RESEARCH OPPORTUNITIES USING THE U.S. GEORGE E. BROWN, JR. NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION (NEES)

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Abstract

The U.S. George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) will be a shared network of 15 earthquake engineering experimental equipment sites, a national centralized data repository, an archive of earthquake engineering simulation software, and collaborative tools, all linked together by ultra-high-speed Internet connections and protocols. NEES is under construction during FY 2000 – FY 2004. NEES will be operated from October 1, 2004, through September 30, 2014, by the nonprofit NEES Consortium, Inc. The NEES Consortium will provide the national leadership and focal point for NEES through operation of the NEES infrastructure; maintenance of the data and simulation tools repositories; allocation of research time at the equipment sites; training, education, and outreach activities; and ties with U.S. and international partners.

Background on NEES

As a result of over a decade of planning by the U.S. earthquake engineering research community, the National Science Foundation (NSF) Directorate for Engineering initiated in fiscal year (FY) 2000 the five-year construction period for the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) to significantly improve our understanding of earthquakes and their effects. (Note: The U.S. federal government fiscal year begins on October 1 of the previous year; e.g., FY 2004 started on October 1, 2003.) The $81.8 million 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. Representative Brown authored the legislation creating the interagency National Earthquake Hazards Reduction Program in 1977, which, in turn, led to the creation of NEES.

NEES will network 15 geographically-distributed, shared use experimental earthquake engineering research equipment sites, with teleobservation and teleoperation capabilities, with a community curated data repository, collaboration tools, and unprecedented access to leading edge compute resources and open source simulation tools. NEES will transform the environment for earthquake engineering research and education through collaborative and integrated experimentation, computation, theory, databases, and model-based simulation across the NEES network to develop new fundamental knowledge in earthquake engineering, seismic design methodologies and mitigation technologies, and computational tools. Ultimately, the goal of NEES is to reduce earthquake losses in the U.S. through improved seismic design and performance of civil and mechanical

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infrastructure systems made possible through discoveries and new technologies enabled by NEES. A NEES web presence will facilitate remote participation in experiments by faculty and students at institutions that do not have experimental facilities of their own. A portion of the web presence will also provide educational information and outreach to the public. Figure 1 shows the concept for the shared NEES infrastructure.

