Abstract - The recent establishment of the U.S. National Science Foundation-sponsored George E. Brown Jr., Network for Earthquake Engineering Simulation (NEES, http://www.nees.org) as one of the more sophisticated cyberinfrastructure projects currently underway, provides an excellent opportunity to frame hazard mitigation education in the very tangible context of earthquake engineering. A plan for implementation of the NEES activities in Education, Outreach and Teaching has been developed. A number of prior activities that contribute to this effort have been successfully employed. Here a few of those activities are summarized briefly. This paper will also provide a description of the planned activities for this unique cyberinfrastructure project, including activities targeting K-12 students, parents, undergraduates, graduate students, and practicing engineers.

Index Terms – Cyberinfrastructure, earthquake engineering, hazard mitigation, execution plan.

INTRODUCTION

While hazard mitigation has been an important addition to civil engineering curriculum in recent years, integration of this multidisciplinary topic’s fundamental concepts, namely the incorporation of structural dynamics and emerging technologies with more traditional structural analysis and design, is not currently a component of a typical civil engineering education. However, one of the most important challenges facing civil engineers is mitigating the severe human and economic consequences of structural dynamic responses (e.g., earthquakes, hurricanes, tsunamis and blasts). Recent national and international events that inflicted widespread human loss together with massive direct and indirect costs—such as the 2004 earthquake and ensuing tsunami in Asia which resulted in over 283,000 deaths, and most recently the 2006 earthquake in Kashmir that resulted in nearly 90,000 deaths and 3.3 million homeless—have demonstrated that in order to more effectively minimize the consequences of such hazards, future practicing engineers and researchers must improve their understanding to the effects of structural dynamics on our infrastructure.

The NEES Education, Outreach and Training (EOT) Strategic Plan was developed in parallel with establishment of NEESinc, the equipment sites and the cyberinfrastructure (Grant CMS-0337808). The plan calls for the development of a Coordination Framework for all of the EOT activities related to NEES, encompassing activities at the sites, by the PIs of research projects, by NEES EOT staff and by external PIs who have a particular interest in earthquake engineering or cyberinfrastructure education initiatives. An Execution Plan, intended to accompany the Strategic Plan, will provide a detailed roadmap to the NEES community for helping them to achieve the goals of the NEES EOT Program. Additionally, a Diversity Strategic Plan has been developed and is available on the website.

The broad group of users of the NEES collaboratory and EOT efforts will include all of the following identified constituents:

- precollege education (both teachers and students)
- undergraduate education (both faculty and students)
- graduate education (both faculty and students)
- researchers and remote users of the NEES collaboratory
- practitioners and decision makers
- lab managers/technicians supporting NEES experiments
- the public-at-large

The Execution Plan will discuss effective means for targeting varied groups of constituents, as the NEES program is comprised of several diverse sub-groups that require different outreach tactics. It will focus on the activities that are planned to take priority over the next two years. NEESinc will pursue funding in cooperation with EOT partners and PIs with a planned flexibility to take advantage of unanticipated opportunities that may arise. Potential funding opportunities will also be suggested and mechanisms for establishing partnerships will be described. Each year the plan will be reviewed and updated by the EOT Committee and the NEES EOT Staff, and the revised document is submitted annually to the Board of Directors of NEESinc for approval.

This paper first provides an overview of NEES and the unique capabilities offered within this cyberenvironment. Next a couple of prior educational activities are briefly described that utilize these capabilities and lay some of the groundwork for the NEES EOT plans. The paper concludes with a description of strategies that will add value and enhance, rather than duplicate and dilute, educational outreach efforts and activities already underway. Furthermore, state-of-the-art cyberinfrastructure tools for research activities have already been developed by the technical support and development

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component of NEES, NEESit (NEES Cyberinfrastructure Center; [http://it.nees.org](http://it.nees.org)). Dissemination of educational outreach efforts can be greatly enhanced by utilizing the NEES cyberinfrastructure, including tele-operation and tele-participation during experiments at one of the 15 NEES Experimental Sites. Partner organizations have also been identified for collaborating on the implementation of these activities.

**THE NEES CYBERENVIRONMENT**

NEES (the George E. Brown Jr. Network for Earthquake Engineering Simulation) is a national networked-resource for the next-generation experimental earthquake engineering research and education. Sponsored by the National Science Foundation (maintained under Grant CMS-0552992), NEES consists of a network of shared-use equipment facilities distributed among 16 universities throughout the US. These facilities include shaking tables, tsunami wave tank, reaction wall facilities, geotechnical centrifuges, mobile field equipment, etc. (see [http://www.nees.org/EQ/index.html](http://www.nees.org/EQ/index.html)).

