

## USE OF EXPERIMENTAL FACILITIES IN NEES COLLABORATORY RESEARCH

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### Abstract

The National Science Foundation, beginning in the late 1990s, laid the foundation for the development of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES), which is under development as of this writing. In 2004, the initial NSF-Funded components of NEES will be in place. The participation of experimental or simulation sites other than the NSF-funded NEES Equipment Sites, and the involvement of researchers, educators, practitioners, and others, will become part of NEES activities as well. The combination of these human, laboratory, and computer resources will inaugurate in 2004 the beginning of a new mode for conducting earthquake engineering research: NEES Collaboratory research.

### Introduction

The components of NEES currently under construction, and which are separately reported on in these *Proceedings*, are: Equipment Sites, System Integration, Consortium Development. As of this writing (prior to the planned awarding by NSF of Phase 2 Equipment Sites in mid 2002), eleven awards have been issued by NSF to create or enhance earthquake engineering experimental facilities at universities in the USA:

- Shake Table Research: State University of New York at Buffalo; University of Nevada at Reno.
- Centrifuge Geotechnical Research: Rensselaer Polytechnic Institute; University of California at Davis.
- Tsunami Wave Basin: Oregon State University

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- Large-Scale Laboratory Experimentation Systems: State University of New York at Buffalo; University of California at Berkeley; University of Colorado at Boulder; University of Minnesota.
- Field Experimentation and Monitoring: University of Texas at Austin; University of California at Los Angeles.

This paper summarizes the topics to be discussed in this panel session, emphasizing the characteristics of the Equipment Sites and their mode of operation that will facilitate the vision for the NEES Collaboratory. A collaboratory model for conducting research, more than the sheer scale of investment in advanced experimental facilities and information technology, is what makes NEES unique in the earthquake engineering field as well as a model for advanced research in other engineering disciplines.

### **Origins of NEES and its Unique Features**

Plans for enhancement of earthquake engineering experimental facilities in the United States extend back several decades, including the influential EERI study on Experimental Research Needs (EERI, 1984), or the related 1995 updated recommendations (Abrams, et al., 1995). The plans for the development of the George E. Brown, Jr. Network for Earthquake Engineering Simulation (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” referred to the fact 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 out:

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 Information Technology (IT) emphasis is indicated by the fact that System Integration is an important facet of the development of NEES. In 2001, the NSF awarded the \$10 million System Integration project to the University of Illinois at Urbana-Champaign (NEESgrid.org, 2001). The System Integration project is implementing NEESgrid to link the NEES Equipment Sites together, provide a curated data repository, access to advanced computational resources for simulation studies by earthquake engineering researchers, and other IT infrastructure features needed to enable collaboratory research.

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: data sharing, data archiving and curating (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 support simulation. For example, providing data so rapidly to model-based simulation researchers that their results can in turn affect experimental operations as they are in progress is a concept well beyond common present practice of conducting an experiment at one point in time and some months later producing paper reports and computer files that other researchers 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)

How will different NEES sites—different university laboratories, being developed with separate awards from NSF—function as a unified whole? How will data be shared in ways that are well beyond common practice in the publication of engineering results today? Who will carry out policies to ensure that NEES Collaboratory research, with this mixing of organizational and individual interests, will be undertaken in a way that is fair, financially sound, and administratively efficient? Those tough questions are now being tackled by the NSF-funded NEES Consortium Development project awarded to the Consortium of Universities for Research in Earthquake Engineering, (CUREE), ([nees.org](http://nees.org), 2001). While those questions are very important, they are not the primary focus of this panel presentation and discussion session on NEES.

### **Brief Overview of NEES Equipment Sites and Panel Presentations**

As noted above, the current eleven NSF-funded NEES Equipment Sites are not the only experimental or simulation facilities to be linked via NEESgrid in the operation of NEES Collaboratory research. Even with the addition of several more laboratory awards in Phase 2 of the NEES Equipment awards (NSF, 2001), which are expected by the fall of 2002, there will still be many university, industry, or national laboratory experimental facilities not funded by NEES that are expected to be a part of NEES Collaboratory research, not to mention simulation resources, individual researchers or centers of research, and international collaborators. Educational applications of NEES research are also very important and constitute another way NEES research can be utilized. The core of effort with the NSF NEES program at present is to construct the NEES Equipment Sites and enable them to conduct NEES Collaboratory research via the components to be provided by the System Integrator and Consortium Developer. In this panel discussion, the presentations will be made by the NSF NEES Equipment Site awardees who are highlighted below in italics, along with Thomas Prudhomme representing the System Integration project, Professor Stephen Mahin of the Consortium Development project addressing the vision for NEES Collaboratory research, and William Holmes of Rutherford & Chekene posing initial questions to the panel during the discussion period from the point of view of a practicing engineer active in building code development.