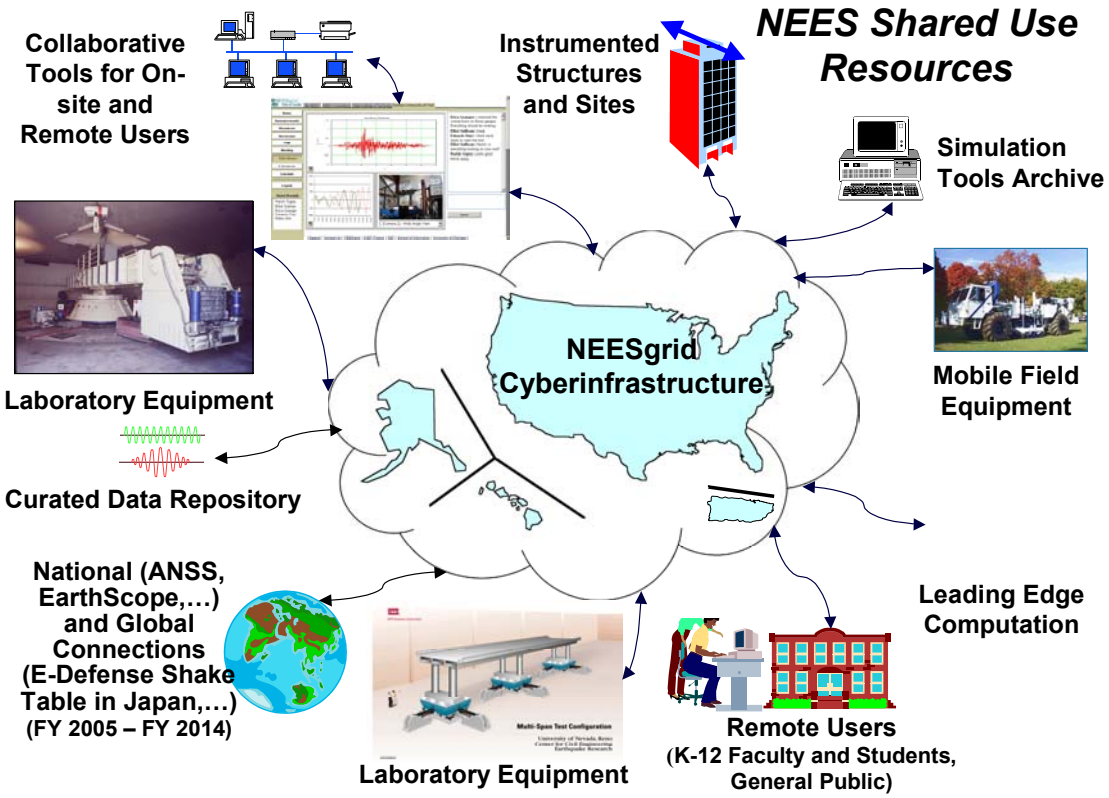

Figure 1. Concept for the NEES Infrastructure

The NEES infrastructure is being constructed during FY 2000 – FY 2004 through 18 awards (cooperative agreements) to 16 university and nonprofit organizations. Table 1 lists all the NEES construction awards. These awards are the outcomes of four competitive NSF program solicitations. The three main components of the NEES infrastructure are the following: (1) 15 equipment sites; (2) a national NEESgrid cyberinfrastructure to link together the 15 equipment sites (and enable teleparticipation), a national data repository, collaborative tools, and a simulation tools archive; and (3) the NEES Consortium, Inc., to operate the NEES infrastructure. NSF envisions that other major earthquake engineering equipment sites that bring unique experimental capabilities to NEES, both within the U.S. and abroad, will participate in NEES.

Table 1. Awards Made for NEES Construction

Award Number	Principal Investigator	Awardee Institution	Project Title
0086612	Bruneau, Michel	SUNY Buffalo	Versatile High Performance Shake Tables Facility towards Real-Time Hybrid Seismic Testing
0086624	Buckle, Ian	University of Nevada, Reno	Development of a Biaxial Multiple Shake Table Research Facility
0217293	Restrepo, Jose	University of California, San Diego	Large High Performance (LHP) Outdoor Shake Table
0086555	Dobry, Ricardo	Rensselaer Polytechnic Institute	Upgrading, Development and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer's 100 g-ton Geotechnical Centrifuge
0086566	Kutter, Bruce	University of California, Davis	A NEES Geotechnical Centrifuge Facility
0086571	Yim, Solomon	Oregon State University	Upgrading Oregon State's Multidirectional Wave Basin for Remote Tsunami Research
0086611	Bruneau, Michel	SUNY Buffalo	Large-Scale High Performance Testing Facility towards Real-Time Hybrid Seismic Testing
0086602	French, Catherine	University of Minnesota	A System for Multi-Axial Subassemblage Testing (MAST)
0086621	Moehle, Jack	University of California at Berkeley	Reconfigurable Reaction Wall-Based Earthquake Simulator Facility
0086592	Shing, P. Benson	University of Colorado, Boulder	Fast Hybrid Test Platform for the Seismic Performance Evaluation of Structural Systems
0217366	Stewart, Harry	Cornell University	Large Displacement Soil-Structure Interaction Facility for Lifeline Systems
0217393	Ricles, James	Lehigh University	Real-Time Multi-Directional Testing Facility for Seismic Performance Simulation of Large-Scale Structural Systems
0217325	Elnashai, Amr	University of Illinois at Urbana-Champaign	Multi-Axial Full-Scale Sub-Structuring Testing and Simulation Facility
0086605	Stokoe II, Kenneth	The University of Texas at Austin	Large-Scale Mobile Shakers and Associated Instrumentation for Dynamic Field Studies of Geotechnical and Structural Systems
0086596	Wallace, John W.	University of California, Los Angeles	Field Testing and Monitoring of Structural Performance
0217421	Youd, Leslie	Brigham Young University	Permanently Instrumented Field Sites for Study of Soil-Foundation-Structure Interaction
0117853	Spencer, Bill	University of Illinois at Urbana-Champaign	NEESgrid: A Distributed Virtual Laboratory for Advanced Earthquake Experimentation and Simulation
0126366	Reitherman, Robert	Consortium of Universities for Research in Earthquake Engineering	NEES Consortium Development Project

