Chapter 1
The George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES): Reducing the Impact of EQs and Tsunamis

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1.1 Introduction

In November 1998, the National Science Board approved the George E. Brown Jr., Network for Earthquake Engineering Simulation (NEES) for construction with funds totalling $ 82 million from the National Science Foundation (NSF) Major Research Equipment and Facilities Construction (MREFC) appropriation. Construction occurred during the period 2000–2004. As part of its contribution to the National Earthquake Hazards Reduction Program, the National Science Foundation (NSF) funds NEES operations (Award # CMMI-0927178) as well as many of the research projects that are conducted in NEES facilities. NEEScomm houses the headquarters of operations of a nationwide network of 14 laboratories. Each of these university-based laboratories enables researchers to explore a different aspect of the complex way that soils and structures behave in response to earthquakes and tsunamis. The laboratories are available not just to researchers at the universities where they are located, but to investigators throughout the USA who are awarded grants through NSF's annual NEES Research (NEESR) Program and other NSF programs.

NEES laboratories are also used for research conducted or funded by other federal, state, and local agencies, by private industry, and by international researchers under the partnerships that NEES has cultivated with research facilities and agencies in Japan, Taiwan, Canada, and China. To date, more than 400 multi-year, multi-investigator projects have been completed or are in progress at NEES sites. These projects are yielding a wealth of valuable experimental data and continue to produce transformational research and outcomes that impact engineering practice from analytical models to design guidelines and codes. The family of NEES researchers, educators, and students encompasses an ever increasing group of universities, industry partners, and research institutions in the US and abroad. Project

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teams and the NEEScomm team have developed a rich set of resources for research and education.

This paper provides a sample of the breadth of the activities of researchers, students, educators, and practitioners collaborating in NEES (http://nees.org/). More information about the activities presented here and others can be found in Buckle and Ramirez (2010), in the 2009–2010 NEES Facility Project Highlights (NEEScomm, 2010), 2010–2011 NEES Activity Highlights (NEEScomm, 2011) at: https://nees.org/about/neescommunications/neesprojecthighlights, and in the retrospective study on NEES requested by IDA Science and Technology Policy Institute of Washington DC on behalf of the National Science Foundation, "STPI Report—NEES Self-Study Report for Science and Technology Policy Institute (STPI)/IDA", at: https://nees.org/resources/3234/supportingdocs.

1.2 Research Accomplishments

Today, NEES is a vibrant collaboratory consisting of world-class laboratories and cyberinfrastructure with its collaboration platform, NEEShub at: http://nees.org/, representing hundreds of millions of dollars of investment. The NEES collaboratory serves tens of thousands of users from over 180 different countries. The NEEShub now has 5700 registered users with thousands of data downloads per quarter and more than 59,000 general users from over 182 nations (Fig. 1.1).

Research at NEES facilities has resulted in a wealth of information produced by large-scale testing facilities such as tsunami wave basins, centrifuges, and

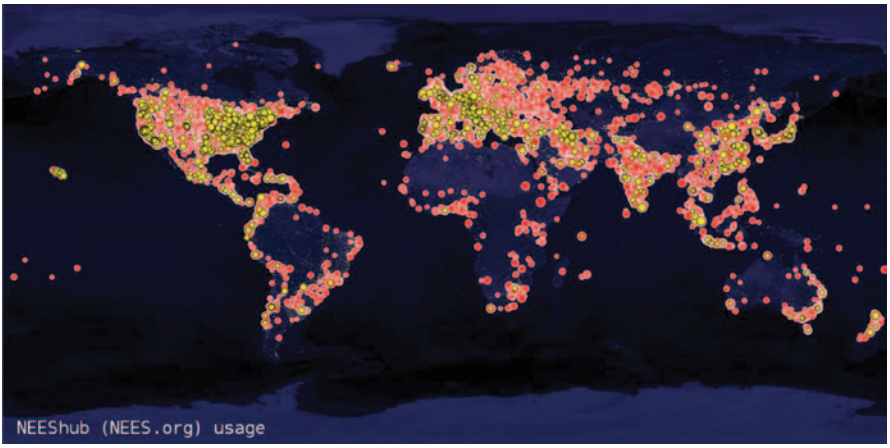


Fig. 1.1 NEEShub global usage. *Red dots* represent researchers and students browsing NEEShub, watching videos, and taking courses while performing 840,656 web and 38,854 tool sessions between August 2010 and April 2013. *Yellow dots* represent users who are running simulations. *Dot size* corresponds to the number of users at a location

