest. In addition to performing research toward program deliverables, SURF students took field trips to critical infrastructure sites in Portland and along the Oregon coast, and participated in the Cascadia Resilience Short Course attended by several industry practitioners and public policy decision makers. The SURF program will be held again in 2017 and be open to engineering undergraduates from across the country.

4.4 ACTIVITIES AT STANFORD UNIVERSITY



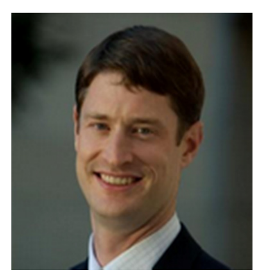
Anne Kiremidjian

Professor Anne Kiremidjian is the PEER institutional board member representing the Stanford University. While there were no PEER-funded projects at Stanford in 2016, there were a couple of publications that were based on PEER funding from the prior year:

Baker, J. W., and Lee, C. "An Improved Algorithm for Selecting Ground Motions to Match a Conditional Spectrum." *Journal of Earthquake Engineering*, (in press).

Baker, J. W., and Bradley, B. A. "Intensity measure correlations observed in the NGA-West2 database, and dependence of correlations on rupture and site parameters." *Earthquake Spectra*, (in press).

In 2016, an update to the "Guidelines for Performance-Based Seismic Design of Tall Buildings" is underway. The project team, led by co-chairs Ron Hamburger and Jack Moehle, include Jack Baker and Gregory Deierlein, of Stanford University.



Jack W. Baker

Eduardo Miranda

On June 16, 2016, the two-month anniversary of the April 16, 2016 Ecuador Earthquake, PEER hosted a seminar about Post-Earthquake Reconnaissance Observations. Eduardo Miranda, Associate Professor, and Luis Alfredo Ceferino Rojas, PhD Candidate, from the John A. Blume Earthquake Engineering Research Center at Stanford University summarized the rapid post-earthquake evaluation and tagging that was conducted by Ecuadorian engineers, and discussed how smartphones facilitated this task for capturing images, geolocating structures and creating centralized databases, often in real-time. Refer to Chapter 6 for additional information in the PEER Seminar Series.

Greg Deierlein and Jack Baker are engaged in the CEA project recently awarded to PEER, “Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single Family Wood-frame Buildings.” Please refer to section 3.7 for additional information on this project.

Greg Deierlein

4.5 ACTIVITIES AT UNIVERSITY OF CALIFORNIA, DAVIS

Bruce Kutter

Professor Bruce Kutter is the PEER institutional board chair and member representing the University of California, Davis. He has served on the PEER institutional Board from 2005–2017. Professor Kutter worked on a series of PEER-funded research projects on the topic of seismic behavior of rocking foundations that concluded in 2012. His work on this topic has continued with funding from NSF and Caltrans. With NSF funding, he is working on LEAP (Liquefaction Experiments and Analysis Projects), which is complementary to PEER’s Next Generation Liquefaction project. Two papers were recently submitted that documented results from past work funded by PEER (and many other sponsors).

Gavras A. G., Kutter, B. L., Hakhamaneshi, M., Gajan S., Tsatsis A., Sharma, K., Kouno, T., Deng, L., Anastasopoulos, I., and Gazetas, G. (2017) Database of Rocking Shallow Foundation Performance – Dynamic Shaking. *Earthquake Spectra*. SUBMITTED.

Hakhamaneshi, M., Kutter, B. L., Gavras A. G., Gajan, S., Tsatsis, A., Liu, W., Sharma, K., Pianese, G., Kouno, T. Deng, L., Paolucci, R., Anastasopoulos, I., and Gazetas, G. (2017) Database of Rocking Shallow Foundation Performance – Slow Cyclic and Monotonic Loading, *Earthquake Spectra*. SUBMITTED.

Sashi Kunnath

Professor Sashi Kunnath has one project with PEER for the bridge fragility workshop from the Lifelines program. It will take place in 2017 on the UC Berkeley campus with several participants from PEER campuses in addition to participants from Georgia Tech and Rice University.

Ross Boulanger’s recent PEER project concluded in March 2016. The topic was “Mitigation of Ground Deformations in Soft Ground”. This research project examined the remediation of liquefaction effects on embankments using soil-cement reinforcements. Specifically, this 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. A paper produced from this project was published in the last year. Although he is not formally involved in NGL, Professor Boulanger periodically discusses NGL activities with Professors Steven

Kramer (University of Washington) and Jon Stewart (UCLA). He sees lots of opportunities for NGL related partnerships with our centrifuge facilities and/or LEAP in filling in the blanks that case history data do not cover, and have discussed this with Professors Kramer and Stewart. Cited publication below is a product of this research.

Boulanger, R. W., Khosravi, M., Khosravi, A., Wilson, D. W., Pulido, A., and Yunlong, W. (2017). "Remediation of liquefaction effects for a dam using soil-cement grids: Centrifuge and numerical modeling." Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul, Korea (September 2017 – in press).

4.6 ACTIVITIES AT UNIVERSITY OF CALIFORNIA, IRVINE

Farzin Zareian

Professor Farzin Zareian is the PEER institutional board member representing the University of California, Irvine. Farzin is engaged in the CEA project recently awarded to PEER, "Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single Family Wood-frame Buildings."

In 2016, an update to the "Guidelines for Performance-Based Seismic Design of Tall Buildings" is being developed. The project team, led by co-chairs Ron Hamburger and Jack Moehle, includes Farzad Naeim, Adjunct Professor and UC Irvine.

Anne Lemnitzer

Anne Lemnitzer, Assistant Professor, Dept. of Civil and Environmental Engineering, is the Principal Investigator for a PEER-funded research project, "Towards Next Generation P-Y Curves–Part 1: Evaluation of the State of Art and Identification of Recent Research Developments and Potentials." The research team includes (collaborators and reviewers in alphabetical order) George Anoyatis, University of West England; Pedro Arduino, University of Washington; Scott Brandenberg, University of California, Los Angeles; Tara Hutchinson, University of California, San Diego; George Mylonakis, University of Bristol, UK; Peter Robertson, Gregg Drilling; Tom Shantz, Caltrans; and Jonathan Stewart, University of California Los Angeles. More details about the project are provided in Chapter 5.

4.7 ACTIVITIES AT UNIVERSITY OF CALIFORNIA, LOS ANGELES

John Wallace

Professor John Wallace is the PEER institutional board member representing the University of California, Los Angeles.

Jonathan P. Stewart, Professor and Chair, Civil and Environmental Engineering, is the project Principal Investigator for "Next Generation Liquefaction (NGL) Project." The research team includes Dong Youp Kwak, Post Doctoral Fellow. Refer to Chapter 5 for additional information about this project.

Jonathan Stewart

In 2016, an update to the "Guidelines for Performance-Based Seismic Design of Tall Buildings" was developed (Section 3.1). The project team, led by co-chairs Ron Hamburger and Jack Moehle, includes Jonathan P. Stewart and John Wallace.

4.8 ACTIVITIES AT UNIVERSITY OF CALIFORNIA, SAN DIEGO

Professor Joel Conte is the PEER institutional board member representing the University of California, San Diego.

4.8.1 Probabilistic Performance-Based Optimal Seismic Design of Seismic Isolated Bridge Structures (funded research, PI: J. P. Conte)

Joel Conte

In the field of earthquake engineering, the advent of the performance-based design philosophy, together with the highly uncertain nature of earthquake ground motions, has brought probabilistic performance-based seismic design to the forefront of seismic design. To design structures that explicitly satisfy probabilistic performance criteria, a probabilistic performance-based optimum seismic design (PPBOSD) framework was proposed as an extension to the state-of-the-art performance-based earthquake engineering (PBEE) methodology. PBEE is traditionally used for risk evaluation of existing or newly designed structural systems, thus referred to as forward PBEE analysis. In contrast, the proposed PPBOSD framework aims to address the inverse PBEE analysis, which is needed for design purposes. To develop this framework, a decision-making layer is wrapped around the forward PBEE analysis procedure for computer-aided optimum structural design/retrofit through mathematical optimization (Li et al., 2016). The PPBOSD framework provides the proper tool to develop, calibrate and validate simplified probabilistic performance-based design procedures.

With the launch of the high-speed train project in California, the seismic risk is a crucial concern to the stakeholders in the transportation sector. To investigate the seismic behavior of future California High-Speed Rail (CHSR) bridge structures, a three-dimensional (3D) nonlinear finite element (FE) model of a CHSR prototype bridge was developed (Li and Conte, 2016). Soil-structure and track-structure interaction are accounted for in this comprehensive numerical model used to simulate the seismic response of the bridge and track system. Using this model as a baseline analytical model, the potential benefits and possible drawbacks of the a priori promising application of seismic isolation in CHSR bridges were examined. Nonlinear time history analyses were performed for this prototype bridge subjected to two bi-directional horizontal historical earthquake ground motions each scaled to two different seismic hazard levels. The effect of seismic isolation on the seismic performance of the bridge was investigated through a detailed comparison of the seismic response of the bridge with and without seismic isolation. It was found that seismic isolation significantly reduces the deck acceleration and the force demand in the bridge substructure (i.e., piers and foundations), especially for high intensity earthquakes. However, seismic isolation increases the deck displacement (relative to the pile cap) and the stresses in the rails. These findings imply that seismic isolation can be promisingly applied to CHSR bridges with due consideration of balancing its beneficial and detrimental effects through using appropriate isolators design. The optimum seismic isolator properties can be sought by solving a performance-based optimum seismic design problem using the nonlinear FE model presented herein.

Increasingly, seismic isolation (SI) has been adopted in buildings and highway bridges to mitigate damage from earthquakes. However, its appropriateness in high-speed rail (HSR) bridges remains a topic of major concern for engineers and stakeholders. The effects of SI on the response of HSR bridge systems during future earthquakes need to be evaluated probabilistically accounting explicitly for all uncertainties associated with the seismic loading. Towards this goal, this study compares the probabilistic seismic responses of a California High-Speed Rail (CHSR) prototype bridge with (IB) and without (NIB) seismic isolation (Li and Conte, 2016b). The uncertainties in the seismic responses for the IB and NIB were quantified and compared to explore the effects of SI when accounting for the uncertainty of the seismic input. The pros and cons of SI identified in probabilistic terms require a trade-off design in applying SI to HSR bridges.

Previous comparison studies on seismic isolation have demonstrated its beneficial and detrimental effects on the structural performance of high-speed rail bridges during earthquakes. Striking a balance between these two competing effects requires proper tuning of the controlling design parameters in the design of seismic isolation. This results in a challenging problem for practical design in performance-based engineering, particularly when the uncertainty in seismic loading needs to be explicitly accounted for. This problem can be tackled using the newly developed probabilistic performance-based optimum seismic design (PPBOSD) framework, proposed as an extension of the performance-based earthquake engineering methodology (Li et al. 2016). For this purpose, a parametric probabilistic demand hazard analysis was performed using high-throughput cloud computing resources for a California high-speed rail (CHSR) prototype bridge with a grid of seismic isolator parameters. Derived probabilistic structural demand hazards, e.g., conditional at a seismic hazard level and unconditional, accounting for all seismic hazard levels, are used to define two families of risk features or metrics, respectively. Various risk features are explored as functions of the varying isolator parameters, and are used to construct probabilistic objective and constraint functions in defining well-posed optimization problems (Li and Conte 2016c, Li et al. 2017). These optimization problems are solved using a grid-based brute-force approach as an application of the framework of PPBOSD, seeking optimum seismic isolator parameters for the CHSR prototype bridge. This application example shows the promising use of seismic isolation for CHSR bridges, as well as the potential of the versatile PPBOSD framework in solving probabilistic performance-based design problems.

PUBLICATIONS

Li, Y, and Conte, J. P. (2016). "Effects of Seismic Isolation on the Seismic Response of a California High-Speed Rail Prototype Bridge with Soil-Structure and Track-Structure Interactions," *Earthq. Eng. Struct. Dyn.*, 45(15): 2415–2434.

Li, Y, Conte, J. P., Gu, Q., and Gill, P. E. (2016). “Framework for Probabilistic Performance-Based Optimum Seismic Design of Structures,” *Structural Safety*, under review.

Li, Y., and Conte, J. P. (2016b). “Probabilistic Performance Evaluation of Seismic Isolation for a California High-Speed Rail Prototype Bridge,” ASCE, *J. Struct. Eng.*, under review.

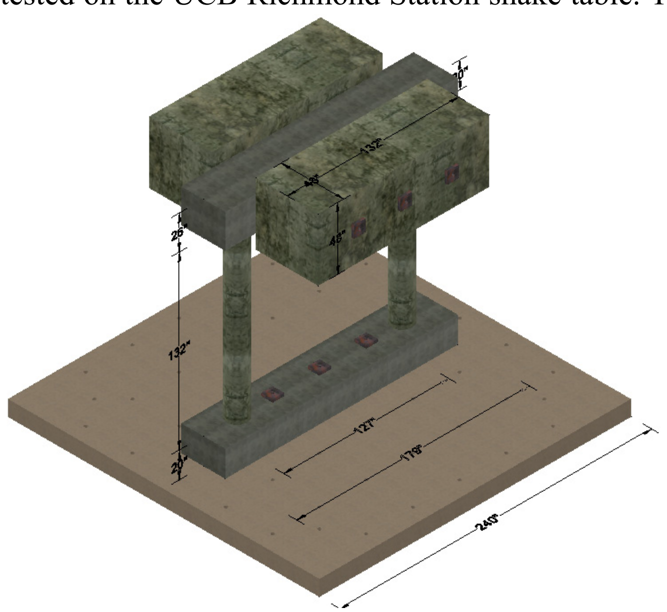
Li, Y., and Conte, J. P. (2016c). “Probabilistic Performance-Based Optimum Seismic Design of Seismic Isolation for a California High-Speed Rail Prototype Bridge,” *Earthq. Eng. Struct. Dyn.*, under review.

Li, Y., Astroza, R., and Conte, J. P. (2017). Investigation of Seismic Isolation for California High-Speed Rail Prototype Bridge in the Context of Probabilistic Performance-Based Optimum Seismic Design, Paper 4478, 16th World Conference in Earthquake Engineering, Santiago, Chile.

4.8.2 Earthquake Resilient Bridge Columns (funded research, PI: J. I. Restrepo)

Jose Restrepo

A transportation system research subgroup at PEER has been very successfully developing earthquake resilient technologies for bridges for a number of years. Because these resilient technologies make use of precast concrete, most of them fall also under the umbrella of Accelerated Bridge Construction (ABC). In 2012, three small-scale (1/3-scale) bridge resilient column proof-of-concept units were designed by teams from the University of Washington (UW) (Stanton & Eberhard), UC Berkeley (Panagiotou and Ostertag), and UC San Diego (Restrepo). Each column unit had specific details to enhance their earthquake resiliency. While the details of the bridge columns developed by PEER researchers at UW and UCB were more tailored at the small diameter, low-weight multi-column bent columns, the UC San Diego resilient bridge column technology was tailored at single large diameter columns, which are commonly used to support freeway connectors. These column units were built and tested on the UCB Richmond Station shake table. The response of these columns compared very favorably with a conventional control column test unit in that damage and residual displacements were reduced. Resilient column units exhibited delayed damage and also exhibited recentering characteristics even when subjected to large drift ratios. The control column test unit behaved as expected, spalling of the concrete occurred at the design earthquake and significant residual displacements were observed when testing at above the design earthquake. Guerrini et al. (2014, 2015, and 2017) summarize the research accomplishments stemming from the work performed by the UC San Diego.



The current project aims at conducting a test at 1/3 scale at the UC Berkeley shake table on a resilient two-column bridge bent, see figure, and conducting in parallel a hybrid simulation test on an identical specimen. In preparation for this shaking table test, a parametric study was conducted on an individual resilient bridge column, resembling a column in a bridge bent, to explore the influence of some key parameters on the behavior. Furthermore, another parametric study was conducted to compare the dynamic response of a completely modeled prototype bridge with conventional and resilient columns. In this parametric study, varying configurations of energy-dissipating mechanisms, prestressed steel, and confining steel, some proposed for use by Caltrans, were studied. The studies on the 3D model demonstrated the superiority of resilient columns over conventional distributed plasticity columns.

PUBLICATIONS

Guerrini, G., Restrepo, J.I., Massari, M. and Vervelidis, A. (2014). "Seismic Behavior of Posttensioned Self-Centering Precast Concrete Dual-Shell Steel Columns," ASCE, *J. Struct. Eng*., 141(4).

Guerrini, G., Restrepo, J.I., Vervelidis, A. and Massari, M. (2015). "Self-Centering Precast Concrete Dual-Steel-Shell Columns for Accelerated Bridge Construction: Seismic Performance, Analysis, and Design," *PEER Report No. 2015/13*, Pacific Earthquake Engineering Research Center, University of California, Berkeley, CA.

Guerrini, G., Restrepo, J.I. and Schoettler, M.J. (2017) "Self-Centering, Low-Damage, Precast Post-Tensioned Columns for Accelerated Bridge Construction in Seismic Regions: Shake Table Tests and Numerical Modeling," *Proceedings*, Paper 3921, 16 World Conference in Earthquake Engineering, Santiago, Chile

4.8.3 Additional Projects

Tara Hutchinson, Chia-Ming Uang, and Gilberto Mosqueda are engaged in the CEA project recently awarded to PEER, "Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single Family Wood-frame Buildings." Please refer to section 3.7 for additional information about this project.

4.9 ACTIVITIES AT UNIVERSITY OF SOUTHERN CALIFORNIA

Erik Johnson

Patrick Lynett

Professor Erik Johnson is the PEER institutional board member, representing the University of Southern California since 2015. He previously served 7 years on the PEER Education Committee.

Professor Patrick Lynett is engaged in the PEER Tsunami Research Program. In 2016, he was recognized by ASCE's Los Angeles chapter as an *Outstanding Civil Engineer in Research* and *Outstanding Civil Engineering Advisor*.

4.9.1 Tsunami Hazard Assessment

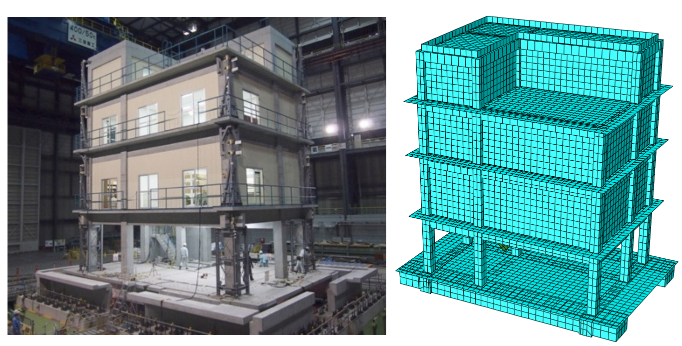
Professor Lynett's tsunami-centric activities supported by PEER focus on quantification of numerical model accuracy and model-to-model variability of tsunami overland flow and velocity predictions. Numerical models are a key component for methodologies used to estimate tsunami risk and model predictions are essential for the development of Tsunami Hazard Assessments (THA). By better understanding model bias and uncertainties and, if possible, minimizing them, a more reliable THA will result. For example, such predictions are needed for calculation of hydrodynamic loadings on structures. A measure of confidence in modeling these complex processes is required prior to more detailed analysis of uncertainties related to onshore physical processes, and it is the purpose of this research to determine this confidence. This goal aligns with an overarching objective of the PEER tsunami research effort: to understand physical and simulation-driven tsunami uncertainties.

4.9.2 Other PEER-Related (but not PEER-Funded) Activities

Many of the faculty of the USC Sonny Astani Department of Civil and Environmental Engineering are engaged in substantial PEER-related earthquake and tsunami engineering research, though almost all of it is funded by sources other than PEER. Some highlights of these research activities are as follows:

- **NSF-Funded Workshops on Seismic Protective Systems**: Erik Johnson and colleagues organized a series of joint international workshops: November 2015 in Tokyo/Sendai, Japan; August 2016 in Christchurch/Wairekei, New Zealand; and January 2017 in Santiago, Chile. These workshops brought together participants from the U.S., Japan, New Zealand and Chile—primarily junior faculty—to assess the state of research in seismic protective systems, evaluate their effectiveness in recent earthquakes in Japan, New Zealand,and Chile, and discuss plans for joint collaborative research in areas of pressing need. Across the three workshops, participants included 34 from the U.S., 28 from Japan, 15 from New Zealand, and 16 from Chile. Acknowledgment: NSF CMMI 14-46424/14-46353.

