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# LONG-TERM VISION FOR THE U.S. NATIONAL SCIENCE FOUNDATION GEORGE E. BROWN, JR. NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION (NEES)

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## SUMMARY

When operations begin on October 1, 2004, the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) in the U.S. will enable state of the art experimental research approaches that will lead to a better understanding of how civil infrastructure systems respond during an earthquake. NEES will be a world class, shared national network consisting of 15 earthquake engineering experimental facilities, a centralized data repository, an archive of earthquake engineering simulation software, and collaborative and visualization tools, all linked together by high-speed Internet connections and protocols. NEES Consortium, Inc., will operate NEES from October 1, 2004, through September 30, 2014. The Consortium will provide national leadership and act as the focal point for NEES, by managing, operating, and maintaining the NEES experimental facilities and NEESgrid cyberinfrastructure; facilitating and scheduling research projects at the experimental facilities; coordinating training, education, and outreach activities; promoting new technology development; and forming partnerships with facilities, research organizations, and other resources in the U.S. and abroad. The National Science Foundation is implementing a ten-year research program that will utilize the NEES infrastructure to develop new methodologies and technologies for earthquake loss reduction.

## INTRODUCTION

As a result of planning for over a decade by the U.S. earthquake engineering research community, the National Science Foundation (NSF) Directorate for Engineering initiated construction of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) in fiscal year (FY) 2000 to significantly improve the understanding of earthquakes and their effects. 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. The NEES infrastructure is being constructed during FY 2000 – FY 2004 through 18 awards (cooperative agreements) to 15 universities and one nonprofit organization. Table 1 lists all the NEES construction awards. These

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awards are the outcomes of four competitive NSF program solicitations and include 15 experimental facilities, the NEESgrid cyberinfrastructure, and Consortium as discussed below. Information about these awards is available at NEES Consortium, Inc. (Consortium), web site (NEES Consortium [1]). During FY 2005 – FY 2014, the NEES infrastructure will be operated and maintained by NEES Consortium, Inc. Figure 1 shows the long-term schedule for NEES.

**Table 1. Awards Made for NEES Infrastructure Construction during FY 2000 – FY 2004**

| NSF Award | Principal Investigator | Awardee Institution | Project Title |
|---|---|---|---|
| 0086612 | Bruneau, Michel | SUNY at 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 at 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 |