Fig. 1.2 NEESR-GC: simulation of the seismic performance of nonstructural systems. NSF Award #: 0721399PI: Emmanuel "Manos" Maragakis. Co-PIs: Robert Reitherman, Steven French, Andre Filiatrault, Tara Hutchinson. Research Sites: University of Nevada, Reno; Hyogo Earthquake Engineering Research Center, aka "E-Defense," Miki, Japan; NEES, University at Buffalo. (Reproduced by permission of PI: Emmanuel "Manos" Maragakis, Dean of Engineering, University of Nevada, Reno)

shake tables. This research community has advanced the understanding of seismic phenomena and laid the groundwork for improvements in design and construction practices to enhance resilience.

A research team led by Manos Maragakis, dean and professor of engineering at the University of Nevada, Reno, has recently completed a major examination of the seismic responses of nonstructural systems. They focused on ceiling-piping-partition systems: identifying their major failure mechanisms, quantifying how their failure affects critical facilities (Fig. 1.2). This grand challenge project provides experimental data and experimentally based simulation tools that will allow better understanding of the seismic behaviour of nonstructural systems.

The Sacramento-San Joaquin River Delta in USA supplies fresh water to 25 million people in southern and central California and irrigates the breadbasket of the San Joaquin Valley. Some 1100 miles of levees protect the region from inundation and serve as a protective lifeline for California agriculture and nearly two-thirds of the state's population. The aging Delta levees are a known flood risk, and many levees are composed of loose granular soils that are susceptible to liquefaction during earthquakes. However, no one knows exactly how the peat underlying many of the levees will behave in an earthquake. A team of researchers led by Scott Brandenberg, a professor of civil and environmental engineering at the University of California, Los Angeles (UCLA) have partnered with the California Department of Water Resources (DWR) to determine how the Delta's peat soil, which serves as the base of the levees, will affect these earthen structures during an earthquake. The research team conducted full-scale shake tests on model levees. To conduct the shake tests, the research team built a model-scale levee six feet tall and 40 ft wide on an island located within the Delta (Fig. 1.3). Unlike existing levees, which were constructed in a haphazard, non-engineered manner, the model levee was constructed

Fig. 1.3 NEESR-II: evaluation of seismic levee deformation potential by destructive cyclic field testing NSF award #: 0830081, PI name: Scott J. Brandenberg, Co-PI: Jonathan P. Stewart, Robb E.S. Moss, Research Sites: University of California, Los Angeles and University of California. (Reproduced by permission of PI: Prof. Scott J. Brandenberg, Department of Civil and Environmental Engineering, University of California, Los Angeles)

from clay that was carefully compacted and reinforced with geogrids. Furthermore, the clay was unsaturated and therefore not susceptible to liquefaction like many Delta levees are.

Other NEES research has developed or validated new seismic protection systems, design methods, or simulation tools that enable engineers to improve the seismic performance of structures. After an earthquake, infrastructure damage can be difficult to detect. In particular, cracks and breaks in underground water pipelines often can't be identified without excavating the pipes. Yet securing lifelines is a high priority for post-quake repairs; undetected or inaccurate information about damage to water-delivery networks can lead to epidemic outbreaks in communities hit by natural disasters.

Earthquake engineers are seeking to design "smart" self-sensing concrete pipes that are able to send wireless messages to signal where and how they were damaged. In a four-year study, Radoslaw Michalowski, professor of civil engineering at the University of Michigan, conducted large-scale tests on buried segmental concrete pipelines to understand exactly how water pipes fail during earthquakes.

These damage-assessment tests mark the first steps toward the development of strategies for wirelessly detecting damage and monitoring the structural health of pipelines (Fig. 1.4). Using data collected from the experiments, Michalowski and his team are now developing protocols for rapid, wireless damage assessment, obviating the need for pipe excavation.

Many of the projects conducted in the NEES laboratories have prompted, or laid the groundwork for, improvements in model building codes and in design and construction practices, enhancing societal resilience to earthquakes and tsunamis.