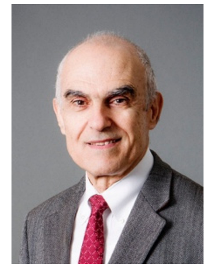
- **NSF-Funded Modeling of a Full-Scale Base-Isolated Building**: Erik Johnson and colleagues have partnered with Japan's E-Defense researchers to develop high-fidelity models of a full-scale four-story base-isolated building specimen that was tested in 2013 on the E-Defense shake table. Data from the full-scale tests are being used to refine the models so that future studies in real-time hybrid simulation and controllable



Full-scale base-isolated building specimen: photo (left) on the E-Defense shake table (courtesy T. Okazaki, Hokkaido Univ.); high-fidelity finite element model (right).

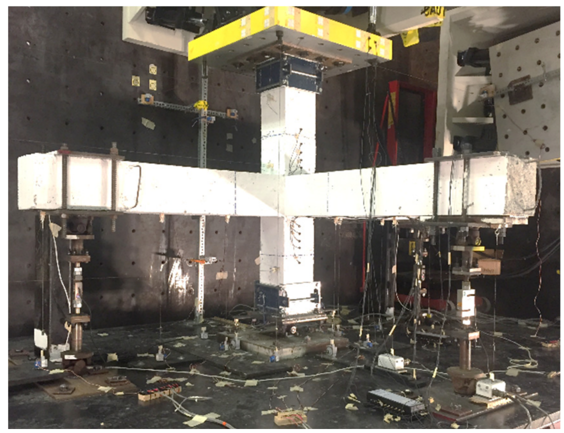
damping strategies can be performed. Acknowledgment: NSF CMMI 13-44937/13-44622.

- **Structural Control and Structural Health Monitoring Research Activities**: Sami Masri and colleagues continue to organize, under the umbrella of the International Association for Structural Control and Monitoring (IASCM), periodic international workshops, and world conferences in the broad area of structural control and health monitoring of civil infrastructure systems. IASCM was established in 1994 with the support of NSF through the collaboration of the U.S Panel on Structural Control Research and affiliated international Panels in Japan, Europe, China, Korea, India, and Australia. The 7th International Workshop on Structural Control and Monitoring (7IWSCM) was held in Incheon, Korea, during the period 24–26 July 2016. In July of 2018, the Seventh World Conference on Structural Control and Monitoring (7WCSCM) will be held in China.

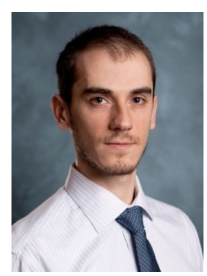


Sami Masri

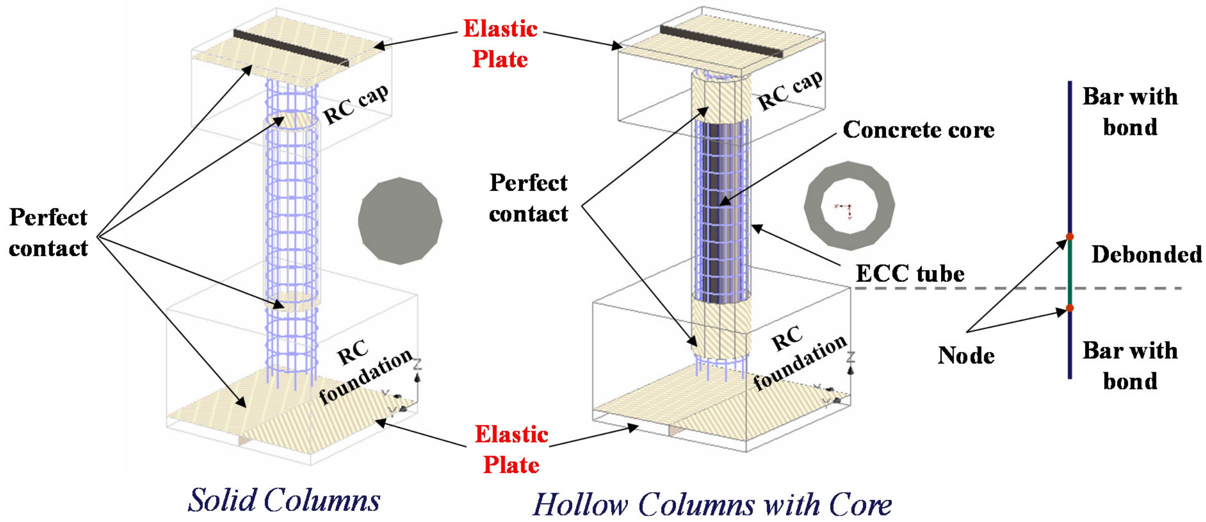
- **NSF-Funded Testing of Beam-Column Joints in Buildings:** Bora Gencturk has successfully tested beam-column joints constructed of high-performance fiber-reinforced concrete. Corner and exterior joints of buildings—for which there is little data in literature—was the focus of this study. Additionally, the effect of torsion on the columns has been studied. This testing has been performed using state-of-the art testing facilities that allow 6-DOF mixed mode control. Acknowledgment: NSF CMMI 1723393.



- **NSF Funded Modeling of Columns with High-Performance Materials:** Bora Gencturk has developed high-fidelity models of bridge columns designed for improved durability and seismic resistance using high-performance materials. Both fiber-reinforced cementitious materials and superelastic alloys were used in the columns. This required the development and implementation of new constitutive models in computer simulation packages. High-fidelity models have been observed to very accurately capture the local and global behavior of such columns as verified with data obtained from experiments. Acknowledgment: NSF CMMI 1642488.



Bora Gencturk



4.10 ACTIVITIES AT UNIVERSITY OF WASHINGTON

Charles Roeder

Professor Charles Roeder is the PEER institutional board member representing the University of Washington. Professor Roeder was the IB member from the founding of the Center and has been an invaluable member of the board with his constructive input over the years.

There was relatively little current PEER funding at the University of Washington, but there was considerable participation in PEER-related activities in 2016. Professor Marc Eberhard is the chair of the Transportation Structures Research Program committee, and Professor Laura Lowes was on the planning committee of the 2016 PEER Annual Meeting held on January 28–29, 2016. In addition, Professors Michael Motley, Marc Eberhard, Pedro Arduino, and Charles Roeder made presentations at this meeting.

Professor Steve Kramer received PEER funding in 2016 to investigate case histories of soil liquefaction at strong-motion sites in Japan. This work involved supplemental field investigations in Japan to obtain previously unavailable data that is needed for liquefaction hazard evaluation in U.S. practice. The combination of detailed subsurface data with strong-motion recordings from the surface of a soil deposit that liquefied allowed new insights into the triggering and consequences of liquefaction. Data from this research, conducted as part of the Next Generation Liquefaction (NGL) project seeded by PEER, will be made publicly available in the web-based NGL database. Professor Kramer recently received additional funding to continue NGL-related research in 2017.

While there has been no other PEER funded research at the University of Washington in 2016, there has been substantial earthquake research at the University of Washington. This research has almost universally employed some PEER developments including OpenSees and ground motion database. These projects include:

- Professors Michael Motley, Marc Eberhard, Pedro Arduino and their students have performed a series of studies on tsunami behavior with funding from the NSF.

- Professors Dawn Lehman and Laura Lowes and their students have been working on the seismic performance of reinforced concrete shear walls.
- Professors John Stanton and Marc Eberhard and their students have been working on the development of seismic resistant methods for accelerated construction of reinforced concrete bridges with funding from the Washington Department of Transportation (WSDOT) and the NSF.
- Professors Dawn Lehman, Jeffrey Berman, and Charles Roeder and their students have been evaluating the seismic performance of older braced frames, developing seismic retrofit strategies of these older braced frames as well as the investigating the design requirements for beams in chevron (or inverted V) braced frames with funding from the NSF and the American Institute of Steel Construction (AISC).
- Professors Dawn Lehman and Charles Roeder have developed economical connections for CFST (Concrete Filled Steel Tube) bridge piers that provide good seismic performance and adequate for accelerated bridge construction with funding from Caltrans. They have also developed methods for predicting the shear resistance of CFST members used as piles and drilled shafts for deep bridge foundation with WSDOT funding.
- Professors John Stanton and Marc Eberhard, with graduate student Kristina Tsvetanova, have developed connection methodologies for precast prestressed concrete bridge girders subjected to longitudinal earthquake loading with funding from WSDOT.
- Professor John Stanton has been working with ABAM Engineers on the development of specifications for Accelerated Bridge Construction in seismic regions.
- Professors John Stanton and Paolo Calvi are working on a project, funded by WSDOT, in which they are investigating the seismic response to seismic motions of hollow prestressed concrete pile-columns, and possible retrofit methods for such columns.
- Professor Pedro Arduino and his students have being working on the development and validation of simplified analysis procedures to estimate liquefaction-induced lateral spreading forces on bridge foundations with consideration for three-dimensional (3D) effects. This research includes the development of large 3D FEM models and consideration of highly nonlinear material conditions and soil-structure interaction effects.
- Professor Arduino and his students have been working on improving the geotechnical capabilities of OpenSees through the development, implementation, and validation of efficient single and multi-phase elements, implementation of advanced 3D constitutive models for soils with consideration of cyclic effects including liquefaction, and advanced interface elements to account for soil-structure interaction effects.

- Professor Arduino and his students have been working on the development of educational tools that make use of OpenSees as an engine. This includes the development of simple GUI’s for pile analysis and a site response analysis tool.
- Professor Arduino continues to participate at the annual OpenSees Days as an instructor.
- Professors Pedro Arduino and Laura Lowes are both serving in DesignSafe and SimCenter. As part of their activities, they are making sure OpenSees is properly installed, disseminated, and used in NHERI infrastructure.
- Professors Jeffrey Berman, Marc Eberhard, Steve Kramer, Joe Wartman, and Mike Motley, along with UW faculty from seismology, urban planning and public policy, have been studying the hazard and consequences of mega-earthquakes generated from the Cascadia Subduction Zone. This NSF-supported research project, called the M9 Project (https://hazards.uw.edu/geology/m9/), is likely to have significant regional impacts on hazard characterization, infrastructure design, as well as planning and public policy. The effects of long duration shaking and amplification from the deep Seattle basin are of key importance.
- Professor Jeffrey Berman has partnered with research from other universities to develop seismic force resisting system for tall timber buildings, including a rocking cross-laminated timber wall concept that received two rounds of NSF support. The project team has been analyzing building response using OpenSees and will be testing rocking timber systems at the Lehigh and UCSD NHERI equipment facilities.
- Professors Joe Wartman, Jeffrey Berman, and Laura Lowes are leading the development of the NHERI Rapid Equipment Facility (http://designsafe-ci.org/rapid), headquartered at the University of Washington. The Rapid facility will house equipment to support collection of perishable data following natural hazards such as earthquakes, hurricanes and tornadoes. The facility will be operational for use as an NSF supported equipment site by September, 2018.

Several University of Washington faculty have been actively involved in PEER committees such as the research coordination committee.

5 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.

5.1 GROUND MOTION AND SELECTION TOOLS FOR PEER RESEARCH PROGRAM

Jack W. Baker

Details of the PEER funded research project, "Ground Motions and Selection Tools for PEER Research Program," are highlighted below. The project Principal Investigator (PI) is Jack W. Baker, Stanford University. The research team includes Cynthia Lee, Graduate Student Researcher, Stanford University.

ABSTRACT

This project developed an algorithm to efficiently select ground motions from a database while matching a target mean and variance of response spectral values at a range of periods. The approach improves an earlier algorithm by Jayaram et al. (2011). Key steps in the process are to screen a ground motion database for suitable motions, simulate response spectra from a target distribution, find motions whose spectra match each simulated response spectrum, and then perform an optimization to further improve the consistency of the selected motions with the target distribution. The computational expense of the algorithm has been greatly improved relative to the previous algorithm. An example selection exercise has been performed to illustrate the type of results that can be obtained. Source code for the algorithm has been provided (https://github.com/bakerjw/CS_Selection), along with metadata for several popular databases of recorded and simulated ground motions, which will facilitate a variety of future exploratory and research studies.

Flow chart of major steps in the ground motion selection algorithm

Additionally, as part of this project, the PI performed an extensive set of ground motion selection in support of PEER research projects related to tall buildings and nuclear power plants. Ultimately, 16 sets of 20 ground motions were developed, representing two locations, a number of hazard levels, and satisfying various design standard requirements.

RESEARCH IMPACT

Selection of ground motions is a topic of great interest as dynamic structural analysis, which requires ground motions as inputs, grows more prevalent. This selection typically involves searching a ground-motion database to find time series produced under appropriate seismological conditions (e.g., earthquake magnitude and source-to-site distance), and that have appropriate response spectral values. In some cases, ground motions are selected based on their individual match to a target spectrum; that is, an optimal set of ground motions would have spectra that all perfectly match the target spectrum. In other cases, however, it is important that the ground motions have variability in response spectra that accurately represents target distributions from predictive models. As such, a number of algorithms have been proposed to select ground motions with some form of specified response spectral variability.

This project developed an efficient algorithm for selecting ground motions from a database that match a target response spectrum distribution (e.g., a Conditional Spectrum). The motivation for this work is that when the target spectrum has a distribution, rather than a single value, it is not possible to evaluate individual ground motions for selection without considering them as part of a suite of ground motions that collectively represent the distribution. But evaluating all possible suites of ground motions is impossible when considering large ground motion databases typical in practice today. This algorithm utilizes several practical strategies to quickly identify ground motion sets with close match to the target spectrum.

5.2 SWARM-ENABLE INFRASTRUCTURE MAPPING FOR RAPID DAMAGE ASSESSMENT FOLLOWING EARTHQUAKES


Tarek Zohdi

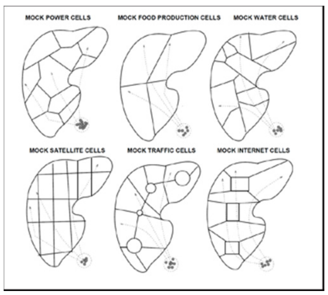
Details of the PEER funded research project, "Swarm-Enabled Infrastructure-Mapping for Rapid Damage Assessment Following Earthquakes," are highlighted below. The project Principal Investigator (PI) is Tarek Zohdi, Will C. Hall Family Endowed Chair in Engineering, UC Berkeley. The research team includes Khalid Mosalam, Taisei Professor of Civil Engineering, UC Berkeley and Yuqing Gao, Graduate Student Researcher, UC Berkeley.

ABSTRACT

The dramatic increase in inexpensive Unmanned Aerial Vehicle (UAV) and camera technology has made the real-time mapping of areas struck by disaster a reality. The objective of this project is to investigate the optimal deployment of multiple UAVs for rapid mapping and assessment before and after a multi-location hazard, such as an earthquake. Because of the complex multi-faceted infrastructures that need to be mapped (roads, bridges, pipelines, power-grid, and water) after a disaster, there exists the need for different mapping strategies. Such sectors need to be mapped with different technologies (infrared, RF, optical, microwave, etc.). Small UAVs are usually battery powered, thus they have limited range and their paths must be planned carefully to conserve power. Simultaneous advances in inexpensive UAVs, computational modeling techniques, and camera and sensor technologies have made rapid pre- and post-hazard mapping a potential reality. Agent-based paradigms for simulation of coupled complex systems have become powerful predictive tools. Because different infrastructures have different grids and different quantities to be mapped, the optimal path for a

set of released swarms will vary over the same terrain. The proposed work develops agent-based models for a team of swarm members (UAVs) intending to map the Bay Area with various optimality conditions: minimum time, minimum energy usage, optical sensing, infrared sensing, acoustical sensing, water spillage sensing, etc. Technological advances and societal changes such as massive numbers of cost-effective drones are now game-changers in terms of the ability to (1) monitor and control events in a hazard, and (2) facilitate long-term planning. The study will develop tools to coordinate activities in heterogeneous infrastructure modeling, simulation, and control. Optimal mapping of various infrastructure is sought, including (a) Power, (b) Water, (c) Transportation, (d) Food distribution, (e) Telecommunication, and (f) Building systems.

RESEARCH IMPACT



Different coexisting infrastructures requiring different mapping strategies and path planning

This study is expected to complement several ongoing PEER projects that are based on developing databases for different infrastructure systems and their earthquake performance. One of these projects is the Seismic Performance Observatory (SPO), which aims at developing a centralized, accessible, extensible, and scalable database that provides pre- and post-earthquake data for buildings and various other infrastructures. The proposed swarm-based pre- and post-earthquake mapping of infrastructure will allow the intended extension objectives of the SPO project. This extension can potentially scale up the SPO database by several orders of magnitude. Currently, this SPO database consists of the information of only few (around 50) structures and the database development is not based on a systematic methodology, but on data uploads by individuals. The proposed project can provide the intended systematic methodology for the development of the SPO database. Moreover, beyond its fundamental objective of providing timely information for emergency responders after earthquakes, the project is expected to provide valuable input for several important infrastructure-related organizations, such as Caltrans for the transportation infrastructure and PG&E for the power grid.

5.3 NEXT GENERATION LIQUEFACTION (NGL) PROJECT

Details of the PEER funded research project, "Next Generation Liquefaction (NGL) Project," are highlighted below. The project Principal Investigator (PI) is Jonathan P. Stewart, Professor and Chair, Civil & Environmental Engineering, UCLA. The research team includes Dong Youp Kwak, Post Doctoral Fellow.

Jonathan Stewart

Locations of ground failure or non-ground failure sites investigated in PEER-supported first phase of NGL characterization work in Japan (base map from Google Earth™)

ABSTRACT

The Next-Generation Liquefaction (NGL) project will (1) substantially improve the quality, transparency, and accessibility of case-history data related to ground failure; (2) provide a coordinated framework for

supporting studies to augment case history data for conditions important for applications but poorly represented in empirical databases; and (3) provide an open, collaborative process for model development in which developer teams have access to common resources and share ideas and results during model development. Work to date has focused on compiling high-value case histories, developing a database template, and planning for the required supporting studies.

RESEARCH IMPACT

This project and others to follow are part of a broad effort that will fundamentally re-define how liquefaction research is undertaken and how liquefaction effects are modeled in practice. The data products will see broad application by researchers, akin to how the NGA databases are an industry standard for ground motion research. Likewise, the NGL models will rapidly become the standard of practice once published.

5.4 NEXT GENERATION LIQUEFACTION: JAPAN DATA COLLECTION

Steven Kramer

Details of the PEER funded research project "Next Generation Liquefaction: Japan Data Collection" is highlighted below. The project Principal Investigator is Steven L. Kramer, University of Washington. The research team includes Mike Greenfield, Graduate Student Researcher, University of Washington.

ABSTRACT

This project is based on the use of case histories where ground motions have been recorded on the surface of soil deposits that liquefied. This new type of case history allows evaluation of the accuracy of existing and proposed procedures for evaluation of liquefaction potential. A series of liquefaction influenced ground motion recordings from the 2011 Tohoku earthquake was carefully examined to evaluate which were most likely to provide insights into aspects of liquefaction that are not well represented in existing liquefaction case history databases. After considering the potential benefits of each, and practical considerations of site access and cost, three sites were investigated for detailed investigation. The sites, all part of the K-Net strong motion instrumentation system, had some available subsurface data, but some subsurface data required for liquefaction potential evaluation procedures commonly used in the U.S. were not available and other data was reported with insufficient resolution for detailed analyses. The three sites were investigated with the aid of Dr. Akio Abe of Tokyo Soil Research. The IBR014 site was located in Tsuchiura, Fukushima prefecture, Japan, about 60 km north of Tokyo, appeared to have potentially have experienced liquefaction of relatively deep strata. Two other sites, MYG010 and MYG013, were located in Ishinomaki, Myagi prefecture, Japan, about 40 km northeast of Sendai. MYG010 appeared likely to provide data on liquefaction of relatively dense soils, and MYG013 appeared likely to have exhibited liquefaction of gravelly soil. All three sites were investigated by drilling and sampling with SPT measurements and by CPT testing in late 2015. Laboratory tests were performed on samples obtained from each of the sites. Detailed analyses of the response of the sites are being performed to confirm and document the conditions under which liquefaction was triggered in the critical layers of each soil profile.