(1) Shared Experimental Equipment Sites

With NSF support, as well as institutional and other agency contributions, 15 universities in the U.S. are creating, expanding, or upgrading the specialized experimental equipment sites to be used in earthquake engineering research and education. These equipment sites include shake tables [one large uniaxial shake table with a high velocity input pulse, two relocatable 6 DOF shake tables, and three relocatable 2 DOF shake tables], reaction wall and strong floor laboratories, facilities for testing soil-foundation-structure interaction, lifelines/pipeline testing facility, geotechnical centrifuges that include biaxial shakers and robots for in-flight testing, a tsunami wave basin, and mobile and permanently installed structural and geotechnical field testing equipment. These facilities will overcome many of the past limitations on testing the seismic performance of geomaterials, foundations, structures, and systems. Each equipment site will be available as a shared use equipment site for researchers, educators, and practitioners around the U.S. These facilities may be used on-site or remotely through teleobservation and teleoperation. Several of the NEES equipment sites already have operational equipment (e.g., Oregon State University; University of California, Los Angeles; University of Colorado, Boulder; University of Nevada, Reno; University of Texas, Austin). The remaining sites will have operational equipment by September 30, 2004.

(2) NEESgrid Cyberinfrastructure

NEES will link the 15 experimental equipment sites, experimental and simulation data, and other shared tools through the NEESgrid cyberinfrastructure. NEESgrid builds upon the existing U.S. Internet network, grid framework, Globus toolkit, and the CompreHensive collaborativE Framework (CHEF) [CHEF is being developed by the University of Michigan http://www.chefproject.org/index.htm]. The result will be a layered, modular architecture, shown in Figure 2, which allows the NEESgrid system to be adapted during the 10-year operation of NEES to accommodate new applications, services, and experimental equipment. When fully linked, these resources will form a seamless, integrated laboratory. NEESgrid is being developed by the University of Illinois at Urbana-Champaign (UIUC), in partnership with Argonne National Laboratory, University of Michigan, University of Oklahoma, and University of Southern California.

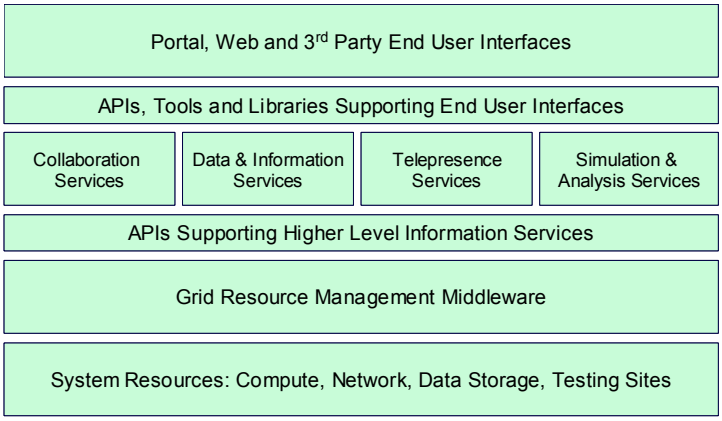

Figure 2. NEESgrid Architecture

NEES is designed to promote the integration of physical testing with simulation and visualization. NEESgrid will enable researchers to develop more comprehensive computational tools for modeling the response of the built environment to earthquakes by providing Internet-based resources that include the following:

- *Telepresence technologies.* Researchers, engineers, and students without direct access to specialized equipment sites can remotely observe (teleobserve) and teleoperate experiments.
- *Centralized data***.** Experimental data and protocols, analytical results, models, and other information will be stored in a curated central repository. Standard formatting and information exchange protocols will facilitate data integration and access. An e-Notebook format will be available for capturing and archiving experimental information.
- *Simulation tools and computing power***.** The software codes required for simulations of earthquake-related problems, along with grid support, will be available to investigators through an online library. Access to high-performance computing capabilities will speed the processing, analysis, and sharing of data and results.
- *Collaboration and visualization tools.* CHEF will enable students and researchers worldwide to collaborate in designing and conducting experiments.
- *Grid services.* Services such as user authentication and authorization, security, and monitoring of NEESgrid resources will enable users to conduct most network transactions and security checks in a single sign-on.
- *Support nodes.* Help desks and online databases will offer tutorials and other information on NEESgrid resources and how to employ them.

A prototype of NEESgrid capabilities was demonstrated on July 30, 2003, through the Multi-site Online Simulation Test (MOST) that brought together the UIUC NEESgrid team, the NEES Multi-Axial Full-Scale Sub-structuring Testing and Simulation (MUST-SIM) equipment site at UIUC, and the NEES Fast Hybrid testing equipment site at the University of Colorado (CU), Boulder. Along with the computational power at the UIUC National Center for Supercomputing Applications (NCSA), the UIUC MUST-SIM and CU equipment sites used a simple one-story, two-bay frame subjected to seismic input to demonstrate the NEESgrid features. During this pseudodynamic test, the response remained in the elastic range so that the results would be known and the demonstration could focus on the performance of the NEESgrid software and multi-site testing protocols. One column of the frame was tested at UIUC; a second column was tested at CU; and the remaining structure was simulated using computational resources at NCSA. During the experiment, force data was input to the computational model at NCSA; the correct displacements were calculated and transmitted to the UIUC and CU equipment sites; displacements were applied to the physical columns at these sites; and the forces for the next iteration were measured and sent to the computational model at NCSA. This cycle was repeated about 1,500 times during the MOST experiment, which lasted for about five hours.

The NEESgrid computational infrastructure plans to incorporate the open-source, object-oriented software framework *OpenSees* (Open System for Earthquake Engineering

Simulation), currently being developed by the NSF-funded Pacific Earthquake Engineering Research (PEER) center headed by the University of California, Berkeley, and Matlab. More information about OpenSees is available at http://opensees.berkeley.edu/. OpenSees includes a set of modules for developing models and simulations for structural and geotechnical systems using nonlinear elements (e.g., beam-column, connection, plate, and continuum elements) and materials (uniaxial and multi-axial for structural materials and soils) as well as providing analysis and solution methods and interfaces for databases and visualization modules. A computational finite element analysis framework is being developed at Berkeley using Matlab that can then dovetail into more advanced simulation using OpenSees.

As NEESgrid capabilities are being developed, the software, APIs, and technical reports about services and protocols are being released on the NEESgrid web site and workshops are being scheduled for system administrators and users. NEESgrid software version 2.0 was released in October 2003. Subsequent versions will be refined using experiment-based deployment at the 15 equipment sites. Version 2.1 is scheduled to be released in December 2003 and version 3.0 will be released in June 2004. Information about NEESgrid software capabilities and release dates, NEESgrid project schedule and workshops, technical reports, and the MOST experiment is available at http://www.neesgrid.org./

(3) NEES Consortium, Inc.

