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Development of the Network for Earthquake Engineering Simulation

R. K. Reitherman

Consortium of Universities for Research in Earthquake Engineering, Richmond, California, USA

ABSTRACT: The Engineering Directorate of the National Science Foundation (NSF) of the United States has initiated a major program designed to advance earthquake engineering by infusing it with recent developments in information technology (IT). The program is the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). The components of NEES are currently under development and are scheduled for completion in the fall of 2004 to be ready for NEES Collaboratory research. "Collaboratory" is a term derived from "collaborative" and "laboratory" that describes how researchers, whether they are conducting experimental or simulation investigations, can use information technology tools to work at the same time on the same research project even though they are not located in the same physical laboratory. NEES is planned to be operational from 2004 through 2014. Further information on NEES is available at http://www.nees.org./.

1. AN OVERVIEW OF THE NETWORK FOR EARTHQUAKE ENGINEERING SIMULATION (NEES)

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a Major Research Equipment and Facilities Construction program of the Engineering Directorate of the US National Science Foundation (NSF). In brief, NEES is the flagship effort of NSF to synthesize recent information technology (IT) advancements with civil engineering, using earthquake engineering as an opportune discipline offering pre-existing research capabilities as well as the potential to reduce losses from a significant hazard. During the developmental period of NEES (2000-2004), $82 million is being spent on three kinds of projects:

- System Integration, to provide the networking and data repository functions;
- Consortium Development, to put in place an organizational capability;
- Equipment Sites, to build or enhance engineering laboratories located at 15 universities.

An international component to this NSF-funded program has been envisaged, with issues such as networking protocols already being tackled. As of this writing, it is likely that an international workshop will be held to explore how data sharing and other activities planned within NEES could find internaional collaboration partners.

The National Science Foundation began planning for the enhancement of earthquake engineering experimental facilities in the United States several decades ago, including the influential EERI study on Experimental Research Needs (EERI, 1984), and the related 1995 updated recommendations (Abrams, et al., 1995). The specific plans for the development of NEES, however, which date from the late 1990s, introduced several key new features. This new vision, captured in phrases such as the term used to describe NEES in 1998, "Network for High-Performance Seismic Simulation," or the term "cybersystem" (Bordogna, 1999), was articulated by then-Assistant Director for Engineering of NSF, Eugene Wong: "We believe that this utilization of advanced IT will enable the earthquake engineering research field to move from a reliance on physical testing to model-based simulation." The reference to "this utilization of advanced IT" meant that "despite their geographic dispersion, the various components of NEES will be interconnected with a computer network, allowing for remote access, the sharing of information, and collaborative research." (Wong, 1999) Three new features of NEES stand

1. The research strategy takes advantage of information technology advances;

2. The priority placed on simulation is elevated, with the value of experimental research being an essential tool for developing improved structural, geotechnical, and tsunami modeling;

3. A collaboratory model for NEES research will be implemented for the first time in the earthquake engineering field.

The priority placed on simulation is indicated by the importance placed on all aspects of the data to be produced by NEES and other experimental sites: sharing, archiving and curating of data (the latter connoting a more active process of organizing data, labeling it with metadata, and exercising a quality control role), and providing data in ways that facilitate simulation. For example, providing data so rapidly to model-based simulation researchers that computational results can in turn affect experimental operations as they are in progress is a concept well beyond common present practice of conducting an experiment and, some months later, producing models and computer algorithms that other researchers can use. Another distinguishing feature that NSF program managers have made a strong character trait of NEES is that it will function as a collaboratory. A collaboratory is a network-enabled "…'center without walls' in which the nation's researchers can perform their research without regard to geographical location, interacting with colleagues, accessing instrumentation, sharing data and computational resources, and accessing information in digital libraries." (National Research Council, 1993). A draft version of White Paper: Towards a Vision for the NEES Collaboratory is available as of this writing for public comment. (nees.org, 2002)

2. SYSTEM INTEGRATION

In 2001, the NSF awarded the System Integration project to the National Center for Supercomputing Applications (NCSA) at the University of Illinois at Urbana-Champaign (NEESgrid.org, 2001). The System Integration project, headed by principal investigator Dan Reed, is implementing NEESgrid to link the NEES Equipment Sites together, designing a curated data repository, providing access to advanced computational resources for simulation studies by earthquake engineering researchers, and providing other IT infrastructure features needed to enable collaboratory research. The System Integration Project team consists largely of information technology experts at NCSA as well as University of Southern California Information Sciences Institute, Argonne National Laboratory, and the University of Michigan School of Information. Further information is available via the World Wide Web at: http://www.neesgrid.org/.