Table 1. Phase 1 NEES Equipment Site awardees

Equipment category	Phase 1 NEES awardees ( <i>7NCEE panelists highlighted in italics</i> )
Shake table research	State University of New York at Buffalo, <i>Prof. Andrei Reinhorn</i> ; University of Nevada at Reno
Centrifuge geotechnical research	Rensselaer Polytechnic Institute; University of California at Davis, <i>Prof. Bruce Kutter</i>
Tsunami wave basin	Oregon State University, <i>Prof. Solomon Yim</i>
Large-scale laboratory experimentation systems	State University of New York at Buffalo, <i>Prof. Andrei Reinhorn</i> ; University of California at Berkeley, <i>Prof. Bozidar Stojadinovic</i> ; University of Colorado at Boulder; University of Minnesota
Field experimentation and monitoring	University of Texas at Austin, <i>Prof. Kenneth Stokoe</i> ; University of California at Los Angeles

The following brief summaries of NEES Equipment Sites provide the reader with information concerning their capabilities for conducting research once these facilities are operational in 2004 (CUREE, 2001). With that as background, the panelists in this session need not describe in detail the physical characteristics of their facilities. The panelists will focus their comments on “how” rather than “what;” that is, they will present ideas on how their facilities may be used in a NEES Collaboratory research program rather than what their equipment specifications are. In the audience comment session that follows the presentations, individuals are encouraged to similarly focus their ideas on how these experimental facilities might be used to conduct exciting new research that can only be realized because of NEES.

## Shake Table Facilities

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

The University at Buffalo’s Structural Engineering and Earthquake Simulation Laboratory (SEESL), which is the flagship laboratory in the Multidisciplinary Center for Earthquake Engineering Research (MCEER), will be an important node of a nationwide “collaboratory” in the NSF’s Network for Earthquake Engineering Simulation (NEES). A key element of the

upgrade of SEESL under NEES is the installation of two moveable, six degrees-of-freedom shake tables. The intent of the NEES Node project at the University at Buffalo is to develop the

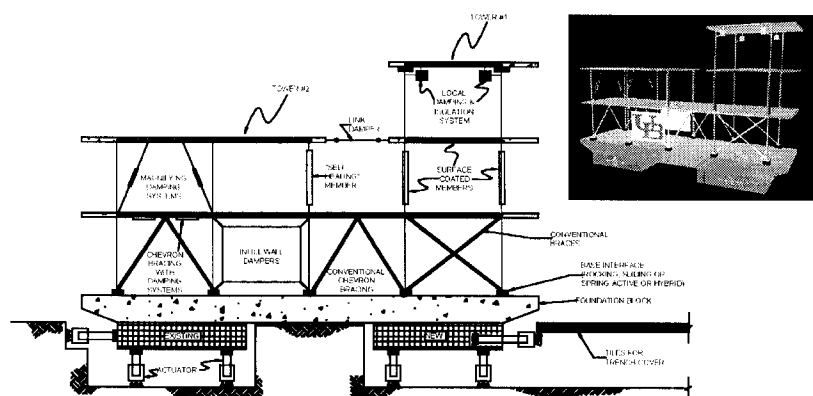


Figure 1. Example of dual-table testing of full-scale structure with alternative protective system

most versatile earthquake engineering research facility possible, designed to provide testing capabilities that will revolutionize the understanding of how very large structures react to a wide range of seismic activity, even when tested to complete failure.