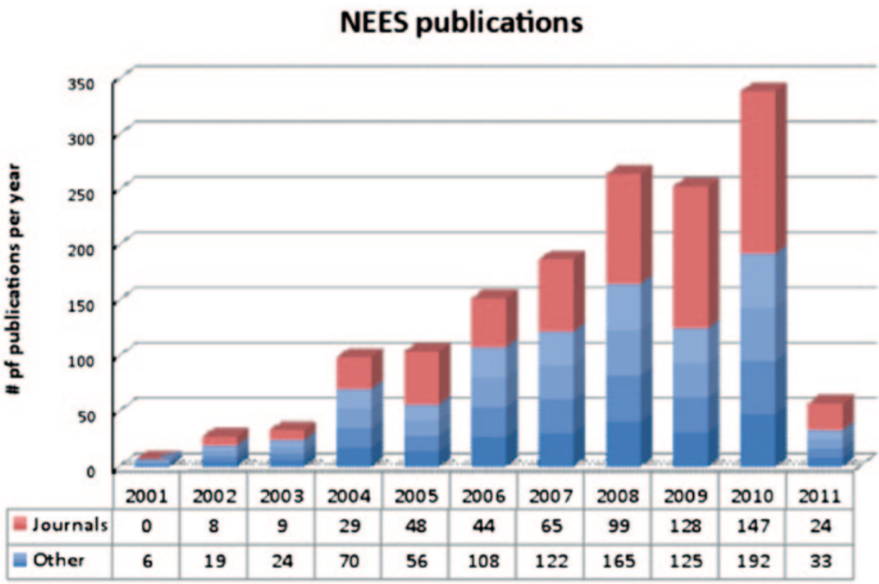
Fig. 1.4 NEESR-SG: damage detection and health monitoring of buried pipelines after earthquake-induced ground movement. NSF Award #: 0724022. PI name: Radoslaw Michalowski. Co-PIs: W. Jason Weiss, Russell Green, Jerome Lynch, Aaron Bradshaw Research Site: Cornell. (Reproduced by permission of PI: Radoslaw Michalowski, Department of Civil and Environmental Engineering, University of Michigan)

Facilitating these outcomes has been the dissemination of NEES findings through publications, NEEShub at nees.org, and NEES Education, Outreach and Training (EOT) activities. NEES research has been cited in more than 1700 publications according to data collected to June 2012, including rising numbers of refereed journal articles. The distribution of these publications as of July 2011 is shown in Fig. 1.5.

In 2012 the National Science Foundation commissioned a number of studies to help elucidate the view of the broader research community regarding grand challenges ahead for earthquake engineering and the type of earthquake research infrastructure needed to meet those challenges. The findings of those studies are in the NRC Report *Grand Challenges in Earthquake Engineering Research: A Community Workshop Report* (available at: http://www.nap.edu/catalog.php?record_id=13167) and the Report *2020 Vision for Earthquake Engineering Research: Report on an OpenSpace Technology Workshop on the Future of Earthquake Engineering* (available at: https://nees.org/resources/1636).

1.3 NEES Cyberinfratructure and the NEEShub

Linking the NEES experimental facilities to each other, to NEEScomm, and to off-site users is the NEES cyberinfrastructure. This unique system of information technology resources enables researchers participating on-site or remotely to collect, view, process, and store data from NEES experiments, to conduct numerical



	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Journals	0	8	9	29	48	44	65	99	128	147	24
Other	6	19	24	70	56	108	122	165	125	192	33

Fig. 1.5 Publications resulting from NEES work as of July 2011

simulation studies, and to perform hybrid (combined experimental and numerical) testing involving one or more NEES equipment sites. At the heart of this system is NEEShub, a platform designed to facilitate information exchange and collaboration among earthquake engineering researchers, educators, students, practitioners, and stakeholders. Accessed via the NEES website, https://nees.org/, NEEShub is powered by HUBzero software developed at Purdue University.

NEEShub features the NEES Project Warehouse (Fig. 1.6), a curated, centralized data repository used to store and share research results. When launched in 2009, NEEScomm prioritized a strong partnership with the NEES sites and targeted what had been a seriously deficient central data repository and cyberinfrastructure for collaboration. Since the first release of the NEEShub "cloud" platform less than three years ago, the community has actively responded to our user-focused cyberinfrastructure improvements with a pace of file and directory creation that has increased sevenfold. Today, the NEES-curated central repository of research data—Project Warehouse—features a vastly populated repository of NEES research data and showcases over 1.9 M data files and folders that engineers can search, sort, download, and manipulate. NEEShub also stores and shares a variety of other earthquake engineering resources, including publications, databases (Browning et al. 2013), computational models, simulation software, educational materials, and data management and visualization tools. Some of these resources and tools have been developed by NEES staff, while others have been contributed by the earthquake engineering community. NEES solicits and welcomes such contributions from the United States and abroad.