3. CONSORTIUM DEVELOPMENT

The task of developing the NEES Consortium that will provide leadership and coordination for NEES activities was assigned by NSF to CUREE, the Consortium of Universities for Research in Earthquake Engineering. The author is the PI of the project, and the Co-PI's are Stephen Mahin, Robert Nigbor, Cherri Pancake, and Sharon Wood. This new consortium will receive the maintenance and operation funds for the Equipment Sites (NEES-funded laboratories at 15 universities—see below). The Consortium must verify that these funds are being allocated to the laboratories in proportion to the degree to which the facilities are shared, and enhanced sharing of data is another function the Consortium will facilitate. A draft Outline of the NEES Consortium in the process of being posted at http://www.nees.org/ as of the time of this writing.

4. EQUIPMENT SITES (NSF-FUNDED NEES ENGINEERING LABORATORIES)

The following brief summaries of 16 NEES Equipment Sites at 15 universities provide the reader with information concerning their capabilities for conducting research once these facilities are operational in 2004 (CUREE, 2001). (PI is used as the abbreviation for principal investigator in the following.)

The descriptions are arranged in order of: shake tables; geotechnical centrifuges; tsunami experimentation; large-scale structural experimentation; and mobile laboratories. A unique aspect of all of these facilities is that they are intended for shared use, allowing off-site researchers to conduct research via features for teleoperation and teleobservation as well as in person.

4.1 University at Buffalo, SUNY –Michel Bruneau, PI; http://civil.eng.buffalo.edu/seesl/

At the University at Buffalo's Structural Engineering and Earthquake Simulation Laboratory (SEESL), one Equipment Site award will accomplish the installation of two moveable, six degrees-of-freedom shake tables. The NEES node project at the University at Buffalo is intended to improve the understanding of how very large structures react to a wide range of seismic activity, even when tested to complete failure.

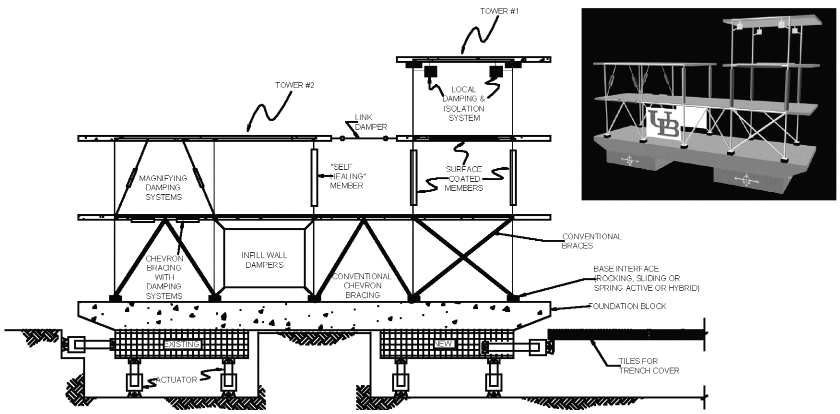

Figure 1. Re-locatable Shake Tables at University at Buffalo SESSL

4.2 University of Nevada, Reno - Ian Buckle, PI; http://bric.ce.unr.edu/nees/nees.htm

The high-bay Large-Scale Structures Laboratory (LSSL) at the University of Nevada, Reno was established in 1992 and equipped with two 450-kN shake tables funded by the Federal Emergency Management Agency in 1995. The building was expanded in 1999 to approximately 780 sq m. A major upgrade and expansion of the LSSL will be undertaken under the NEES Equipment Award from the National Science Foundation, supplemented by awards from the Department of Housing and Urban Development and the Department of Energy. Together the three tables can host specimens up to 1.35 MN in total weight, and can be separated a minimum distance of about 9 m up to a maximum of 36.5 m, centerline-to-centerline. Each table may be operated independently of the other two tables, in-phase with the other two tables thus forming a single large table, or differentially with the other two tables for the simulation of spatial variation effects in earthquake ground motions.

