A

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

In 2001, the National Science Foundation (NSF) announced a major research equipment (MRE) award for the George E. Brown, Jr., Network for Earthquake Engineering Simulation (NEES). This MRE, the first to be funded under the NSF engineering directorate, is intended to "provide a national resource that will shift the emphasis of earthquake engineering research from its current reliance on physical testing to integrated experimentation, computation, theory, databases, and model-based simulation" (from the NSF Web site "About NEES").

The award is divided into three main components: (1) consortium development, (2) system integration, and (3) equipment, with the last mentioned including two phases of awards (see Table A.1). These three components will work together to form a national earthquake engineering research collaboratory through which researchers will share data and have access to equipment at remote sites. The three award areas total more than $80 million. The collaboratory is mandated to be operational by September 30, 2004, with an initial 10-year research plan.

TABLE A.1 Summary of NEES Awards

Principal Investigator(s)	Goal(s)/Title	Award Amount (in dollars)
Task/Consortium Development		
Robert Reitherman, Stephen Mahin, Robert Nigbor, Cherri Pancake, Sharon Wood	To develop the NEES Consortium and its 10-year (2004-2014) plan for managing NEES	1,999,907
Task/System Integration		
Thomas Prudhomme, Jean-Pierre Bardet, Ian Foster, Carl Kesselman	To design, develop, implement, test, and make operational the Internet-based, national-scale high-performance network system for NEES, called the NEESgrid.	10,000,000
Task/Phase I Equipment		
Michel Bruneau, State University of New York at Buffalo	Versatile High Performance Shake Tables Facility Towards Real-Time Hybrid Seismic Testing	6,160,785
Michel Bruneau, State University of New York at Buffalo	Large-scale High Performance Testing Facility Towards Real-Time Hybrid Seismic Testing	4,379,865
Ian Buckle, University of Nevada Reno	Development of a Biaxial Multiple Shake Table Research Facility	4,398,450

Ricardo Dobry, Rensselaer Polytechnic Institute	Upgrading, Development, and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer's 100 gton Geotechnical Centrifuge	2,380,579
Catherine French, University of Minnesota, Twin Cities	System for Multiaxial Subassemblage Testing	6,472,049
Bruce Kutter, University of California, Davis	NEES Geotechnical Centrifuge Facility	4,614,294
Jack Moehle, University of California, Berkeley	Reconfigurable Reaction Wall-based Earthquake Simulator Facility	4,268,323
P. Benson Shing, University of Colorado, Boulder	Fast Hybrid Test Platform for the Seismic Performance Evaluation of Structural Systems	1,983,553
Kenneth Stokoe, University of Texas, Austin	Large-Scale Mobile Shakers and Associated Instrumentation for Dynamic Field Studies of Geotechnical and Structural Systems	2,937,036
John Wallace, University of California, Los Angeles	Field Testing and Monitoring of Structural Performance	2,652,761
Solomon Yim, Oregon State University	Upgrading Oregon State's Multidirectional Wave Basin for Remote Tsunami Research	4,775,832
Task/Phase II Equipment		
T. Leslie Youd, Brigham Young University	Permanently Instrumented Field Sites for Study of Soil-Foundation-Structure Interaction	1,944,423
Harry Stewart, Cornell University	Large Displacement Soil-Structure Interaction Facility for Lifeline Systems	2,072,716
James Ricles, Lehigh University	Real-Time Multidirectional Testing Facility for Seismic Performance Simulation of Large-Scale Structural Systems	2,593,317
Frieder Seible, University of California, San Diego	Large High Performance Outdoor Shake Table Facility	5,890,000
Amr Elnashai, University of Illinois, Urbana-Champaign	Multiaxial Full-scale Substructure Testing and Simulation Facility	2,958,011
TOTAL		72,481,901

SOURCE: National Science Foundation

CONSORTIUM DEVELOPMENT

The Consortium Development group is charged with developing and establishing the NEES Consortium and a 10-year (2004-2014) plan for managing NEES. The objectives of the Consortium Development group are threefold:

- To obtain community input and consensus on NEES structure and governance,
- To obtain community input and consensus needed for NEES system integration, and
- To coordinate outreach and training for the NEES equipment sites.