RESEARCH IMPACT

Sand ejecta observed in lower parking lot

Soil liquefaction causes damage to buildings, bridges, pipelines, and other elements of the built and natural environments during earthquakes. Because few sites underlain by liquefiable soils are instrumented with strong-motion seismographs, ground motions at liquefaction case-history sites must usually be estimated from nearby recordings, ShakeMaps, or GMPEs. Sites at which ground motions were recorded on the surface of profiles that liquefied offer the potential, through careful interpretation of time-frequency analyses, to determine the level of shaking at the time liquefaction was triggered. These case histories are fundamentally different than most case histories, which offer a binary indication of whether liquefaction did or did not occur under an estimated level of shaking. Existing case history databases are incomplete with respect to many conditions for which geotechnical engineers are often required to evaluate liquefaction potential. These include liquefaction at depth, liquefaction of relatively dense soils, and liquefaction of gravelly soils. The three case histories investigated as part of this project will add to the sparse existing data for those conditions and their interpretation will aid in the validation/development of predictive procedures for liquefaction potential evaluation.

5.5 TOWARDS NEXT GENERATION P-Y CURVES, PART 1: EVALUATION OF THE STATE OF ART AND IDENTIFICATION OF RECENT RESEARCH DEVELOPMENTS AND POTENTIALS

Anne Lemnitzer

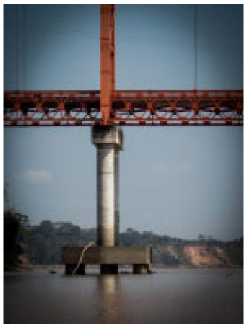
Details of the PEER funded research project "Towards Next Generation P-Y Curves – Part 1: Evaluation of the State of Art and Identification of Recent Research Developments and Potentials" are highlighted below. The project Principal Investigator (PI) is Anne Lemnitzer, Assistant Professor, Department of Civil & Environmental Engineering, UC Irvine. The research team includes (collaborators & reviewers in alphabetical order) George Anoyatis, University of West England; Pedro Arduino, University of Washington; Scott Brandenberg, University of California, Los Angeles; Tara Hutchinson, University of California, San Diego; George Mylonakis, University of Bristol, UK; Peter Robertson, Gregg Drilling; Tom Shantz, Caltrans; Jonathan Stewart, University of California, Los Angeles.

ABSTRACT

Deep-pile foundation systems are an integral, albeit costly, component of our urban living and infrastructure system, especially in mega-cities such as New York and Los Angeles. The daily operational performance (and maintenance) of both the super- and sub-structure systems is paramount in influencing the structure's integrity and its service life, particularly when subject to severe hazard events. The proposed research program will consist of a well-coordinated literature study of analytical, model scale and large-scale deep foundation systems under lateral loading with the objective to (i) identify limitations with existing *p-y* curves and *p-y* design recommendations; (ii) summarize recent research that can help address these limitations; and (iii) identify additional research needs required to formulate *Next Generation P-Y (NGPY)* relations.

The specific outcome consists of a comprehensive report which will compile foundation studies performed in the last 40 years and help develop a new set of "*Next Generation P-Y Curves*" in the near future.

RESEARCH IMPACT



In many areas of the U.S., the design of deep foundation systems for large (e.g., bridges and tall buildings) and movement-sensitive structures (e.g., machine supported foundations) is governed by increasingly complex, multidirectional loading demands and interaction mechanisms resulting from a combination of axial and lateral loading imposed by wind forces, earth pressure, and/or seismic excitation and foundation interaction. While the approach to design for axial loading has been well established and thoroughly tested, methodologies for lateral and combined loading mechanisms have received much less attention. The most frequently used lateral soil-pile interaction relationships (i.e., *p-y* curves) were developed for static and slow cyclic loading conditions using a limited range of soil and structural systems. Extensive research efforts have produced considerable progress in advancing our understanding of individual *p-y* curve parameters; however, most commonly used *p-y* formulations (e.g., in API RP 2A, 2000) have not experienced significant revisions since their formulation more than 40 years ago. In order to systematically address the lack of "state of the art recommendations" for *p-y* formulations and to improve the safety and economy of lateral pile design in non-liquefiable soils, this project will approach the research need identified above by producing a comprehensive document that lays an important foundation for the development of *Next Generation P-Y Curves* in the future. Along with a state-of-the-art assessment of existing knowledge and research progress, the project publications will highlight and propose future research needs and efforts. Additionally, generated publications will facilitate a better transfer of existing knowledge into the practicing geotechnical community, as current research progress on deep foundation systems has only experienced slow and limited industry integration.

5.6 SYSTEM-LEVEL PERFORMANCE EVALUATION OF EARTHQUAKE RESILIENT BRIDGES USING HYBRID SIMULATION

Khalid Mosalam

Details of the PEER funded research project "System Level Performance Evaluation of Earthquake Resilient Bridges Using Hybrid Simulation" are highlighted below. The project Principal Investigator is Khalid M. Mosalam, Taisei Professor of Civil Engineering, UC Berkeley. The research team includes Selim Günay, Project Scientist, UC Berkeley; Yingjie Wu, Graduate Student Researcher, UC Berkeley.

ABSTRACT

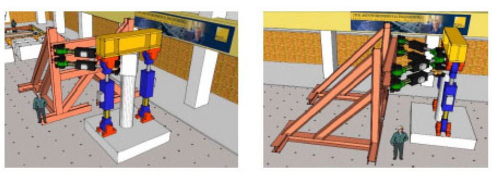
In order to complement and extend the previously conducted research on resilient bridge columns, seismic performance of complete, full-scale bridge systems with resilient columns is investigated in this project using the hybrid simulation (HS) approach. Several HS tests of a multi-column, multi-span California highway bridge, with resilient dual shell rocking columns post-tensioned

with a high strength bar, will be conducted. In the conducted HS tests, either a single column or a single bent will be simulated as the experimental substructure, while the remainder of the bridge will be simulated as the analytical substructure. Hybrid simulation tests will be performed using three directional ground motions**.**

In order to capture the interaction of the tested column and the modeled bridge superstructure in the most possible accurate manner, the test setup will control four (two translational and two rotational) experimental degrees of freedom (DOF). Four specifically arranged horizontal actuators will be used to control these four DOF. Meanwhile, two vertical actuators will be used to apply the axial force that varies as a result of the gravity loading, the vertical component of the earthquake excitation, and the overturning moments due to the horizontal earthquake components.

The conducted tests will be used to tune analytical models that will in turn be utilized in the context of performance based earthquake engineering (PBEE) for the considered prototype and similar bridges. The HS tests and consequent analyses are expected to provide valuable insight into the seismic response enhancement of California bridges due to the use of resilient dual-shell rocking columns.

RESEARCH IMPACT



Experimental setup for the planned hybrid simulation tests

Highway bridges in California constitute one of the most important components of the transportation system. Proper functioning and operation of these bridges are essential for resiliency of the California communities as well as for purposes of post-earthquake recovery. Conventional CALTRANS bridge design philosophy is based on preventing any damage to the deck, cap beam, joints, etc., while dissipating the energy due to ground motion through inelastic ductile response of the bridge columns.

Although this approach is useful to prevent significant damage or collapse of the bridges, it involves risks affecting the resilience and post-earthquake recovery because of the need to close the bridge for traffic for potential column repairs. Furthermore, the presence of residual drifts at the end of inelastic response introduces challenges for the repair operations, which may increase the downtime and monetary losses. For increasing the highway bridge resilience, research has been conducted in recent years, which consists of the development of damage-resistant, re-centering column designs (referred to as resilient columns), and evaluation of these designs with quasi-static and shaking table tests. Although these experiments provided valuable information on the performance of the developed designs and their corresponding response enhancement, the obtained results were limited to the local column level and did not include the investigation of a complete bridge that contains these resilient columns (i.e., without consideration of the response of the entire bridge system and the interaction of the resilient column with the remainder of the bridge).

The conducted system level HS tests and the accompanying performance-based earthquake engineering (PBEE) are expected to complement the previous and ongoing research efforts on resilient columns and extend the outcome of such research to resilient bridges and transportation systems.

5.7 INFLUENCE OF KINEMATIC SSI ON FOUNDATION INPUT MOTIONS FOR BRIDGES ON DEEP FOUNDATIONS

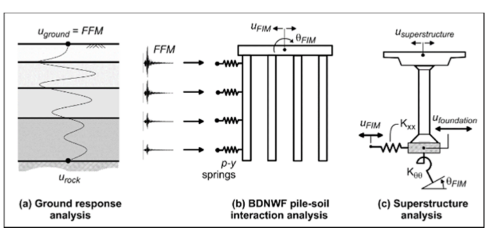
Scott Brandenberg

Details of the PEER funded research project, “Influence of Kinematic SSI on Foundation Input Motions for Bridges on Deep Foundations,” are highlighted below. The project Principal Investigators are Scott J. Brandenberg, Associate Professor, University of California, Los Angeles and Jonathan P. Stewart, Professor and Chair, University of California, Los Angeles. The research team includes Benjamin J. Turner, Dan Brown, and Associates.

ABSTRACT

The seismic analysis of bridge structures is often performed using the substructure method, in which the foundation is replaced by an equivalent set of “springs” representing foundation impedance. Ground motions from seismic hazard analysis correspond to a free-field condition and must be modified to account for kinematic soil–structure interaction to obtain the appropriate foundation input motion. The modification arises from the pile movement being different from the free-field soil movement and is most prominent when the wavelength of the free-field wave is short relative to the pile length. At typical earthquake frequencies, this condition corresponds to large-diameter stiff pile foundations embedded in soft soils. Although a number of studies have been performed to quantify the effects of kinematic soil–structure interaction, they are often limited to idealized boundary conditions (e.g., uniform elastic soil, linear soil–structure interaction, and linear pile response), and do not provide spectral modification factors for use in structural design of bridges for earthquake loads. This project performed a suite of dynamic analyses of deep foundations embedded in realistic soil profiles and subjected to realistic earthquake ground motions. The results are presented as transfer functions intended to be applied to a free-field ground motion time series for the purpose of obtaining a foundation input motion time series for a dynamic response analysis, and also as response spectrum modification factors intended to be applied to a design free-field response spectrum to obtain a design foundation-input spectrum for spectral analysis.

RESEARCH IMPACT



The impact of this research will be the improved assessment of the seismic response of bridges founded on deep foundations, particularly for large-diameter stiff foundations in soft soils. Piles that are restrained rotationally by a pile cap result in the foundation input motion being lower than the free-field motion, particularly at high frequencies. Free-head piles exhibit kinematic amplification over certain frequency ranges, and reductions at high frequency. Hence, the foundation input motion may be either higher or lower than the free-field motion. We anticipate that the transfer functions and spectral modification factors will be most important for bridge structures involving large-diameter foundations and poor soil conditions. These important bridges are typically expensive, and the added complexity of considering kinematic soil–structure interaction is worthwhile.

5.8 PERFORMANCE-BASED TSUNAMI ENGINEERING II

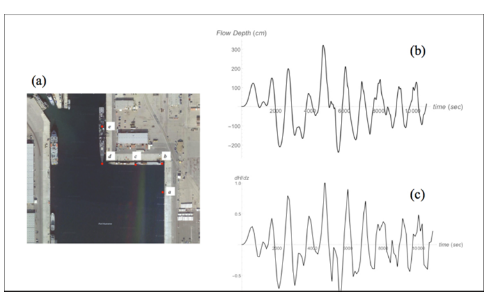
Harry Yeh

Details of the PEER funded research project "Performance Based Tsunami Engineering II" are highlighted below. The project Principal Investigator is Harry Yeh, Professor of Civil and Construction Engineering, Oregon State University. The research team includes Dylan Keon, Associate Director of NACSE, Oregon State University and Juan Restrepo, Professor of Mathematics, Oregon State University.

ABSTRACT

In spite of the advances in numerical modeling and computer power, coastal buildings and infrastructures are still designed for tsunami hazards based on parametric criteria with engineering conservatism, largely because the complex numerical simulations take time and efforts to obtain adequate results for a specific structure at the specific location of interest. It is especially challenging when we need to conduct multiple scenarios with a variety of probabilistic tsunami occurrence. Numerical computations with high resolution in time and space yield extremely large datasets. This project introduces a new web-based tool (we call it the Data Explorer) to facilitate extraction of numerical tsunami simulation data. The concept for retrieving pre-computed simulation data is not new. Nonetheless, the Data Explorer is unique in its ability to retrieve a time-series data extremely fast from massive output datasets, to run in a standard web browser, and in its engineering user-centric design. The tool's usability, together with nearly instantaneous retrieval of the data, makes the simulation-based analysis more accessible; consequently the model-based quantification of the uncertainties is achievable, instead of determination based simply on expert judgment. The Data Explorer is designed for use in conjunction with the methodology called Performance Based Tsunami Engineering (PBTE) for examining critical coastal structures and lifelines such as ports and harbors, coastal bridges, oil and LNG refinery and storage facilities, and nuclear and other gas and coal-fired power plants. Presently, the coastal area of Port Hueneme, California is implemented as a test case, and the portal contains total fifteen tsunami inundation scenarios.

RESEARCH IMPACT



Quantification of uncertainties using the Data Explorer for the quay wall of the port of Port Huename.

The development of Performance Based Tsunami Engineering (PBTE) together with the effective IT tool–the Data Explorer–drastically improves the engineering design (or retrofit) practice for critical coastal facilities and structures. The Data Explorer represents an effective tool for the analysis of critical structures that require probabilistic considerations with regard to uncertainty quantification. Significant advances in information technology–in particular, computational speed, data handling, and the ability to store massive datasets and quickly index through them–have facilitated the development of this tool. The Data Explorer can be used to evaluate quantifiable uncertainty supported by the data for a given critical structure. In spite of the presence of substantial uncertainty in tsunami hazard estimates, this tool enables users to comprehensively analyze a structure using the best available engineering models and knowledge, minimizing potentially unreliable expert judgment and guesswork.

Tsunami destruction in the town of Onagawa Japan: before and after

The present methodology is necessary for critical facilities that require analysis beyond the justification made via the forthcoming ASCE 7 guidelines. Further development of the Data Explorer is being pursued, including the ability to automate the calculation of additional parameters and the production of additional charts and graphs, as well as the ability to define multiple points of interest in the interface itself and download a spreadsheet containing all simulated and calculated data for all points. The technique called the polynomial chaos method is used for part of the analysis of uncertainty quantification. The development of the Data Explorer was reported in *Computer* (Keon et al. 2015), the *Journal of Disaster Research* (Keon et al. 2016), and at the ASCE *Coastal Structures & Solutions to Coastal Disasters Joint Conference* (Yeh et al. 2015).

5.9 PERFORMANCE-BASED TSUNAMI ENGINEERING II: DATASET

Hong Kie Thio

Details of the PEER funded research project, "Performance Based Tsunami Engineering II – Data Set," is highlighted below. The project Principal Investigator (PI) is Hong Kie Thio, Principal Seismologist, AECOM, Los Angeles. The research team includes Wenwen Li, Coastal Engineer, AECOM, Los Angeles.

ABSTRACT

The PBTE Data Explorer is a web-based, user-friendly portal that runs on a GIS platform and allows users to retrieve high-resolution tsunami data at any grid point in the inundation zone (with data produced from numerical tsunami simulations). The portal provides the inundation zone and maximum depths, time series data on flow depth, velocity, specific force, and moment at a user-specified location. Those data can serve as the basis for estimating hydrodynamic forces, impulse forces, debris impact forces, and moments, as well as tsunami-induced soil instabilities and buoyancy forces (note that buoyancy force depends on the pore-water pressure underneath the structure). Presently, the coastal area of Port Hueneme, California, has been implemented as a test case, but the portal contains only a few tsunami inundation scenarios. AECOM has expanded current portal functionality to handle the probabilistic tsunami analysis by running 25 simulations and providing series data of inundation depths and velocities to the platform.

Data Explorer Interface

RESEARCH IMPACT

The scenarios account for a wide range of return times in terms of tsunami amplitudes. This dataset will allow us to build a probabilistic interface to the platform, which will be consistent with the ASCE 7-16 tsunami design maps, and could potentially be used in the application of ASCE 7-16 for engineering purposes.

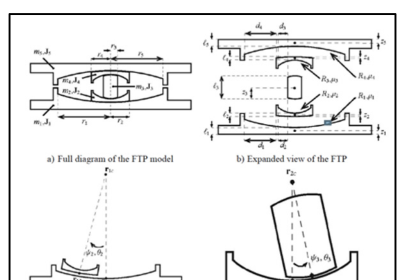
5.10 GEOMETRICALLY EXACT NONLINEAR MODELING OF MULTI-STAGE FRICTION PENDULUM SYSTEMS

Sanjay Govindjee

Details of the PEER funded research project, "Geometrically Exact Nonlinear Modeling of Multi-stage Friction Pendulum Systems," are highlighted below. The project Principal Investigator is Sanjay Govindjee, Professor of Civil Engineering, UC Berkeley. The research team includes Paul Drazin, Graduate Student Researcher, UC Berkeley.

ABSTRACT

The primary goal of this project is to improve the analytical and numerical modeling of multi-stage friction pendulum systems (MSFPs). Single, double, and triple friction pendulums have been proposed as seismic isolation devices for a wide range of structural and non-structural systems. However, no current model for MSFPs utilizes a rigorous setup for the kinematics of the internal sliders; they start directly with scalar equations. The rigorous use of vectors to describe the kinematics of the internal sliders will help to clarify the overall motion of MSFPs. This will also aid in the setup of the kinetics of the MSFPs, with no linearization assumption, as well as facilitating the modeling of multi-directional motion. The model to be developed will incorporate full vectorially described motion with trajectories constrained to the configuration manifold as defined by mathematically precise constraints. Constructing the model in this way directly facilitates a number of modeling advances and can naturally lead to robust numerical approximations. The advantages of the proposed model are as follows: (1) it will be a geometrically fully nonlinear model; (2) it will be able to naturally handle multi-directional motions, including complex rotary motions on the sliding surfaces, uplift, top, and bottom plate rotations, etc.; (3) by construction, it will be fully dynamic and permit the modeling of multi-surface sliding during shock-like loading situations; and (4) it will be modular and permit the use of advanced friction models. The first stage of this project is to apply the vectorized motion to that of the friction triple pendulum (FTP) system, a type of MSFP, as a benchmark for the new model, as shown in the Project Images. The motion of each slider is described via a set of Euler angles with respect to the previous slider. This easily allows for expansion to other, more complicated MSFP systems.



a) Full diagram of the FTP model
b) Expanded view of the FTP
c) Views of the individual sliders showing the vectors and angles used to describe the kinematics

RESEARCH IMPACT

California is at a constant risk of a major earthquake, and the proper usage of seismic isolators, such as MSFPs, can drastically reduce the damage sustained to buildings, bridges, etc. due to a seismic event. For this reason, well-functioning models of MSFPs are of importance to make sure that structures are properly isolated in the event of an earthquake. However, current models lack the ability to properly predict isolator response under seismic excitation, which can potentially lead to more physical damage to a structure than was predicted by the model. The proposed developments are designed to directly replace and enhance currently available models for performing design computations on MSFP isolated structural systems. Enhancements are envisaged with respect to both modeling fidelity as well as the robustness of the models within the context of time history analysis systems. These enhanced models are foreseen to help reduce the damage and downtime of bridge and building structures during post-earthquake recovery. The proposed model will also lead to cost and time savings since there will be less need to physically test either full-scale or scaled-down MSFPs in a laboratory setting to get accurate results. There is also potential impact for isolating systems other than standard civil structures. Certain machine tools and instruments need to be seismically isolated for proper use, and a more effective and efficient model will make it easier for MSFPs to be developed for these non-structural situations.

