

# THE GEORGE E. BROWN, JR., NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION (NEES): Reducing the impact of EQs and Tsunamis



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## **SUMMARY:**

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a network of 14 advanced laboratories (<https://nees.org/sites-mainpage/laboratories>) connected by a state-of-the-art cyberinfrastructure that fosters collaboration in research and education (<https://nees.org/>). In its eight-year of operations, over 300 multi-year, multi-investigator projects have been completed or are in progress in NEES, yielding many advances in earthquake engineering and a wealth of valuable experimental data. The NEES platform for collaboration, NEEShub, provides convenient access to the NEES central data repository (Project Warehouse) and hosts a range of tools for data visualization, analysis, computational simulation, education, collaboration and hosts a rich set of resources aimed at disseminating new earthquake engineering knowledge to the profession as well as educating the next generation of researchers and practitioners. In this paper, brief descriptions of some of the many research, outreach, information technology, and educational accomplishments of NEES are given.

*Keywords: Earthquakes and Tsunamis, Network of Laboratories, Cyberinfrastructure, Data, Collaboration*

## **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. NEES operations are managed by the NEES Community and Communications (NEEScomm) Center, which is headquartered at Purdue University in West Lafayette, IN, and includes key administrative partners at the University of Texas at Austin, San Jose State University, the University of Washington at Seattle, the University of Kansas at Lawrence, and Fermi National Accelerator Laboratory.

NEEScomm manages 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. Researchers located at colleges or universities remote from the NEES site used have led 80% of NEESR projects.

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 300 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 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>.

## 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. Research at NEES facilities has contributed to the advancement of understanding of seismic phenomena, such as the characteristics and effects of tsunamis and the potential for soil liquefaction (Figure 1).

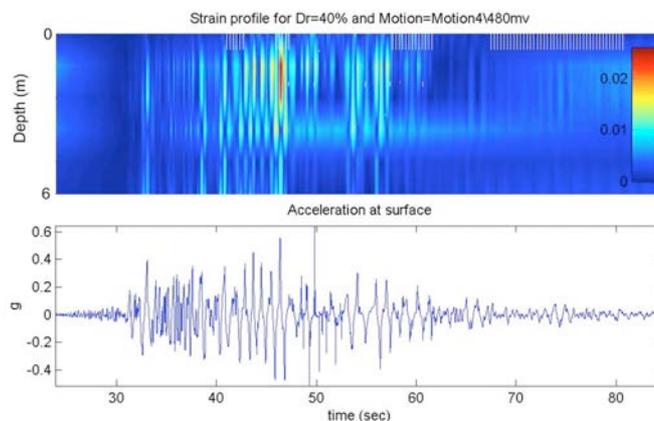


Figure 1. Colormap of Induced Shear Strain vs. Depth and Time (upper plot) and Recorded Ground Surface Accelerogram (lower plot) in Model Tested in the NEES at Rensselaer Polytechnic Institute (RPI) Centrifuge

Award Title: NEESR-CR: Evolutionary Intensity Measures for More Accurate and Informative Liquefaction Hazard Evaluation. Award NSF Number: CMMI-0936408

Start Date: October 1, 2009. End Date: September 30, 2012

Award PI/PI Affiliation: Steven Kramer/ University of Washington, Award co-PI/co-PI Affiliation: Kenan Hazirbaba /University of Alaska, Matthew Kuhn/ University of Portland.

NEES Laboratory at which research occurred: RPI

Research at NEES has also strengthened our knowledge of how the built environment responds to earthquakes. NEES investigators have studied the responses of a variety of structures, from reinforced concrete columns used in buildings and bridges (Figure 2) to wind turbines and port container cranes.

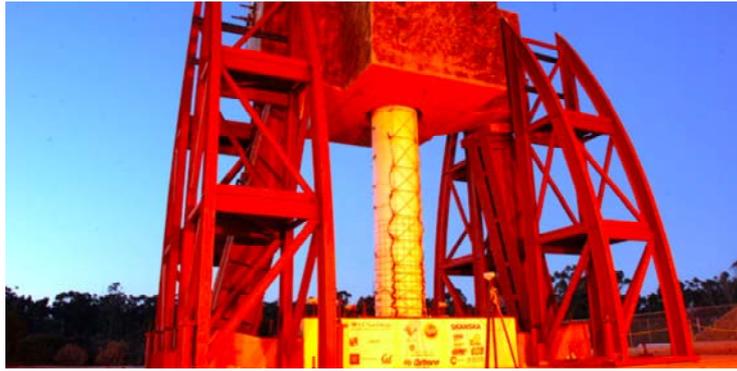


Figure 2. Full-scale Bridge Column on the University of California, San Diego NEES@UCSD Shake Table