**University of Nevada at Reno – Ian Buckle, PI; <http://bric.ce.unr.edu/nees/nees.htm>**

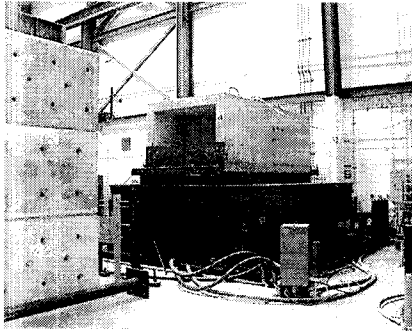


Figure 2. View of an existing shake table at UN-Reno

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. As part of the expanded system (upgraded and new shake tables), the following equipment will also be obtained and installed: new hydraulic distribution lines, blowdown bank, upgraded hydraulic power supply (addition of a third 700 l/min pump), digital control system for three tables, expansion of data acquisition system, and hardware/software to accommodate teleparticipation and data storage. The new facility will also be telecapable, in the sense that it will be equipped and connected to the university's high bandwidth, Internet-2 network for remote participation of off-site researchers in real-time.

## Centrifuges for Geotechnical Experimentation

**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. The future use of dense arrays of advanced sensors and high speed cameras to provide high resolution measured model response is central to the vision embodied in NEES. Features include: teleobservation, shared-

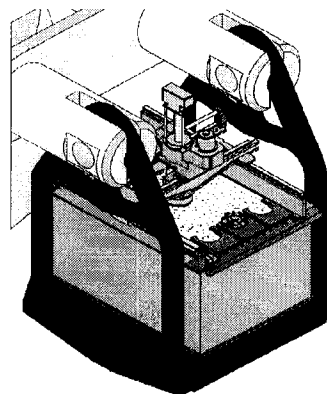


Figure 3. In-flight 4 degree-of-freedom robot at the LCPC centrifuge in France, similar to a planned component at RPI

used of data, test visualizations, system identification, numerical computations and development of model-based simulations. In addition, the NEES equipment will allow for teleoperation/control over the Internet.

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

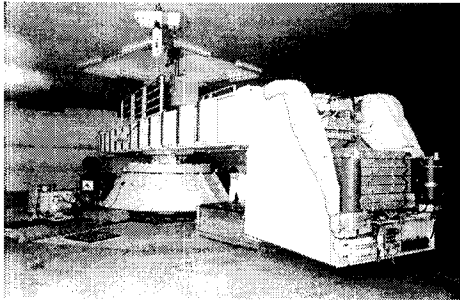


Figure 4. Existing UCD centrifuge

In the fall of 2000, University of California at Davis received a \$4.6 million award, “A NEES Geotechnical Centrifuge,” NSF-CMS 0086566. All of the following upgrades of the existing centrifuge at UC Davis are to be in place by fall of 2004:

- 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

## **Tsunami Wave Basin**

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

In 2000, the O. H. Hinsdale Wave Research Laboratory received a \$4.8 million grant from the National Science Foundation (NSF) Network for Earthquake Engineering Simulation

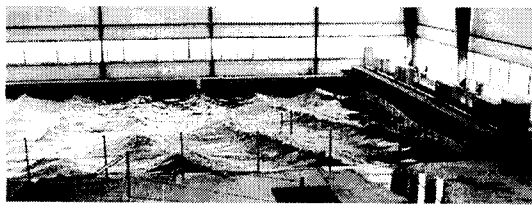


Figure 5. Three-dimensional wave basin

Program (NEES) to construct the world’s largest and most advanced tsunami testing facility in support of national experimental and computer simulation research. Currently, the 3-D basin is being extended to 49.4 m (160 ft) long, 26.5m (87 ft) wide and 2 m (6.6 ft) deep with a 29-segment directional, spectral wave generator located along one of the 26.5 m (87 ft) walls. Each segment of the new wave generator

will have a maximum stroke of 2 m (6.6 ft) and a maximum velocity of 2 m/s (6.6 ft/s). The WRL will have a comprehensive information architecture to support remote users and a tsunami experiment databank for the broader research community to use.