5.11 PROBABILISTIC PERFORMANCE-BASED OPTIMAL SEISMIC DESIGN OF ISOLATION BRIDGE STRUCTURES

Joel Conte

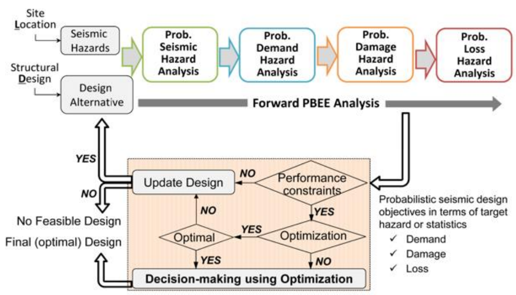
Details of the PEER funded research project "Probabilistic Performance-Based Optimal Seismic Design of Isolated Bridge Structures" are highlighted below. The project Principal Investigator is Joel P. Conte, Professor of Structural Engineering, UC San Diego. The research team includes Yong Li, Post-doctoral Fellow, UC San Diego.

ABSTRACT

The emerging transportation needs in California, together with significant success of high-speed rail systems all through the world, has prompted the initiation of California high-speed rail (CHSR) project. In areas with high seismic activity (e.g., San Francisco and Los Angeles), the seismic risk mitigation of high-speed rail bridges is a topic of major concern to stakeholders, policy makers, and engineers. Seismic isolation offers a promising solution for high-speed rail bridges in high seismic regions. However, its effectiveness in enhancing the seismic performance of CHSR bridges needs to be evaluated reliably based on a comprehensive numerical model of a bridge system considering its various components with their nonlinearities and interactions. Thus, a nine-span CHSR prototype bridge is designed, and a detailed three-dimensional (3-D) nonlinear finite element (FE) model, with soil foundation- structure and rail-structure interactions, was developed in OpenSees. Using this FE model, seismic responses (including the bridge structural and rail responses) of the prototype bridge with and without seismic isolation were compared deterministically and probabilistically, and the beneficial and detrimental effects of seismic isolation identified. To evaluate the effects of isolator characteristics, a parametric probabilistic seismic demand hazard analysis was performed with respect to key isolator model parameters. For an optimum isolator design that strikes a balance between beneficial and detrimental effects, a probabilistic performance-based optimum seismic design (PPBOSD) framework was proposed and validated with a proof-of-concept example. This framework was applied to seek the optimum seismic

isolator design for the CHSR prototype bridge considered. Several well-posed design optimization problems, with different probabilistic objective and constraint functions, were defined and solved. This research illustrates the power of the proposed PPBOSD framework, and investigated the suitability of seismic isolation for CHSR bridges.

RESEARCH IMPACT



Probabilistic performance-based optimum seismic design (PPBOSD) framework

California high-speed rail (CHSR) bridges will constitute one of the most important components of the transportation infrastructure. Proper design and seismic risk-mitigation of CHSR bridges are essential for the reliable operation of high-speed trains, seismic safety during high intensity earthquake events, and the earthquake resilience of California communities. For damage-free or low-damage performance objectives, seismic isolation is identified as one of the promising earthquake protection strategies. However, the feasibility and optimality of the design of seismic isolation for CHSR bridges needs to be evaluated in a probabilistic framework due to the pertinent sources of uncertainty (e.g., seismic input). Thus, the PEER performance-based earthquake engineering (PBEE) methodology was used with emphasis on the probabilistic demand hazard analysis to evaluate the effects of seismic isolation on the seismic response of a high-speed rail prototype bridge system. Considering the conflicting effects of seismic isolation on different key response quantities (e.g., pier drift, deck displacement and acceleration, and rail stress) of CHSR bridge systems, the proposed and validated PPBOSD framework was used as a decision-making tool for isolator design in the face of uncertainty, to strike a trade-off between the beneficial and detrimental effects. It was found that seismic isolation can be used to satisfy the seismic design requirements of the considered CHSR prototype bridge in a highly seismic region, and that the isolator characteristics can be optimally tuned to satisfy the probabilistic design objectives and constraints using the proposed PPBOSD framework. This framework can also be used to develop and calibrate simplified and practical probabilistic performance-based seismic design methods for ordinary highway bridges and for building structures. This research work provides significant insight to decision makers (e.g., structural engineers and stakeholders) on the potential use of seismic isolation for risk mitigation of future CHSR bridges.

5.12 PEER REPORTS 2016–2017

PEER 2017/06 *Guidelines for Performance-Based Seismic Design of Tall Buildings, Version 2.0.* TBI Working Group Ron Hamburger (Co-Chair), Jack Moehle (Co-Chair), 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. 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 2017/05 *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 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 (PGA_r) is often used. The use of PGA_r (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 PGA_r 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 (PGA_r). 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 2017/04 *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).

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. Site-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 2017/03 *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 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 2017/02 *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.

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

A Summary of research, educational and outreach activities at PEER from January 2016.

PEER 2016/10 *Performance-Based Robust Nonlinear Seismic Analysis with Application to Reinforced Concrete Highway Bridge Systems*. Xiao Liang and Khalid M. Mosalam, December 2016.

The performance-based earthquake engineering (PBEE) approach, developed at the Pacific Earthquake Engineering Research Center (PEER), aims to robustly decompose the performance assessment and design process into four logical stages that can be studied and resolved in a systematic and consistent manner. However, the PBEE approach faces two key challenges: (1) an accurate seismic structural analysis and (2) the selection and modification of ground motions (GMs). This report addresses these two challenges with application to reinforced concrete (RC) bridge systems.

In nonlinear structural dynamics, the most accurate analytical simulation method is the nonlinear time history analysis (NTHA). It involves the use of different types of direct integration algorithms and nonlinear equation solvers where their stability performance and convergence behaviors are of great significance. Based on Lyapunov stability theory, a new nonlinear equation solver is developed and its convergence performance theoretically formulated and verified by several examples. Two Lyapunov-based approaches are proposed to perform stability analysis for nonlinear structural systems. The first approach transforms the stability analysis to a problem of existence, which can be solved via convex optimization. The second approach is specifically applicable to explicit algorithms for nonlinear single-degree-of-freedom and multi-degree-of-freedom systems considering strictly positive real lemma. Herein, the stability analysis of the formulated nonlinear system is transformed to investigating the strictly positive realness of its corresponding transfer function matrix. A framework for probabilistic evaluation of the GMSM procedures in the context of a selected large earthquake scenario with bidirectional GM excitations is developed.

In urban societies, RC highway bridges are key components of transportation infrastructure systems and play a significant role in transporting goods and people around natural terrains. Therefore, they are expected to sustain minor damage and maintain their functionality in the aftermath of major earthquakes, a common occurrence in California due to its many active faults. Accurate seismic structural analysis of existing and newly designed RC highway bridges is fundamental to estimate their seismic demands. As important lifeline structures, RC highway bridge systems are investigated as an application of the previously discussed theoretical developments proposed in this report to address the two key challenges in the PEER PBEE approach.

PEER 2016/07 *Hybrid Simulation Theory for a Classical Nonlinear Dynamical System*. Paul L. Drazin and Sanjay Govindjee. September 2016.

Hybrid simulation is an experimental and computational technique that allows one to study the time evolution of a system by physically testing a subset of it while the remainder is represented by a numerical model that is attached to the physical portion via sensors and actuators. The technique allows the study of large or complicated mechanical systems while only requiring a subset of the complete system to be present in the laboratory. This results in vast cost savings as well as the ability to study systems that simply cannot be tested due to scale. However, the errors that arise from splitting the system in two requires careful attention if a valid simulation is to be guaranteed. To date, efforts to understand the theoretical limitations of hybrid simulation have been restricted to linear dynamical systems. The research reported herein considers the behavior of hybrid simulation when applied to nonlinear dynamical systems. The model problem focuses on the damped, harmonically-driven nonlinear pendulum. This system offers complex nonlinear characteristics, in particular periodic and chaotic motions. We are able to demonstrate that the application of hybrid simulation to nonlinear systems requires careful understanding of what one expects from such an experiment. In particular, when system response is chaotic we advocate using multiple metrics to characterize the difference between two chaotic systems via Lyapunov exponents and Lyapunov dimensions, as well as correlation exponents. When system response is periodic we advocate using L2 norms. Further, we demonstrate that hybrid simulation can falsely predict chaotic or periodic response when the true system has the opposite characteristic. In certain cases, control system parameters can mitigate this issue.

PEER 2016/06 *California Earthquake Early Warning System Benefit Study*. Laurie A. Johnson, Sharyl Rabinovici, Grace S. Kang, and Stephen A. Mahin. July 2016.

The California Governor’s Office of Emergency Services (Cal OES) in partnership with the Alfred E. Alquist Seismic Safety Commission (SSC) engaged the Pacific Earthquake

Engineering Research Center (PEER) to independently explore the anticipated value of a statewide earthquake early warning system (EEWS) to the state's economy and infrastructure. As detailed in Section 1 of the report, since 2013, Cal OES has been leading a public-private partnership to develop a statewide EEWS. The capital cost to construct and launch a statewide EEWS is estimated at $28 million, and the personnel and operating expenses are estimated at $17 million annually.

In a six-month investigation, researchers conducted 18 semi-structured interviews with 24 organizations representing 14 important sectors of the state's infrastructure and economy. The interviews focused on the perceived value of a statewide EEWS for each organization as well as specific types and settings for EEWS use that could benefit public and employee safety, business resiliency, and the protection of critical operations and assets that serve local communities and the economy. Information from the interviews was then consolidated and interpreted into this summary, which is primarily aimed at informing future study needed to quantitatively assess the costs and benefits of a statewide EEWS. More information about the organizations participating in the study and the study approach is provided in Section 2, as well as the appendices of the report.

PEER 2016/05 *Ground-Motion Prediction Equations for Arias Intensity Consistent with the NGA-West2 Ground-Motion Models.* Charlotte Abrahamson, Hao-Jun Michael Shi, and Brian Yang. July 2016.

Following the approach outlined in the Watson-Lamprey and Abrahamson [2006] conditional model for Arias intensity, we use the NGA-West2 database to derive a new scaling model for Arias intensity given peak ground acceleration (PGA), T = 1 sec spectral acceleration (SA_{T1}), shear-wave velocity in the top 30 m (V_{S30}), and magnitude. By combining this conditional model with each of five NGA-West2 ground-motion models for PGA and SA_{T1}, we derived five new ground motion prediction equations (GMPEs) for the median and standard deviation of Arias intensity. These five GMPEs for Arias intensity capture the more complex ground-motion scaling effects found in some of the NGA-West2 GMPEs, such as hanging-wall effects, sediment-depth effects, soil nonlinearity effects, and regionalization effects. This allows for Arias intensity values to be estimated that are consistent with the NGA-West2 GMPEs.

PEER 2016/04 *The M_W 6.0 South Napa Earthquake of August 24, 2014: A Wake-Up Call for Renewed Investment in Seismic Resilience Across California.* Prepared for the California Seismic Safety Commission, Laurie A. Johnson and Stephen A. Mahin. May 2016.

The magnitude 6.0 South Napa Earthquake of August 24, 2014, took the lives of two people, injured 300 others, and caused moderate to severe damage to more than 2,000 structures. It is one of the first damaging earthquakes to strike a major metropolitan area in the State of California in over two decades. During that time period, California's population has grown by over 25%, the state's economy has tripled, and a great many of the state's new residents and businesses have never experienced a major earthquake. It is almost guaranteed that there will be a major damaging earthquake somewhere in the state within the next 30 years, and thus the South Napa earthquake is our "wake-up call" to renew investment and action to enhance the seismic resilience of communities, businesses, and residents across the state.

On October 8, 2014, the Alfred E. Alquist Seismic Safety Commission (Commission) held a hearing in American Canyon, California, to better understand impacts and lessons learned from local, State and federal representatives, and residents and businesses impacted by the South Napa earthquake. The Commission subsequently engaged the Pacific Earthquake Engineering Research Center (PEER), headquartered at the University of California, Berkeley, to synthesize and analyze observations and studies resulting over the first year following the earthquake. As part of its work, PEER was asked to review relevant and transferable lessons from other recent earthquakes and, in addition, to consider how scientific, engineering, and technological advances of the last few decades have affected emergency response and recovery following the 2014 earthquake. PEER presented a set of 20 findings of the study to the Commission at its meeting on January 14, 2016, and then worked with the Commission's staff to incorporate feedback into a revised draft that included 41 recommendations for consideration at the Commission's workshop on March 9, 2016. At that time, the Commission identified the 12 priority recommendations. Both the 20 findings and 12 priority recommendations are organized around the areas of Geosciences, Infrastructure, Buildings, People and Businesses, and Government and Institutions.

PEER 2016/03 *Simulation Confidence in Tsunami-Driven Overland Flow.* Patrick Lynett. May 2016.

Numerical models are a key component for methodologies used to estimate tsunami risk, and model predictions are essential for the development of Tsunami Hazard Assessments (THAs). By better understanding model bias and uncertainties and, if possible, minimizing them, a more reliable THA will result. This study compares the run-up height, inundation lines, and flowvelocity field measurements between GeoClaw and the Method of Splitting Tsunami (MOST) model predictions in the Sendai Plain. In general, run-up elevation and average inundation distance are overpredicted by the models. However, both models agree relatively well with each other when predicting maximum sea surface elevation and maximum flow velocities. To explore the variability and uncertainties in the numerical models, the MOST model is used to compare predictions from four different grid resolutions (30 m, 20 m, 15 m, and 10m). Our work shows that predictions of statistically stable products (run-up, inundation lines, and flow velocities) do not require use of high-resolution (less than 30 m) Digital Elevation Maps (DEMs) at this particular location. In addition, the Froude number variation in overland flow is presented. The results provided in this paper will help understand the uncertainties in model predictions and locate possible sources of errors within a model.

PEER 2016/02 *Semi-Automated Procedure for Windowing Time Series and Computing Fourier Amplitude Spectra for the NGA-West2 Database.* Tadahiro Kishida, Olga-Joan Ktenidou, Robert B. Darragh, and Walter J. Silva. May 2016.

This document introduces and describes the data processing methods developed for computing Fourier amplitude spectra (FAS) in the NGA-West2 project. The products of this study can be used to estimate high-frequency attenuation, kappa (κ), to estimate site amplification through empirical spectral ratios, as well as to aid in the development of ground-motion models (GMMs) based on FAS. To accommodate different potential user objectives, we selected five time windows in the acceleration time series (noise, P-wave, S-wave, coda, and the entire record) for which we compute the FAS. The processing starts with the time-aligned, instrument-corrected, tapered, and filtered acceleration time series. The proposed window selection method is developed through trial and error, and tested against a range of ground motions with different magnitudes and hypocentral distances from different regions. This document summarizes the steps for window selection and FAS computation, and describes the output data format. This report will be accompanied by the final products of the PEER NGA-West2 Project, namely, the published report describing the database and the flatfile, which can be downloaded in excel format at: http://peer.berkeley.edu/ngawest2/databases/.

PEER 2016/01 *A Methodology for the Estimation of Kappa (κ) from Large Datasets: Example Application to Rock Sites in the NGA-East Database and Implications on Design Motions.* Olga-Joan Ktenidou, Norman A. Abrahamson, Robert B. Darragh, and Walter J. Silva. April 2016.

This report reviews four of the main approaches (two band-limited and two broadband) currently used for estimating the site κ_0: the acceleration slope (AS) above the corner frequency, the displacement slope (DS) below the corner frequency, the broadband (BB) fit of the spectrum, and the response spectral shape (RESP) template.

Using these four methods, estimates of κ_0 for rock sites in Central Eastern North America (CENA) in the shallow crustal dataset from NGAEast are computed for distances less than 100 km. Using all of the data within 100 km, the mean κ0 values are 8 msec for the AS approach and 27 msec for the DS approach. These mean values include negative κ estimates for some sites. If the negative κ values are removed, then the mean values are 25 msec and 42 msec, respectively. Stacking all spectra together led to mean κ_0 values of 7 and 29 msec, respectively. Overall, the DS approach yields 2–3 times higher values than the AS, which agrees with previous observations, but the uncertainty of the estimates in each case is large. The AS approach seems consistent for magnitudes down to **M**3 but not below.

Based on the available profile, the individual spectra are corrected for crustal amplification and only affect results below 15 Hz. Since the AS and DS approaches are applied over different frequency ranges, we find that only the DS results are sensitive to the amplification correction. More detailed knowledge of individual near-surface profiles may have effects on AS results, too. Although κ is considered to be caused solely by damping in the shallow crust, measurement techniques often cannot separate the effects of damping and amplification, and yield the net effect of both phenomena.

The two broadband approaches, BB and RESP, yield similar results. The mean κ_{0_BB} is 5±0.5 msec across all NEHRP class A sites. The κ_{0_RESP} for the two events examined is 5 and 6 msec. From literature, the average value of κ0 in CENA is 6 ± 2 msec. This typical value is similar to the broadband estimates of this study and to the mean κ_{AS} when all available recordings are used along with all flags. When only recordings with down-going FAS slope are selected from the dataset, the mean value of κ_{AS} increases by a factor of 2–3.

To evaluate the scaling of high-frequency ground motion with κ, we analyze residuals from ground motion prediction equations (GMPEs) versus κ estimates. Using the κ values from the AS approach, the average trend of the ln(PSA) residuals for hard-rock data do not show the expected strong dependence on κ, but when using κ values from the DS approach, there is a stronger correlation of the residuals, i.e., a κ that is more consistent with the commonly used analytically based scaling. The κ_{DS} estimates may better reflect the damping in the shallow crust, while the κ_{AS} estimates may reflect a net effect of damping and amplification that has not been decoupled. The κ_{DS} estimates are higher than the κ_{AS} estimates, so the expected effect on the high-frequency ground motion is smaller than that expected for the κ_{AS} estimates.

An empirical hard-rock site factor model is developed that represents the combined *Vs*- κ_0 site factor relative to a 760 m/sec reference-site condition. At low frequencies (< 3 Hz), the empirical site factors are consistent with the scaling due to the change in the impedance contrast. At high frequencies (> 10 Hz), the residuals do not show the strong increase in the site factors as seen in the analytical model results. A second hard-rock dataset from British Columbia, Canada, is also used. This BC hard-rock residuals show an increase in the 15–50 Hz range that is consistent with the analytical κ_0 scaling for a hard-rock κ_0 of about 0.015 sec.

The variability of the PSA residuals is also used to evaluate the κ_0 scaling for hard-rock sites from analytical modeling. The scatter in existing κ_0 values found in literature is disproportionately large compared to the observed variability in high-frequency ground motions. We compared the predicted ground-motion variability based on analytical modeling to the observed variability in our residuals. While the hard-rock sites are more variable at high frequencies due to the additional κ_0 variability, this additional variability is much less than the variability predicted by the analytical modeling using the variability from κ_0-Vs_{30} correlations. This is consistent with weaker κ_0 scaling compared to that predicted by the analytical modeling seen in the mean residuals.

6 Events and Outreach Activities

PEER organized several events and was involved in numerous outreach activities in the past year. PEER researchers were active participants in national and international seminars. Eight 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.

6.1 CALIFORNIA SEISMIC SAFETY COMMISSION

PEER has completed several projects with the California Seismic Safety Commission (CSSC) and California Governor's Office of Emergency Services (CalOES). These projects are summarized in *PEER Reports 2016/04* and *2016/06*, respectively. PEER is currently working with USGS & CSSC for the HayWired rollout initiative and how it relates to PEER's mission. More information will be released in 2017.

6.2 INTERNATIONAL ORGANIZATIONS

PEER is now an active board member of two prominent international organizations, "International Joint Research Laboratory of Earthquake Engineering" (ILEE) and "Global Alliance of Disaster Research Institutes (GADRI), as noted in Chapter 2. Furthermore, PEER has signed Memoranda of Understanding (MOU) with institutions in Canada, China, and Romania. These engagements extend PEER's outreach to global research collaborators, and gives PEER the opportunity to have input on research agendas.

6.3 CALIFORNIA EARTHQUAKE AUTHORITY (CEA)

PEER's engagement with the California Earthquake Authority (CEA) includes the research project "Quantifying the Performance of Retrofit of Cripple Walls and Sill Anchorage in Single Family Wood-frame Buildings," noted in Chapter 7. PEER also participated in CEA's Research Forum held in Sacramento in February 2017.

