Construction, Operation and Application of the George E. Brown, Jr. Network For Earthquake Engineering Simulation

by

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ABSTRACT

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) recently funded by the National Science Foundation is described in this paper. Its origins, the current awards and the management of NEES is discussed. Plans for the usage of this system in large-scale research studies also are discussed.

1.0 INTRODUCTION

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a major investment in the study of structural, geotechnical, hydraulic and infrastructure systems and their response to earthquake excitation. The NEES system is now in its final 18 months of construction and will be fully operational on October 1, 2004. Once operational, the NEES Laboratory will link researchers across the United States and the world, enabling collaboration on a scale not possible in the past.

This paper is a summary of the current status of the initiative and the plans for future use of this unique shared use system, a first of its kind in the United States.

2.0 THE INVESTMENT

NEES was developed by the National Science Foundation (NSF) based on input from the Community as to earthquake engineering experimental equipment needs as well as supportive Congressional testimony and support from the four NEHRP agencies (National Earthquake Hazards Reduction Program) that include FEMA (Federal Emergency Management Agency), NIST (National Institute for Standards and Technology), NSF, and USGS (US Geological Survey). A total of $82 million dollars (USD) was appropriated by the US Congress to fund the NEES initiative as part of a Major Research Equipment and Facilities Construction (MREFC) initiative. This is the first such large installation that has been funded by the NSF Engineering Directorate and was approved by the National Science Board in November 1998. The initial solicitation called for proposals to establish NEES equipment sites at universities within the United States as part of a Phase 1 effort. There also were solicitations for Phase 2 equipment sites, for a system developer to establish the information technology necessary to connect the sites with state-of-the-art Internet 2-based communications software and lastly for a consortium to manage the system.

The goals for NEES were to develop a system to integrate resources for research and education to serve the earthquake

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engineering community. The resources include shared use experimental facilities, data repository, simulation tools, collaborative/communication tools, leading edge computation, and model-based simulation capability.

The goals for NEES can be summarized by these items from the NEES.org website:

- Improve the seismic design and performance of our Nation's civil and mechanical infrastructure systems.
- Use advanced experimental and simulation capabilities to test and validate more complex and comprehensive analytical and computer numerical models.
- Provide end-to-end system connectivity to operate distributed experimental research equipment, including teleobservation and teleoperation, and to enable computation and distributed simulation for earthquake engineering experimentation.
- Provide researchers with remote access to a curated repository of databases, user-developed simulation software, and models for use in model-based simulation and visualization through access to a computational grid.
- Form an integrated network that facilitates interdisciplinary global collaboration among scientists and engineers.
- Enable participation from a broader earthquake engineering community, including educators, students, practitioners, and public sector organizations and individuals, who will have access to the equipment, data, models and software from NEES.

Proposals were sought by NSF from the research community in the following broad categories:

a. Shake table research equipment
b. Centrifuge research equipment
c. Tsunami/wave tank research equipment
d. Large-scale laboratory experimentation systems
e. Field experimentation and monitoring installations
f. System Integration

Proposals were reviewed and awards made. The system now is under contract with all sites actively working towards operational status. The sites that have been selected for awards are as follows:

Shake Table Research Equipment

- Award CMS-0217293
  "Large High Performance Outdoor Shake Table Facility"
  University of California, San Diego
  Frieder Seible, PI
  $5,890,000 NEES Project Web Camera:
  http://cecam.hpwren.ucsd.edu

- Award CMS-0086624
  "Development of a Biaxial Multiple Shake Table Research Facility"
  University of Nevada, Reno
  Ian Buckle, PI
  $4,398,450
  NEES project home page:
  http://bric.ce.unr.edu/nees/nees.htm
  Major equipment: Three (two upgraded) 4.3 m x 4.5 m biaxial (H-H) shake tables with two moveable, in-phase or uncorrelated motions, total specimen capacity of 1.35 MN.

