

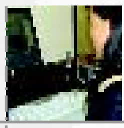

National Science Foundation



George E. Brown, Jr. Network for Earthquake Engineering Simulation

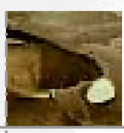
OVERVIEW

ON THE COVER:

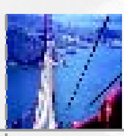


Based on the Multisite Online Simulation Test (MOST), which used numerical simulation and experimentation to test three subassemblies representing part of a steel frame, the mini-MOST test environment uses a combination of simulation and a physical model to test and demonstrate NEESgrid capabilities, to help train researchers to use the software, and to facilitate getting additional NEESgrid nodes up to the reference implementation.

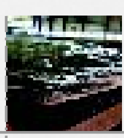
Researchers at the NEES experimental facility at Lehigh University conduct real-time tests, such as the one depicted on the cover, to evaluate how large-scale structures, such as buildings and bridges, respond to earthquakes of varying intensity. The results of research at Lehigh's Advanced Technology for Large Structural Systems laboratory will improve our understanding of the interactions between structures and soils during an earthquake. This understanding will lead to the development of more earthquake-resistant materials and building methods.



NEES supports the construction and operation of large-scale field laboratories for studying the effects of earthquakes on rocks and soil. The sand boil depicted on the cover is a combination of sand and water that comes out onto the ground surface during an earthquake as a result of soil liquefaction at shallow depth.



More than 1.5 billion people have crossed the Golden Gate Bridge since it opened to vehicular traffic in 1937. While the bridge has so far survived earthquakes with little damage, earthquake engineers believe that the bridge could not withstand a major tremor. With the help of facilities such as those operated by NEES, engineers are working to design a retrofit of the bridge to ensure that it will continue to survive as a symbol of San Francisco, California, and as a vital link for millions of commuters every day.



Tsunamis are generated mainly by submarine earthquakes. Although tsunamis are rare, they can cause significant damage to coastal regions around the world. The NEES tsunami wave basin at Oregon State University, the world's most sophisticated facility for tsunami research, enables accurate evaluation of the characteristics of tsunami phenomena and their effects on coastal regions.

STRONGER & SAFER

Earthquake Engineering Research Builds a Stronger and Safer World

From the coastal states of California and Alaska to the interior states of Missouri and Tennessee, Americans face the threat of devastating earthquakes. The cost of these seismic events—in human lives, property losses, interrupted productivity, and damage to vital services—can be enormous. California's 1989 Loma Prieta earthquake, which lasted only 20 seconds, damaged or destroyed more than 30,000 structures and resulted in an estimated $5.9 billion in losses. Just five years later, the Northridge earthquake caused an additional $30 billion in damages and destruction in California.

According to the U.S. Geological Survey, more than 5,000 earthquakes occur each year in the United States, and 10 of them are large enough to inflict significant damage. More than 75 million Americans in 39 states are at risk, and the threat is increasing because of expanding urban development in areas susceptible to earthquakes.

Although earthquakes cannot be prevented, planning and designing buildings, bridges, utility and transportation systems, and other built infrastructure with earthquakes in mind can reduce their consequences. Thanks to steady advances in science and engineering, society now has a variety of tools to monitor earthquakes and mitigate their effects. Yet damage observed during recent earthquakes in the United States reveals that much still remains to be learned about seismic hazards and how to better protect life and property.

The National Science Foundation (NSF) created the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) to improve our understanding of earthquakes and their effects. NEES is a shared national network of 15 experimental facilities, collaborative tools, a centralized data repository, and earthquake simulation software, all linked by the ultra-high-speed Internet2 connections of NEESgrid. Together, these resources provide the means for collaboration and discovery in the form of more advanced research based on experimentation and computational simulations of the ways buildings, bridges, and utility systems, as well as coastal regions and geomaterials, perform during seismic events.

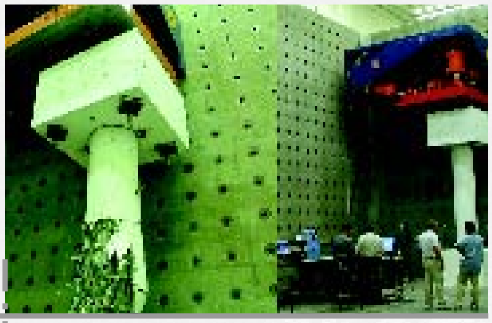
NEES will revolutionize earthquake engineering research and education. NEES research will enable engineers to develop better and more cost-effective ways of mitigating earthquake damage through the innovative use of improved designs, materials, construction techniques, and monitoring tools. This research can also help prevent infrastructure damage from other natural disasters and from terrorism. Preparing for and protecting against these threats makes American communities more resilient and enhances their ability to meet the challenges posed by future disasters.