NEES will be operated from October 1, 2004, through September 30, 2014, by the NEES Consortium, Inc. The NEES Consortium was formally incorporated as a public benefit, nonprofit organization in January 2003. The Consortium will be the funding mechanism through which NSF provides support for NEES shared resources, including the 15 NEES equipment sites and the NEESgrid cyberinfrastructure. In its leadership role in the U.S. for NEES, the NEES Consortium will also allocate research time at the equipment sites; facilitate research planning by potential proposers to funding agencies; lead training, education, and outreach activities; and develop connections with U.S. and international partners. A critical role of the Consortium is to develop and implement policies governing open access and use of NEES research facilities and data. It is also expected to foster broad participation in NEES by all sectors of the earthquake engineering community, including researchers, teachers, students, and practitioners.

The Consortium of Universities for Research in Earthquake Engineering (CUREE), under an NSF NEES construction award, led the project to establish the NEES Consortium, Inc. The Civil Engineering Research Foundation (the research arm of the American Society of Civil Engineers), the Earthquake Engineering Research Institute (EERI), faculty members from academic institutions across the U.S., and practicing engineers were partners in the Consortium's development

During FY 2005 – FY 2014, the NEES Consortium, Inc., will:

- Manage NEES resources, including shared use operations at the NEES equipment sites and all other components of the Network.

- Establish policies and procedures for issues such as shared use access, user fees, and reimbursement of operating costs for the NEES equipment sites, as well as data policies and protocols for the curated repository.
- Work to enhance the integration of NEES resources to form a linked system of experimentation, computation, theory, databases, and model-based simulation.
- Plan, conduct, and coordinate outreach and training activities for the NEES equipment sites to encourage broad participation in NEES within the earthquake engineering community.
- Develop relationships with other U.S. and international experimentation, computational, grid, and visualization programs that could bring unique capabilities to NEES.
- Explore technological advances that could enhance the capabilities of the NEES experimental facilities and cyberinfrastructure.
- Interact with NSF and earthquake hazard reduction programs at other Federal agencies.

The Consortium is run by an elected and appointed Board of Directors. Those involved in the organization's planning, leadership, and management broadly represent the earthquake engineering community and provide expertise in areas such as organizational planning, earthquake engineering research, information technology, simulation, and assessment. Both individuals and institutions are eligible to join the NEES Consortium. During FY 2004, the Consortium will ramp-up operations and hire an Executive Director who will handle day-to-day operations. In addition, the Consortium has six committees to develop and oversee policies and procedures for the use of the NEES infrastructure and to facilitate its own operations:

- Site Operations
- Information Technology
- Data Sharing and Data Archiving
- Education, Outreach, and Training
- Nominations
- Finance

Further information about the NEES Consortium, Inc., is available at http://www.nees.org/.

Research, Education, and Outreach

(1) New Research Capabilities through the NEES Network

NEES unique experimental and cyberinfastructure capabilities will facilitate a variety of innovative experimental approaches, which, in turn, will lead to a better understanding of how the built environment responds during an earthquake. For example, various components representing parts of a large structural system might be tested in different laboratories. Hybrid methods based on real-time dynamic testing are being developed at several NEES equipment sites and could lead to more efficient ways of testing critical

components. This approach entails testing the seismic performance of a critical substructure component while simulating the response of the rest of the structure by computer. As another example, soil and rock, in both natural deposits and engineered fills, are the least investigated, most variable, and least controlled of all materials, but they significantly affect the performance of the built environment during earthquakes. NEES field equipment will enable researchers to advance our fundamental understanding of how natural and engineered geologic materials; earth structures such as dams, levees, and retaining walls; and soil-foundation-structure systems respond to earthquakes.

NEES will provide 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 of the National Academies has developed a long-term research agenda for the earthquake engineering research community – *Preventing Earthquake Disasters: The Grand Challenge in Earthquake Engineering (A Research Agenda for the Network for Earthquake Engineering Simulation)* (August 2003) available at http://www.eng.nsf.gov/nees. In addition, the EERI published a research plan in 2002 for earthquake engineering field entitled *Securing Society Against Catastrophic Earthquake Losses.*

NEES research will provide the foundation for the development of new technologies in critical areas such as

- High-performance materials used to strengthen buildings, bridges, soils, and critical lifelines;
- 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 post-earthquake condition assessment of the built environment;
- Advanced warning systems to protect coastal regions from earthquake-generated tsunamis;
- In situ site evaluation and remediation to improve and stabilize soil response during earthquakes;
- Improved techniques to protect critical lifelines such as above- and below-ground fuel, water, and sewer pipelines and electrical, communication, and transit systems during earthquakes;
- Improved simulation tools for analyzing more complete and comprehensive models of seismic performance; and
- Methods to improve decision making with regard to planning and evacuation, emergency response, and post-earthquake recovery.