Award Title: Large-Scale Validation of Seismic Performance of Bridge Columns. Funded by Caltrans through the PEER Center. Award PI/PI Affiliation: Steve Mahin/ University of California, Berkeley. Award co-PI/co-PI Affiliation: José Restrepo / University of California, San Diego Ian Buckle/ University of Nevada, Reno. NEES Laboratory at which research occurred: NEES @ UCSD

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. For example, NEES projects have validated the improved seismic performance of bridge piers made with innovative polymer materials (Figure 3); of base-isolated designs for steel structures; of reinforced masonry shear-wall structures; and of retrofit techniques for nonductile, reinforced concrete frames with infill walls. New design methods have been developed for mid-rise wood-framed buildings, metal building systems, precast concrete floors, and reinforced concrete wall systems. NEES research has also produced new simulation tools and fragility data for nonstructural building systems.



Figure 3. The Bridge Model with Glass Fiber Reinforced Polymer Wrapped Columns mounted on three shake tables at the University of Nevada, Reno (UNR) NEES Laboratory

Award Title: Seismic Performance of Bridge Systems with Conventional and Innovative Design. Award NSF Number: CMS-0420347, CMMI-0650935, and CMS-0402490  
Start Date: November 2004. End Date: April 2011  
Award PI/PI Affiliation: M. Saiid Saiidi, University of Nevada, Reno, Award co-PI/co-PI Affiliation: A. Elgamal, UCSD; A. Mirmiran, Florida Int. U.; I. Buckle, UNR; G. Fenves, University of Texas, Austin  
NEES Laboratories at which research occurred: UNR and UCSD

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. 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 1,700 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 Figure 4.

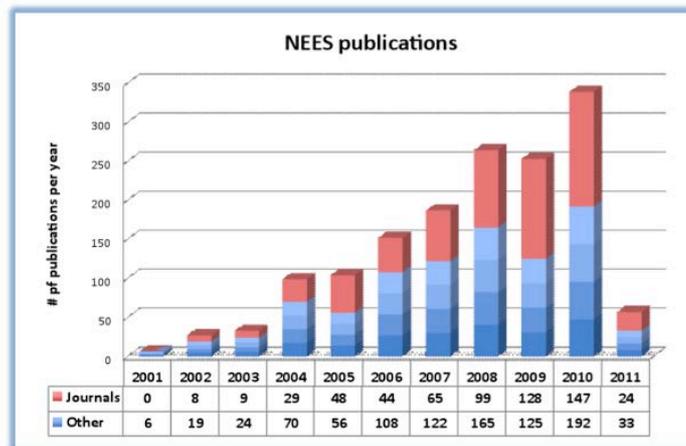


Figure 4. Publications Resulting from NEES work as of July 2011

In 2012 the National Science Foundation is studying the future of NEES beyond 2014 and has 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](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>).

### 3. NEES CYBERINFRASTRUCTURE 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 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 (Figure 5).

NEEShub features the NEES Project Warehouse (Figure 6), a curated, centralized data repository used to store and share research results. As more NEES research projects have been completed in recent years, the number of files in the warehouse has increased rapidly and now exceeds one million (Figure 7). NEEShub also stores and shares a variety of other earthquake engineering resources, including publications, databases, 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.