6.4 U.S.-JAPAN-NEW ZEALAND WORKSHOP ON LIQUEFACTION, BERKELEY, CAMPUS, 2-4 NOVEMBER 2016

Liquefaction Workshop attendees

The "Liquefaction-Induced Ground Movements Effects" workshop was an NSF-funded workshop organized by UC Berkeley Professor Jon Bray with support from PEER. The workshop provided an opportunity to make use of recent research investments following these earthquake events to develop a path forward for an improved 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. Five research themes emerged: (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 workshop also advanced the development of younger researchers by identifying promising research opportunities and approaches, and promoting future collaborations among participants. Findings from the workshop are summarized in *PEER Report No. 2017/02*.

6.5 PACIFIC RIM FORUM ON EARTHQUAKE RESILIENCE OF NUCLEAR FACILITIES

Panel Discussion during Pacific Rim Forum

On January 23-24, 2017, PEER hosted the latest Pacific Rim Forum focusing on the critical issue of earthquake resilience of nuclear facilities. This forum brought together governmental leaders, practitioners and researchers from around the Pacific Rim and elsewhere to address the current state of practice, recent research advancements, and unresolved challenges related to seismic performance of nuclear facilities. The Forum was hosted in collaboration with the Lawrence Berkeley National Lab, U.S. Department of Energy, American Association of Structural Mechanics in Reactor Technology (AASMiRT), Japan Atomic Industrial Forum (JAIF), and Pacific Gas & Electric Company. Specific topics of discussion included the following:

- Recent developments and future needs in seismic hazard characterization,
- Advancements in risk-informed, performance based earthquake guidelines,
- Advanced simulations for transformational hazard and risk assessments,
- Decommissioning, including under extreme conditions,
- Experimental simulation for advanced understanding,

- Recent industrial experiences in Probabilistic Risk Assessments, and
- Advanced technologies for performance modification, monitoring and detection.

Participants of the Pacific Rim Forum

PEER participants joined other invited international experts and leaders from around the Pacific Rim and Europe, from a broad cross-section of academic institutions, national laboratories, commercial sector entities, and governmental agencies. International perspectives were presented by Hirobumi Kayama, Special Advisor to the Ministry of Economy Trade and Industry (METI), Japan, Garrett Smith, Acting Director, DOE Office of Nuclear Safety, United States, and Xin-Zheng Lu, Rong Pan, Director of Plant Siting and Civil Engineering, Nuclear Safety and Radiation Safety Center, China. PEER researchers and colleagues who made presentations included: Khalid Mosalam, Norm Abrahamson, Yousef Bozorgnia, Steve Mahin, Greg Ashley, Ian Buckle, Laurie Johnson, Boris Jeremic, Kenichi Soga, and Andreas Schellenberg. After the event, feedback from many participants indicated great appreciation for the range and perspectives of topics covered, the high technical quality of the presentations, and the incisive and far-ranging discussions of opportunities and challenges related to risk assessment and resilience.

6.6 2016 NATIONAL EARTHQUAKE CONFERENCE, MAY 4-6, 2016, LONG BEACH

PEER was on the steering committee of the National Earthquake conference, which was attended by earthquake scientists, engineers, Cal OES and municipal emergency managers, FEMA, and city officials and policy makers. PEER Communications Director Grace Kang delivered a summary of the conference highlights at the end of the first two days.

6.7 16WCEE, JANUARY 2017, SANTIAGO, CHILE

16WCEE Presenters Based on PEER Funded Research

Many PEER-affiliated researchers participated at the 16th World Conference on Earthquake Engineering (WCEE) held in Santiago, Chile, January 9–13, 2017. Over a dozen faculty, post-docs, and students presented on PEER-funded research. Additionally, 50 PEER-affiliated researchers from PEER core institutions as well as other institutions throughout the world presented and shared posters during the conference.

Tribute session for emeritus Prof. Vitelmo Bertero

6.8 SUMMER 2016 INTERNSHIP PROGRAM

PEER offers exciting opportunities for students to explore new directions in earthquake studies and research. In 2016, eight students participated in the PEER Summer Internship Program. Below, they shared some of the highlights and valuable learning opportunities they experienced during their 2016 summer internship.

Megan Perley and Judy Guo

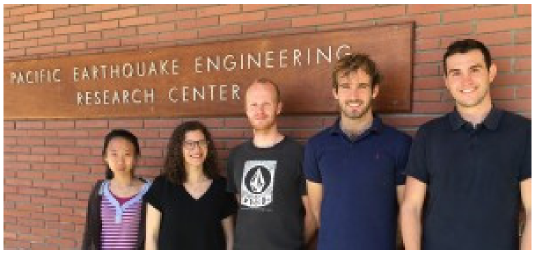
Megan Perley, a senior studying geophysics at UC Berkeley, participated in the 2016 Heising-Simons Natural Disaster Risk Reduction, UC Berkeley-GeoHazards International (GHI) Internship under the guidance of GHI staff Janise Rodgers and UC Berkeley Professors Khalid Mosalam and Doug Dreger. The summer's project was a building inventory conducted in Aizawl, a city in the northeast Indian state of Mizoram that is highly vulnerable to both earthquakes and landslides. She spent the summer taking inventory of existing school buildings in Aizawl, and she hopes the report she worked on during her internship will prevent unnecessary loss of life by minimizing landslide risk and ensuring schools built in the future are earthquake resistant. She found this internship experience highly rewarding as it introduced her to new areas of research, such as landslide and earthquake probability analysis, which she plans to work on in the future.

Judy Guo, a fourth year undergraduate civil engineering student at UC Berkeley, also participated in the 2016 Heising-Simons Natural Disaster Risk Reduction, UC Berkeley GeoHazards International (GHI) Internship. She also conducted the inventory of 22 existing school facilities in Aizawl, India, and compiled the inventory documents into a report for the local government. Judy mentioned that the internship provided her with invaluable exposure and first-hand experience in structural and earthquake engineering concepts. Judy hopes to use her structural engineering knowledge in the future to help other vulnerable communities like Aizawl.

Yennis Barros Atuesta and Cesar Pajaro Miranda (with Grace Kang, PEER Communications, center)

Yennis Yulieth Barros Atuesta is an undergraduate civil engineering student at Universidad del Norte (UNINORTE) in Barranquilla, Colombia, and she worked with Jiaqi Li, a graduate student of UC Berkeley Professor Paulo Monteiro. Yennis collaborated on a project to study the influence of chemical reactions on the mechanical properties of concrete. Specifically, she documented concrete mechanical properties as influenced by tri-calcium aluminate reactions with gypsum and other parameters. She found the internship both professionally and personally enriching and benefited greatly from the interaction with UC Berkeley professors. She intends to pursue an engineering research career and hopes to apply her skills to improve social conditions.

Cesar Pajaro Miranda is an undergraduate civil engineering student at UNINORTE and collaborated with Jorge Macedo, a Ph.D. candidate at UC Berkeley, and Professor Jonathan D. Bray. Cesar was involved in two projects: (1) the validation of a BMT17 simplified slope displacement procedure, which is relevant to subduction zones; and (2) post-processing centrifuge test data results performed by previous UC Berkeley students and updating geotechnical numerical analyses with additional data. The internship exposed him to new trends and topics in geotechnical earthquake engineering research, which he is certain will enhance both his professional and personal life in the years to come.



Yu Cai, Khawla Seffar, Baptiste Goussard, Jerome Aubourg, Jeremy Boussidan

Yu Cai is a graduate student at the University of Paris. She worked with PEER-UC Berkeley Lab Manager Clement Barthes on automation and electronics with an emphasis in a laboratory control room. She worked on a platform of piezo-electric sensors that can ultimately be applied to reinforcing steel in buildings, as well as aerospace applications. Part of her research was initiated with Barthes in France, and she came to UC Berkeley for the summer to continue her work.

Khawla Seffar is a graduate student at Ecole Speciale des Travaux Publics (ESTP), France, and she had an extended PEER internship through October 2016. Her area of research is modeling the spatial variability of seismic input motion and studying induced soil-structure interaction effects. She also worked on an OpenSees model of a highway bridge, performing nonlinear time history analyses.

Baptiste Goussard is also a graduate student at ESTP and had an extended PEER internship through October 2016. He worked on developing a numerical isolator model that incorporates kinematic behavior more accurately.

Jeremy Boussidan**,** a graduate student at ESTP, had an extended PEER internship through October 2016. With Baptiste, he studied a new way of numerically modeling isolators, using OpenSees software.

Jerome Aubourg**,** a graduate student at ESTP, was an intern with PEER through October 2016, and he worked on digital correlation and measurements of materials subjected to ballistics. He worked with Clement Barthes on the study of modeling deformation caused by bullets fired from a cannon, using a high-speed camera.

6.9 QUAKECAFE

PEER played an advisory role on new mobile-friendly website called QuakeCAFE, an initiative by the Center for Information Technology Research in the Interest of Society (CITRIS). Launched by the CITRIS Connected Communities Initiative at UC Berkeley in collaboration with the Office of the Lt. Governor of California, QuakeCAFE provides Californians with a powerful tool that allows them to quickly and easily assess their level of preparedness, and compare their readiness for the expected large-magnitude California earthquake with others across the state. It works on all screens and takes only a minute to complete: http://quakecafe.org.

In February 2016, a public forum was held to discuss the data and lessons learned from QuakeCAFE followed by a panel discussion on innovations for earthquake early warning, preparedness, and response. Professor Ken Goldberg and the QuakeCAFE team were joined by Professor Peggy Hellweg from the UC Berkeley Seismological Lab; Dr. Ross Stein, co-founder of Temblor, a startup that enables people to learn their seismic hazard and how to reduce their risk; Amina Assefa, Manager of the Office of Emergency Management, UC Berkeley, and Grace Kang, PEER.

6.10 PEER ANNUAL MEETING

PEER Director Mosalam

The PEER Annual Meeting took place on January 28–29, 2016, at the International House on the UC Berkeley campus. The first day started with a comprehensive overview of PEER accomplishments in several thrust areas of research and education, including Geohazards, Tsunami, and the Built Environment focusing on old and new reinforced concrete and steel structures, tall buildings, and rapid bridge construction. Also on this day, important future directions towards "Resilient Infrastructure Systems" were discussed. Some of the highlights of these future directions are NIST-supported activities related to community resilience, the need to pay attention to the interdependencies of the infrastructure systems, research challenges in expanding Performance-Based Earthquake Engineering (PBEE) to encompass resiliency for community recovery, and expanding the resilience definition beyond the direct engineering and ecological context to be also transformative, especially after extreme events.

The second day was structured around breakout sessions to develop forward-thinking research directions in Geohazards, Computational Modeling and Simulation, Tsunami, Transportation, and New and Existing Buildings. This day was concluded by an overview of results from these important research directions as well as the PEER Resilience Involvement Quick Survey, which was highly beneficial to acquire participant feedback about the resilience involvement of PEER. Converting these forward-thinking guidelines to future research agenda items, in the direction of adopting PBEE methodologies and related technologies for achieving resilience of our built environment, is the next important goal for the PEER community.

Former Director Mahin at PEER Annual Meeting

Similar statements about the necessity in going beyond code objectives to achieve post-earthquake functionality and the public's misinterpretation of code objectives were mentioned in various presentations during the PEER Annual Meeting. With PEER's efforts in PBEE methodology and its extension to resilience, it is PEER's priority to do more towards fulfilling this public expectation of resiliency. Particularly, PEER will increase interaction and collaboration with ongoing efforts towards resilience such as the ATC-58 efforts in developing probabilistic performance-based design guidelines, the US Resiliency Council's building rating system, NIST Community resilience program, the San Francisco Bay Area Planning and Urban

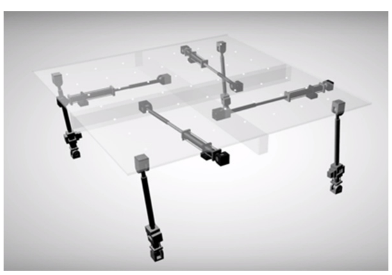
Research (SPUR) Resilient City approach, and research related to protective systems and modeling of community functioning following earthquakes. PEER will also collaborate with the practicing earthquake engineering community to reflect this resiliency extension on the design, assessment and retrofit applications.

6.11 PEER ADVISING ON NBC NEWS REPORT: IMPETUS FOR PROPOSED LEGISLATION FOR SCHOOL SEISMIC SAFETY

Soon after the South Napa Earthquake in August 2014, PEER responded to NBC News and provided resource information that led to a broadcast report about unexpected seismic risks in California public schools that aired in February 2015. Assembly member Bill Dodd (District 4 which includes parts of Napa County, CA) proposed new seismic legislation in Assembly Bill (AB) 1783, and says that the report was the “impetus for the bill…because we were very concerned.” The proposed legislation in AB-1783 would for the first time require school districts to inspect the contents of classrooms and school equipment, and fix seismic hazards. In February 2016, NBC News released an updated broadcast report that provided more detail about their investigation.

6.12 KQED SCIENCE SERIES - PEER LAB SHAKING TABLE

KQED-Science, as part of their “Engineering Is…” Quest Series, visited the PEER-UC Berkeley lab and produced the video “Simulating Earthquakes with a Shaking Table”. The five-minute video, released in March 2016, showcases the important shaking table testing being done at the PEER-UC Berkeley lab. The graphic video footage of structures violently shaking and crumbling on the shaking table emphasizes the need for testing to improve the way structures will respond to an earthquake *before* the next earthquake hits.



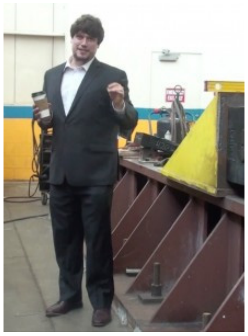
Shaking table

The video also highlights one of the most significant developments to come out of testing on the shaking table: proof-of-concept testing of seismic protective systems. As a result, facilities such as airports, hospitals, and government buildings have been retrofitted or newly designed with seismic protective systems such as base isolators and dampers, which will significantly reduce structural and non-structural damage so that operations can resume quickly after an earthquake. PEER is grateful to KQED-Science for recognizing the importance of shaking table testing in improving the seismic performance of the built environment.

6.13 ASCE SEI – EARTHQUAKE SIMULATOR LAB TOUR

On March 24, 2016, PEER and ASCE SEI hosted a tour of the PEER Earthquake Simulator Laboratory at the UC Berkeley Richmond Field Station. This free event was an excellent opportunity for industry professionals, equipment manufacturers, and anyone interested in seismic certification. The tour included visits to the Earthquake Simulator Lab, Large-scale and Model Structures Lab, and NISEE/PEER Library.

Lab Manager Dr. Clement Barthes gave a brief presentation on wireless remote sensors to monitor bridge dampers. After lunch, the lab tour began with a visit to the high-capacity (4 million pounds) universal testing machine (UTM) which is used to perform various tension and compression tests. Visitors learned how experimental testing is conducted and watched a demonstration of the damper testing machine. The tour included observing damaged test specimens stored in the outdoor yard.



Clement Barthes

Tour of Damaged Specimens

6.14 OPENSEES DAYS 2016

Pedro Arduino and Frank McKenna during OpenSees Days

PEER hosted OpenSees Days 2016 on May 19–20, 2016, that brought together a diverse group of twenty-nine students, faculty and practitioners from California, Nevada, Utah, Louisiana, and Lima, Peru to the Berkeley Global Campus at Richmond Bay (also known as the Richmond Field Station). Students, researchers, and practitioners were invited to attend either or both days.

On Day 1, Frank McKenna presented the fundamentals of the OpenSees framework: basic modeling and analysis techniques, OpenSees interpreter, nonlinear analysis in OpenSees, and he closed the first day with a hands-on exercise.

Day 2 "Beyond the Basics" presentations offered users the chance to share their varied experiences using OpenSees:

• "Impressions from a 1st Year Graduate Student," Arnkjell Lokke

• "How I used OpenSees from a Soon-to-Be-Finished PhD Student," Reagan Chandramohan

• "New Models for Nonlinear Modeling of Reinforced Concrete Walls," Kristjian Kolozvari, Assistant Professor, Cal State Fullerton

• "Geotechnical Modeling in OpenSees", Pedro Arduino, Professor, Geotechnical Engineering, University of Washington

These presentations demonstrated how to model using OpenSees, including geotechnical modeling, soil–structure interaction, concrete and steel frame modeling options and capabilities, seismic isolation, and supplemental damping modeling. Presentations were made on parallel processing capabilities, and attendees learned how to use Amazon ci to run their simulations in the "cloud" and NHERI DesignSafe-ci to run simulations on XSEDE High-Performance Computing Resources.

6.15 PEER SEMINAR SERIES

6.15.1 March 14: Earthquake Resilience: A New Context

David Bonowitz

David Bonowitz, S.E., delivered a lecture on the shift to earthquake resilience-based design as the new basis for seismic mitigation policy. Using case studies from current projects and recent policy initiatives, Bonowitz discussed what this will mean for structural engineers, and how they can maintain their influence with confidence and expertise in this new era.

The lecture was presented in conjunction with SEMM–Structural Engineering Mechanics and Materials Department of Civil and Environmental Engineering, UC Berkeley.

David Bonowitz is a past chair of SEAONC's Seismology and Existing Buildings committees, and he currently chairs the NCSEA Existing Buildings committee. He represents SEAONC on SEAOC's Legislative Committee, is a member of EERI's Advocacy and Public Policy Committee, and is active in the SPUR Resilient City initiative and in the NIST Community Resilience Program. He is a Fellow Member of both SEAONC and SEAOC. Bonowitz is a graduate of Princeton University and holds a Master of Engineering in Structural Engineering from UC Berkeley.

6.15.2 March 30: The Temblor App

Ross Stein

Ross Stein, Ph.D., Co-Founder & CEO of Temblor Inc. presented Temblor, a mobile web app that provides personal and immediate seismic risk understanding resources and solutions for everyone. In this lecture, Stein demonstrated how Temblor estimates the likelihood of seismic shaking and home damage and shows how the damage or its costs could be decreased by buying or renting a seismically safe home, securing fragile objects inside your home, or retrofitting your older home.

Ross Stein is a Consulting Professor of Geophysics at Stanford University, a Scientist Emeritus at the USGS, and President-Elect of the Tectonophysics section of the American Geophysical Union (AGU). He received the 2012 Gilbert F. White Natural Hazards Award of the AGU, and has delivered AGU's Francis Birch Lecture, Gilbert White Lecture, and its Frontiers of Geophysics Lecture. He gave a 2012 TEDx talk, 'Defeating Earthquakes,' and was keynote speaker at the Smithsonian for the Presidential Awards for Excellence in Mathematics and Science Teaching. He was Winter 2014 Distinguished Lecturer of the Stanford School of Earth Sciences, and is a speaker in the 2015–2016 MPSF Speaker Series, the largest community speaker series in the U.S., with 7000 subscribers.

6.15.3 April 5: Quantifying the Resilience of Civil Infrastructure Systems

Professor Božidar Stojadinović, Ph.D., Chair of Structural Dynamics and Earthquake Engineering at the Swiss Federal Institute of Technology (ETH) Zürich, presented a supply/demand approach to modeling the resilience of a civil infrastructure system that involves component vulnerability and recovery functions and a model of system operation.

Professor Stojadinović

In this presentation, Professor Stojadinović evaluated the seismic resilience of the electrical power supply system in Nepal after the 2015 Gorkha earthquake. He presented two classes of resilience measures, examined how to evaluate them probabalistically, and offered options to develop resilience acceptance criteria. Finally, he discussed a process to design resilient civil infrastructure systems.

Professor Stojadinović is the Chair of Structural Dynamics and Earthquake Engineering at the Swiss Federal Institute of Technology (ETH) Zürich. Before working at ETH, he was a Professor at the University of California, Berkeley and the University of Michigan, Ann Arbor. His degrees are in Civil Engineering: PhD from the University of California at Berkeley, MS from Carnegie-Mellon University, and BS from the University of Belgrade, Serbia.