With funding from NSF, NEES will operate from October 1, 2004, through September 30, 2014. It is managed by the nonprofit NEES Consortium, Inc. (NEESinc), which provides access to and allocates research time at 15 experimental facilities; operates NEESgrid software; leads training, education, and outreach activities; and establishes ties with U.S. and international partners. Through NEES,

- **Researchers** can conduct joint experiments across geographically dispersed facilities, greatly expanding their experimental and analytical capabilities to discover new ideas and develop new technologies in the earthquake engineering field;
- **Students** have opportunities to work with real data and learn directly how research can lead to practical ways of reducing the seismic vulnerability of the built environment; and
- **Decision makers and planners** can benefit from the practical lessons that emerge from conducting large-scale experiments in the laboratory or field.

As a part of NEES, the Structural Engineering and Earthquake Simulation Laboratory at the University at Buffalo, State University of New York, is upgraded with dual shake tables to enable researchers to investigate the behavior of large structural systems and components when subjected to complex seismic excitations at a scale and complexity not previously possible. The laboratory has a modular and highly flexible framework that allows multiple configurations of full-scale and component tests combined simultaneously with real-time numerical simulations. This illustration is from an animation that depicts a bridge experiment in the new facility.

Illustration courtesy of University at Buffalo, SUNY, Structural Engineering and Earthquake Simulation Laboratory



The NEES facility at the University of Illinois at Urbana-Champaign has three large capacity load and boundary condition boxes (LBCB). The photo shows one LBCB mounted to the reaction wall and a bridge pier to test the bridge pier response during an earthquake. The bridge pier is part of a large model of the Santa Monica Freeway (I-10) that suffered extensive damage in the 1994 Northridge, California earthquake. A computer model representing the rest of the freeway was running in parallel during the test. The successful replication of the failure of the freeway during the test, as evidenced by the damage to the bridge pier in the photo, will enable engineers to improve the seismic design of future structures.
Photo courtesy of University of Illinois at Urbana-Champaign

Networking Facilities and Cyberinfrastructure

NEESgrid—the cyberinfrastructure that connects the network's experimental facilities and tools—forms a seamless, integrated national laboratory.

Shared Experimental Facilities

From 2000 to 2004, with NSF support, 15 universities in the United States created, expanded, or upgraded the specialized experimental facilities used in earthquake engineering studies. These facilities include shake tables, reaction wall and strong floor laboratories with one-of-a-kind testing equipment and capabilities, geotechnical centrifuges, a tsunami wave basin, and mobile and permanently installed field-testing equipment. These facilities overcome many past limitations on testing the seismic performance of geomaterials, foundations, structures, and systems. Moreover, researchers can now conduct more realistic experiments, thereby increasing confidence in the efficacy of new designs and technologies for reducing earthquake damage to the constructed environment.

NEES' unique capabilities facilitate a variety of innovative experimental approaches that will lead to a better understanding of how the built environment responds during an earthquake. NEESgrid telecontrol protocols enable various components representing parts of a large structural system to be tested in different laboratories. Hybrid methods based on real-time dynamic testing have been developed at several NEES experimental facilities and provide more efficient ways of testing critical components. This approach entails physically testing a critical substructure component while simulating the response of the rest of the structure by computer.

Another example is the use of NEES facilities to replicate the response of soil deposits and their effects on the foundations of buildings, bridges, and other infrastructure. By means of advanced physical testing techniques made possible by the NEES geotechnical centrifuge and field-testing facilities, complex phenomena such as liquefaction—the process by which the soil starts to behave like a heavy fluid—and its effects on structures can be studied both in the laboratory and in the field. The extensive damage to port facilities observed in the 1995 earthquake in Kobe, Japan, and in the marina district in San Francisco during the 1989 Loma Prieta earthquake are dramatic examples of the devastating effects of liquefaction. NEES field equipment enables researchers to advance our fundamental understanding of how natural and engineered geomaterials; earth structures such as dams, levees, and retaining walls; and soil-foundation-structure systems respond to earthquakes.

Shared Cyberinfrastructure

NEES is designed to promote the integration of physical testing with computer simulation and visualization. NEES facilitates this integration by enabling researchers to develop more comprehensive computational tools for modeling the response of the built environment to earthquakes. NEES supports this emerging research paradigm through NEESgrid. Developed between 2000 and 2004, NEESgrid is a collection of collaborative Internet resources that include

- **Telepresence technologies.** Researchers, engineers, and students without direct access to specialized NEES facilities can remotely observe and participate in experiments. In addition, users can hold discussions, exchange documents, and plan joint projects.
- **Centralized data.** Experimental data and protocols, analytical results, models, and other information are stored in a curated central repository. Standard formatting and information exchange protocols facilitate the integration of and access to data. Researchers will find this archive invaluable in developing and validating increasingly sophisticated computer models that simulate the seismic performance of entire structural systems.
- **Simulation tools and computing power.** The software codes required for simulating earthquake-related problems, along with grid support, are available to investigators through an online library and portal. Access to high-performance computing capabilities speeds the processing, analysis, and sharing of data and results.