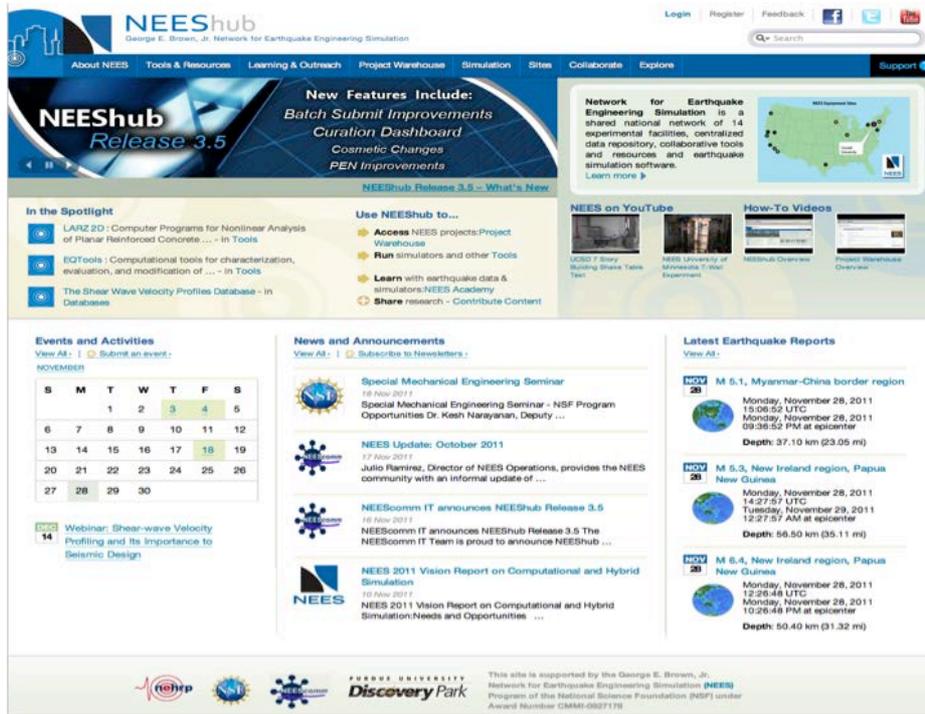


Figure 5. NEEShub: NEES Platform for Collaboration

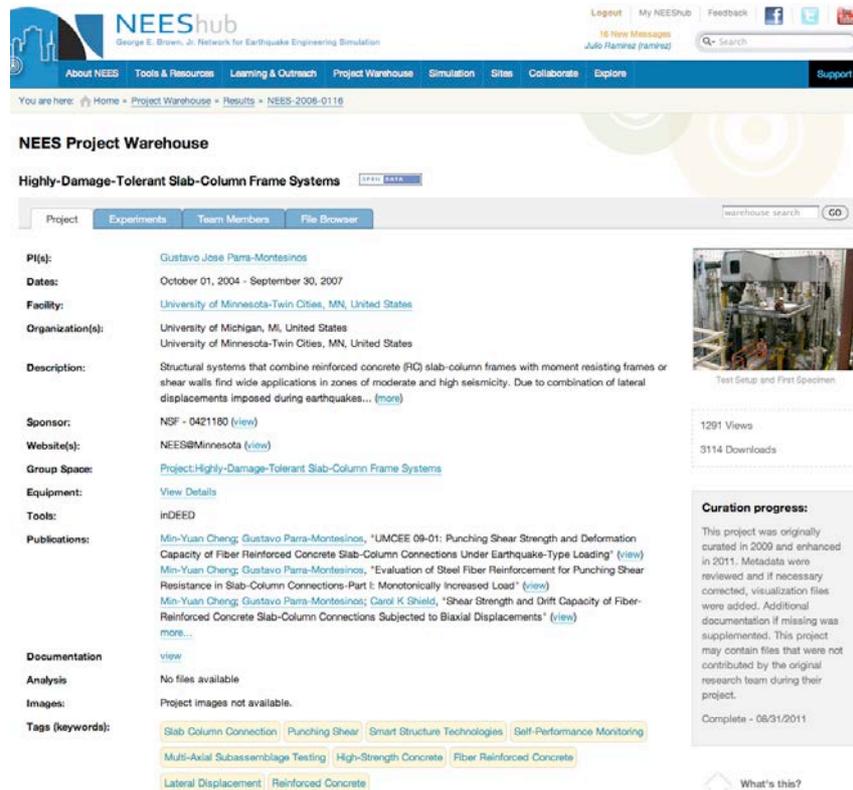


Figure 6. NEES Data Repository: Project Warehouse

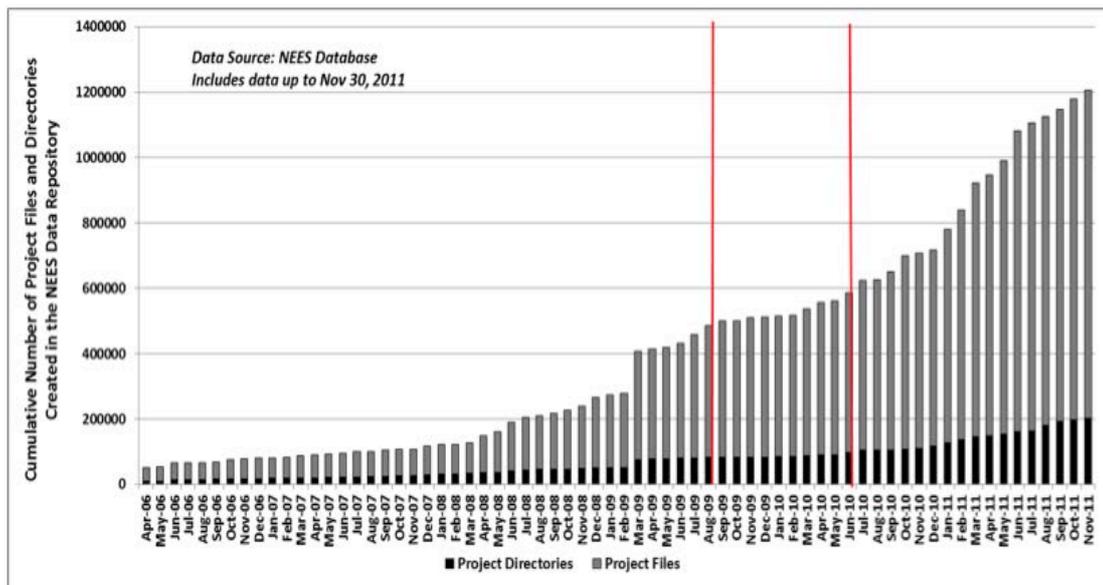


Figure 7. Project Files and Directories in the NEES Project Warehouse

In addition to enabling sharing and collaboration that can accelerate advances in earthquake risk reduction, NEEShub is also helping to disseminate these advances. NEESacademy, a section of NEEShub maintained by NEEScomm’s education, outreach, and training (EOT) staff, provides access to varied resources tailored for students, teachers, engineering professionals, and the public. NEES is helping to build the workforces needed to discover and implement research findings. NEES is also 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.

#### 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 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 (Figure 8). 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.



Figure 8. Testing the NEESWood Capstone Building on the E-Defense Shake Table

Another significant milestone was reached on July 8, 2010 with the official signature at the Port and Airport Research Institute (PARI) in Japan, of the Memorandum of Understanding (MoU) on use of facilities and research collaboration between PARI and NEES. PARI has developed and operates experimental facilities for 1) marine environment and engineering, 2) geotechnical and structural engineering, and 3) construction and control systems in close collaboration with the Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan. Among those facilities are the “Large Hydro-Geo Flume (LHGF)”, an “Underwater Shake Table (UST)” to investigate earthquake and tsunami engineering (Figure 9) and a “Large Geotechnical and Hydrodynamic Centrifuge (LGHC)” to investigate the multi-hazards of earthquakes and tsunamis.



Figure 9. PARI Underwater Shake Table (UST)