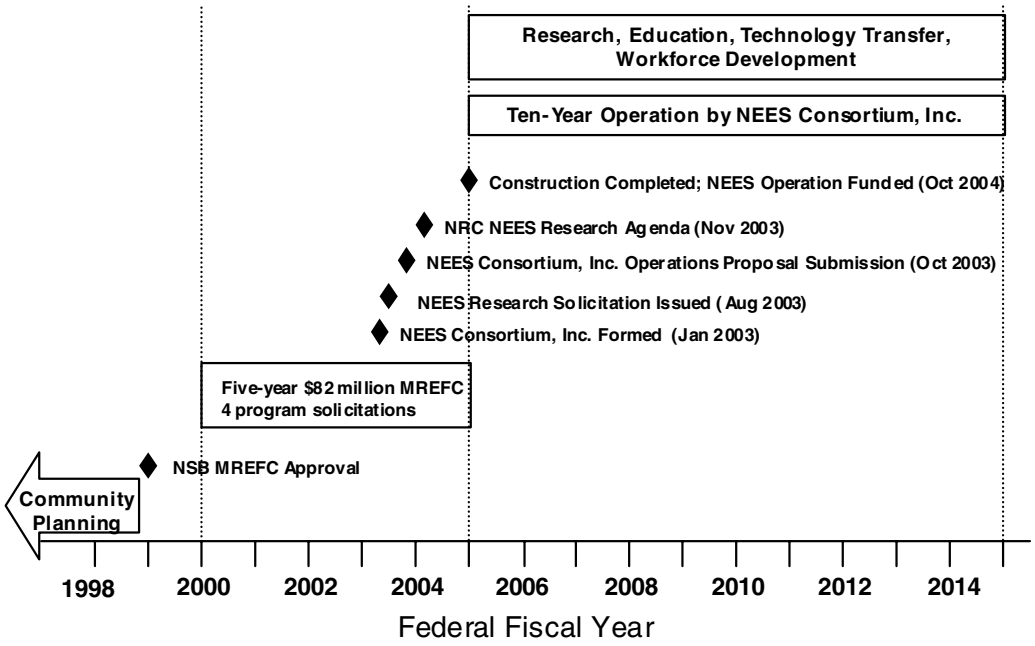



**Figure 1. Schedule for NEES**

## NEES CONSORTIUM, INC.

The NEES infrastructure (15 experimental facilities, NEESgrid cyberinfrastructure, and education, outreach and training activities) will be operated from October 1, 2004, through September 30, 2014, by NEES Consortium, Inc. The Consortium of Universities for Research in Earthquake Engineering (CUREE), under an NSF NEES construction award, led the project to establish the Consortium. The Consortium was formally incorporated as a public-benefit, nonprofit organization in January 2003 (NEES Consortium [1]). The Consortium will be the entity through which NSF provides support for operation of the 15 NEES experimental facilities and the NEESgrid cyberinfrastructure. During the ten-year operations period, the Consortium will:

- Manage NEES resources, including shared use operations at the 15 NEES experimental facilities and the NEESgrid cyberinfrastructure. This includes scheduling experimental research time at the experimental facilities and facilitating planning of research projects by potential proposers to funding agencies.
- Establish policies and procedures for issues such as shared use access, user fees, and reimbursement of operating costs for the NEES experimental facilities, as well as data policies and protocols for the curated data repository.
- Facilitate the integration of NEES resources to form a linked system of experimentation, computation, theory, databases, and model-based simulation.
- Plan, conduct, and coordinate education, outreach, and training activities for the NEES experimental facilities and the broader earthquake engineering community.
- Develop partnerships with other U.S. and international experimental facilities and computational, grid, and visualization programs that can bring unique and complementary capabilities to NEES.

- Explore technological advances to 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 a Board of Directors representing the broad earthquake engineering community. Day-to-day operations will be run by the Consortium's Executive Director. The Consortium membership comprises individual, institutional, and equipment site members. 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 organizational needs: data sharing and archiving; education, outreach and training; finance; information technology; nominations; and site operations.

## NEES SHARED USE EXPERIMENTAL FACILITIES

With support from NSF and institutional and other agency contributions, 15 universities in the U.S. are creating, expanding, or upgrading specialized experimental facilities to be used in earthquake engineering research and education. These 15 NEES experimental facilities, listed in Table 1, include shake tables [one large uniaxial outdoor shake table with a high velocity input pulse, two relocatable six degree of freedom (DOF) shake tables, and three relocatable two 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, mobile structural and geotechnical field testing equipment, and permanently instrumented field sites in southern California. These facilities will overcome many of the past limitations on testing the seismic performance of geomaterials, foundations, structures, nonstructural components, and systems. These shared use facilities may be used on site or remotely by guest researchers through teleobservation and teleoperation. Each experimental facility will have at least Gigabit Ethernet connection to the Internet. A web-based searchable database will provide detailed information about the equipment, sensors, instrumentation, training materials, and personnel at each facility (NEES Consortium [1]).

The NEES experimental facilities, shown in Figures 2 – 6, bring new testing capabilities to the U.S. For example, hybrid methods based on real-time dynamic testing are being developed at several NEES experimental facilities and could lead to more efficient ways of testing critical components. This approach entails physically testing the seismic performance of a critical substructure component while simulating the response of the rest of the structure numerically. Various components representing parts of a large structural system might be tested in different NEES laboratories through distributed experimentation and teleoperations control protocols. 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 fundamental knowledge of how natural and engineered geologic materials; earth structures such as dams, levees, and retaining walls; and soil-foundation-structure systems respond to earthquakes.