- Award CMS-0086612
  "Versatile High Performance Shake Tables Facility towards Real-Time Hybrid Seismic Testing"
  State University of New York, University at Buffalo
  Michel Bruneau, PI
  $6,160,785
  NEES project home page:
  http://nees.buffalo.edu
  Major equipment: Two (one upgraded) 3.6 m x 3.6 m, 6 DOF shake tables (one moveable 50 metric ton, 100 Hz capacity), in-phase or uncorrelated motions, total specimen capacity of 100 metric tons.

Geotechnical Centrifuge Research Equipment

- Award CMS-0086566
  "A NEES Geotechnical Centrifuge Facility"
  University of California, Davis
  Bruce Kutter, PI
  $4,614,294
  NEES project home page:
  http://cgm.engr.ucdavis.edu/NEES
  Major equipment: Upgrades to existing centrifuge to enable operation up to 80 g, 2D H-V shaker, 4 DOF in-flight robot and MEMS accelerometers.

- Award CMS-0086555
  "Upgrading, Development and Integration of Next Generation Earthquake Engineering Experimental Capability at Rensselaer's 100 g-ton Geotechnical Centrifuge"
  Rensselaer Polytechnic Institute
  Ricardo Dobry, PI
  $2,380,579
  NEES project home page:
  http://www.ce.rpi.edu/centrifuge
  Major equipment: Upgrades to existing centrifuge with 2D H-H shaker, 4 DOF in-flight robot and MEMS accelerometers.

Tsunami Wave Basin

- Award CMS-0086571
  "Upgrading Oregon State's Multidirectional Wave Basin for Remote Tsunami Research"
  Oregon State University, Corvallis, Oregon
  Solomon Yim, PI
  $4,775,832
  NEES project home page:
  http://nees.orst.edu
  Major equipment: Upgrades existing wave basin to 3D tsunami testing facility, 48.8 m x 26.5 m x 2.0 m, wave maker, extensive sensors and imaging, comprehensive information architecture to support remote users, and tsunami experiment databank.

Large-Scale Laboratory Experimentation Systems

- Award CMS-0217366
  "Large Displacement Soil-Structure Interaction Facility for Lifeline Systems"
  Cornell University
  Harry Stewart, PI
  $2,072,716
  NEES project home page:
  http://nees.cornell.edu

- Award CMS-0217393
  "Real-time Multi-directional Testing Facility for Seismic Performance Simulation of Large-Scale Structural Systems"
  Lehigh University
  James Ricles, PI
  $2,593,317
  NEES project home page:
  http://nees.atlss.lehigh.edu

- Award CMS-0086611
  "Large-Scale High Performance Testing Facility towards Real-Time Hybrid Seismic Testing"
  State University of New York, University at Buffalo
  Michel Bruneau, PI
  $4,379,865
  NEES project home page:
  http://nees.buffalo.edu
  Major equipment: Three 100-ton dynamic actuators, two 200-ton static actuators, hydraulic pumps, digital control system

- Award CMS-0086621
  "Reconfigurable Reaction Wall-Based Earthquake Simulator Facility"
  University of California at Berkeley
  Jack Moehle, PI
  $4,268,323
  NEES project home page:
  http://nees.berkeley.edu
  Major equipment: Reconfigurable reaction wall blocks (14 - each 3.3m x 5.2 m), seven dynamic and static actuators, high performance digital control system. Equipment used to develop new hybrid testing methods.

- Award CMS-0086592
  "Fast Hybrid Test Platform for the Seismic Performance Evaluation of Structural Systems"
  University of Colorado, Boulder
  P. Benson Shing, PI
  $1,983,553
  NEES project home page:
  http://ceae.colorado.edu/nees
  Major equipment: High speed actuator, 980 kN, +/- 120 mm stroke, 950-lpm servo valve with max. velocity of 120 mm/sec; upgrade two 490 kN actuators, +/- 120 mm stroke, with 950 lpm servo-valves to attain 450 mm/sec velocity; three channel digital controller; 32-channel data acquisition system

- Award CMS-0086602
  "A System for Multi-Axial Subassemblage Testing (MAST)"
  University of Minnesota-Twin Cities
  Catherine French, PI
  $6,472,049
  NEES project home page:
  http://www.ce.umn.edu/mast
  Major equipment: MAST system consisting of cross heads (large steel weldments for the top and bottom reaction surfaces), digital controller with 6 DOF control system, and high performance actuators.

