



EARLY ADOPTER EXPERIENCE WITH TELEPRESENCE AT THE UNR SHAKE TABLE FACILITY

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SUMMARY

The NEES Equipment Site at the University of Nevada, Reno is a biaxial, multiple shake-table facility that is suitable for researching long, spatially distributed, structural and geotechnical systems. Major equipment includes three, re-locatable, biaxial, 445 kN (50 ton) shake tables, servo-controlled hydraulic actuators and three data acquisition systems for the simulation and observation of earthquake loads and their effects. The facility is also capable of testing conventional structural and non-structural systems by using the tables in large-table mode, and operating them as a single unit. UNR NEES site offers a wide range of telepresence hardware, software, services and tools to remote and local participants of a particular experimental research project to facilitate teleparticipation during various stages. In late 2001, UNR agreed to be an early adopter of these telepresence technologies and acted as a *test bed* for early NEESgrid deployment. Working closely with the System Integrator (<http://www.neesgrid.org>), this exercise led to the first successful public demonstration of NEESgrid in November 2002.

DESCRIPTION OF UNR NEES EQUIPMENT SITE

The Large-Scale Structures Laboratory at UNR is a NEES Equipment Site under the NSF-funded George E. Brown Jr. Network for Earthquake Engineering Simulation (NEES). The Site is housed within the 780 m² (8,400 ft²) Large-Scale Structural Laboratory on the university's main campus in downtown Reno, Nevada. The Laboratory is equipped with three identical, biaxial, 50-ton shake-tables, capable of being relocated on the Laboratory's tie-down strong floor. The shake-tables are 4.25 m (14 ft) square and may carry up to a 445 kN (50-ton) payload at 1g acceleration. They may carry higher loads at lower accelerations, provided bearing capacities are not exceeded. For example, 890 kN (100-ton) payloads with low centers of gravity are possible, if table accelerations are limited to 0.5g. Other peak performance characteristics include 1000 mm/sec (40 in/sec) velocity and +300 mm (+12 inches) stroke. Three banks of blowdown accumulators are used to achieve this performance. Maximum velocity in continuous operation is 625 mm/sec (25 in/sec). Each table may be operated *independently* of the other two tables, *in-phase* with the other tables thus forming a single large table, or *differentially* with the other tables for simulation of spatial variation effects in earthquake ground motions.

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In addition, the Laboratory also has seven MTS servo-controlled actuators ranging in size from 245 kN @ +75 mm stroke (55 kips @ + 3 in stroke) to 3.1 MN @ +600 mm stroke (700 kips @ + 24 in stroke). These actuators are used for large-scale experiments on structural components that are unsuitable for shake table execution and are mounted directly on the strong floor.

Three high speed, data acquisition systems from National Instruments, Pacific Instruments and OPTIM Electronics are used for table-mounted and floor-mounted experiments. Total channel capacity is 340-channels. Data is currently archived on a data storage server and backed-up on CD-ROM. Data will also be stored in the NEESgrid data repository when operational late summer 2004. An SGI Origin 2200 Server with a library of simulation codes is available for data processing and numerical simulation studies.

For medium-scale geotechnical studies, the Laboratory has a 530-kN (120 kip) biaxial laminar soil box with dimensions 3.2 x 3.2 x 1.9 m (10'-4" x 10'-4" x 6'-2"). The walls consist of alternating sections of aluminum and elastomer bonded together over the height of the box, and rest on a stiffened steel base plate. The box is flexible under horizontal shear and will deform laterally when shaken. It is provided with an inflatable air bag at the top of the soil, which may be inflated to provide an overburden pressure of up to 200 kPa (29 Lb/in²).

Hydraulic pumps are located in a separate pump-house connected to the Laboratory through large diameter hardlines. Pumping capacity (continuous rating) is 1566 l/min (415 gpm). Blowdown accumulators lift this rate to 9084 l/min (2400 gpm) on demand, for short periods of time.



Figure 1 Model bridge used in the UNR Early Adopter demonstration

The Laboratory was completed in 1992 and expanded to increase the area of the strong floor by 50% in 1999. The 780 m² (8400 ft²) precisely leveled strong floor, is a 4-cell box girder with tie-down holes in the upper slab at 600 mm (24-inch) centers. It weighs about 22 MN (5000 kips). To accommodate future needs of unknown shape and form, the facility is modular in design. Reaction buttresses are assembled from 85 kN (19-kip) concrete blocks, which are stressed together, and to the floor, in customized configurations. In like manner, the three shake tables are relocatable into different configurations according to the demand of present and future needs. Figure 1 shows the shake-tables arranged to accommodate a 0.4 scale model of a base-isolated two-span concrete slab-on-steel girder bridge.