**Figure 2. NEES Experimental Facilities (from upper left, clockwise): SUNY Buffalo - Dual Relocatable 6DOF Shake Tables; University of Nevada, Reno – Three Relocatable Biaxial Shake Tables; Oregon State University - Tsunami Wave Basin; and University of California, San Diego – Large High Performance Outdoor Shake Table.**

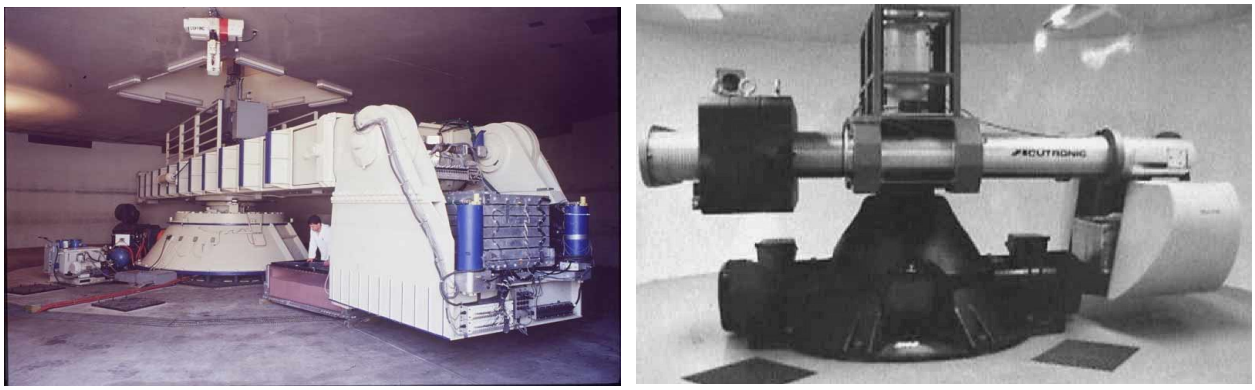


**Figure 3. NEES Experimental Facilities (from left to right): University of California, Davis - Geotechnical Centrifuge; Rensselaer Polytechnic Institute - Geotechnical Centrifuge.**