NEES has established a collaboratory that enables open access to and use of the distributed facilities by the earthquake engineering researchers, accelerate the generation and dissemination of basic knowledge and support the development of education programs (see Figure 1). NEES’s facilities and research data are accessible remotely by all members of the earthquake engineering community.

**NEESgrid – A Virtual Collaboratory CyberInfrastructure**

The system infrastructure to support the NEES activities is the NEESgrid which is a distributed virtual “collaboratory” cyberinfrastructure for earthquake experimentation and simulation. To provide broad-based collaborations among earthquake engineering researchers, advanced information and communication technologies are being adapted, enhanced and extended. Building on grid technologies, the “virtual” collaboratory will allow researchers to gain remote, shared access to experimental equipment and data. The system integration effort was led by the National Center for Supercomputer Applications, headquartered at the University of Illinois at Urbana-Champaign, and was a collaborative effort with a consortium of other universities and national laboratories (NSF Grant CMS-0117853). A suite of software services has been developed, including web interfaces, data acquisition and streaming services, visualization, data repository and management, and telepresence services. The services being implemented support secure and dependable access to NEES resources and allow the sharing, access, and utilization of NEESgrid data repository.

NEESit has taken on the task of continuing this effort. Based at the San Diego Supercomputer Center (SDSC), NEESit is a service-focused organization created to deliver information technology tools and infrastructure to enable earthquake engineers to remotely participate in experiments, perform hybrid simulations, organize and share data, and collaborate with colleagues (NSF Grant CMS-0402490). The support of NEES users to facilitate earthquake engineering research is a core value of NEESit. To this end, NEESit has pursued outreach and training strategies to promote learning and communication amongst the IT and earthquake engineering communities. In March 2006, NEESit released a greatly enhanced public website. The site now features transparent paths for its audiences to find information about NEESit software, services and activities as well as a variety of learning tools for support and training purposes. Future plans include the development of an on-line Knowledge Base to provide a means to discover solutions to issues and questions that have known solutions which can be then re-applied by others less experienced in the problem area.

**Examples of Prior EOT Activities**

There are a number of education, outreach and training activities that have been developed within the NEES framework prior to the development of an execution plan. Here, two examples of such activities that revolve around laboratory experiments involving hybrid testing/simulation and tele-operation across the NEESgrid are discussed briefly.

**The Mini-Most Experiment**

To illustrate the capabilities of the various NEESgrid services and to aid in the training of students for participation in experiments, the Mini-MOST (Multi-site Online Simulation Test) experimental set-up, which consists of a steel beam anchored at one end, was developed at the University of Illinois by the System Integration team (CMS-0117853, [http://wusceel.cive.wustl.edu/mini-most/](http://wusceel.cive.wustl.edu/mini-most/)). The Mini-MOST experimental hardware is small in size and can be easily packaged and shipped to experimental sites (see Figure 2). A multi-site experiment involves a simulation coordinator for the overall experiment which interacts (sends actions and receives messages) with computational and experimental modules through the NEESgrid Tele-Operation Control Protocol (NTCP) (see Figure 3). Mini-MOST represents an inexpensive
but comprehensive platform for students to interact and learn about the NEESgrid services without costly utilization of full scale research equipment. This reference implementation also provided a means for NEESgrid software developers to see how the software and hardware components interact. A number of user sites have been established with mini-MOSTs.

Remote Instructional Shake Table Operation
In 1998 Prof. Dyke facilitated the deployment of 22 instructional shake tables (see Figure 4) to universities affiliated with the three national earthquake centers in the US through an NSF-CCLI project (Grant DUE-9950340). The equipment consists of a Shaker II (STII), a bench-scale seismic simulator with a 46x46 cm slip-table driven by a ball-screw mechanism with an operating frequency of 0-20 Hz, a +/-7.6 cm stroke and a peak acceleration +/-1 g with an 11.3 kg payload. The STII interfaces with a PC through the Quanser Q4 board and is controlled using WinCon real-time software. This equipment is ideal for educational uses, and has also been implemented for K-12 outreach [8], demonstrations, and small research projects [2, 9].