These objectives will be accomplished through activities such as national and regional workshops and interaction on the NEES Web site, http://www.nees.org. The group will prepare annual reports and a final summary report (September 30, 2004) to assess community reactions, visibility, and the performance of the executive council.

SYSTEM INTEGRATION

The System Integration group will design, develop, implement, test, and make operational the Internet-based, national-scale high-performance network system, NEESgrid.

EQUIPMENT SITES

Sixteen projects at 15 different institutions throughout the United States were funded with NEES equipment awards for Phases I and II (see Table A.1). A brief description of each project follows.[1]

Phase I Awards

Versatile High Performance Shake Tables Facility towards Real-Time Hybrid Seismic Testing, University at Buffalo, State University of New York (SUNY) and Large-Scale High Performance Testing Facility Towards Real-time Hybrid Seismic Testing, State University of New York at Buffalo

These two projects will result in a versatile research facility, which will have two shake tables with 6 degrees of freedom. The tables will be able to contain specimens as long as 120 meters and up to 100 metric tons. Large-scale, high-performance actuators will provide immediate capabilities for dynamic testing and pseudodynamic testing as well as the platform needed for the development of new testing methodologies. In addition, the tables will be operated with equipment such as high-capacity, high-performance hydraulic supply and distribution systems and will be networked for teleexperimentation capabilities.

---

[1] Information on the 16 equipment sites is summarized from the NEES Web site, http://www.nees.org.

Development of a Biaxial Multiple Shake Table Research Facility, University of Nevada, Reno

This project will upgrade and expand the existing facilities at the University of Nevada, Reno. The two existing tables and a third new table will have the following specifications:

- 14-ft^2, 50-ton payload capability and 24-in. peak-to-peak stroke in the horizontal plane;
- Mounted on the strong floor of the hi-bay Structures Laboratory; and
- Relocatable so that a variety of table configurations may be assembled to meet present and future research needs.

In addition, it will be possible to operate the tables independently, in phase, or differentially. The facility will be telecapable, connected to the Internet-2 network for remote participation (allowing both teleobservation and teleoperation).

Upgrading, Development, and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer's 100 Gton Geotechnical Centrifuge

The upgraded centrifuge will include the following:

- A two-dimensional (2-D) in-flight earthquake shaker (two prototype components) and associated 2-D laminar box container for more realistic 2-D modeling,
- A 4 degrees-of-freedom robot capable of performing in-flight operations,
- A networked data acquisition system with Internet teleobservation and teleoperation,
- Two high-speed cameras and image-processing software,
- New-generation sensors with better resolution of the measured model response, and
- Other equipment for increasing the capabilities of the centrifuge.

A System for Multi-axial Subassemblage Testing (MAST), University of Minnesota, Twin Cities

The MAST system will link large-scale testing of structures with three-dimensional nonlinear analyses of structural components and systems. The system will allow multi-axial cyclic and pseudo-dynamic tests of large-scale structural subassemblages. The equipment will include the following:

- High-performance actuators,
- Cross heads,
- A digital controller with 6 degrees of freedom,
- A hydraulic distribution system, and
- An L-shaped reaction wall system for lateral load resistance for the horizontal actuators.

With this system, a full 6 degrees-of-freedom loading condition can be imposed on test structures. In addition, the MAST system will have teleobservation and teleoperation capabilities.

A NEES Geotechnical Centrifuge Facility, University of California, Davis

This facility will be upgraded to include the following:

- Modification to enable operation up to 80 g;
- Upgrades to the existing horizontal shaker;
- One large hinged-plate container;
- One biaxial horizontal-vertical shaker;
- One 4 degree-of-freedom robot, robot tools, and associated software, capable of installing and/or operating test devices;
- Networked data acquisition systems with tele-operation and tele-observation capability;
- Data visualization capabilities with a high-resolution projection system;
- Ten strands of 20 dual-axis digital MEMS accelerometers; and
- Topographic imaging and geophysical testing tools and methodologies.