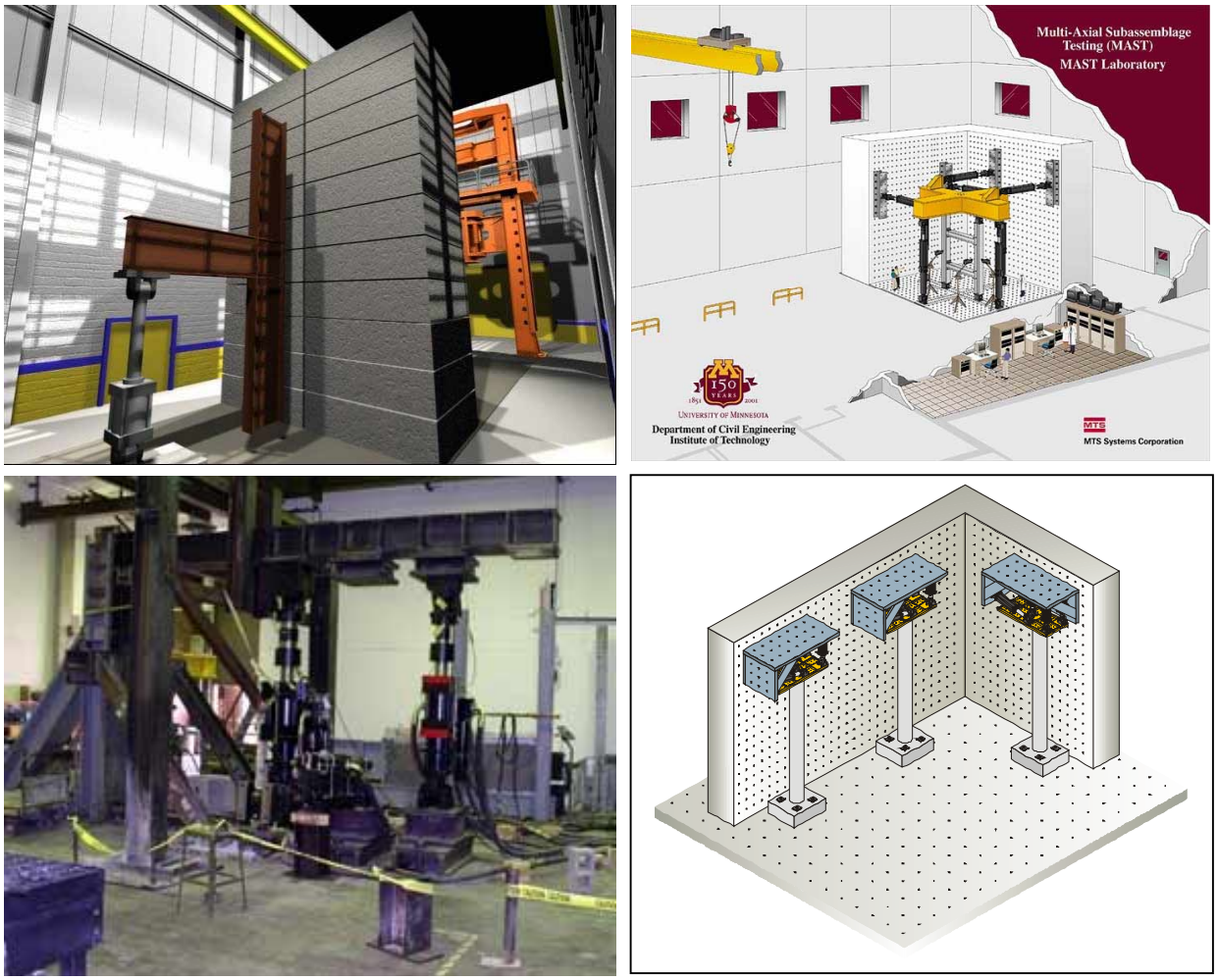



**Figure 4. NEES Experimental Facilities (from upper left, clockwise): University of California, Berkeley - Reconfigurable Reaction Wall; University of Minnesota - Multi-Axial Subassemblage Testing Facility; University of Illinois at Urbana-Champaign - Multi-Axial Full-scale Sub-Structuring Testing and Simulation Facility; and University of Colorado, Boulder - Fast Hybrid Testing Platform.**

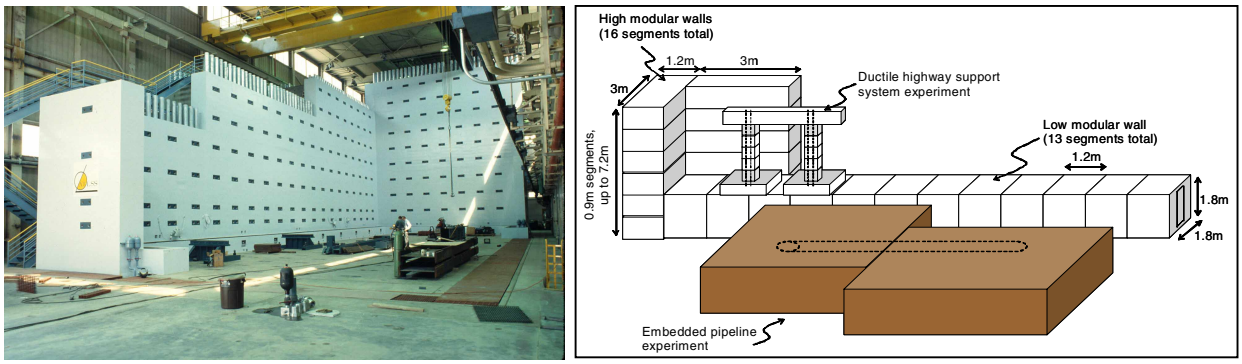
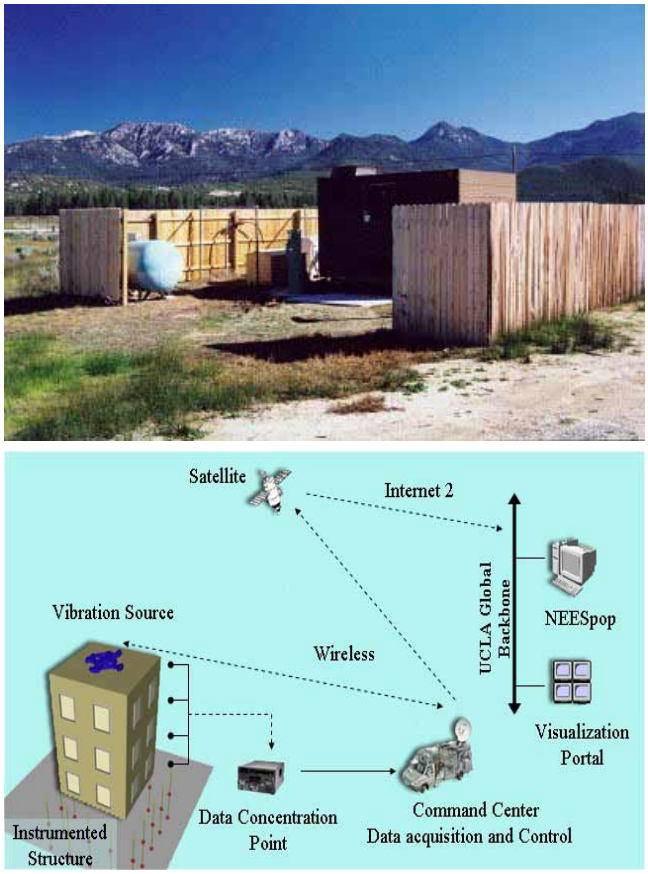