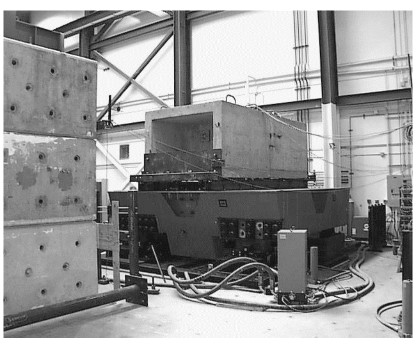

Figure 2. Shake table at UN-Reno

4.3 UC San Diego – Frieder Seible, PI; http:// http//www.structures.ucsd.edu/

An outdoor shake table 7.6 m x 12.2 m is being constructed on a Southern California site called Camp Mathews located 15 km from the University of California at San Diego campus. Large specimens can be constructed at the site and placed for testing on the table, and an adjacent soil pit will allow soil-foundation-structure interaction experimentation at full scale. The table will provide single-degree-of-freedom motion, with the possibility for future upgrades. The stroke of 0.75 m and maximum velocity of 1.8 m/s.

Figure3. Large-scale Outdoor Shake Table

4.4 Rensselaer Polytechnic Institute - Ricardo Dobry, PI; http://www.ce.rpi.edu/centrifuge

Rensselaer's centrifuge was commissioned in 1989 and started conducting physical model simulations of soil and soil-structure systems subjected to in-flight earthquake shaking in 1991. This centrifuge earthquake research has been conducted with two existing one-dimensional in-flight shakers, which can accommodate respectively 90 kg and 450 kg payloads. In conjunction with a networked data acquisition system, this will allow for a tremendous advance in the use of the data at RPI and throughout NEES, including teleobservation, shared-used of data, test visualizations, system identification, numerical computations and development of model-based simulations.

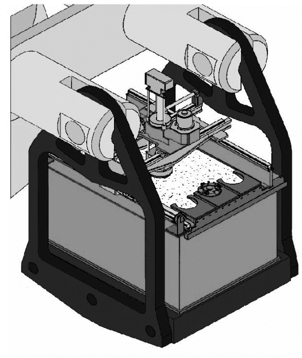

Figure4. In-flight 4 degree-of-freedom robot at the LCPC centrifuge in France, similar to a planned component at RPI

4.5 University of California at Davis – Bruce Kutter, PI; http://cgm.engr.ucdavis.edu/NEES/

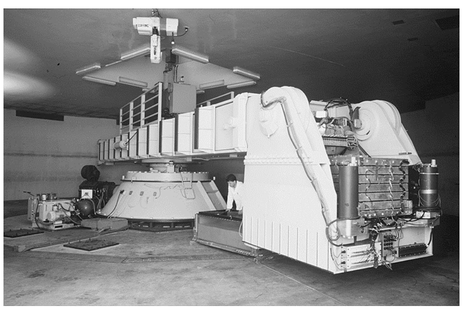

Figure 5. UC Davis Centrifuge

The existing centrifuge facility at the University of California at Davis will be upgraded in the following ways as part of the NEES program:

- Increase the centrifuge capacity from 40 to 80 g
- Hundreds of networked advanced sensors
- High resolution, high-speed digital cameras
- 4 Degree-of-freedom gantry robot for in-flight inspection and construction; vertical-horizontal biaxial shaking table
- In-flight geophysical testing and tomography

In addition to the equipment upgrade, information technology is being utilized to enable remote teleoperational and teleoperation, and data visualization using a 3 m x 3 m power wall.

4.6 Cornell University – Harry Stewart, PI; http://www.cee.cornell.edu/

Cornell University is upgrading its laboratory facilities that allow for full-scale testing of buried pipelines. Hydraulic equipment, electronic controllers, and a reaction wall are being added or enhanced. In partnership with Rensselaer Polytechnic Institute, where a NEES-funded centrifuge facility is located, combined small-scale/large-scale studies will be conducted. Examples of topics that can be studied with the facility include the effects of liquefaction or slope failure on buried pipelines. Shown in the illustration (left) is an experiment prior to soil placement and (right) resulting deformation of the pipeline after the experiment and removal of the soil.