## **Large-Scale Structural Experimental Facilities**

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

The University at Buffalo’s Structural Engineering and Earthquake Simulation Laboratory (SEESL), which is the central laboratory in the Multidisciplinary Center for Earthquake Engineering Research (MCEER), will be an important node of a nationwide “collaboratory” in the NSF’s Network for Earthquake Engineering Simulation (NEES). Key

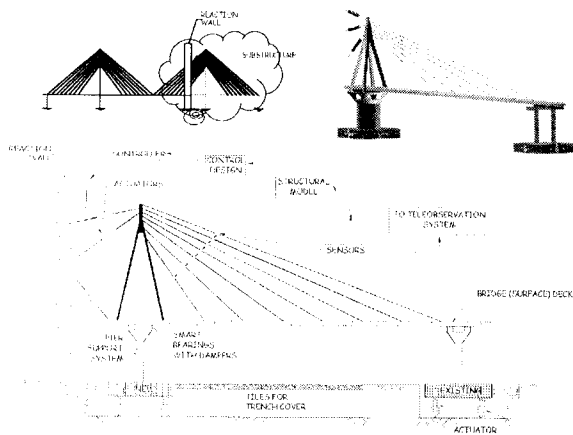


Figure 6. Real-Time Dynamic Hybrid Testing of a bridge using two shake tables and a reaction wall

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. The use of modern techniques such as Pseudo-Dynamic, Effective Force, and Real-Time Dynamic/Pseudo-Dynamic Hybrid will be possible, along with conventional Static, Quasi-static, and Dynamic Force techniques. Real-Time Dynamic Hybrid Testing (RTDHT) is a new form of testing being explored at UB.

**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, is one of four large-scale structural testing facilities awarded through the National Science Foundation George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program. The MAST system enables multi-axial cyclic static tests of large-scale structural subassemblages, including portions of beam-column frame systems, walls, and bridge piers.

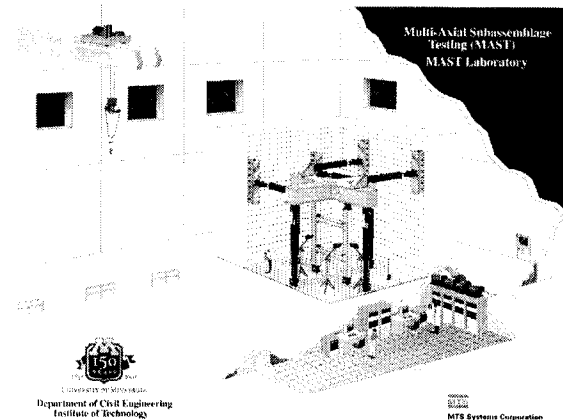


Figure 7. Perspective view of MAST

Six-degree-of-freedom control technology advances the current state of technology in which case boundary effects are often reduced to simple uniaxial loading configurations because of difficulties encountered in imposing multiple-degree-of-freedom states of deformation and load using conventional structural testing means.

**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. Such hybrid testing methods, better known as

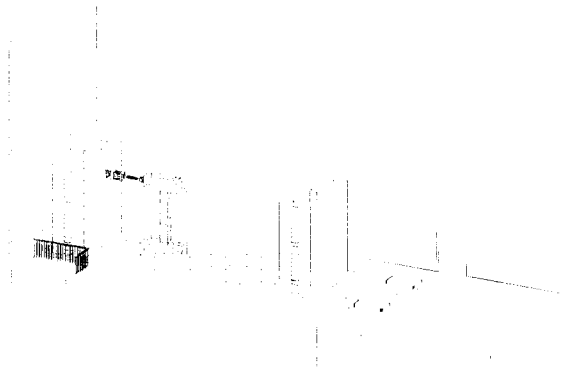


Figure 8. Reconfigurable Reaction Wall-Based Earthquake Simulation Facility

methods, the real-time multiply-substructured pseudo-dynamic testing methods (RT MS-PDTM). The sub-structures, physical or numerical, involved in an MS-PDTM test need not be at the same geographic location. Instead, the network connecting them becomes the simulation.

derivatives of the pseudo-dynamic testing method, have been pioneered at Berkeley in the early 1980s and were subsequently adopted world-wide.