Installation and acceptance of the tables were completed in November 2002. Development and commissioning of related telepresence facilities will be complete by September 30, 2004.

UNR NEESgrid NODE

When complete, the UNR NEES site will offer a wide range of telepresence hardware, software, services and tools to remote participants of research projects to facilitate their teleparticipation during all stages of the research program. All of these telepresence components are supported by NEESgrid infrastructure as outlined by Kesselman et al. [1] and summarized below.

Overview of NEESgrid System Architecture

NEESgrid system architecture distinguishes three major groups of essential components which will facilitate the NEES collaboratory. These groups are *physical elements* that are to be connected such as equipment located at geographically distributed NEES sites; *capabilities* for the essential NEESgrid operations; and *principal software* to provide these capabilities.

In essence, *physical elements* consist of NEES equipment housed at the fifteen NEES equipment sites and other resources in the form of computer systems, data acquisition hardware, and data repositories that are part of dedicated high performance local and/or wide area network(s). While these local resources allow and enhance the ways that conventional experimental and numerical earthquake engineering research conducted, it is the vision of NEES to enable these sites to operate as a single virtual laboratory with “remote access” and “sharing” of these resources.

In this respect, NEESgrid is perceived as the backbone that provides essential *capabilities* to realize this objective. Most of the desired features and functionality within the NEESgrid framework have been identified by numerous national and international community meetings, and surveys which form the basis of the still-evolving NEES User Requirements Document [2]. Accordingly, *core capabilities* cross cut every aspect of NEESgrid operations by facilitating remote resource discovery and monitoring with strict authentication and authorization requirements. It is noted that NEES will allow researchers to gain remote, shared access not only to equipment, but also to data. In the context of NEES, data includes information obtained from physical experiments as well as from simulation results (e.g. output, models, input files, visualization files), and literature (e.g. journal papers, technical reports, construction drawings, technical specifications, users manuals, lab notes) [3]. In fact, a revolutionizing aspect of NEES will be the formalization of *data management* by providing capabilities in terms of standards in *data discovery, access and publication* along with associated *metadata*. All forms of data will be stored and achieved on local as well as central repositories for later retrieval. Moreover, repositories will allow secure and reliable uniform resource access to *simulation* tools. And finally, NEESgrid will provide capabilities to facilitate *telepresence*, i.e. teleobservation of experiments (remote observation of video and data streams) and teleoperation (remote operation) of equipment.

The overall NEESgrid system architecture defines a set of *principal software* services and categorizes them with respect to capabilities provided to users and their locations. Accordingly, NEESgrid Global Services are located at the operations center and provide services for resource discovery and monitoring. Designated resource sites provide services for secure remote access to resources for the purpose of data storage and access (data repositories) and simulation (computer resources). Finally, both standard hardware (the NEESgrid Point of Presence server, or NEESpop) and standard NEESpop software that enables secure remote access to equipment for the purposes of telepresence, and secure publication of data produced by experiments to data repositories are located at the equipment sites. Details of NEESgrid architecture from the perspective of an equipment site is presented in Figure 2.