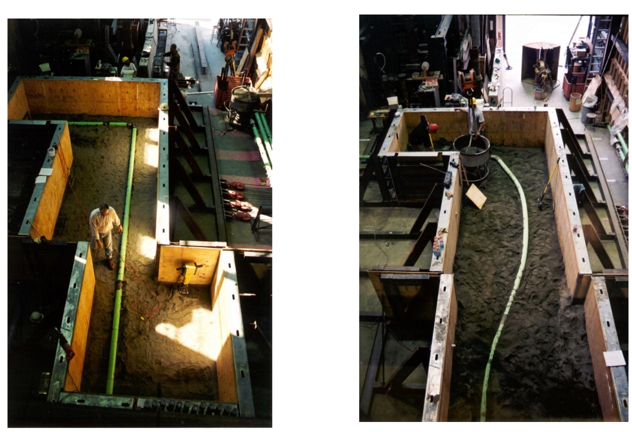

Figure 6. Large Displacement Soil-Structure Interaciton Facility

4.7 Oregon State University – Solomon Yim, PI; http://www.nees.orst.edu/

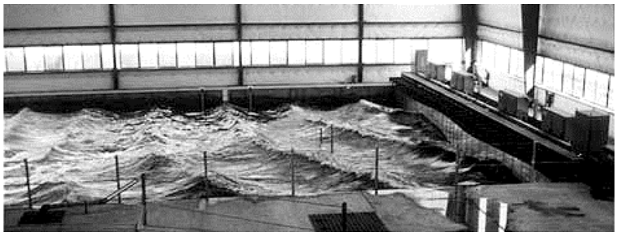

Figure 7. Three-dimensional wave basin (prior to NEES upgrade)

The O. H. Hinsdale Wave Research Laboratory will become one of the world's largest and most advanced tsunami testing facility as part of the NEES program. The 3-D basin is being extended to 49.4 m long, 26.5m wide and 2 m deep with a 29-segment directional, spectral wave generator located along one of the 26.5 m walls. Each segment of the new wave generator will have a maximum stroke of 2 m and a maximum velocity of 2 m/s.

4.8 University at Buffalo, SUNY –Michel Bruneau, PI; http://civil.eng.buffalo.edu/seesl/

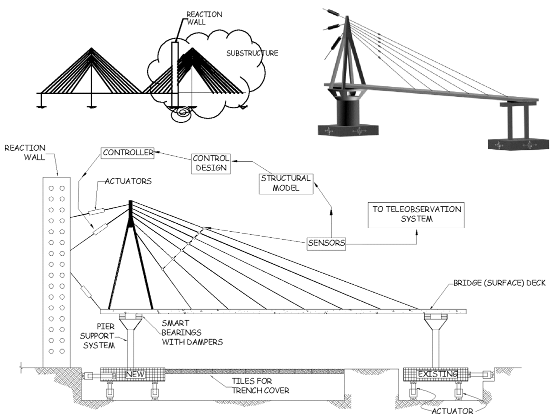

Figure 8. Real-Time Dynamic Hybrid Testing

Real-Time Dynamic Hybrid Testing (RTDHT) is being implemented at UB. Key elements of the upgrade of SEESL under NEES include new reaction walls, significant enlargement of the strong floor area, dynamic and static actuators, and associated control systems – all integrated into a new dual shake table facility. The facility will be capable of conducting testing of full or large-scale structures using static or dynamic loading. Pseudo-Dynamic, Effective Force, and Real-Time Dynamic/Pseudo-Dynamic Hybrid will be possible, along with Static, Quasi-static, and Dynamic Force techniques.

4.9 University of Minnesota – Catherine French, PI; http://www.ce.umn.edu/mast

The University of Minnesota Multi-Axial Subassemblage Testing (MAST) system, to be housed in a new laboratory on the Minneapolis campus, enables multi-axial cyclic static tests of large-scale structural subassemblages, including portions of beam-column frame systems, walls, and bridge piers. Up to 5870 kN of vertical force and up to 3910 kN on each horizontal axis can be applied to a specimen. The plane of the cruciform crosshead can impose pure translation or translation with desired degrees of rotation to simulate overturning, while maintaining a constant simulated gravity load. Specimens can be up to 6.1m in height. As with the other NEES Equipment Sites, a considerable investment is being made in instrumentation, networking, data analysis, and other information technology aspects.