On 3 May 2010, through a Memorandum of Understanding, the research partnership between NEES and the Canadian Seismic Research Network (CSRN) was formalized. CSRN was established to undertake research leading to the development of national guidelines for seismic rehabilitation of existing buildings and bridges, microzonation of Canadian urban regions, and scenarios for policy and planning decisions. CSRN, led by Prof. Denis Mitchell, is headquartered at McGill University in Montreal, Quebec, Canada, and coordinates research projects conducted by 26 researchers from eight universities across Canada. Large-scale structural testing is conducted at most of the eight universities

and forms an important component of the CSRN research program. In this MoU, NEES and CSRN agree to cooperate in the implementation of joint research in earthquake engineering, including but not limited to experimental research utilizing CSRN and NEES laboratories.

As part of the ongoing effort by NEES to explore and nurture research and partnerships, the National Science Foundation (NSF) and the National Natural Science Foundation of China (NSFC) have sponsored two workshops to develop research topics and proposal teams on China-United States collaboration for disaster evolution/resilience of civil infrastructure and urban environment with participation of the NEES research community and researchers from China. The first Workshop was held at Purdue University on China-United States Collaboration for Disaster Evolution/Resilience of Civil Infrastructure and Urban Environment on August 23-24, 2010 and the second workshop in Shanghai on December 9-10, 2011 (Figure 10). The final reports for both workshops can be found at: <http://nees.org/announcements/2ndworkshopchinaus>. The reports include workshop discussions, recommendations, key resolutions, and future plans.



Figure 10. 2<sup>nd</sup> Workshop on China-US Collaboration

#### **ACKNOWLEDGEMENT**

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