6.15.4 April 18: Post Earthquake Responses to Risk – 1906 to Now

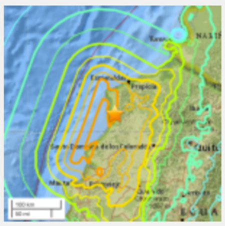
Photo Credit: Chadwick, H.D. (US Government War Department), National Archives, Washington, D.C., April 1906

In commemoration of the 110th anniversary of the Great San Francisco Earthquake and Fire, Dr. Laurie A. Johnson, Visiting Project Scientist and urban planner specializing in disaster recovery and catastrophe risk management, looked back at some of the major community-scale seismic risk reduction policies that have been implemented in the aftermath of damaging earthquakes in San Francisco (1906 and 1989), Kobe Japan (1995), Sichuan China (2008), Canterbury New Zealand (2010-2011), and the Tohoku region of Japan (2011).

Laurie Johnson

Dr. Laurie A. Johnson is a PEER Visiting Project Scientist and an urban planner specializing in disaster recovery and catastrophe risk management. She has been active in research and consulting on recovery planning and management following many of the world's major urban disasters, including the Loma Prieta and Northridge earthquakes, the Kobe and Tohoku Japan earthquakes, Hurricane Katrina, and Canterbury New Zealand earthquake sequence.

6.15.5 June 16: Post Earthquake Reconnaissance Observations of the April 16 Ecuador Earthquake



(USGS)

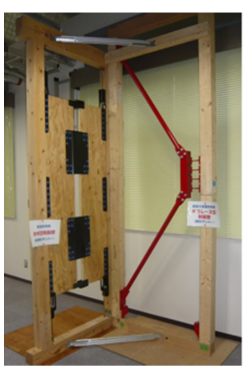
On Saturday, April 16, 2016, at 6:58pm local time, a M7.8 earthquake struck on the subduction region of western Ecuador near the city of Pedernales. The seismic event resulted in the loss of 660 lives, more than 27,000 injured, and more than 30,000 people displaced from their residences. The earthquake produced ground motions with peak ground accelerations in excess of 1.4g, peak ground velocities of more than 100 cm/s, and records with durations of more than 250 seconds.

Eduardo Miranda

Eduardo Miranda, Associate Professor, Stanford University; Luis Alfredo Ceferino Rojas, PhD Candidate, Stanford University; and Roberto Luque, PhD Candidate, UC Berkeley spent one week in Ecuador conducting an earthquake reconnaissance and summarized recorded ground motions as well as the seismic performance of buildings, bridges, dams, highways, and critical facilities such as hospitals. Some of the structures they visited include one of the longest seismically isolated bridges that has been subjected to a major earthquake, and one of the most important ports in the country, where damage was observed. Many major landslides occurred along the coast, which could have important consequences for California where important highways and structures are located on or close to slopes where similar landslides could occur.

On the two-month anniversary of the April 16, 2016, Ecuador earthquake, PEER hosted a seminar about Post-Earthquake Reconnaissance Observations. The researchers summarized the rapid post-earthquake evaluation and tagging that was conducted by Ecuadorian engineers, and discussed how smartphones facilitated this task for capturing images, geolocating structures, and creating centralized databases, often in real-time.

6.15.6 October 3: Vibration Control Systems for Japanese Houses



Vibration control dampers

There are more than 25 million houses in Japan, and improvement of their seismic performance is imperative to realize resilient cities against earthquakes. Kazuhiko Kasai, Ph.D., Professor, Tokyo Institute of Technology, Japan, has been leading the Tokyo Institute of Technology research program for fourteen years on vibration control systems for the houses of either timber or light-gage steel construction. The program seeks economical and sound schemes assuring functional continuity and quick recovery of houses against large earthquakes.

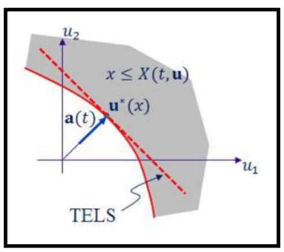
This presentation explained the research program with focus on the following: efficient vibration control dampers and systems, methods to evaluate control effectiveness based on frame and connection properties, design methods based on equivalent linearization, unified analytical modeling for various hysteresis curves of devices and systems, and the first design specifications on house vibration control.

Kazuhiko Kasai

Kazuhiko Kasai, Ph.D., Professor, Tokyo Institute of Technology, Japan, received his Ph.D. degree from University of California, Berkeley in 1985. He was a faculty member at Illinois Institute of Technology and later at Lehigh University, and became a professor in 1997 at Tokyo Institute of Technology. Professor Kasai was the Japan-side leader of the NEES and E-Defense U.S.-Japan steel building research project conducting full-scale shaking table experiments. He was also the Japan-side leader of the China-Japan joint research on seismic evaluation and mitigation for super-tall buildings, sponsored by the National Natural Science Foundation of China and Japan Science and Technology Agency. He has been chairing various committees on experimental methods, building protective systems, and house vibration control.

6.15.7 November 14: Tail-Equivalent Linearization for Nonlinear Stochastic Dynamic Analysis

Professor Armen Der Kiureghian provided an overview of the development of the tail-equivalent linearization method for stochastic dynamic analysis of inelastic structures subjected to earthquake ground motions. The method, which is based on the principles of the first-order reliability method (FORM), was described in terms of geometry in the high-dimensional space of Gaussian random variables. The presentation also covered the application to structures subjected to multiple components of ground motion and bridges with differential support motions.



Professor Armen Der Kiureghian is the fourth President of the American University of Armenia (AUA). He is the Taisei Professor of Civil Engineering Emeritus of UC Berkeley, where he served for 37 years in various positions, including Chair of the Structural Engineering, Mechanics and Materials Program and Vice Chair for Academic Affairs of the Department of Civil and Environmental Engineering. He is one of the founders of the AUA and previously served as the Founding Dean of Engineering, Founding Director of the Engineering Research Center, then Interim Provost, all concurrently with his UC Berkeley position.

Armen Der Kiureghian

Professor Der Kiureghian has held visiting professorships at the University of Ljubljana, Slovenia; University of Tokyo, Japan; ROSE School in Pavia, Italy; Technical University of Denmark; Indian Institute of Science, Bangalore; and Technical University of Munich, Germany. Professor Der Kiureghian's teaching and research have been in the areas of risk and reliability of constructed facilities and systems, stochastic structural dynamics, earthquake engineering, and engineering decision-making. He has authored more than 400 publications, including 120 in archival journals and supervised 30 doctoral candidates. Der Kiureghian received his B.S. and M.S. in Civil Engineering from Tehran University, Iran, and his Ph.D. in Civil Engineering from the University of Illinois at Urbana-Champaign.

7 2016 Major Awards

7.1 MAJOR PROJECT AWARDED TO PEER BY THE CALIFORNIA EARTHQUAKE AUTHORITY (CEA)

The California Earthquake Authority (CEA) awarded a $3.4 million, 3.5-year research contract to PEER. The research project, "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. The project will directly contribute to the improvement of seismic resiliency of California's housing stock. This multi-year project will be 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.

7.2 RFP'S FROM PEER'S TSRP AND CALTRANS LIFELINES PROGRAM

PEER has been working with Caltrans to issue RFP's from PEER's TSRP and Caltrans Lifelines program. One RFP has already been issued from the Lifelines Program on developing methods and criteria for distinguishing between non-convergence in nonlinear time-history analysis and physical collapse. After a thorough review of the proposals, the first award in response to this reinstated RFP process has been granted. Other RFPs are being drafted and either approved or awaiting approvals from Caltrans or from the PEER research committee.

7.3 CSSC – SOUTH NAPA EARTHQUAKE

The Alfred E. Alquist Seismic Safety Commission (CSSC) engaged PEER to conduct a study to better understand impacts and lessons learned from local, State, and Federal representatives, and residents and businesses impacted by the earthquake. The study entitled "The Mw 6.0 South Napa Earthquake of August 24, 2014: A Wake-up Call for Renewed Investment in Seismic Resilience across California," was authored by Laurie A. Johnson and Stephen A. Mahin, who indicated, among other things, that the earthquake demonstrated the long-term benefits of California's highway bridge earthquake strengthening program. However, it also highlighted the need for additional investment to make Californians safer.

The 12 priority recommendations in the study are the result of public testimony, interviews of local government and businesses, and a workshop involving the Commission, Commission staff, and PEER. The study is jointly published by CSSC (Publication 16-03) and PEER (*Report No. 2016/04*).

7.4 CAL-OES, CSSC – EARTHQUAKE EARLY WARNING SYSTEM

The California Governor's Office of Emergency Services (Cal OES) in partnership with the Alfred E. Alquist Seismic Safety Commission (CSSC) engaged PEER to independently explore the anticipated value of a statewide earthquake early warning system (EEWS) to the state's economy and infrastructure. The report titled "California Earthquake Early Warning System Benefit Study," was authored by Laurie A. Johnson, Sharyl Rabinovici, Grace S. Kang, and Stephen A. Mahin. As detailed in Chapter 1 of the report, Cal OES has been leading a public-private partnership since 2013 to develop a statewide EEWS. The capital cost to construct and launch a statewide EEWS is estimated at $28 million, and the personnel and operating expenses are estimated at $17 million annually. The study is jointly published by CSSC (Publication 16-04) and PEER (*Report No. 2016/06*).

7.5 NSF PROJECT – WAVE CARPET OCEAN DEMONSTRATION

Professor Khalid Mosalam has been invited to be a co-PI on Professor Reza Alam's subaward "Wave Carpet Ocean Demonstration," from California Wave (CalWave) Power Technologies. The funding agency is NSF. The duration of the project is from 4/1/2017 through 9/30/2017. The total sub-award amount is $112,500, and is equally shared by Professors Alam and Mosalam.

TAFLab – PI: Professor M.-Reza Alam

A postdoctoral scholar, under the supervision of Professor Alam, will collaborate with the industry partner to design and develop a hydraulic power conversion chain (PCC) suitable for a multi-degree-of-freedom submerged pressure differential ocean wave energy converter (WEC). The PI and his students have performed preliminary experimental and numerical investigations on this type of WEC but have always used representative components for the PCC when testing smaller model scale prototypes. This PCC will be simulated using both MathWorks Simscape Fluids and a custom dynamic MATLAB model that will allow for increased model flexibility and control. In order to better size different components in the PCC, these models are required to capture the interaction between various elements in the system. The dynamic model will be developed based on cycle-average behavior of each subsystem such as the hydraulic cylinder, accumulator, check-valves, and hydraulic motor, and validated with the Simscape Fluids simulation. Once components have been selected, the PCC will be physically constructed as a 1:6-scale prototype using components procured by the industry partner. This 1:6-scale prototype will be experimentally tested by CE/PEER. The postdoctoral scholar will work with the industry partner to reduce an existing hydrodynamic device model such that it can be used for real time hybrid simulation during prototype testing. The scholar will oversee the testing of the prototype PCC and compare experimental results with simulated values.

CE/PEER – PI: Professor Khalid Mosalam

The following scope of work is going to be conducted at Structures Laboratory, Department of Civil and Environmental Engineering, UC Berkeley. The work is going to be conducted in two phases. In the first phase, the energy harvesting system will be validated with cyclic testing by utilizing a self-equilibrating setup that consists of a single actuator. In this phase, all components of the wave energy harvesting system will be integrated into a complete system. The test setup and hardware will simulate cyclic loading of the waves. In this phase of the work, the system will be validated and performance of all components of the system will be evaluated and optimized.

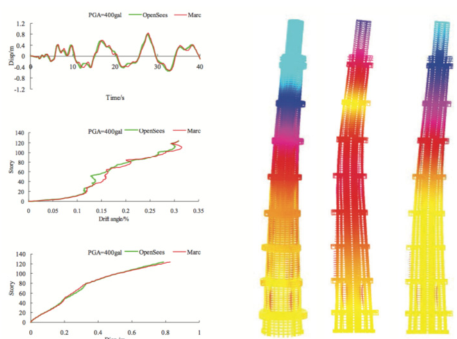
In the second phase, a brand new test frame for testing energy harvesting systems in a more realistic 2D setting will be constructed. A system of a larger scale will be evaluated in this experimental setup. Once assembled together, the system will be tested and its performance will be evaluated in cyclic loading. In the final step, the system will be tested and evaluated in hybrid simulation when the impact of ocean waves will be provided by a numerical simulation of mathematical model seamlessly integrated with the physical test setup into a coupled system.

8 Technology Tools and Resources

8.1 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 parameter studies.

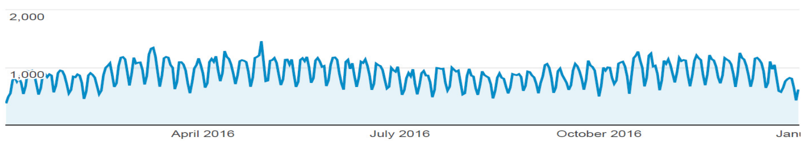


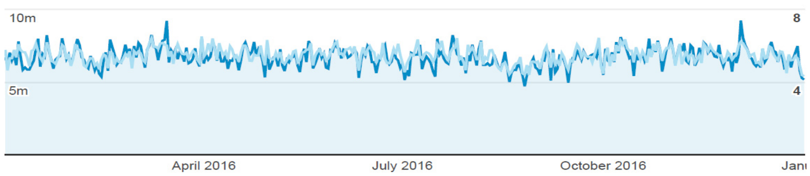
OpenSees provides beam–column elements and continuum elements for structural and geotechnical models. A wide range of uniaxial materials and section models are available for beam/columns. Nonlinear analysis requires a wide range of algorithms and solution methods, and OpenSees provides a large variety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

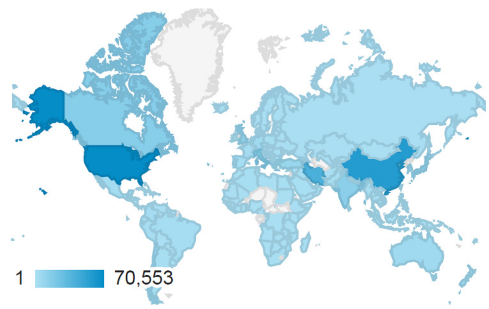
As an open source framework, OpenSees provides a computational environment for researchers from different disciplines and different parts of the world to work together, helping bind the PEER earthquake engineering community together. It is under continual development, so users and developers should expect 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.

Selected Key OpenSees Statistics for 2016

- Completed Downloads 11,736
- 112,104 Google Visitors (not all unique persons, some people can come in from different devices or I.P. addresses)
- 1,809,743 web page views
- visits from most countries around the world and from all states in US







NEW FUNCTIONALITY TO OPENSEES

- Concrete Shear Wall Modeling: Faria Concrete model for plane stress, layered plane stress section,
- Bearings: BoucWen model for Elastomeric bearings
- UniaxialMaterial: FRPConfinedConcrete

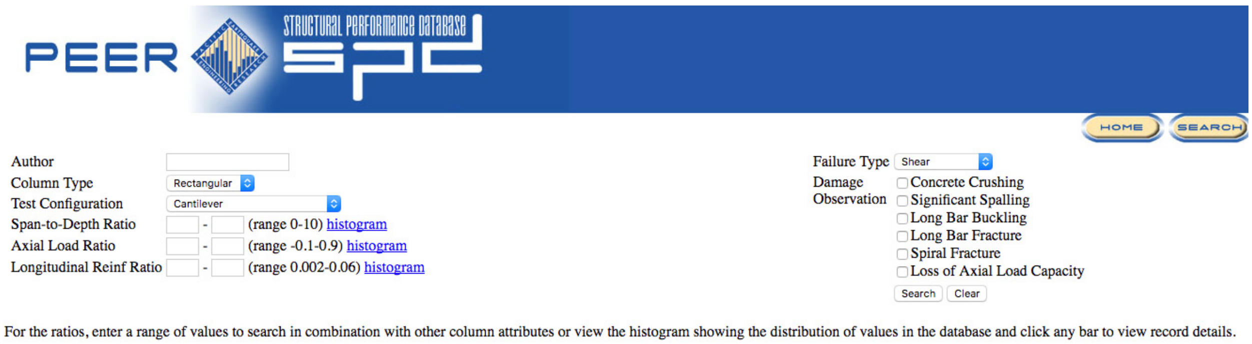
NEW RELEASES

- Beta Release of OpenSeesIDE (an integrated interpreter, file editor, graphical display)
- Alpha Release of OpenSees Python interpreter.

OpenSees Days 2016 was held in May, 2016. Refer to Chapter 6 for more details.

8.2 DATABASES

8.2.1 Structural Performance Database



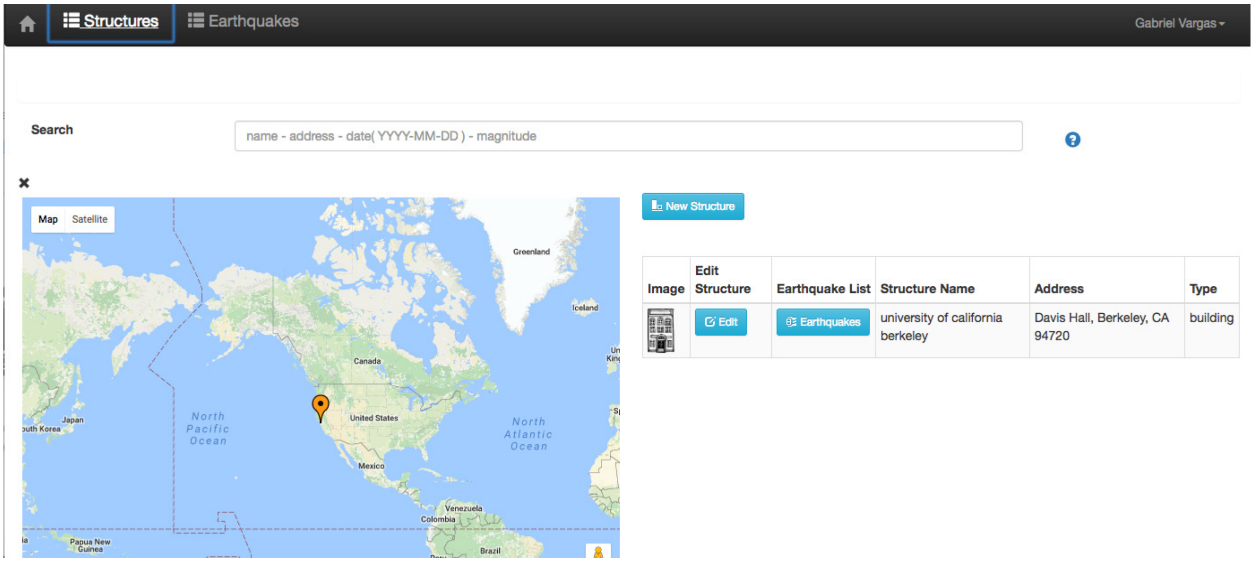
This site (nisee.berkeley.edu/spd) provides the results of over 400 cyclic, lateral-load tests of reinforced concrete columns. The database describes tests of:

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

8.2.2 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 earthquakes 5.5 and up data that happened since 1900 and linked to structures
- provide pre-earthquake data for comparison purposes
- unify the post-earthquake data collection efforts



8.3 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. The Library underwent several significant changes during 2016:

- Charles James, the Library Director retired in June. Christina Bodnar-Anderson is sole library staff at 20 hours a week.
- The NISEE/PEER Online Archive moved from local servers to the UC Berkeley Cloud in Spring 2016.
- The payment system for membership and image use fees changed from Cybersource (Jan-April) to RegOnline (July onward). Membership was free for May and June during the transition between financial systems.
- The membership registration process changed and included an additional step (Recaptcha) to prevent robots from overloading the system.