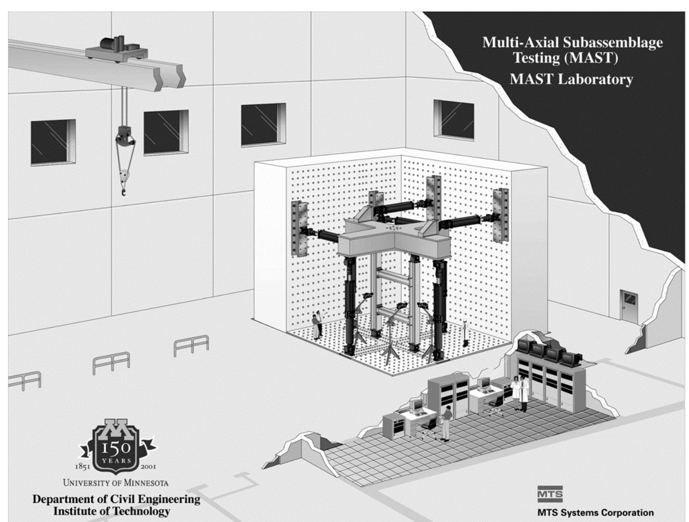

Figure 9. Perspective View of MAST

4.10 University of California at Berkeley – Jack Moehle, PI; http://nees.berkeley.edu/

The Reconfigurable Reaction Wall-Based Earthquake Simulation Facility (RRW ESF) is designed to support the development of a new generation of hybrid testing methods that smoothly integrate physical and numerical simulations. These methods are based on the concept of sub-structuring: portions of the structure expected to behave in a predictable manner are modeled numerically, while one or more complex sub-assemblies are modeled using scaled physical models. Using numerical integration algorithms, the physical and numerical sub-structures can be analyzed as a single structure. Using real-time multiply-substructured pseudo-dynamic testing methods (RT MS-PDTM), the sub-structures, physical or numerical, need not be at the same geographic location. The Reconfigurable concrete reaction wall units can be moved and stacked to provide a variety of test set-ups, including use of the adjacent existing 18,000 kN vertical axial compression-tension testing machine.

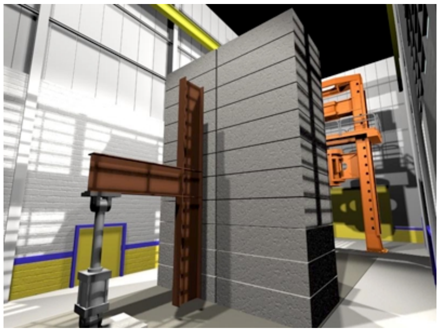

Figure 10.. Reconfigurable Reaction Wall-Based Facility

4.11 University of Colorado at Boulder – P. Benson Shing, PI; http://civil.colorado.edu/nees

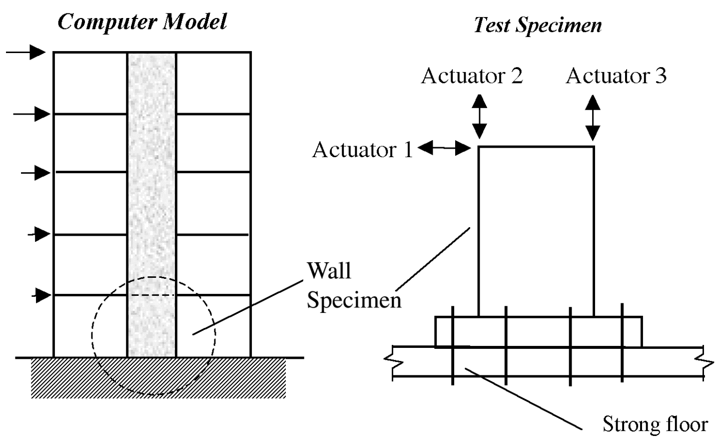

Figure11. Model-based simulation of overall structural response (left) with physical testing of a key structural element, in this case a ground story shearwall (right)

A Fast Hybrid Test (FHT) System is currently under development at the University of Colorado, Boulder as part of the NEES program. The system will allow efficient and realistic evaluation
system is able to achieve a rate of loading that is significantly higher than that in a conventional pseudodynamic test, approaching the real-time response of a structure under earthquake loads. In such a test, the hydraulic actuators will move continuously based on command signals generated by a closed-loop feedback and numerical computations.

4.12 UI-Urbana-Champaign – Amir Elnashai, PI; http://www.cee.uiuc.edu/research/nees/

The actuator "pods" or "boxes" to be installed in the Newmark Laboratory at the University of Illinois provide three relocatable points of connection to a specimen, at each of which 6 degree-of-freedom control can be provided. A dense array of non-contact measurement devices of three types are planned: Stress Photonics digital photoelasticity, Krypton Rodyum coordinate measuring, and close-range photogrammetry The relocatable pods provide the versatility of a larger, more expensive facility.