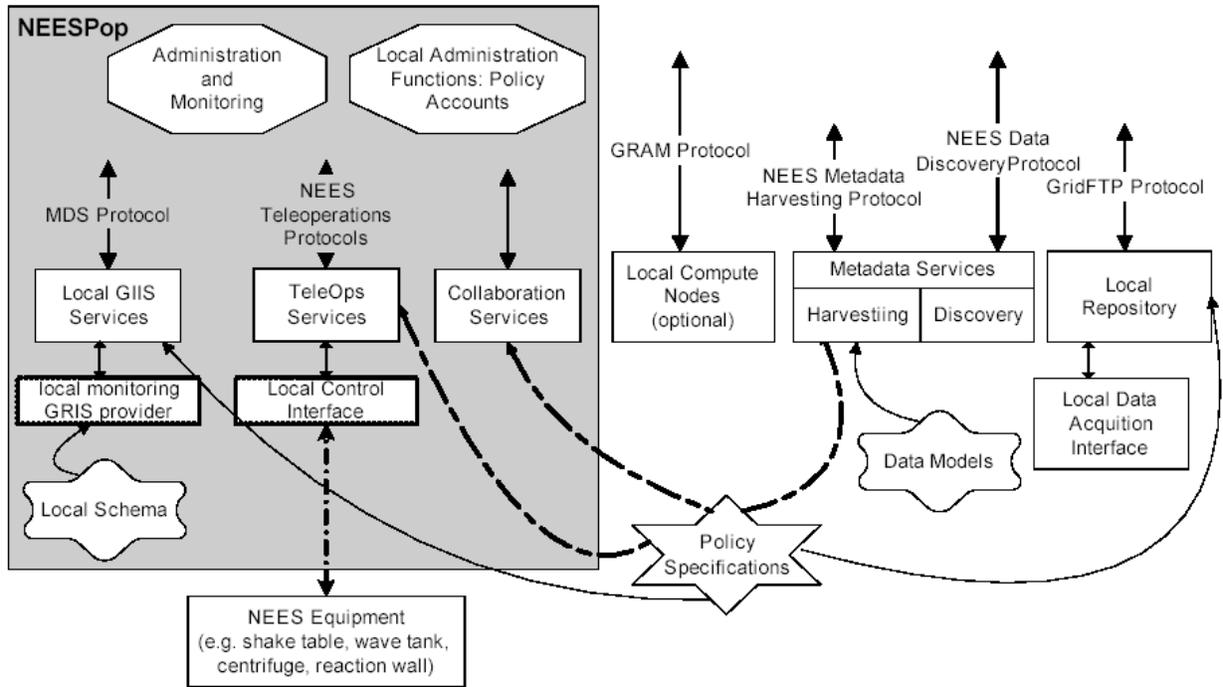


Figure 2 Details of NEESgrid system architecture from the perspective of an equipment site [1]