Reconfigurable Reaction-Wall-Based Earthquake Simulator Facility, University of California, Berkeley

The facility will be designed to support the development of a new generation of hybrid testing methods and will leverage the capabilities of existing facilities at the university. The existing equipment includes a strong floor, a 4-million-pound Southwork-Emery Universal testing machine, and hydraulic oil pumps and piping. The new equipment includes the following:

- Advanced Hybrid Testing System (dynamic and static actuator assemblies, hydraulic distribution systems, high-performance accumulation system, digital control system with real-time hybrid control package and integrated data acquisition channels),
- Advanced 128- channel data acquisition system,
- Reconfigurable reaction wall with 13 3-ft reinforced concrete blocks and post-tensioning bars,
- Digital teleobservation equipment,
- Mobile robot avatar,
- Specimen instrumentation, and
- Local network equipment.

Fast Hybrid Test Platform for the Seismic Performance Evaluation of Structural Systems, University of Colorado, Boulder

The facility will incorporate high-speed actuators, a digital controller, a data acquisition system, computers, and simulation software for full-size and large-scale models of wall, columns, frames, and subassemblies under hybrid testing. Load rates will be between 10 and 100 percent of that experienced during an earthquake, which is higher than the capabilities currently available in pseudodynamic tests. The system will include the following:

- One new, high-speed actuator;

- Upgrades to two existing actuators;
- High-performance digital servocontroller with three control channels and three-variable control capability;
- High-speed data acquisition;
- Three digital displacement transducers;
- Ten analog displacement transducers;
- Three accelerometers with frequency range up to 500 Hz;
- Three computers for numerical simulation, data processing, and data display/tele-observation,
- Expansion of existing data acquisition system; and
- Equipment for teleobservation and teleoperation.

Large-Scale Mobile Shakers and Associated Instrumentation for Dynamic Field Studies of Geotechnical and Structural Systems, University of Texas, Austin

For this project, field equipment will be developed, including the following:

- A large triaxial mobile shaker and associated transportation vehicle;
- Two stand-alone, three-dimensional cubical shakers on a support trailer;
- An instrumentation van with electrical generators;
- Field instrumentation; and
- Tele-participation equipment.

This coordinated set of equipment will be used to generate large dynamic forces over a wide range of frequencies, while simultaneously measuring the appropriate response parameters with sensors. The equipment will be mobile and self-supporting and will be designed to test geotechnical systems (rock, soil, basins, earth dams, landfills) as well as foundations and structural systems.

Field Testing and Monitoring of Structural Performance, University of California, Los Angeles

This project will result in a mobile field laboratory for forced-vibration testing and earthquake-aftershock monitoring of full-scale structures. The equipment included in this field laboratory is as follows:

- Four forced-vibration sources:
  —One omnidirectional eccentric mass vibrator with maximum force of 10 to 20 kips (1000-lb loads) having continuous to intermittent operation and a frequency range of 0.1 to 4.2 Hz;
  —Two unidirectional eccentric mass vibrators with maximum force of 100 kips and a frequency range of 0 to 25 Hz;
  —One linear inertial shaker with maximum force of 5 kips and programmable arbitrary force (or acceleration) time history over a frequency range of 0 to 60 Hz;
- A wireless sensor and data acquisition system;

- A cone penetration truck with a seismic piezocone, 20-ton hydraulic push capacity, side augers, and in situ soil vibration sensors; and
- Networking equipment for real-time data acquisition, processing, and broadcasting.

Upgrading Oregon State University's Multidirectional Wave Basin for Remote Tsunami Research

This project will upgrade Oregon State University's multidirectional wave basin for tsunami research. After construction, the basin will be 48.8 m long, 26.5 m wide, and 2 m deep. A directional wave generator to be located at one end will be composed of 29 independent vertical bulkhead wave generator segments, each 0.91 m wide and 2 m high, moving as a piston capable of a 2.07-m maximum displacement with a maximum velocity of 1.87 m/s. The segments can be programmed to move together to produce long-crested, nonlinear, transient translatory long waves approaching the opposite end of the basin with the crest line perpendicular or oblique to the basin sidewalls.

The following data acquisitions systems and instrumentation will be available for tsunami research:

<u>Data Acquisition Systems</u>

- A new data acquisition system is being assembled for the tsunami basin. At this time the system consists of a National Instruments PCI-6071E 64 channel data acquisition card, its host Dell computer, and 16 channels of Rockland Model 432 filters, which are used as anti-aliasing filters.
- A 16-channel IO Tech Wave Book 512 provides portable data acquisition for less data-intense experiments. Antialiasing filters are the Rockland 432 filters presently being used by the tsunami basin data acquisition system. This system uses simple IO Tech data acquisition software and is easy for students to configure and use.