Tele-operation, remotely controlling the UCIST shake tables using the NEES cyberinfrastructure, was first accomplished by Prof. Richard Christenson in December 2004. More recently, an expansion of this effort has been undertaken involving tele-participation, streaming of data and video through NEES cyberinfrastructure tools. For this implementation, the instructional shake tables are connected to the NEES cyberinfrastructure by configuring the STII control PC and a MATLAB configured NTCP machine. Both methods of tele-operation for the STII shake tables have been accomplished [9]. Tele-operation using a java applet allows for remote control of the shake tables from any PC over the internet.

Tele-operation of the STII shake tables was demonstrated by two REU students, Leah Loebach and Chris Ward, working as participants in the NSF-sponsored Research Experiences for Undergraduates in Japan in Advanced Technologies (REUJAT, NSF EEC-0243809) program during the Summer of 2005. The focus of the students’ international research was to setup and conduct a multi-site test, controlling one STII shake table in Colorado and a second in Tokyo (Nihon University, Professors Kazuto Seto and Toru Watanabe), to examine the effect of soil-structure interaction on the performance of a passive structural control strategy. In addition to tele-operation, the students used the NEES collaborative environment to communicate and share data.

Tele-participation through the NEES cyberinfrastructure has also been demonstrated with this experiment and allows for synchronized streaming video and data to be extracted from and input into the STII shake table operations through Data Turbine. Data Turbine, also known as the Ring Buffer Network Bus (RBNet), is the data management tool used by NEES to synchronize and buffer video and data for tele-observation. Data turbinet is also a feature linked to the software for the shake table operation using the NEESpop. The NEES Real-time Data Viewer (RDV) is then used to view the time synchronized streaming video and data from any PC over the internet. Figure 4 is a snapshot of the streaming video and data from the STII shake table displayed through RDV.
The role of the engineer in society is changing drastically. Financial, cultural and technological borders across nations are becoming increasingly transparent. The problems the world will face in the not-so-distance future (e.g., pollution, sustainable energy, potable water and natural resource shortages, transportation needs, aging population, etc.) will require the creativity and expertise of a new generation of engineers. To compete in the global, technological society of the future, students must be well prepared to enter Science, Technology, Engineering and Math (STEM) fields [11].

The development of the NEES cyberenvironment provides a unique opportunity for the implementation of an innovative education and outreach program. NEES is a premier cyberinfrastructure project and, as such, provides a means to engage students at all levels through applied and realistic learning experiences. The availability of real-world data and video, combined with advanced collaborative software and tele-participation capabilities, provides an opportunity for NEES to play a unique and significant role as a leader in building a virtual educational laboratory.

The Execution Plan provides a roadmap for making progress toward the goals of the NEES EOT Program. This roadmap lays the groundwork for exploitation of the NEES capabilities, data and cyberinfrastructure to provide unique and attractive learning opportunities for students at all levels — from K to Practitioner. Effective implementation of the EOT plan will require input from a variety of sources to ensure that activities are created and implemented that meet performance based teaching standards and attract the broadest participation of all learning styles. Thus, many of the EOT activities described herein are being pursued in partnership with agencies, investigators, and organizations with a strong interest in the education of the next generation of engineers and scientists. For each of the constituencies, priorities are discussed that have been identified, potential partners for each activity, anticipated time frames, means for targeting the participants, and possible mechanisms for funding high priority, targeted activities. Additionally, opportunities will be sought to leverage funding to achieve the broad mission of NEES. Efficiency of scale will be sought through the coordination and integration of the activities and products to the benefit of NEES as a whole to both avoid duplication and to enhance the value proposition for all participants.

Evaluation is also an essential component of the plan and should be pursued from the very beginning. Each element (project) of the EOT plan will have an evaluation component, and the impact of the EOT plan as a whole will also be evaluated. Therefore, NEESinc EOT staff will partner with an evaluation expert to develop a strategy for assessment of the activities. The strategy should focus on developing the metrics, selecting methods to be employed in the assessment, and identifying data required for an assessment of the complete NEES EOT plan so that a framework can be put in place as soon as possible for collecting, analyzing and reporting of the necessary data. Essential to the evaluation process will be the continued feedback from the evaluator to NEES to improve and revise the EOT tools and plan over the years.