(2) NSF NEES Research Funding

In August 2003, NSF initiated the first year of the planned ten-year competitive George E. Brown, Jr. Network for Earthquake Engineering Simulation Research (NEESR) Program

Solicitation http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03589. Projects funded under this solicitation must make use of one or more of the 15 NEES equipment sites. Research will be funded under this solicitation as follows:

- Individual Investigator (II) awards will be made to individuals and small research teams to address a significant problem in earthquake engineering.
- Small Group (SG) awards will be made to cross-disciplinary, and preferably multi-organizational, teams of researchers to address a significant problem in earthquake engineering requiring extensive use of the NEES equipment sites.
- Grand Challenge (GC) awards will support geographically distributed, cross-disciplinary, and multi-organizational teams that take a comprehensive systems approach to address a significant problem in earthquake engineering requiring extensive use of the NEES equipment sites.

The GC and SG NEESR projects offer a unique opportunity for researchers outside the project team to utilize the project's test set-up to accommodate a considerably smaller experimental investigation of a "payload" component, referred to as a "payload project." The payload concept is modeled after the payload projects aboard the NASA space shuttle flights. A NEES payload component is not necessarily part of the main structural, geotechnical, or infrastructure system, e.g., the payload may be a mechanical, control, sensing, or nonstructural component that may detect or support operation of the overall system, but is not part of the load carrying system. Payload projects also may concern the load carrying structural system or its components. The GC or SG project's test set-up would provide the vehicle for testing the payload component(s). GC and SG projects may identify and include potential payload projects as part of the base proposal submission to this program solicitation. Alternatively, after a GC or SG award is made, NSF may fund payload projects separately, either to the project team or to researchers outside the project team, through the Small Grants for Exploratory Research (SGER) program.

For NSF-funded NEESR projects, access to and scheduling and announcing of experiments at the NEES equipment sites will be coordinated by NEES Consortium, Inc. As it becomes available, information about the use of NEES resources, i.e., the evolving policies on the shared use of the NEES equipment sites, sharing of data, and the evolving formats for data, metadata, and E-Notebooks, can be found at http://www.nees.org/ and http://www.neesgrid.org. Because these policies and formats are currently being developed by NEES Consortium, Inc., and the NEESgrid system integration project in conjunction with the earthquake engineering community, NSF expects researchers funded under this program solicitation to comply with these policies and formats, when established, for equipment facilities usage and documenting and sharing of NEESR experimental and analytical results. An important component of all NSF NEESR funded research is that all experimental data generated must be submitted electronically to the central NEES data repository. Data includes all measurements, calibrations, observations, analyses, images, commentary, reports, logs, notes and/or electronic notebook entries which relate directly to the conducted experiments. Any data (as described above), which is recorded in hardcopy of any form, must be losslessly transcribed/converted into an appropriate searchable format on to electronic media. In addition, this information

must be properly characterized with appropriate metadata descriptors and then subsequently stored into one of the NEES accepted digital formats to facilitate archiving in accordance with the data, metadata, and formats and policies established by the earthquake engineering community through NEES Consortium, Inc. (http://www.nees.org) and the NEES system integration project (http://www.neesgrid.org).

NEES construction is not funding the development of advanced simulation and visualization tools for earthquake engineering. Rather, researchers are encouraged to pursue other sources of funding within and outside of NSF for such development. NSF funded the NEES Consortium, Inc., in September 2003 to hold a community workshop at the University of Kansas, Lawrence, on December 1-2, 2003, to develop concepts for a computational simulation and visualization environment for NEES (https://www.fastlane.nsf.gov/servlet/showaward?award=0337807).