<u>Instrumentation</u>

Wave gauges. Sixteen channels of differentially driven resistive wave gauges will be available for use in the laboratory's basins. The signal conditioning units for these gauges allows for the length of the wave probes (and hence their range) to be scaled from 1 to 20 feet.

Current meters. Three Sensordata Minilab SD-12 three axis acoustic doppler current meters are used to make velocity measurements in the three basins of the wave laboratory.

Strain gauge signal conditioners. Twenty channels of Vishay 2100 system strain gauge signal conditioning are available. These provide signal conditioning for force transducers and pressure gauges at the Wave Research Laboratory.

Pressure transducers. Ten Druck model PDCR 10 pressure gauges (5 psi range) are available.

Force transducers. Force transducers are generally experiment specific. Therefore, they are usually designed and fabricated onsite for a given experiment. The Wave Research Laboratory has a large number of previously constructed force gauges available.

String potentiometers. The Wave Research Laboratory has a number of UniMeasure string potentiometers for the measurement of displacement. Eight units with a range of 75 inches are available. An additional 75-in. unit with a built-in velocity sensor is available. A unit with an 800-in. range and a velocity sensor is available. Signal conditioners exist for all units.

Phase II Awards

Permanently Instrumented Field Sites for Study of Soil-Foundation-Structure Interaction, Brigham Young University

The project will augment and upgrade the instrumentation of two field sites with state-of-the-art technology for the study of dynamic ground response, deformation, and the resulting structural response, from both active shaking experiments and local and regional earthquake excitation of the sites. The two sites are the Garner Valley Array and the Salton Sea Wildlife Refuge Liquefaction Array. Previously these two sites focused on the dynamic response of soils under seismic input by the monitoring of ground motion and pore water pressure response. Both sites, which are located adjacent to major southern California faults, have a previous history of recording ground motions from local and regional earthquakes and have been extremely well characterized. At Garner Valley, a structure will be built with sensors embedded in the soil, foundation and building, and a shaker will be installed for active excitation experiments. At Salton Sea, there will be modernization and enhancement of existing equipment and the installation of a surface pad for mounting active shakers.

Large-Displacement Soil-Structure Interaction Facility for Lifeline Systems, Cornell University

This project, which is a partnership with Rensselaer Polytechnic Institute, will utilize advanced experimental facilities to simulate, at both centrifuge scale and full scale, capabilities for testing, evaluation, and analysis of soil-structure interaction in critical lifeline facilities. Full-scale testing will be supplemented with centrifuge experimental models, and analytical/numerical simulations will be used to expand the scope of the testing, as well as to investigate parameter sensitivity and to identify possible unforeseen effects prior to full-scale tests. Equipment at Cornell will consist of upgrades to the existing servo-hydraulic system for large geotechnical and structural testing of lifeline systems, including

- A hydraulic distribution system with one 190-L/min three-station hydraulic service manifold and three one-station manifolds, each with 115-V controls and a 1-L accumulator;
- Electronic control systems and controllers;

- Two large-stroke hydraulic structural actuators with load capacities of 295-kN tension to 500-kN compression with strokes of ±0.91m,
- One large-stroke hydraulic structural actuator with load capacities of 445-kN tension to 650-kN compression with a stroke of ±0.64 m;
- One 227L/min, 21-megapascal (MPa) hydraulic pump; and
- Friction grips for use in cyclic testing of advanced composites used in lifeline retrofit and design.

In addition, a modular reaction wall will be designed, constructed, and installed to accommodate the actuators used for large-scale physical models of the reinforced composite materials used in bridge structures.