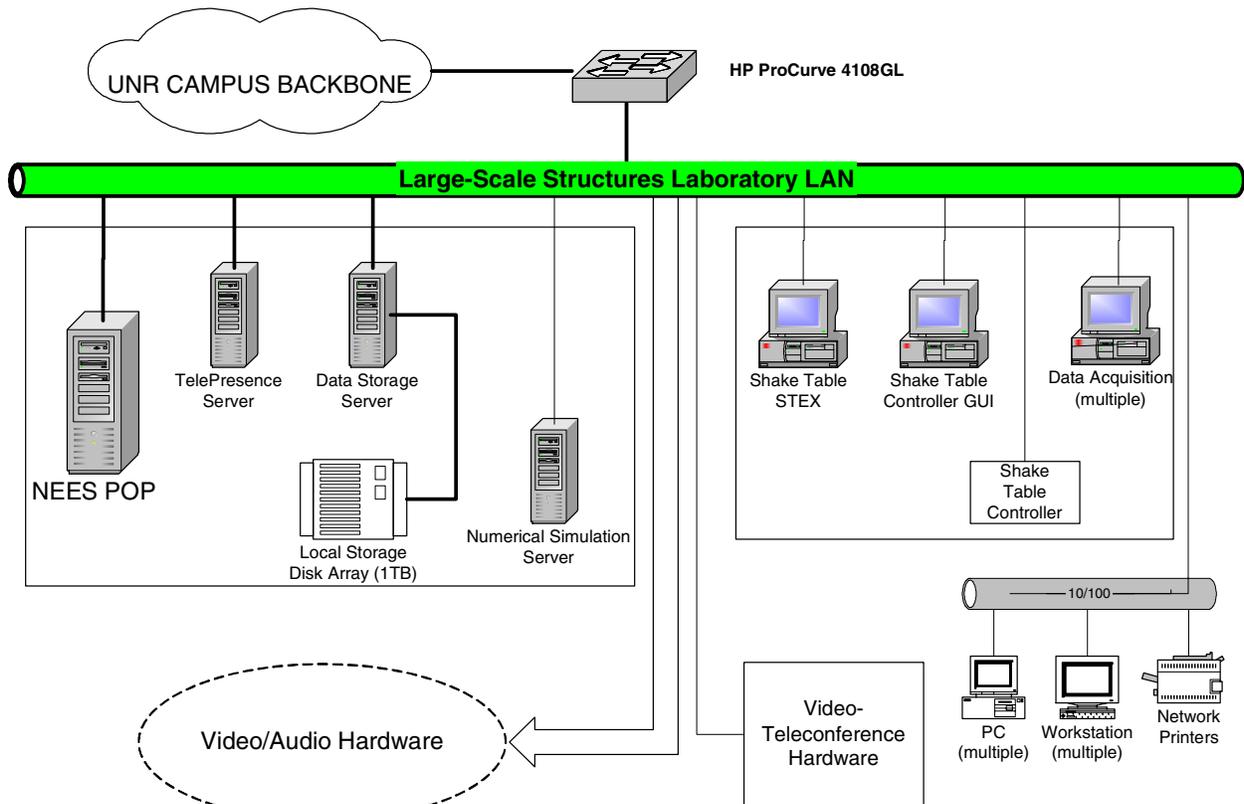


Figure 3 UNR Large-Scale Structure Laboratory LAN

It is important to note that in developing the NEESgrid software, the overall architecture is being constructed by the integration of a series of existing components of the NSF Middleware Initiative (NMI) software system. Through NMI, NSF funded the GRIDS Center to create a more uniform middleware infrastructure upon which communities can build their applications, achieving efficiency and interoperability that would otherwise not be possible. From this perspective, GRIDS suite will provide NEES with a long-term, sustainable base for the continued evolution of NEESgrid software and services. Additionally, a relatively small set of custom software is also being coded by the NEESgrid System Integrator (SI) (<http://www.neesgrid.org>) and participating NEES Equipment Sites.

UNR NEES Telecapabilities

At the UNR NEESgrid node (<http://nees.unr.edu>), telepresence equipment is categorized in four major groups in terms of their functions (Figure 3). The first group consists of servers and NEESgrid services that reside on them. The NEES Telepresence Management Server (TPM; <http://tpm.ce.unr.edu>) provides first generation near real-time streaming video capabilities, PZT camera control and E-notebook. On the other hand, the NEES Point-of-Presence server (NEESpop; <http://neespop.ce.unr.edu>) hosts all other NEESgrid services including an online collaborative environment (CHEF), grid information systems, and telecontrol services. A data archive system including a data archive server coupled with a data storage media is designed to provide 1 TB storage space for storing experimental data. Finally, various PC workstations will provide on-campus remote access to the UNR-LAN and NEES equipment for the local and/or visiting PI/Co-PI. All servers and computers are outfitted with 2 – Gigabit network interface cards (NIC).

The second group is intended and designed for streaming MJPEG video through the Internet to remote sites. This is achieved by using eight (8) tele-robotic (P/T/Z) and four (4) stationary network cameras. Remote PI's and/or remote observers, with proper authorization, will be able to control eight cameras of the twelve cameras during a particular experiment, thus giving them a virtual presence. Output from all of the twelve cameras will be recorded and stored digitally on UNR's local data storage for later retrieval through NEESpop. Two microphones will provide for audio streaming and recording, as well.

The third group is designed for encoding the output from four high-resolution cameras using Mpeg-2 technology (i-frame). This technology allows encoding good quality video (DVD quality) with the capability of capturing/retrieving single frames for subsequent qualitative studies (e.g. image analysis). This is achieved by using four VBRICK encoders. Output from two of the four cameras will be routed to a PC where the signal will be encoded to Mpeg-1 for streaming purpose. A second video router will be used to facilitate switching between various cameras as well as amplifying the signal. A control unit is used to allow remote control of the four cameras over the Internet. Audio and video output from the four cameras will be recorded and stored on UNR's local data storage for later retrieval through NEES POP.

Finally, the fourth group is designed to facilitate communications between local and remote PIs. Two different systems; one fully equipped Zydacron system and three Polycom View Stations, will be used for this purpose.

Additional equipment that will be used to enhance the telepresence function will be i) one high speed camera for slow motion play back (available offline), and ii) one projection system to project images collected from different cameras in front of a large number of audience.

When complete, telepresence facilities supported by the Laboratory will enable both passive and active observation of experiments by remote participants. Numerical and video data streaming will be available using NEESgrid services, which are based on standard web-based browser technologies.

THE EARLY ADOPTER (EA) PROGRAM: A SPIRAL DEVELOPMENT MODEL

A spiral evolutionary development scheme (referred as spiral model) as opposed to standard waterfall model has been adopted by the System Integrator (SI) for the development of NEESgrid software and related services. It is noted that this exercise has required significant interactions between the two different (but historically complementary) disciplines. As it has become a major challenge for the Earthquake Engineering community to transform traditional practices and methods used to conduct research, it has been equally – if not more – challenging for the SI to comprehend, design and implement effective tools and services. Hence, because of the anticipated complexities and difficulties in bridging gaps towards a system that will be accepted by the entire community, an iterative development scheme was the inevitable choice.