(3) Promoting Integration of Education and Research and Broader Participation

NEES will lead to a new era of collaboration in earthquake engineering research and education. Teams of experts in the U.S. and around the world will have unprecedented opportunities to jointly plan, conduct, and analyze the results of experiments and models. Easy access to NEES resources will facilitate broad participation—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. The NEES Consortium, Inc., will facilitate the development of formal partnerships within the U.S. and internationally to expand the capabilities of NEES.

As a program of NSF, NEES fosters the integration of research and education and broadens opportunities, encouraging the participation of early career faculty, women, underrepresented minorities, and persons with disabilities. Widespread public interest in earthquake engineering and disaster preparedness makes highly visible national science and engineering initiatives such as NEES a natural vehicle for enhancing earthquake engineering knowledge. NEES enables many avenues for increasing public understanding and awareness of earthquakes through educational programs, such as museum exhibits, community forums, field trips or onsite demonstrations, and Internet-based activities.

NEES provides national resources for developing, coordinating, and sharing new educational programs and curricular materials to train the next generation of the earthquake engineering workforce. The NEES infrastructure has been designed to make it easy for researchers to share their expertise with educators and students, other scientists and engineers, professionals, and the public, often 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 the importance of such research to society and may inspire some of them to become researchers and engineers. To facilitate the use of NEES for integrating research and education, in September 2003

NSF funded the NEES Consortium, Inc., to develop an educational strategic plan for NEES (https://www.fastlane.nsf.gov/servlet/showaward?award=0337808). This project will hold three workshops during FY 2004 to develop the educational strategy. More information about the workshops will be available at http://www.nees.org.

To Learn More About NEES

NEES inaugurates a new generation of earthquake engineering research capabilities in the U.S. and provides a pathway to engage broad participation in research and education by the earthquake engineering community. Partnerships with international facilities and resources will complement and expand the capabilities in the U.S. Ultimately, enhanced understanding of earthquakes and seismic performance made possible by the use of the NEES infrastructure for research and education will lead to innovative, cost-effective measures for better protecting the vast civil and mechanical infrastructure of facilities and services on which we all depend.

Further information about NEES resources and opportunities is available as follows:

- George E. Brown, Jr. Network for Earthquake Engineering Simulation
  http://www.eng.nsf.gov/nees
- NSF Directorate for Engineering, Division of Civil and Mechanical Systems
  http://www.eng.nsf.gov/cms
- NEES Research Solicitation
  http://www.nsf.gov/pubsys/ods/getpub.cfm?nsf03589
- NEES Consortium, Inc.
  http://www.nees.org/
- NEESgrid Network System Integration
  http://www.neesgrid.org/
- NEES Equipment Sites
  - Brigham Young University
    http://nees.crustal.ucsb.edu/
  - Cornell University
    http://nees.cornell.edu/
  - Lehigh University
    http://nees.atlss.lehigh.edu/
  - Oregon State University
    http://nees.orst.edu/
  - Rensselaer Polytechnic Institute
    http://nees.rpi.edu/
  - State University of New York, University at Buffalo
    http://nees.buffalo.edu/
  - University of California, Berkeley
    http://nees.berkeley.edu/
  - University of California, Davis
    http://nees.ucdavis.edu/
  - University of California, Los Angeles

http://www.cee.ucla.edu/nees
- University of California, San Diego
  http://www.structures.ucsd.edu/NEES/
- University of Colorado, Boulder
  http://ceae.colorado.edu/NEES
- University of Illinois, Urbana-Champaign
  http://www.cee.uiuc.edu/research/nees
- University of Minnesota, Twin Cities
  http://nees.umn.edu/
- University of Nevada, Reno
  http://nees.unr.edu/
- University of Texas, Austin
  http://www.geo.utexas.edu/nees