Real-Time Multidirectional Testing Facility for Seismic Performance Simulation of Large-Scale Structural Systems, Lehigh University

For this project, Lehigh University will design, construct, install, commission, and operate a real-time multidirectional testing facility for seismic performance simulation of large-scale structural systems. The equipment will be installed at the Advanced Technology for Large Structural Systems Engineering Research Center and will make use of the existing strong floor (372 m^2 in surface area), the existing multidirectional reaction wall (15.2 m tall at one end and stepping down incrementally over a distance of 32 m from 12.2 m to 9.1 m to 6.1 m), an existing mechanical testing laboratory, existing hydraulic systems, and existing static actuators. The following equipment is provided under this award:

- Two 2,050-kN dynamic actuators ported for three 400g/min servovalves, ±500-mm stroke;
- Three 1,500-kN dynamic actuators ported for three 400g/min servovalves, ±500 mm stroke;
- Ten 400-gpm high-flow-rate servovalves;
- Hydraulic distribution lines and service manifolds;
- Surge tank and accumulators that will enable strong ground motion effects to be sustained for more than 30 seconds;
- Hydraulic system modifications;
- Digital eight-channel control system with real-time hybrid control packages;
- Digital video teleobservation system including a system of digital high-quality video cameras, network video cameras, a digital video server, a data server, a restricted access Web server, and a public access Web server;
- High-speed 256-channel data acquisition system; and
- Advanced sensors that include wireless MEMS-based accelerometers, piezoelectric transducers (strain and acceleration measurement), and fiber-optic strain gages.

The experimental facility will allow for multidirectional real-time seismic testing, combined with real-time analytical simulations, for investigation of the seismic behavior of large-scale structural components, structural subassemblages, and superassemblages (systems) through the combined use of the dynamic actuators, reaction wall, and strong floor. The experimental facility is also designed to support the development of new hybrid testing methods for multidirectional real-time testing of large-scale structures, including hybrid testing of multiple substructures, where the substructures involved are at different geographic locations connected by the NEES network.

Large High-Performance Outdoor Shake Table Facility, University of California, San Diego

This project establishes a NEES large high-performance outdoor shake table, which will be 7.6 m wide by 12.2 m long and have a single (horizontal) degree-of-freedom system. The table will have the following capabilities:

- A peak horizontal velocity of 1.8 m/s,
- Maximum stroke of ±0.75 m,
- Maximum gravity (vertical) payload of 200 MN,
- Maximum overturning moment of 50 MN·m,
- Force capacity of actuators of 6.8 MN, and
- A frequency bandwidth from 0 to 20 Hz.

The major equipment for this facility will include servocontrolled, dynamically rated actuators with large servo valves, a large power supply, a vertical load/overturning moment bearing system, a digital three-variable, real-time controller, concrete foundation and reaction mass, and a weatherproofing system. The facility will be the only outdoor shake table in the United States and will enable large- to full-scale testing of structural systems and soil-foundation-structure interaction. These tests will be useful under conditions that cannot be readily extrapolated from testing at a smaller scale and for quasi-static or pseudodynamic test conditions, as well as for testing large-scale systems to observe their response under near-source ground motion.

Multiaxial Full-Scale Substructuring Testing and Simulation Facility, University of Illinois, Urbana-Champaign

This project, whose acronym is MUST-SIM, is planned to allow testing of full-scale structures or parts of structures, including foundations and soil mass, while simulating the remaining parts. The primary objective of the proposed effort will be to create a facility in which a full-scale subassembly can be subjected to complex loading and imposed deformation states at multiple connection points on the subassembly, including the connection between the structure and its foundation. The proposed Multiaxial Full-Scale Substructuring Testing-Simulation facility has the following components:

- Six-degrees-of-freedom load and position control at three connection points,
- System modularity to allow for easy expansion, and low-cost maintenance and operation;
- Multiple dense arrays of noncontact measurement devices;
- T-section strong wall creating two testing compartments, each providing support in three loading planes; and
- Advanced visualization and data-mining capabilities for integrated teleoperation and teleobservation.

The proposed MUST-SIM facility will develop modular, 6-degrees-of-freedom loading and boundary condition boxes, which will allow for precise application of complex load and boundary conditions. The boxes, which will be 3.5 m x 1.5 m x 1.5 m and will house six actuators each, will be able to impose motions on the test structures to be determined from the results of concurrently running numerical models of the test specimen and the surrounding structure-foundation-soil system employing pseudodynamic testing methods. Dense arrays of state-of-the-art, noncontact instrumentation will allow near-real-time model updating for the model-based simulation.