Dissemination of the NEES EOT activities to additional organizations, universities, and cyberenvironments is also an important aspect of the plan. Effective dissemination requires not only providing the tools and materials, but in some cases requires the provision to provide training on the use of these components, i.e. professional development activities. For instance providing teaching materials in the form of a K-12 module is not useful unless teachers have appropriate district and school administrative curricular enhancement support and are able to convey the material appropriately. Training guidelines and/or workshops should be developed in parallel with any activity that would require specialized training to fully utilize and deploy. Partnerships with organizations that can reach the appropriate audiences will be particularly helpful in this task. Whenever possible, electronic EOT
materials should be made available in a metadata format (metamanagement.comm.nsdlib.org/outline.html; including exercises, sample data, video footage, etc) that can be indexed and cataloged in the National Science Digital Library (www.nsdlib.org). Throughout the program opportunities for securing additional funding to maintain these activities beyond the 10 year NSF funding period will be sought.

The goals of the NEES EOT program, as stated in the original EOT Strategic Plan, as shown in Table 1 [1]. In developing the Execution Plan, these goals have been integrated and refined, resulting in the following set of deliverables. The deliverables of the NEES EOT Plan are to:

- Provide a framework for the establishment of programs and activities that will contribute to the education of students at all levels from K to practitioner, and that NEESR and NSF PIs can build upon and plug into;
- Through the innovative use of cyberinfrastructure, develop a matrix of educational modules and activities that fully utilize these tools for the education and training of the constituents;
- Develop appropriate tools for K-12 students that are aligned with curricular guidelines that meet local teaching and learning standards, while providing the teachers with the professional development necessary to instruct using the materials;
- Establish activities that are suitable for engaging undergraduates and graduate students in NEES research activities;
- Impact the current state of practice by engaging engineers in NEES activities through the development and offering of real-world, hands-on and exciting learning opportunities;
- Conduct formative and summative evaluation of the program to provide ongoing feedback on the efficacy and impact of the activities on the constituents served; and
- Disseminate the outcomes of the program through appropriate media such as the National Science Digital Library (NSDL) and Newspapers in Education (NIE) etc.

Priorities have been identified by the NEESinc EOT Committee for each of the constituencies. These activities will be pursued and executed by the external PIs, the NEESinc staff and partner organizations and individuals. In addition NEESit will play a significant role in the execution of EOT activities through partnerships with other investigators as well as their detailed plans for training and outreach.

At the undergraduate level, the top priority is to implement the recently funded REU program within the NEES framework (CMS-0552992) to engage undergraduate students in state of the art research activities at the NEES sites. Other priorities include: the development of teaching modules suitable for undergraduates and utilizing the NEES cyberinfrastructure; national design competitions; modules for non-engineers (future teachers); international experiences for students; and internships with partners.

Priorities for graduate students are threefold: research, education, and professional development; opportunities and activities related to these three key thrusts are very much intertwined. Many of the research activities will occur naturally through graduate student participation in NEESR projects. Through NEESR activities, international research/education trips and student exchanges, i.e. semester or year, shall be encouraged. The NEESR environment lends itself very well to Fellowship opportunities through existing programs at NSF, for instance. NEESR projects are expected to serve as a rich source for graduate level course module development or enhancement of existing course modules. Educators may choose to take advantage of NEES multi-site experiment capabilities for demonstrations or student projects. Furthermore, cross-institutional courses may be developed; a positive by-product will be a community of scholars. This community will also serve as a strong base for the students’ professional networks as they embark on their own careers. A student organization and leadership council will be a more formal mechanism, i.e. environment, for students to share and exchange ideas, and to encourage professional friendships that

### Table 1

| Education | E1 | Promote and support the use of NEES Equipment Sites, NEESit tools, research and research results in undergraduate, graduate and K-12 education through development of an active NEES educational community. |
| Outreach | O1 | Promote interaction of practitioners with researchers and transfer of results of NEES research into practice through an active NEES professional community |
| Outreach | O2 | Promote NEES by disseminating information about NEES laboratory facilities, tools, research activities and research results |
| Outreach | O3 | Increase the pool of outstanding and diverse students interested in earthquake engineering and supporting disciplines by taking advantage of NEES activities |
| Outreach | O4 | Advance earthquake engineering research by partnering with other organizations to identify and promote community needs in the areas of engineering, information technology, education, outreach, and public policy |
| Training | T1 | Promote participation in NEES by providing training in the use of NEES Equipment Sites and telepresence, collaboration, data archiving, analysis, visualization, and simulation tools |
will extend beyond NEES throughout their careers.

At the K-12 level, activities such as technical tours at the facilities have dominated the events to date. Plans for future activities include: modules for informal and formal educational experiences; Research Experiences for Teachers program; workshops for K-12 teachers to develop professional skills related to the modules provided; programs to inform parents about STEM careers; and, research programs for high school students.