**Figure 5. NEES Experimental Facilities (from left to right): Lehigh University - Multi-directional Reaction Wall Facility; Cornell University - Lifeline Testing Facility.**



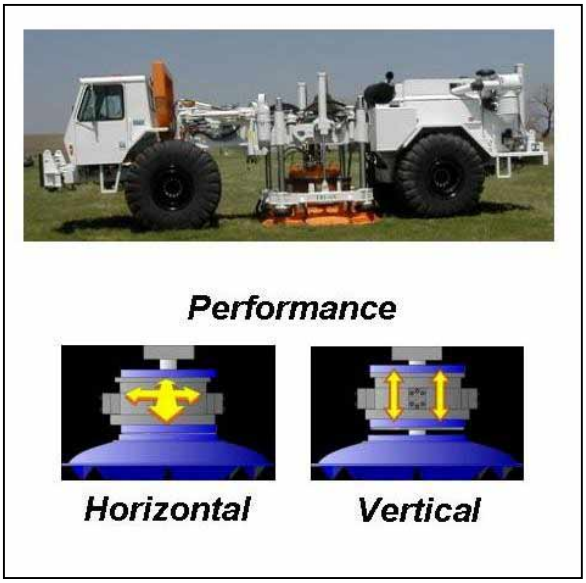




**Figure 6. NEES Experimental Facilities (from upper left, clockwise): Brigham Young University - Permanently Instrumented Field Sites and Soil-Foundation-Structure Test Structure; University of Texas at Austin - Geotechnical Fielding Testing Equipment; University of California, Los Angeles - Structural Field Testing Equipment.**

## NEESGRID CYBERINFRASTRUCTURE

NEES forges new ground in merging a domain (earthquake engineering) with cutting edge grid-based cyberinfrastructure tools and services. The NEESgrid cyberinfrastructure (NEESgrid [2]) is a pioneering effort within the U.S. to develop and operate an integrated system of state of the art computing, communications, information, and experimental (equipment, instruments, sensors, and measurement devices) resources, tools, and services designed to advance earthquake engineering research and education. NEESgrid builds upon the existing U.S. Internet network, National Middleware Initiative (NMI) software and grid framework (NMI [3]), Globus toolkit (Globus, [4]), and the CompreHensive collaborativE Framework (CHEF) (CHEF [5]). The result will be a layered, modular architecture, shown in Figure 7, which allows the NEESgrid system to be adapted during the ten-year operation of NEES to accommodate new applications, services, user requirements, 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, in partnership with Argonne National Laboratory, Mississippi State University, Pacific Northwest National Laboratory, University of California at Berkeley, University of Michigan, University of Southern California, and Washington University.