- Award CMS-0217325
  "Multi-Axial Full-Scale Sub-Structuring Testing and Simulation Facility"
  University of Illinois at Urbana-Champaign
  Amr Elnashai, PI
  $2,958,011
  NEES Project Home Page:
  http://cee.uiuc.edu/research/nees

Experimentation and Monitoring Installations

- Award CMS-0217421
  "Permanently Instrumented Field Sites for Study of Soil-Foundation-Structure Interaction"
  Brigham Young University
  T. Leslie Youd, PI
  $1,944,423
  NEES Project Home Page:
  http://nees.crustal.ucsb.edu/

- Award CMS-0086596
  "Field Testing and Monitoring of Structural Performance"
  University of California, Los Angeles
  John Wallace, PI
  $2,652,761
  NEES project home page:
  http://www.cee.ucla.edu
  Major equipment: One omni-directional and two uni-directional eccentric mass vibrators, one linear inertial shaker, cone penetration truck (seismic piezocone, 20-ton hydraulic push capacity, side augers, and in situ-soil vibration sensors)

- Award CMS-0086605
  "Large-Scale Mobile Shakers and Associated Instrumentation for Dynamic Field Studies of Geotechnical and Structural Systems"
  University of Texas at Austin
  Kenneth Stokoe II, PI
  $2,937,036
  NEES Project Home Page:
  http://www.geo.utexas.edu/nees
  Major equipment: One 3-D mobile shaker, 2 cubical stand alone 3D shakers, instrumentation van with field equipment and multi-channel data acquisition and processing system.

NSF 00-7, NEES: System Integration

- Award CMS-0117853
  "NEESgrid: A Distributed Virtual Laboratory for Advanced Earthquake Experimentation and Simulation"
  University of Illinois at Urbana-Champaign
  Daniel Reed, PI
  $10,000,000
  NEES Project Home Page:
  http://www.neesgrid.org.

- Award CMS-0004246
  "Earthquake Engineering Research Community Workshop"
  University of Illinois at Urbana-Champaign
  Thomas I. Prudhomme, PI
  $89,100
  Workshop Report:
  http://www.neesgrid.org

NSF 01-56, NEES: Consortium Development

- Award CMS-0126366
  "George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) Consortium Development Project"
  Consortium of Universities for Research in Earthquake Engineering
  Robert Reitherman, PI
  $1,999, 907
  NEES project home page:
  http://www.nees.org

In addition to the awards listed above, additional funding is being provided by NSF to assist the NEES equipment sites in developing their local information technology infrastructure. This funding is in addition to the specific equipment and the overall system integration awards

Two studies have been awarded to provide NSF with input as to future usage of the NEES system:

Developing a Long-Term Research Agenda for the Network for Earthquake Engineering Simulation, Richard Little, PI, National Academy of Sciences, rlittle@nas.edu

The Earthquake Research Plan: Research Needs and Opportunities for Earthquake Engineering, Susan K. Tubbesing, PI, Earthquake Engineering Research Institute, skt@eeri.org

Results of the EERI study is available from EERI; the NAS study will be published

shortly. These studies will be utilized by NSF and by researchers in the development and selection of research topics for study using NEES.

It can be seen that there are three shake table facilities (UCSD, Reno and SUNY-Buffalo); one tsunami facility at Oregon State, three filed monitoring awards (UCLA, BYU and UT-Austin), two geotechnical centrifuge facilities (UC-Davis and Rensselaer), one award for system integration (Illinois) and seven large equipment sites (Colorado, Minnesota, UC-Berkeley, SUNY-Buffalo, Illinois, Lehigh and Cornell), Figs. 1-4. A total of 16 equipment awards at 15 different equipment sites, all at universities, plus awards for the overall system integrator and for NEES system management were made. At this time there are three sites that are operational, including the facilities at UN-Reno, Rensselaer and the tsunami facility at Oregon State.