Outreach to the public-at-large is also a priority of NEES. Plans include: the development of on-line activities to provide a layman’s perspective of the NEES equipment sites; informal activities for museums after establishing appropriate partnerships; and, the establishment of a public policy working group. Another focal activity will be to articulate the pathway to advanced study in STEM careers. This information will be particularly beneficial to parents having an interest in getting their children involved in math and science at an early age so that they are prepared to enter the STEM workforce.

Training activities are essential to the success of NEES. To be an active participant in NEES, users must be familiar with the equipment at the sites, the IT infrastructure, the data repository, and the simulation tools, as well as state-of-the-art techniques for instrumenting specimens and collecting data. So far these outstanding training workshops have been developed independently. Each equipment site has developed its own material using its own staff, without oversight from NEESinc. NEESit has also hosted a series of workshops and training sessions targeting users of NEES software and services, both earthquake engineering researchers and professionals. Some of these have also involved the international research and education community. The Execution Plan calls for the NEES equipment sites, NEESit and NEESinc will develop some guidelines for training materials that would promote both consistency and dissemination. A top priority is to develop a system to track and announce these training events.

NEES priorities for practitioners are extensive in that the research outcomes of the entire NEES community must address the needs of designers, i.e. practitioners. This objective can be achieved through the design code community, many of which are also NEES researchers. In addition, a robust effort to provide research finding in society newsletters and at meetings should be pursued in an organized fashion. This effort could include a monthly article in the EERI newsletter, or even a newsletter specifically devoted to NEES EOT. In order to provide a mechanism for practitioner involvement, interaction, and most importantly collaboration, web-based educational modules could be developed that allow the designers to receive professional development credits online and are linked with experimental results. The nature of NEESR experiments is such that some of the tests are landmark tests in that they present a unique opportunity for practitioners to observe, participate, learn, and teach. Such an experimental effort should be coupled with a symposium for practitioners that will allow them to link their understanding of design and implementation to the experiments.

To date a few of the activities within the EOT Plans are underway. The NEESreu program has just been formally funded by the NSF. NEESinc will centrally coordinate access for approximately 15 upper-division undergraduate students annually to participate in one of several “REU Tracks” offered at the 17 NEES REU locations known as “node sites.” The node sites consist of the 15 NEES Experimental Sites (ES) located at top engineering research universities throughout the nation, NEESit, and the NEESinc Headquarters located in Davis, CA. In the summer of 2006 three node sites will include: NEESit at the University of California, San Diego, and equipment sites at the State University of New York, Buffalo, the University of California, Davis, and Lehigh University. Additional activities that are now underway include: the feasibility of an engineering AP course module related to earthquake engineering; the implementation of e-portfolios for student tracking; and, the formation of a collaboratory on the development of undergraduate modules for education using the experimental remote capabilities of the bench-scale shake tables.

Because several of the activities would benefit from the leveraging of resources and sharing of developed materials, at every appropriate opportunity strong consideration will be given to the strategic and tactical integration of programmatic components. The tools and materials developed within one project may be useful for scaling up of the activities of the PIs and partners on other complementary and synergistic projects. Two exemplar activities have been identified that illustrate the role of education, outreach and training across grade levels and constituencies, such as: i) instructional bench-scale shake tables with remote operational capabilities across the NEES network, and ii) toolkits to facilitate the development of online modules. For example, the instructional shake tables initially would be used at the undergraduate level for experiments (remote and local) and for design competitions nationally. In addition, activities for practitioners would benefit by using scaled representations of key concepts using controlled test specimens.

Furthermore, the NEES toolkit for developing online experiments is envisioned to be a robust toolkit, with new instruments and features added through continual development and testing. The initial tools will provide the foundation for their development. The initial toolkit will focus on K-12 level students and will be opensource. Subsequent projects will leverage these opensource tools to progressively add complexity and dimension to the set of tools and the toolkit. The modular tools in combination with and integrated toolkit will be useful in the development and refinement of NEES centric educational materials for kindergarten through to practitioners.
REMARKS

The NEES Education, Outreach and Training program will leverage the geographically-distributed network of world-class experimental facilities, its connecting cyberinfrastructure, and its extended community of engineering and cross-disciplinary faculty from academic programs across the nation to provide its constituents with exceptional learning opportunities. Tools available for remote control (tele-operation) and viewing and analysis of streaming data and video (tele-participation) will play a significant role in these activities. Most of these tools are open-source and are being continually updated and improved. Additionally, the availability of high-quality, real-world data is a clear strength of the program that will be exploited for the benefit of students at all levels.

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