NISEE/PEER Online Archive (e-library) Membership Information:

- **Total number of full access users by Feb 2017**: **8698**
- **New Memberships (Jan 2016–Feb 2017)**: **361** (This does not include two free months - May/June 2016 where memberships were not tracked during this time so we do not have exact numbers, however, it is estimated that approximately **840** new members enrolled during the free period, which would make total memberships for the year: **1201).**
- **Total UC Berkeley Memberships: 540**
- **UC Berkeley New Memberships (Jan 2016–Feb 2017): 31** (excluding May-June 2016)

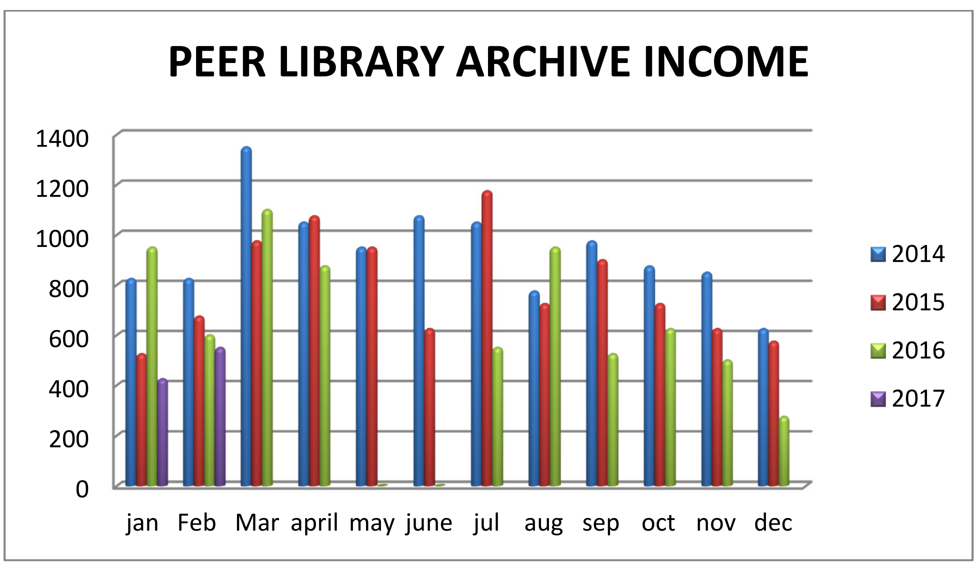
- **Total Downloads from NISEE/PEER archive** (Jul 2016 - Feb 2017): **15,118** (nearly **2,000** downloads per month). Tracking downloads was handled differently previous to July and is not accessible at this time. If the monthly average is used to calculate all months Jan 2016–Feb 2017, the total downloads would be approximately**: 26,000.**

Memberships are down this year, possibly due to several factors:

- Moving to a new registration and payment system caused some challenges. Changing the membership login process to include Recaptcha was one issue. It was discovered that those from China could not purchase a membership nor access their accounts because the Chinese government is blocking Recaptca (Google Ban). A new Recaptcha that would work in China was found and implemented.
- Membership was free for two months during the transition from one payment system to another.
- Phantom security warnings appeared on NISEE/PEER website: 1. First time, warning was due to certificate needing renewing, and 2. The second time, Google Ads no longer supported HTTPS pages. These problems have been resolved.

Income from Memberships, 2014-Feb 2017 (in U.S. Dollars):

	Jan	Feb	Mar	APR	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2014	825	825	1350	1050	950	1075	1050	775	975	875	850	625
2015	525	675	975	1075	950	625	1175	725	900	725	625	575
2016	950	600	1100	875	0	0	550	950	525	625	500	275
2017	425	550										



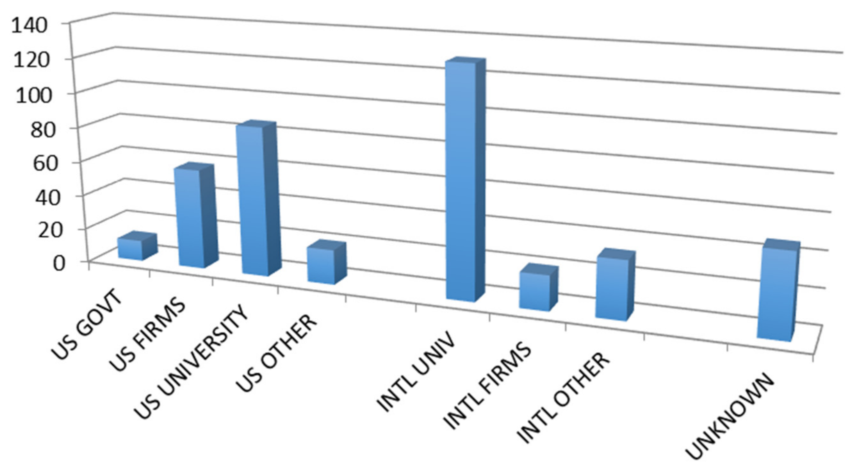
Digital Items in NISEE/PEER online archive: 51,093

- Digital document - reports, papers, e-books (PDF): **16,980**
- Images (jpg): **33,691**
- Software (Zip-File): **422**

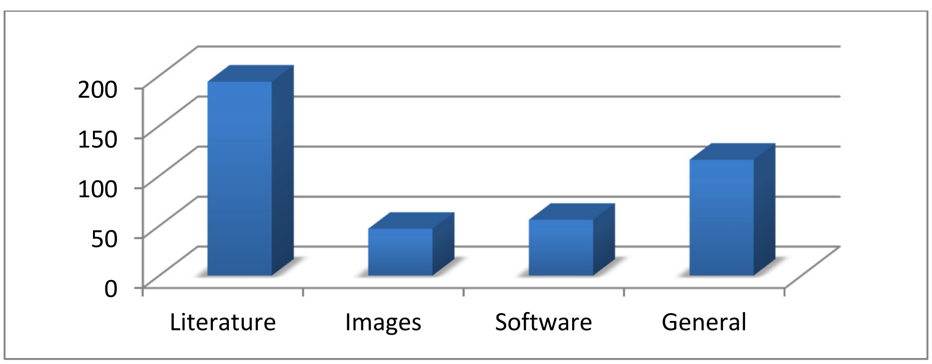
Requests from Library Patrons:

These charts show number of requests, but not how many items were requested per inquiry. Many inquiries contain requests for multiple documents or images.

2016: Where requests came from:



2016: Type of materials requested per inquiry:



- Literature: Report, paper, book, etc.
- Images: High resolution image use and permissions
- Software: Request for software or technical assistance
- General: Request for Information, membership inquiries and issues

Donations to the PEER Library

- Degenkolb – 8 boxes of books
- Ephraim Hirsch – 2 boxes of books/journals and blue prints
- David Messinger – 10 boxes of books
- Professor Anil Chopra – textbooks
- Professor Armen Der Kiureghian – books and slides
- CUREE – Entire collection of digital reports over 25 years
- Upcoming – Professor Vitelmo Bertero collection

Library Membership by Country

America Samoa
Argentina
Australia
Austria
Bangladesh
Belgium
Belize
Bosnia and Herzegovina
Brazil
Bulgaria
Myanmar
Canada
Chile
China
Cocos (Keeling) Islands
Colombia
Costa Rica
Croatia
Cyprus
Czech Republic
Denmark
Dominican republic
Ecuador
Egypt
El Salvador
Ethiopia
France
Georgia
Germany
Great Britain
Greece
Guatemala
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
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Nicaragua
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Pakistan
Panama
Peru
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Russia
West Samoa
Saudi Arabia
Serbia
Singapore
Slovakia
Slovenia
South Africa
South Korea
Spain
Sri Lanka
Sweden
Switzerland
Taiwan
Thailand
Trinidad & Tobago
Tunisia
Turkey
United Arab Emirates
United Kingdom
United States
Venezuela
Vietnam

9 Business and Industry Partnership

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.

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.

Director Mosalam with BIP Members at a Recent Gathering

PEER works with industry and government partners to develop and manage long-term major practical research programs using leveraged funding. User-driven research projects are frequently formulated and jointly managed by PEER, agencies of the State of California, and private industry. An example success story is the Next Generation Attenuation West models (NGA-West1) project, jointly funded by California Department of Transportation, California Energy Commission, and Pacific Gas & Electric Company. The NGA project has had a major practical impact on seismic hazard of the western U.S. Another success story is the Tall Buildings Initiative (TBI), which was awarded the ATC-SEI 2015 Champions of Earthquake Resilience Award for an "Exceptional Public-and-Private Sector Research and Development (R&D) Program."

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. 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
- Earthquake Protection Systems
- Exponent
- FM Global
- Forell/Elsesser Engineers, Inc.
- Holmes Structures
- Micron Optics
- SAGE Engineers
- Skidmore, Owings & Merrill LLP
- Walter P Moore
- Wiss, Janney, Elstner Associates, Inc.

10 Facilities and Resources

10.1 KEY PERSONNEL (HEADQUARTERS)

Khalid Mosalam
Director

Amarnath Kasalanati
Associate Director for Operations & Strategic Initiatives

Stephen Mahin
Former Director
(2009–2015)

Jack Moehle
Founding Director
(1996–2008)

Yousef Bozorgnia
Former Executive Director
(2009–2016)

Darlene Wright
Administrative Director

Grace Kang
Communications Director

Clement Barthes
Experimental Testing Facilities Manager

Christina Bodnar-Anderson
Library & Information Services

Robert Cerney
Laboratory Mechanician

Erika Donald
Electronic Communications & Web Specialist

Charles James
Librarian
(retired in June 2016)

Claire Johnson
Technical Editor

Nathaniel Knight
Development Technician

Zulema Lara
Financial Analyst and Subaward Coordinator

Frank McKenna
Chief Information Officer/Manager

Gabriel Vargas
Database Specialist

Yolanda West
Administrative Assistant (retired in Feb 2017)

Selim Günay
Project Scientist

10.2 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. Among its duties are:

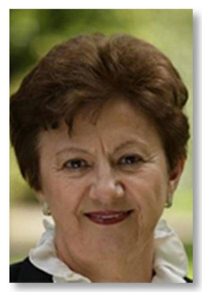
- To establish basic policies for the operation, management and administration of the Center;
- To approve any changes or additions to the rosters of Core Institutions and Affiliated Institutions;
- To review and approve the general research directions of the Center;

- To review the general financial and administrative aspects of the Center, including the annual budget, annual research plan, reports and proposals to sponsors, and similar major administrative actions;
- To approve criteria for selection of key personnel, and to approve the appointment and terms of appointment of individuals to key positions;
- To participate in the selection of the Director of the Center; and
- To ensure that the interests of the participating universities are represented and achieved, while preserving through its actions the concept of PEER as a consortium of universities.

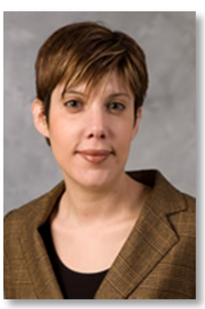
Bruce Kutter,
Chair, Institutional Board
University of California, Davis

Joel P. Conte
University of California, San Diego

Erik A. Johnson
University of Southern California



Anne Kiremidjian
Stanford University



Dominiki Asimaki
California Institute of Technology

Jack Moehle
University of California, Berkeley

Charles Roeder
University of Washington

Michael Scott
Oregon State University

John Wallace
University of California, Los Angeles

Farzin Zareian
University of California, Irvine

10.3 ADDITIONAL PEER STAFF

RESEARCH ENGINEERS AND PROJECT SCIENTISTS

Sahar Derakhshan	Assistant Specialist
Christine Goulet	Assistant Researcher
Laurie Johnson	Visiting Project Scientist
Tadahiro Kishida	Assistant Project Scientist
Nicolas Kuehn	Assistant Project Scientist
Silvia Mazzoni	Visiting Assistant Researcher
Sifat Sharmeen Muin	Research Engineer
Sharyl Rabinovici	Visiting Researcher
Charles Scawthorn	Visiting Research Engineer
Andreas Schellenberg	Research Engineer
Matthew Schoettler	Research Engineer

10.4 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.

10.4.1 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 setups 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. See 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.

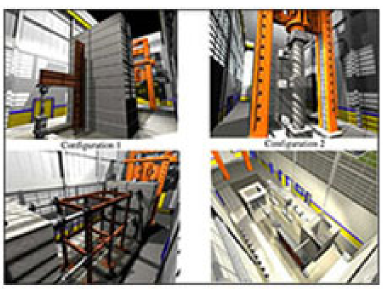
The PEER-UC Berkeley Labs are available to both the research community and to private industry that may require large capacity testing services. Published recharge rates are utilized in the development of project budgets. Priority in scheduling a given test always favors the research community, and time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

10.4.2 Six-Degree-of-Freedom (6 DOF) (Shaking Table)

The earthquake shaking table, dedicated in 1972, was the first modern shaking table and is still the largest six-degree-of-freedom (6 DOF) shaking table in the U.S. The shaking table is configured to produce three translational components of motion; vertical and two horizontal, plus three rotational components; pitch, roll and yaw. These 6 DOF can be programmed to reproduce any wave form within the capacities of force, velocity, displacement and frequency of the shaking table system. The Shaking Table which weighs 100 kips can subject structures, weighing 100 kips, to horizontal accelerations up to 1.5 *g*. Given that shaking table performance is a function of mass, overturning and model interaction, actual system performance is a function of these variables. Models exceeding 150 kips have been successfully tested on the PEER-UC Berkeley Shaking Table. A 10-ton bridge crane services the shaking table lab.

The concrete shaking table is heavily reinforced, with both traditional reinforcement and post-tensioning tendons. Structurally, the table may be considered as a 1-ft-thick diaphragm, stiffened by central transverse ribs that extend below the table's bottom surface. The eight hydraulic actuators that drive *X* and *Y* motion, along with yaw, are attached between the shaking table foundation and the tables transverse ribs. The four vertical actuators, as well as the test structure, are attached to the table by post-tensioning rods, inserted through a 3 ft × 3 ft matrix of 2-5/8 in. conduits, penetrating the shaking table surface. The length of the actuator assemblies, ranging from 8 ft-8 in. in the vertical direction and 10 ft-6 in. in the horizontal direction, serve to effectively de-couple the motions in different degrees of freedom. The high-performance capabilities of the actuators, along with corrective commands from the sophisticated, MTS 469D controller, complete the de-coupling.

10.4.3 Single Degree of Freedom Shaking Table



The single degree of freedom shaking table has a maximum stroke of +/-20 in. The platform is 7 ft × 19 ft. The payload can be as high as 200 kips, with lateral capacity of 150 kips. The controller is connected to a SCRAMNet ring buffer; hence, this shaking table is capable of performing real-time hybrid simulation. This platform is ideal for projects requiring large displacement such as seismically isolated structures or large velocity such as the floor response of multi-story buildings.

10.4.4 Large Damper Test Machine

The Large Damper, uniaxial test machine, is designed for the testing of full-size dampers. The test machine is a self-reacting system comprised of a dynamic, servo-hydraulic actuator and a reaction frame. The actuator generates a displacement that develops a compression or tension load in the damper that is attached between the actuator and the reaction frame. The actuator can deliver 900 kN (200 kips) at 0.38 m/sec (15 in/sec) during dynamic tests. In static loading, the actuator delivers a 1560 kN (346 kips) static force with a peak-to-peak stroke limit of (600 mm) 24 in.

10.4.5 Small Damper Test Machine

The small damper test machine is designed for the testing of small to mid-size dampers, friction devices and other structural components. The test machine consists of two, dynamic servo-hydraulic actuators installed in a self-equilibrating system that consists of two, dynamic servo-hydraulic actuators and a reaction frame. The actuators generate vertical displacement that develops a compression or tension load in the damper or friction device attached between the top and bottom platens of the test machine. The system capacity is 445 kN (100 kips) at 0.50 m/sec (20 in/sec) during dynamic tests. In static loading, the actuators have a peak-to-peak stroke limit of 500 mm (20 in.).

10.4.6 4-Million Pound Universal Testing Machine

A Southwark-Emery, 4000-kip Load Frame, originally built in 1932, was moved from the main campus and installed at the current PEER-UC Berkeley Lab in 1964. The uniaxial load frame can impose a 4000-kip compression load and a 3000-kip tension load. The maximum horizontal clearance between the vertical columns is 10 ft. The maximum length of a compression test element is 33.5 ft. In tension, the maximum specimen length is 22 ft. The stroke limit is 48 in. and the maximum rate of loading, at full capacity, is 0.071 in. per second. A dedicated hydraulic system provides high-pressure oil to the 4000-kip Load Frame. The load measuring emery-capsule and the associated electronic read-outs are routinely calibrated with NIST traceable equipment and procedure. A 12-ton bridge crane is accessible to the entire lab where the 4000-kip load frame is sited. A dedicated 8-ton crane and a perimeter elevator platform, provide additional utility to the 4000-kip load frame. The below the crane hook ceiling height of the Lab is 65 ft and the truck entry door to the Lab is 11 ft wide and 16 ft tall. The 4000-kip load frame is routinely utilized for research projects and is also available to commercial clients who require large loads to complete their required testing. An inventory of test machine specific hardware is maintained by PEER, as well as transducers, controllers, and data systems.

10.4.7 Fleet of Actuators

Static				
Manufacturer	**Model**	**Load Capacity kN (kip)**	**Stroke mm (in)**	**Quantity**
MTS	243.70T	1460 (328)	1829 (72)	3
Sheffer	20HHC12	4180/3110 (940/700)	300 (12)	2
Sheffer	14HHC20	2000/1500 (460/340)	500 (20)	2
Sheffer	14HHC10	2000/1500 (460/340)	250 (10)	2
Parker	CBB 2HL 40C	1070 (240)	600 (24)	1
Parker	CD 2H 14C	530 (120)	900 (36)	2
Parker	BB 2H LT18A	270 (60)	900 (36)	1

Dynamic					
Manufacturer	**Model**	**Load Capacity kN (kip)**	**Stroke mm (in)**	**Quantity**	**Velocity, mm/sec (in/sec)**
MTS	244.51S	1000 (220)	508 (20)	2	508 (20)
MTS	244.50	667 (150)	1016 (40)	2	508 (20)
Parker	14.0.TM3Sh 24.000	1560/1560 (350/350)	600 (24)	1	375 (15)
Parker	CD 2H 14C	530 (120)	900 (36)	2	175 (7)
Sheffer	N/A	530 (120)	500 (20)	1	500 (20)
Sheffer	6HHTF/RHF20	380/270 (85/60)	500 (20)	2	> 500 (20)
MOOG	85 446	330 (75)	300 (12)	1	750 (30)
MTS	N/A	310 (70)	300 (12)	1	750 (30)
RexRoth	MT4-HH	170 (38)	2500 (100)	2	1125 (45)
Cunningham	Nitrogen jack, AP	90/60 (20/13)	250 (10)	2	> 1250 (50)
Sheffer	2.5HHTF15	50/50 (12/12)	375 (15)	2	625 (25)

10.4.8 Reaction Wall and Floor

The structural tie-down floor is located on the east end of the main bay of the laboratory. The overall plan dimensions of the tie-down slab are 20 × 60 ft. The slab has 2-1/2 in. holes located in an array of 36 in. on center over the 20 × 60 ft area. The test floor provides a completely versatile facility for testing large structural assemblies. Static or dynamic loads may be applied to specimens using tie rods, hydraulic actuators and steel loading frames. The test floor was designed to act as a hollow box girder in the longitudinal direction and as a Vierendeel girder in the transverse.

10.4.9 Service-to-Industry

In addition to regular research work, PEER Labs at UC Berkeley partner with private industry and perform shaking table testing of critical equipment–e.g., emergency power generators, air handlers, electrical switchgear–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,

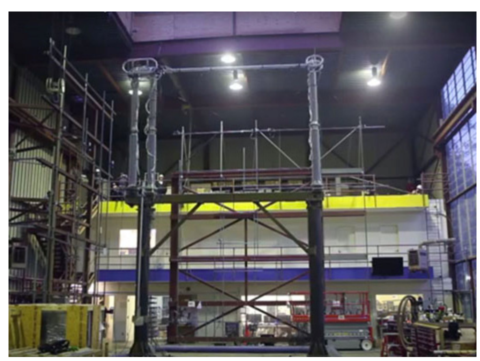
(ii) AC156, Seismic Certification by Shake-table Testing of Non-structural Components–This standard establishes criteria for a specific input motion, duration, and range of frequencies to which nonstructural components should be subjected,

(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



Switchgear Testing

10.5 RECOGNITIONS

10.5.1 ATC-SEI Champions of Earthquake Resilience Award for TBI Seismic Design Guidelines

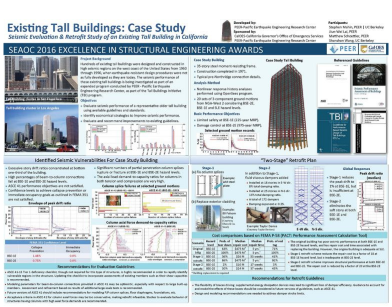
The jury commissioned by ATC-SEI for the 2015 Champions of Earthquake Resilience Awards Program selected PEER and the Los Angeles Tall Buildings Structural Design Council as the joint recipient of an ATC-SEI Award for an "Exceptional Public- and Private-Sector Research and Development (R&D) Program" for "Tall Building Seismic Design Guidelines." The Award was announced in December 2015.