In addition to enabling sharing and collaboration that can accelerate advances in earthquake risk reduction, NEEShub is also helping to disseminate these advances

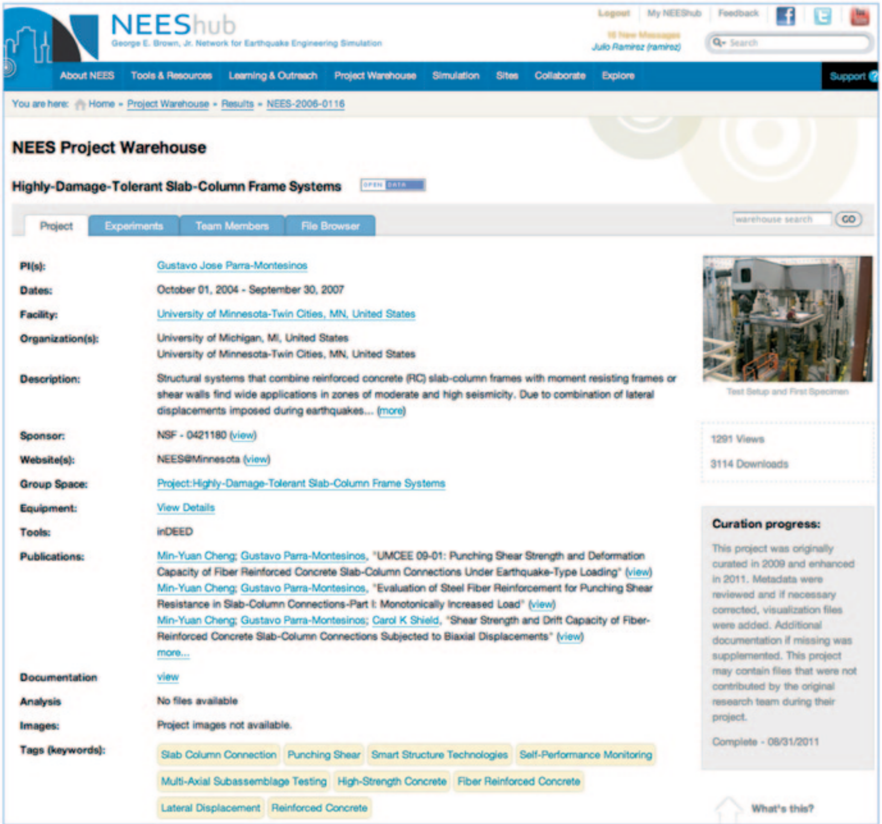


Fig. 1.6 NEES data repository: project warehouse

and to build the workforces needed to discover and implement research findings. NEES is enabling students to learn earthquake engineering through involvement in research projects, undergraduates through NEES' annual Research Experiences for Undergraduates program, and graduate students by directly assisting NEES investigators. In a recent survey, NEEScomm found that at least 559 graduate students, including 191 PhD candidates, have been trained through participation in NEES research. Many of those receiving PhDs now hold faculty positions at major research universities worldwide.

1.4 International Collaborations

NEES has cultivated partnerships with research facilities and agencies in Japan, Taiwan, Canada, and China (Ramirez 2010). The development of a Memorandum of Understanding with The National Research Institute for Earth Science and Disaster

Fig. 1.7 Testing the NEES-Wood Capstone building on the E-defense shake table. (Reproduced by permission of PI: John W. van de Lindt, Colorado State University)

Prevention (NIED) on earthquake engineering research using E-Defense and NEES Facilities represents an important accomplishment with significant realizations in the collaborative research arena. Japan's E-Defense shake table, operated by NIED, is the world's largest multi-degree shake table. In September 2005, the NSF and the Japanese Ministry of Education, Culture, Sports, Science, and Technology (MEXT) signed a memorandum concerning cooperation in the area of disaster prevention research. NSF-supported NEESR projects addressing the seismic performance of midrise wood frame buildings, steel frames, and base-isolated structures utilized both NEES facilities and E-Defense during the 2009–2010 timeframe. An example of the successes is the testing on July 14, 2009, of a six-story condominium building on the shake table at the E-Defense facility, located in the city of Miki, north of Kobe (Fig. 1.7). This was the culminating experiment of the National Science Foundation (NSF) multi-year NEESWood project under the direction of Prof. John van de Lindt. The enabling agreement originally was intended to last five years. NSF and NIED supported the extension of this program for another 5-year term.

Thus, on 7 June 2010, the Memorandum of Understanding with The National Research Institute for Earth Science and Disaster Prevention (NIED) on earthquake engineering research using E-Defense and NEES Facilities was renewed for up to five more years.

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