Recent advances in digital control theory, as well as exponential increases in numerical processing power and speed of inter-processor communication, make it possible to develop a new generation of hybrid simulation

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

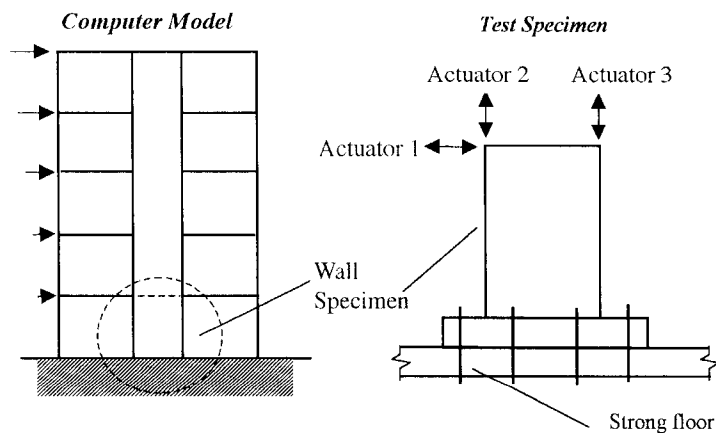


Figure 9. Model-based simulation of overall structural response (left) with physical testing of a key structural element, in this case a ground story shearwall (right)

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 of the performance of structural systems and components under earthquake loads. The FHT system is based on the pseudodynamic test concept, and it combines physical testing with model-based simulation. The main distinction is, however, that the 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. The system will incorporate a substructuring capability, whereby only a portion of a structure can be tested and the rest of it is simulated by a finite element model using nonlinear beam-column elements. With this, one can test the most critical structural subassemblage, where severe inelastic deformation is expected to develop, and model the rest of the structure in a computer to provide a realistic boundary



condition for testing. Furthermore, via a high-performance information network, the FHT System can be used to link geographically distributed laboratories to test different structural subassemblages and components of a large structural system using a single simulation model. Similar to other NEES sites, the system will be connected to a high-performance network via Gigabit Ethernet to allow teleparticipation by remote users.

## Field Experimentation and Monitoring Installations

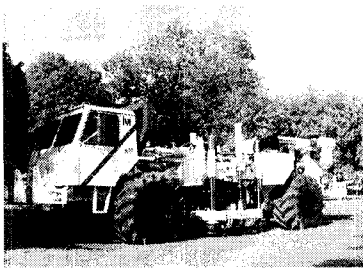


Figure 10. Mobile shaker

*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. It is capable of generating a theoretical peak vertical force of 250 kN over a frequency range of 11 to 200 Hz and a theoretical peak horizontal force of 125 kN over the frequency range of 5 to 200 Hz. 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. The vibroseis can also be used to passively excite, through ground-borne vibrations, soil deposits, foundations, buildings, and bridges.

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

Previous studies of the seismic performance of full-scale structural systems have traditionally been extremely limited in their coupling of detailed performance data

with nonlinear response. To achieve that objective, this project seeks to develop and implement the next generation of forced-vibration testing and seismic structural monitoring equipment. Three categories of equipment are being developed for this mobile field laboratory: (1) detailed forced vibration testing of structural systems, (2) efficient, rapid evaluation of structural (i.e., acceleration, displacement, strain) and soil conditions (i.e., consistency, density, shear wave velocity, pore pressures, etc.) and for deployment of in situ sensors to monitor soil response during forced and ambient vibration testing of structural systems, and (3) rapid data acquisition, processing, and distribution to enable near real-time teleobservation and teleoperation.

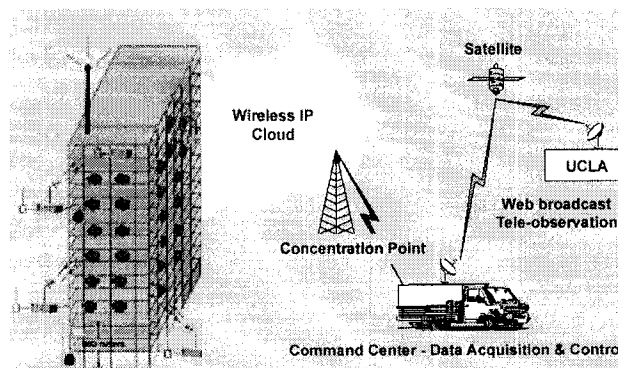


Figure 11. Schematic of Mobile Field Laboratory

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nees.org, 2001. Operated by CUREE, the nees.org website provides information on the NEES Consortium Development project, as well as providing synopses of and portals to the separate NEES Equipment Site and System Integration websites. The Principal Investigator of the Consortium Development project for CUREE is Robert Reitherman.

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