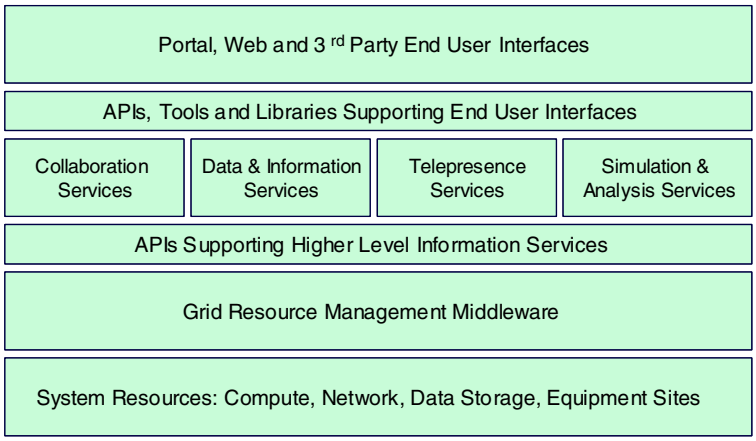



**Figure 7. NEESgrid Architecture**

The NEESgrid cyberinfrastructure networks the 15 earthquake engineering experimental research facilities and is designed to promote the integration of physical testing at the experimental facilities with simulation and visualization. As such, NEES will transform the environment for earthquake engineering research and education through collaborative and integrated experimentation, computation, theory, databases, and model-based simulation to develop new fundamental knowledge in earthquake engineering, seismic design methodologies, mitigation technologies, and computational tools. NEESgrid will facilitate remote participation in experiments by faculty and students at institutions that do not have experimental facilities of their own.

NEESgrid will enable researchers to develop more comprehensive computational and visualization tools for modeling the response of the built and natural environment to earthquakes by providing Internet/grid-based resources that include the following (NEESgrid [6]):

- *Telepresence technologies.* Researchers, engineers, and students without direct access to specialized experimental facilities can remotely observe (teleobserve) and teleoperate experiments. Through the NEESgrid Teleoperations Control Protocol (Pearlman et al. [7]), researchers can conduct distributed experimentation across the NEES experimental facilities.
- *Centralized data***.** Experimental data and protocols, analytical results, models, and other information will be stored in a curated central data repository. Standard data and metadata formatting and information exchange protocols will facilitate data integration and access. The Consortium is establishing a data sharing policy that will include the timing for the public release of data in the repository. 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. The NEESgrid computational infrastructure incorporates the open source Open System for Earthquake Engineering Simulation (OpenSees) software currently being developed by the NSF-funded Pacific Earthquake Engineering Research (PEER) center headed by the University of California, Berkeley (PEER [8]), and FedeasLab.
- *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.

Information about NEESgrid software capabilities and release dates, software downloads, project schedule, workshops, and technical reports is available at NEESgrid [2].

## NEW RESEARCH CAPABILITIES PROVIDED BY NEES

The ultimate goal of NEES is to reduce earthquake losses in the U.S. through improved seismic design and performance of civil infrastructure systems through the new discoveries, methodologies, and technologies enabled by NEES. 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 research 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 (National Research Council [9]). In addition, the Earthquake Engineering Research Institute published a research and outreach plan for earthquake engineering (EERI [10]). NEES provides resources to integrate experimentation, computation, theory, databases, and model-based simulation. To facilitate this integration, a workshop was recently held at the University of Kansas in December 2003 to discuss advanced computational needs for NEES (NEES Consortium [11]).

NEES research will provide the foundation for the development of new technologies and methodologies 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 for 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;
- Advanced 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.

## NSF NEES RESEARCH PROGRAM

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 (NSF [12]). Research projects funded under this solicitation must make use of one or more of the 15 NEES experimental facilities operated by the Consortium. Each NEES experimental facility has allocated shared use time as well as personnel to help guest users with research planning and the conduct of experiments.