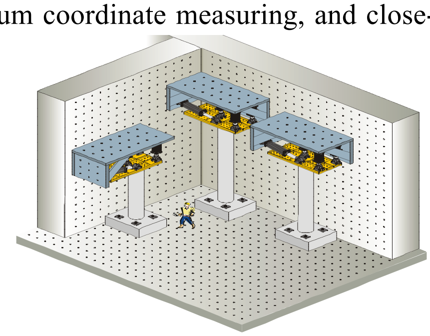

Figure12 .Multi-Axial Full-Scale Sub-Structures Testing and Simulation, Newmark Laboratory, University of Illinois

4.13 Lehigh University – James Ricles, PI; http://www.lehigh.edu/~incee/incee.html

The ATLSS Engineering Research Center, including its 32m-long reaction wall, is being enhanced with this NEES Equipment Site award to support new hybrid testing methods for multi-directional real-time testing of large-scale structures, including hybrid testing of multi-substructures, where the sub-structures involved in such testing are at different geographic locations connected by the NEES network. Actuator and other upgrades are being conducted in association with the NEES project.

Figure 13. The ATLSS facility, which has this existing strong wall, will be upgraded to conduct Real-time Multi-directional Testing

4.14 University of Texas at Austin – Kenneth Stokoe, PI; http://www.geo.utexas.edu/nees

The NEES Equipment Award at the University of Texas involves development of large-scale field equipment aimed at advancing the state-of-the-art in in-situ dynamic material property characterization and field testing of soil deposits and soil-structure systems. The next-generation field equipment includes a large triaxial mobile shaker called a vibroseis, two cubical shakers, field instrumentation, and teleparticipation equipment. The triaxial vibroseis, manufactured by Industrial Vehicles International, consists of an electro-hydraulic shaker that can generate forces in the X, Y, or Z directions. The vibroseis can be used to actively excite the ground surface, foundation elements over which it can be positioned, and bridges or other structural systems upon which it can be driven.

Figure 14. Mobile shaker

4.15 University of California at Los Angeles – John Wallace, PI; http://www.cee.ucla.edu/nees

This mobile laboratory features four vibration sources, three of which can be synchronized to produce greater excitation. Wireless sensors will allow for installation of high-density instrument arrays. Sensors include accelerometers, linear variable differential transducers, and fiber optic sensors for local displacement measurements. Digitized data are sent to an on-site command center through a wireless IP network surrounding the tested structure. Data can be accessed by local computers as well as transmitted via satellite to UCLA.

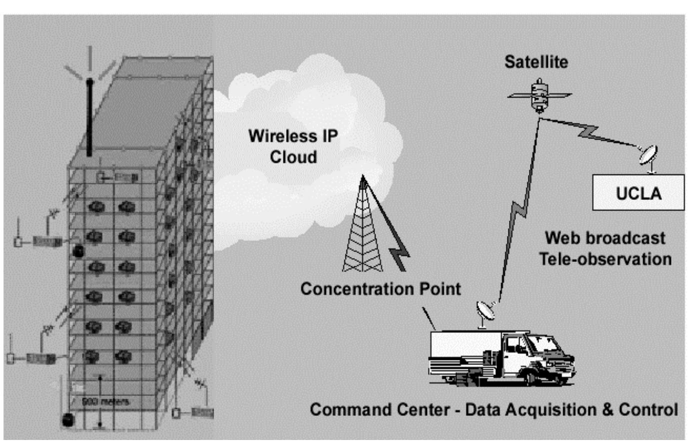

Figure 15. Schematic of Mobile Field Laboratory

4.16 Brigham Young University – Les Youd, PI; http://www.et.byu.edu/ce/

Fig. 16. Garner Valley Downhole Array

At two field sites in Southern California, studies will be made of dynamic ground response, deformation, and the resulting structural response, from both active shaking experiments and local and regional earthquake excitation of the sites. At Garner Valley Downhole Array, a structure will be built with sensors embedded in the soil, foundation and building, and a shaker installed for active excitation experiments. At Salton Sea Wildlife Refuge Liquefaction Array modernization and enhancement of existing equipment and the installation of a surface pad for mounting active shakers will occur.

Acknowledgements

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NEESgrid.org, 2001. The NEESgrid.org website is operated by the National Center for Supercomputing Applications of the University of Illinois at Urbana-Champaign. The Principal Investigator for the System Integration project is Thomas Prudhomme.

nees.org, 2001, 2002. Operated by CUREE, the http://www.nees.org/ website provides information on the NEES Consortium Development project, as well as providing synopses of and portals with updated weblinks to the separate NEES Equipment Site, System Integration, and NSF websites. Interested parties may also email curee@curee.org with inquiries regarding NEES.

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