In terms of the equipment, briefly the system provides the capability of examining performance of large systems-level problems. The three shake table facilities each have unique capabilities. UCSD is building an outside shake table facility that will have no headroom or crane limitations. Moreover, a soil pit is located adjacent to the table to enable studies of soil-foundation-structure interaction issues. The Reno and Buffalo facilities have the ability to input differential movements on the various tables (two at Buffalo and three at Reno). These movement permit study of motions exciting bridge piers and similar large structures where input motions are not identical at each support location.
The centrifuge facilities and tsunami tank provide abilities to study soil behavior and tsunami effects. The filed systems permit detailed monitoring of shaking and other attributes of soil or structural sites in real time. The large equipment sites provide servo-hydraulic actuator capabilities with advanced control features to impose motions, or forces, on structural elements.

The unique aspect of this overall system is that the telepresence and teleobservation features permit researchers to monitor testing conducted at another site in real time. Moreover, motions from one test can be imposed on another test specimen at another site. This permits large scale tests coupled with more detailed component tests of subsystems at other sites. The computational capabilities of the sites also permit researchers to substructure large systems so as to compute displacements and rotations of subassemblies and to impose these movements on test specimens at their or other sites. These capabilities are collectively referred to as NEESgrid and represent a significant advancement in distributed connectivity to permit real time data and audio and video communication. The system is schematically shown in Fig. 5.

3.0 NEES – A NEW APPROACH TO RESEARCH

The NEES Laboratory provides a large investment in state-of-the-art equipment for the various equipment sites. What is revolutionary is the collaboratory that also is set in place as part of NEES. With the IT system, the NEES equipment sites, as well as researchers worldwide are able to participate in research and to share and view results in real time. It will be possible for remote collaborators to participate actively in experiments in real time – to witness and even control testing as it occurs through telepresence features of NEES. Moreover, as part of the system, researchers are required to post results and to *share* data. This will permit greater usage of test results from those directly involved, as well as independent studies that may follow. All data will be placed in an archive to permit long-term storage and retrieval. Lastly, NEES will permit the use of secondary, or payload, experiments. Here tests will include nonstructural items such as sensors and transducers, mechanical systems and other important nonload carrying systems that may be tested as part of the overall structural testing. It is hoped that in this

way, next generation sensors and other new technologies may be developed and tested.

The NEES system will operate over the ten-year period from October 1, 2004 through September 30, 2014. Additional support will be provided by NSF during this ten year period to help the equipment sites operate and maintain this virtual laboratory. These funds will be separate from any research funding or other equipment awards from NSF.

A major part of the NEES system does not involve technology but people. The system provides a means for researchers anywhere in the world to actively participate in research. The integrated nature of the system and the NEESgrid infrastructure will permit researchers to truly collaborate with colleagues who may be located at other equipment sites, US universities or other institutions where there are no NEES awards, and with colleagues outside the United States. It becomes a truly universal laboratory that is not limited by the constraints of time or place.

Management issues with NEES also are significant. Figure 6 shows the NSF management team that is in place to manage this project. The team is located within the Civil and Mechanical Systems Division of NSF and draws on input from the various program directors within CMS. Research funding for NEES projects is being developed separate from the NEES project team but also within CMS, and draws on input from the NEES team. Figure 7 shows the overall NSF management plan during the 10 year operational period of NEES.

4.0 APPLICATION OF NEES IN RESEARCH

At the present time, NSF is preparing a major solicitation for research proposals to utilize the NEES System. This solicitation for NEES research will invite researchers to propose studies of three levels support: Individual Investigator Awards, Small Group Awards and Grand Challenge Awards. These awards range from small individual studies to larger systems investigations:

Individual Investigator Awards will be studies of a specific problem that will involve some level of experimental work at a NEES site. These projects are anticipated to be three years in duration. One or more principal investigators may be involved.

Small Group Awards will be made for larger projects that involve colleagues from more than one institution or organization. These problems will be of larger size and will involve usage of at least one NEES facility plus use of experimental facilities at other sites. More than one principal investigator will be involved. These awards will be of up to four years in duration.