In fact, spiral model means a sequence of iterations of development, deployment, testing and refinement of a system. The SI has adopted a two-level approach for developing and implementing NEESgrid for the NEES community [4]. A small subset of the NEES equipment sites has been solicited and selected to assist in the early development of the system. This approach was intended to allow SI and the EQ community to develop and test an initial implementation of grid software for NEES with limited features and capabilities. It was planned to install these software and services at a small number of the NEES equipment sites called Early Adopters, followed by testing of the system via representative experiments. The second level consists of subsequent iterations of software, documents, hardware installation and testing procedures based on the lessons learned in the initial step, i.e. Early Adopter implementation. This second level has since been called “Experiment-Based Deployment Strategy [5].” Each iteration of the system is expected to further flush out and address the problems that arise, provide bug fixes, add new features and capabilities. Therefore, the final result is expected a robust system for production use by the Earthquake Engineering community.

In summary, the Early Adopter program was used to drive an initial set of NEESgrid capability demonstrations in a very short time (approximately six months). Following the conclusion of the program, the SI has continued to work with all of the equipment sites to develop and deploy NEESgrid software and services with continuing refinements and new features throughout the length of the project. It is noted that Early Adopter program was one of the first major milestones, in terms of demonstrating NEESgrid capabilities as early as November 2002.

EARLY ADOPTER PROGRAM IMPLEMENTATION AT UNR

As mentioned above, three of the fifteen equipment sites; namely University of Nevada, Reno (UNR); Rensselaer Polytechnic Institute (RPI); and Oregon State University, Corvallis (ORST), were selected to assist in the early development and deployment of the NEESgrid software and services. The main objective of this exercise was to develop a common base infrastructure that would be used across all NEES sites. The importance of validating these developments against the user requirements was recognized and therefore the entire Earthquake Engineering community was solicited for its input at various stages. As a result, the Early Adopter program commenced by extending existing Grid technologies and custom solutions to meet NEESgrid specific requirements with respect to data collection, streaming and storage; data acquisition hardware and software; and video services.

To facilitate the development of NEESgrid System Architecture, UNR agreed in December 2001 to be one of the three Early Adopters of the NEESgrid services and technologies and to act as a test bed for NEESgrid development. Three major reasons for selecting UNR as an Early Adopter include: i) UNR has one the representative technologies, i.e. shake-tables that are common to at least three other NEES equipment sites; ii) all three shake-tables were constructed and ready in the time-frame of the Early

Adopter program; iii) UNR was able to provide staff and personnel to assist the SI with the development and installation of NEESgrid software, and the design of appropriate experiments to test and shake out Grid software. Not surprisingly, successful implementation of the program required continuous feedback from the Early Adopters with rapid turnaround times.

Working closely with the NEES System Integrator (SI) (<http://neesgrid.org>), this exercise led to the first public demonstration of NEESgrid in November 2002. Using a two span, 0.4-scale model of a concrete slab-on-steel-girder bridge (Figure 1), experimentally derived numerical and video data was streamed from the laboratory, stored, displayed and analyzed in real time. Remote interactions with the shake-table operator permitted re-runs of the model at higher magnitudes to approach the limit states of the model. Simple visualization tools facilitated this collaborative environment. These demonstrations included early versions of newly developed software that would eventually be hardened and included in future software releases. Lessons learned from this experience have since led to improvements in the NEESgrid software, the development of a data schema for shake table experiments and user interfaces for storing and retrieving data from the NEES data repository.

This first demonstration of the use of NEESgrid software was representative of ongoing development efforts by the SI that met the requirements of the Early Adopters. The subsequent NEESgrid software releases include most of the major functionality and services that are being provided by the SI as identified from the user requirements surveys. These services were demonstrated during the recent MOST experiment (<http://neesgrid.org/most/>). According to the SI, the release of the final version of NEESgrid software will require only minimal additional development by the SI.

CONCLUDING REMARKS

The Early Adopter program has demonstrated that identifying and performing experiments representative of an equipment site area of interest was the most efficient way to engage the sites in the development and deployment of NEESgrid. Through the Early Adopter program, it was possible for both the equipment sites and System Integrator to identify and implement necessary steps and procedures that led to the establishment of foundation of NEESgrid.

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