Promoting Broader Participation

NEES ushers in a new era of collaboration in earthquake engineering research. Research teams in the United States and around the world now have unprecedented opportunities to jointly plan, conduct, and analyze experimental results. Easy access to NEES resources facilitates broad participation in research activities—both informally and through official partnerships—by many communities of users, including researchers, educators and students, engineers, government agencies, professional organizations, industry, and disaster preparedness and response teams.

Teams and individuals can take part in NEES activities onsite or at remote locations and participate in different kinds of research—from individual and small-group studies to "grand challenge" projects in which teams from different

This photo shows the shake table component of the geotechnical centrifuge built by the University of California, Davis. This equipment will help researchers more accurately assess the safety and seismic performance of buildings, bridges, ports, dams, and other elements of the Nation's civil infrastructure.
Photo courtesy of University of California, Davis

institutions and organizations pursue a comprehensive systems approach to a specific broad-based earthquake engineering problem. Its framework and vast array of integrated resources make NEES especially well suited to strategically drive grand challenge research. For example, one such project might address how to transfer new knowledge about earthquake engineering, derived from experiments at one or more NEES facilities, into guidelines on seismic design and informed regulations and strategies for disaster preparedness, emergency response, and post-earthquake recovery.

Like other NSF research grants and programs, NEES fosters the strong integration of research and education and broadens opportunities by enabling the participation of women, underrepresented minorities, and persons with disabilities. Widespread public interest in earthquake engineering and disaster preparedness makes highly visible science and engineering initiatives such as NEES a natural vehicle for enhancing earthquake engineering knowledge. NEES also offers many avenues for increasing public understanding of earthquakes through a wide variety of educational programs, such as museum exhibits, community forums, field trips or onsite demonstrations, and activities on the World Wide Web. Increasing public awareness and understanding will help decision makers plan more earthquake-resilient communities.

NEES provides national resources for developing, coordinating, and sharing new educational programs and materials to train the next generation of the earthquake engineering workforce. NEES makes it easy for researchers to share their expertise with educators and students, other scientists and engineers, professionals, and the public. In many instances, this exchange of knowledge can take place while experiments are being conducted. NEES can also enrich lessons for K–12 students and teachers by making them "virtual partners" in the process of experimental discovery and analysis. Learning about earthquake engineering research will make students aware of its importance to society and may inspire them to become researchers and engineers themselves.

Protecting Society

NEES provides unique opportunities to pursue high-priority research, to demonstrate the validity of design concepts and guidelines, to speed the transfer of research into seismic design guidelines and specifications, and to develop well-informed preparedness and recovery strategies. To help guide NEES through the next decade, a panel organized by the National Research Council (NRC) of the National Academies developed *Preventing Earthquake Disasters: The Grand Challenge in Earthquake Engineering* (NRC, 2003), a long-term agenda for the earthquake engineering research community. This plan identifies important research needs that are well suited to the investigative techniques made possible by NEES experimental facilities.

NEES research will provide the knowledge base for developing new technologies in such critical areas as

- High-performance materials to strengthen buildings, bridges, soils, and critical utility systems;
- Performance-based engineering involving codes and decisions related to seismic risk, new design, and retrofitting;
- Structural controls to protect buildings, bridges, and other structures;
- Monitoring tools and sensors to conduct rapid assessment of the constructed environment after an earthquake;
- Advance warning systems to protect coastal regions from earthquake-generated tsunamis;
- *In situ* site evaluation and remediation to improve and stabilize soil response during an earthquake;
- Improved techniques to protect critical lifelines such as above- and below-ground fuel, water, and sewer pipelines, and electrical, communication, and transit systems during an earthquake;
- Improved simulation tools to provide more complete and comprehensive models of seismic performance; and
- Methods to improve planning for evacuation, emergency response, and post-earthquake recovery.

NEES ushers in a new generation of earthquake engineering research that will help create a stronger and safer world. Enhanced understanding of earthquakes and seismic performance made possible by NEES will lead to innovative, cost-effective measures to better protect the vast network of facilities and services on which we all depend.

George E. Brown, Jr.

The NEES project was named in honor of the late George E. Brown, Jr., former chairman of the House Science Committee and a champion of engineering and science in Congress for more than 30 years. In 1977, Representative Brown authored the legislation creating the Federal Interagency National Earthquake Hazards Reduction Program, which led to the creation of the George E. Brown, Jr. Network for Earthquake Engineering Simulation.

Photo Credits
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George E. Brown, Jr. Network for Earthquake Engineering Simulation

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National Science Foundation
4201 Wilson Boulevard
Arlington, VA 22230
703.292.5111
703.292.5090 (TDD)

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