The PEER Tall Buildings Initiative (TBI) brought together a broad array of researchers, practitioners, and stakeholders to explore performance objectives, conduct research on building response and performance characteristics, and develop the TBI "Guidelines for Performance-Based Seismic Design of Tall Buildings" (*PEER Report 2010/05*). Additionally, practical guidance for analysis and acceptance criteria was developed in conjunction with and co-published with ATC as "Modeling and Acceptance Criteria for Seismic Design and Analysis of Tall Buildings" (ATC-72). The TBI Guidelines and supporting documents, developed by the project team led by Jack Moehle and Ron Hamburger, are widely used today in the performance-based design of tall buildings in California and worldwide.

The ATC-SEI award for PEER's Tall Buildings Initiative "Guidelines for Performance-Based Seismic Design of Tall Buildings" (*PEER Report 2010/05*) is in addition to previous recognitions received:

- 2013, Western States Seismic Policy Council (WSSPC) Awards in Excellence, Overall Award in Excellence for Innovations
- 2011, Structural Engineers Association of Northern California (SEAONC) Excellence in Structural Engineering Awards, Award of Excellence in Study / Research / Guidelines

10.5.2 SEAOC 2016 Excellence in Structural Engineering Award for Existing Tall Buildings Case Study Project



"Existing Tall Buildings: Case Study Project," led by former PEER Director Steve Mahin, received a *2016 Excellence in Structural Engineering Award* from the Structural Engineers Association of California (SEAOC) in the category of Study / Research / Guidelines.

Sponsored by PEER and Cal OES, the case-study project investigated the seismic evaluation and retrofit study of a 35-story steel building designed in 1968. Major seismic vulnerabilities were identified and considered indicative of potential vulnerabilities in similar existing tall buildings built between 1960 and 1990 on the west coast of the U.S.

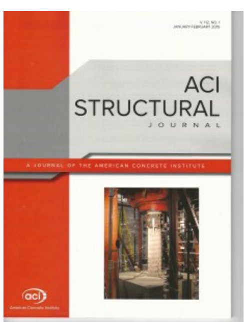
Two primary earthquake hazard levels were used for the evaluations. Additionally, several different numerical models with high fidelity were developed in accordance with recommendations of ASCE 41-13 and other relevant guidelines, and analyses were performed using the program "Open System for Earthquake Engineering Simulation" (OpenSees). Analysis results were evaluated using methodologies and performance criteria outlined in guidelines ASCE 41-13, FEMA 351, and FEMA P-58. More than 300 sets of sophisticated structural analyses were performed to evaluate the building's seismic behaviors, and to assess the efficacy of retrofit strategies.

Steve Mahin, Grace Kang (PEER), Shanshan Wang (UC Berkeley)

Several retrofit strategies were explored, including conventional methods such as fixing brittle connections and replacing the heavy exterior cladding with a lightweight curtain wall, and state-of-the-art techniques incorporating supplemental energy-dissipating fluid viscous damping devices, to improve the building's seismic performance in a cost-effective manner.

This case study project serves as a comprehensive demonstration of how to assess an existing tall building using guidelines ASCE 41-13, FEMA 351 and FEMA P-58. Modeling techniques of critical structural components and connections provide the engineering profession with better tools for structural analysis. The research conducted provides valuable and conclusive data to encourage seismic performance upgrades of problematic buildings, thus providing benefit to a community's safety, economy and resilience.

10.5.3 ACI "Excellence in Structural Engineering Research" Award for Bridge Column Capacity Research Paper



Vesna Terzic and Bozidar Stojadinović were selected to receive the ACI Chester Paul Siess Award for Excellence in Structural Research for the paper, "Evaluation of Post-Earthquake Axial Load Capacity of Circular Bridge Columns," which investigates the relationship between earthquake-induced damage in bridge columns and their axial load capacity in a damaged condition. The paper was published in the January/February 2015 issue of the *ACI Structural Journal*. Sponsored by PEER and Caltrans, this project examined post-earthquake traffic capacity of typical highway overpass bridges.

Abstract: Objective evaluation of the capacity of a bridge to carry self-weight and traffic loads after an earthquake is essential for a safe and timely re-opening of the bridge. The ability of a bridge to function depends directly on the remaining capacity of the bridge columns to carry gravity and lateral loads. An experimental study on models of modern circular reinforced concrete bridge columns was performed to investigate the relationship between earthquake-induced damage in bridge columns and the capacity of the columns to carry axial load in a damaged condition. The earthquake-like damage was induced in the column specimens in bi-directional quasi-static lateral load tests. The damaged column specimens were then re-centered to eliminate the residual drifts and tested in compression to failure to evaluate their remaining

axial load strength. It was found that well-confined modern bridge columns lose approximately 20% of their axial load capacity after sustaining displacement ductility demands of 4.5.

10.5.4 SEAONC Awards

The Structural Engineering Association of Northern California (SEAONC) honored two PEER colleagues during the June 2016 Awards dinner meeting. Greg Deierlein, Professor at Stanford University, received the Helmut Krawinkler Award, and Grace Kang, PEER Director of Communications, was elevated to SEAONC Fellow Member.

Greg Deierlein

Gregory Deierlein is the John A. Blume Professor of Engineering at Stanford University where he specializes in research on the design and behavior of steel and concrete structures, nonlinear structural analysis, fracture of metal structures, and performance-based design of structures for earthquakes and other extreme loads. He is the Director of the John A. Blume Earthquake Engineering Center at Stanford and former (2000–2007) Deputy Director of the Pacific Earthquake Engineering Research (PEER) Center. Deierlein is active in national technical organizations involved with developing building codes and standards, and he has served as a seismic design consultant and peer reviewer for buildings in California.

Grace Kang

Grace Kang, SE, is an accomplished designer of wood frame and reinforced concrete residential facilities, and the engineer behind the seismic retrofit of a variety of important cultural and academic buildings in the San Francisco Bay Area. She has also provided significant energy and time serving Structural Engineers Association of Northern California (SEAONC), SEAOC, and other organizations, including serving as SEAONC President, SEAOC Director, and as a member and past-chair of Cal Poly San Luis Obispo's Architectural Engineering Advisory Board. As PEER's Director of Communications, she uses her background as a practicing engineer to translate research findings at PEER into language the profession and general public can appreciate, helping to build understanding through education. She was inducted to the SEAOC College of Fellows in 2015.

A SEAONC Fellow member shall be a Member SE so designated by the SEAONC Board of Directors in recognition of outstanding service to the Association or accomplishments in the field of structural engineering. S/he shall have been a member in good standing for 15 years.

10.5.5 EERI Outstanding Paper Award

Khalid Mosalam and Selim Günay received the 2015 Outstanding *Earthquake Spectra* Paper award of Earthquake Engineering Research Institute (EERI). Mosalam and Günay were presented the award at the EERI Annual Meeting, held in Portland, Oregon, March 7-10, 2017. Their paper is titled "Progressive Collapse Analysis of Reinforced Concrete Frames with Unreinforced Masonry Infill Walls Considering In-Plane/Out-of-Plane Interaction" and was published in the May 2015 issue of *Earthquake Spectra*; the cover page of this issue featured one of the figures from this paper.

Unreinforced masonry (URM) infill walls are widely used throughout the world, particularly in seismically active regions, as partitions in reinforced concrete (RC) or steel building frames. It is known that infill walls affect both the structural and nonstructural performance of these buildings. When seismic vulnerabilities in the RC system (e.g., lack of confinement at the beam and column ends and beam–column joints, strong beam–weak column proportions, and shear-critical columns) are combined with the complexity of the interaction between the infill walls and the surrounding frame and the brittleness of the URM materials, non-ductile RC buildings with URM infill walls are considered one of the world's most seismically vulnerable. Such buildings exhibit unpredictable damage patterns even if designed according to modern seismic codes without considering the effect of infill walls in the design. Therefore, proper modeling of infill walls and the infill wall-frame interaction is essential to identify the beneficial and detrimental effects of the infill walls and to realistically evaluate the seismic performance and vulnerability of such buildings.

Selim Günay and Khalid Mosalam

Mosalam and Günay's paper attempted to achieve the aforementioned proper modeling by considering three critical modeling aspects: (1) explicit consideration of the physical collapse of an infill wall by removing the corresponding elements from the structural model during the simulation; (2) consideration of the interaction between the in-plane (IP) and out-of-plane (OOP) responses of the infill wall; and (3) consideration of the infill wall effect in inducing shear failure of columns with nonlinear shear springs that take account of shear-axial force interaction. Developed modeling aspects were implemented in OpenSees for immediate access by structural engineers and researchers, and subsequently used in the modeling and simulation of 2D and 3D models of RC buildings with URM infill walls. Observations of damage to RC buildings with URM infill walls from past earthquakes were used in the paper to rationalize the considered modeling aspects.

The study presented in this EERI Outstanding *Earthquake Spectra* paper built upon several studies published as PEER technical reports, namely PEER 2007/10, PEER 2007/100, PEER 2007/101, and PEER 2008/102. The upcoming version of ASCE41 (ASCE41-17) will adopt the interaction between the IP and OOP responses of the infill wall presented in this paper and in previous studies.

10.6 IN MEMORIAM

PEER and the earthquake engineering community lost two legends in the past year, Ray Clough and Vitelmo Bertero. Both were former directors of Earthquake Engineering Research Center (EERC) at UC Berkeley, the predecessor to PEER.

10.6.1 Ray W. Clough (1920–2016)

Ray W. Clough

Born on July 23, 1920, Ray W. Clough was Professor Emeritus of Civil and Environmental Engineering at the University of California, Berkeley. From 1950–1995 Professor Clough significantly contributed to the field of earthquake engineering through teaching, research, and consulting. He is renowned for pioneering the field of earthquake engineering, and his most important research contribution in structural engineering was as a co-developer in the "Finite Element Method," beginning with a classic paper in 1956 that he co-authored, which forever revolutionized the field of structural analysis and design of buildings and other structures such as dams, as well as many other disciplines that now use this method for analysis. His co-development of the method stemmed back to 1953 during research he conducted with engineers at Boeing. He was an early visionary of the capability of increasingly powerful computers in conducting structural analyses that would have been impossible only a few years before. In the 1960s, he developed a series of publications that contained pioneering methods for computer earthquake analysis of tall buildings, which became the basis for commercial computer programs, such as SAP2000, now standard in engineering practice. In 1975 he co-authored the definitive text still widely used today, *Dynamics of Structures*, with Joseph Penzien.

In the 1970s, Professor Clough was Director of the Earthquake Engineering Research Center (EERC) at UC Berkeley, the predecessor to PEER, and a hub for analytical and experimental earthquake engineering research, information resources, and public service programs. Clough worked with Professor Joseph Penzien on the design of UC Berkeley's shaking table, one of the world's largest multi-directional shaking tables, whose innovative features were later adopted by tables in Japan, Mexico, and Peru. Professor Clough served on the National Academy of Sciences Committee on Earthquake Engineering and is the recipient of many honors including the George W. Housner Medal from the Earthquake Engineering Research Institute and the Prince Philip Medal from the Royal Academy of Engineering in London. He was a member of the National Academy of Sciences (1979), the National Academy of Engineering (1968), the Royal Norwegian Scientists Society, and the Chinese Academy of Engineering.

In 1994, President Clinton presented Professor Clough with a National Medal of Science "for his outstanding contributions in the fields of finite element analysis, structural dynamics, and earthquake engineering which had extraordinary influence in the development of modern engineering." In 2006 Professor Clough was awarded the Benjamin Franklin Medal in Civil Engineering "for revolutionizing engineering and scientific computation and engineering design methods through his formulation and development of the finite element method, and for his innovative leadership in applying the method to the field of earthquake engineering with special emphasis on the seismic performance of dams." In 2008, at the 14th World Conference on Earthquake Engineering in Beijing, China, Professor Clough was recognized as one of the "legends of earthquake engineering."

The impact of his work and his legacy in the field of earthquake engineering will continue through the generations of students he taught, advised, and mentored in his nearly 40 years at UC Berkeley.

10.6.2 Vitelmo V. Bertero (1923–2016)

Vitelmo V. Bertero

Vitelmo V. Bertero was Professor Emeritus of Civil and Environmental Engineering at the University of California, Berkeley. Professor Bertero was a world-renowned pioneer, expert, and leader in the field of earthquake engineering. In 1947 Bertero received his degree in Civil Engineering from the Facultad de Ciencias Matemáticas, Físico-Químicas y Naturales, Universidad del Litoral, Rosario, Argentina, his native country. He received his M.S. and his Sc.D. degree in civil engineering from Massachusetts Institute of Technology. In 1958 he joined the Department of Civil Engineering at UC Berkeley, where, from 1988 to 1990, he was the Director of the Earthquake Engineering Research Center (EERC) at Berkeley, the predecessor to PEER, and a hub for analytical and experimental earthquake engineering research, information resources, and public service programs.

Bertero conducted numerous integrated analytical and experimental studies on seismic behavior of civil engineering facilities. He developed comprehensive methods of seismic design of steel moment frames, steel braced frames, reinforced concrete (RC) frames, RC shear walls, and masonry structures. He conducted many pioneering research studies including: elastic and inelastic seismic structural response due to near-fault directivity pulses in the early 1970s; classic experimental work on cyclic behavior of beam-column steel and RC sub-assemblages; original experimental work on cyclic versus monotonically deformed behavior of RC moment resisting frames and shear walls; innovative study on the understanding and applications of energy-based methods in earthquake-resistant design and damage evaluation; and the development of conceptual framework and the design-objective matrix for performance-based earthquake engineering.

Bertero inspected structural and non-structural damage after numerous major earthquakes throughout the world, including the 1964 Alaska, 1967 Caracas (Venezuela), 1971 San Fernando (CA), 1972 Managua (Nicaragua), 1976 Guatemala, 1977 Caucete, San Juan (Argentina), 1979 Imperial Valley (CA), 1980 El Asnam (Algeria), 1983 Oga Peninsula (Japan); 1983 Coalinga (CA), 1985 Chile, 1985 Michoacan (Mexico), 1986 San Salvador, 1987 Whittier Narrows (CA), 1988 Spitak (Armenia), 1989 Loma Prieta (CA), 1990 Luzon (Philippines), 1992 Erzincan (Turkey), 1992 Flores (Indonesia), 1994 Northridge (CA), and 1995 Kobe (Japan) earthquakes. He brought his observations into his research and the classroom. Professor Bertero published more than 350 papers and reports on various issues in earthquake engineering, and received numerous national and international awards for his teaching and original research efforts. For decades he collaborated on joint research with his colleague at UC Berkeley, Egor Popov.

In 1990 he was awarded the Berkeley Citation, UC's highest honor. Among other awards in the U.S., he received the ASCE Nathan Newmark Award (1991); ACI Arthur Anderson Award (1989); AISC T.R. Higgins Lectureship Award (1990); and EERI Housner Medal (1995). In 1990, *Engineering News Record* recognized him as the "Construction Man of the Year" for "advancing the science of earthquake engineering," and described him as the "impassioned professor who advances earthquake engineering through research." His international awards and honors include the Jai Krishna Award from the India Society of Earthquake Technology (1974); First International Gold Medal Eduardo Torroja from the CSIC, Spain (1989); appointment as the Extraordinary Chair of Javier Barrios Siera at the National University of Mexico (1986); appointment as Honorary Professor in seven universities in South American countries; and Honorary Doctoral degrees including “Doctorado Honoris Causa en Ingeniería” from the University of Los Andes, Mérida, Venezuela (1993), and from “CUYO” University, Mendoza, Argentina (1997).

Professor Bertero was elected to the Academy of Science of Argentina (1971); Academy of Engineers of Argentina (1989); and the U.S. National Academy of Engineering as Foreign Associate (1990). He was an Honorary Member of the American Concrete Institute (ACI), Fellow of the American Society of Civil Engineers (ASCE), Honorary Member of the Structural Engineers Association of Northern California, and member of EERI. From 1988 to 1992 he was a member of the Advisory Committee to the U.S. Congress regarding the National Earthquake Hazards Reduction Program (NEHRP). From 1992 to 2000 he was a Director, representing the United States, of the International Association of Earthquake Engineering (IAEE).

In 1997 the EERC-CUREe Symposium in Honor of Vitelmo V. Bertero was held at UC Berkeley, where a global assembly of individuals and organizations of researchers and engineering practitioners participated during the two-day event. In 2004, Professor Bertero co-edited the comprehensive book Earthquake Engineering: From Engineering Seismology to Performance-Based Engineering, (CRC Press, 2004). In 2006 he was named one of the “Top 10 Seismic Engineers of the 20th Century” by the Applied Technology Council and *Engineering News Record*. In 2007, he co-founded BFP Engineers, Inc., with Eduardo Fierro and Cynthia Perry. In 2010 he was awarded the Rose School Prize for his “long and distinguished career, during which he emphasized the need to understand structural performance under seismic loading, and to learn lessons from structural damage and failure in earthquakes. He led a whole new field of research emphasizing the importance of energy demand and capacity in seismic performance.”

During his nearly 50-year career at UC Berkeley and with international activities, Professor Bertero taught, advised, and mentored generations of students, postdoctoral fellows, research associates, as well as practicing engineers, many of whom are now well-known experts and leaders in earthquake engineering. Professor Bertero said “nothing is more rewarding than witnessing the success of former students and research associates.”

10.7 FACULTY PARTICIPANTS

10.7.1 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
Doug Dreger
Filip Filippou
Sanjay Govindjee
Peggy Hellweg
Roberto Horowitz
Dwight Jaffee
James Kelly
Shaofan Li
Stephen Mahin
Jack Moehle
Paulo J.M. Monteiro
Khalid Mosalam
Mark Wilfried Mueller
Claudia Ostertag
Juan Pestana
Michael Riemer
Ray Seed
Nicholas Sitar
Kenichi Soga
David Sunding
Tarek Zohdi

California Institute of Technology

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
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

10.7.2 Faculty Participants (Affiliate Institutions & 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 Nevada, Reno	Ian Buckle Mohamed Moustafa
University of Texas at Austin	Gregory Fenves Ellen Rathje Kenneth Stokoe
Virginia Tech University	Martin Chapman Adrian Rodriguez-Marek
Western University, Canada	Gail Atkinson

10.7.3 Industry Partners

AICP Consulting Research	Laurie Johnson
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	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	Mehmet Celebi Dale Cox
U.S. Resiliency Council	Evan Reis

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

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)
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 II
TSRP	Hong Kie Thio	AECOM	Tsunami Engineering: Performance Based Tsunami Engineering II
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 to water/biner ratio and voids affect the performance of hardened concrete subjected to firk
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
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

Fund Source	PI	Institution	Project Title
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 Structure
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 Liquifaction 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 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	PE&A	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
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

Fund Source	PI	Institution	Project Title
NC2T01	Scott J. Brandenberg	UCLA	Influence of Kinematic SSI on Foundation Input Motions for Bridges on Deep Foundations
DOE	Robert R. Youngs	AMEC Enviroment & Infrastructure	NGA-East: SSHAC and TI Seismic Research Review
NRC	Dr. Walt Silva	Pacific Engineering and Analysis	NGA-East: GMPE Implementation
NRC	Robert R. Youngs	AMEC Enviroment & Infrastructure	NGA-East: SSHAC and TI Seismic Research Review
DOE	Walt Silva	Pacific Engineering	Development of Vertical Amplification Factors
DOE	Robert R. Youngs	AMEC Enviroment & 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 NGAWest GMPE's
CEA	Mark Patersen	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 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	Walt Silva	Pacific Engineering & Analysis	Update NGA-W Strong Motion Database and Develop Vertical Amplification Factors
FM Global	Walt 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

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