Users may use the experimental facilities either on site or through the remote capabilities provided by the facility. Research will be funded under this solicitation as follows:

- Individual Investigator (II) awards to individuals and small research teams to address a significant problem in earthquake engineering.
- Small Group (SG) awards to multidisciplinary, and preferably multi-organizational, teams of researchers to address a significant problem in earthquake engineering requiring extensive use of the NEES experimental facilities.
- Grand Challenge (GC) awards to 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 experimental facilities.

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 U.S. 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 NSF Small Grants for Exploratory Research (SGER) program.

The focus of the SG and GC awards is to conduct multidisciplinary research to address a significant problem related to seismic risk. It is anticipated that this multidisciplinary research will reach into other disciplines such as social sciences. To achieve goal of earthquake loss reduction, it is important that public policies be developed based on the outcomes of NEES research. To translate the research into public policy is an arduous process and it is recommended that public policymakers/influencers be brought into these projects at the initial planning stages (proposal stage) to incorporate the social science discipline into the design of research problems.

For NSF-funded NEESR projects, access to and scheduling and announcing of experiments at the NEES experimental facilities will be coordinated by the Consortium. As it becomes available, information about the use of NEES resources, i.e., the evolving policies on the shared use of the NEES experimental facilities, sharing of data, and the evolving formats for data, metadata, and E-Notebooks, can be found at NEES Consortium [1] and NEESgrid [2]. 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 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 established data and metadata formats and policies. NSF encourages international participation on NEESR projects since the NEESgrid cyberinfrastructure, which will be used for all experimental set-ups, easily facilitates collaborative teams through its grid-based Internet resources and tools.

## EDUCATION, OUTREACH, AND TRAINING

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 Consortium to develop an educational strategic plan for NEES (NEES Consortium [13]). This project will hold three workshops during FY 2004 to develop an educational strategy. More information about this award and the education workshops are available at NEES Consortium [13] and Anagnos and Frante [14].

## INTERNATIONAL PARTNERSHIPS

NEES leads 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 as shown in Figure 8—by many communities of users, including researchers, educators and students, engineers, government agencies, professional organizations, industry, and disaster preparedness and response teams. The Consortium will facilitate the development of formal partnerships within the U.S. and internationally to expand the capabilities of NEES. Through the CHEF framework, NEESgrid provides the tools needed for teams around the world to collaborate, plan and conduct experiments, and share and archive experimental and analytical results. As in the U.S., many countries are now undergoing grid-based, e-science initiatives that will enable NEESgrid to be adapted for use world-wide. The Consortium was recently funded by NSF to hold a world summit on collaborative NEES research opportunities for NEES international collaboration (NEES Consortium [15]).

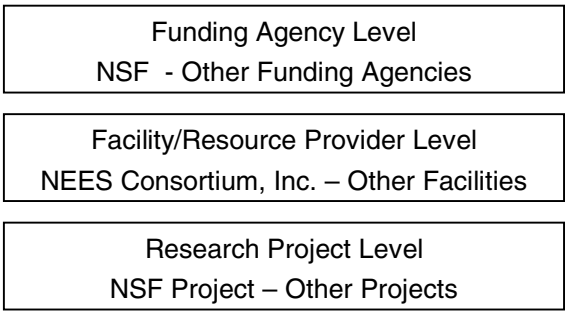



**Figure 8. Potential NEES Partnerships**

## CONCLUSIONS

NEES inaugurates a new, world-class generation of earthquake engineering experimental 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 other national and international facilities, organizations, and resources will complement and expand the capabilities in the U.S. Ultimately, enhanced understanding of earthquakes and seismic performance of the built environment made possible by the use of NEES for research and education will lead to innovative, cost-effective measures for better protecting the vast civil infrastructure of facilities and services on which citizenry in the U.S. and around the world depend.

## ACKNOWLEDGMENTS

The authors acknowledge the graphics and photos provided by the NEES Principal Investigators and from the NEES experimental facilities web sites (links to web sites are provided at NEES Consortium [1]).

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