Grand Challenge Awards will be made for large systems level projects that attack important problems that have not been studied previously. These projects will utilize the full capability of the NEES system and will involve many colleagues at a variety of institutions and will utilize testing facilities at NEES and other laboratories. Grand Challenge problems will be multidisciplinary in nature to examine *system* response. These large awards will be of up to five-year duration and will require a broad constituency to be involved. Colleagues from NEES and other facilities are required, as is representation from institutions from other geographical regions of the United States. Projects funded as Grand Challenge problems will be seminal in nature, that is, projects will be of a size and scope that a significant advance in the state of knowledge will be achieved. Incremental studies will not be funded as Grand Challenge problems.

In all of these awards, proposers are encouraged to involve underrepresented groups in the research teams. Colleagues from institutions not normally involved in earthquake engineering research are

encouraged to be included in these teams. Thus PI's from undergraduate, minority or from other schools that have not had a significant role in earthquake engineering research are strongly encouraged to be involved. These requirements are in addition to the typical goals of including colleagues from underrepresented groups that include racial, social and gender considerations.

In this way, NSF is attempting to put in place a system that will enable participants from across the United States to be involved. The technical limitations are being removed via the technology that is being employed. Social limitations are being removed by the proposal rules in place so that no one region, university system or NSF-sponsored engineering center will be permitted to solely submit proposals as Grand Challenge projects.

Funding levels for these projects are to be based on availability of funds. It is anticipated that significant new levels of funding will be required to sustain NEES-related research during the 10-year operation period overall and above current funding levels within CMS. The Grand Challenge projects are anticipated to be funded at levels up to $1.4 million per year over the five-year term. Support from the Community will be critical to ensure that the support for NEES research in terms of increased funding for earthquake engineering research will continue to be maintained during this 10 years of NEES operation.

One particular aspect of this new research tool is the role of international laboratories in NEES. Research. It is hoped that colleagues from institutions outside the United States will be interested in participating in NEES research. While NSF funding cannot directly go to support research in non-US locations, there is the strong interest within NSF and the Community to have colleagues from international locations actively participate via NEESgrid and related IT tools. Thus NEES becomes a truly international resource in which colleagues, no matter where they are located, can observe experiments, share data and fully participate in research at one or more of the NEES sites. International laboratories will have to opportunity to essentially become nodes on the NEESgrid so that geography will be eliminated and that the best possible research teams can be formed to tackle important research problems.

5.0 THE US-JAPAN JOINT PANEL AND NEES

The introduction of NEES as a research tool offers significant possibilities for future collaboration between institutions in Japan and the United States. One can easily foresee a series of connection points to NEES, or so-called "NEES nodes," that lay both inside and outside of the United States. While these international nodes will be funded by the appropriate "local" funding agency, the technical connection and interoperability of systems can be readily achieved. The possibility of having colleagues in the US work together with colleagues from other countries is an outcome of NEES that the Joint Panel should encourage. In particular, the strong cooperation of the research communities in Japan and the US over the years should serve both as a model and as a vehicle to empower this cooperation. The evaluation of different solutions developed in Japan and the US in response to common problems can be a very useful aspect of future research using NEES.

The role of Task Committee B in NEES also can be significant. The charge of the Committee is to promote the next generation of buildings and infrastructure technology. With the capability that NEES has, together with the focus of the upcoming NSF research solicitation, it is apparent that the goals of Task Committee B and of the NEES group within NSF are quite similar. Thus, it is important for Task Committee B to act as a mechanism to promote collaboration in

research among Japanese and American researchers. Moreover, Task Committee B – and the Joint Panel – can assist in helping to set the research agenda and to help identify the critical problems that the NEES System should be used to investigate.

6.0 CONCLUSION

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) funded by the National Science Foundation will be operational on October 1, 2004. It is hoped that NEES will usher in a new era in truly collaborative research, involving the entire earthquake engineering community from across the US and across the world. The equipment that is being installed at the various sites will provide resources to study systems-level problems that have not been studied before due to facility limitations. During the 10-year operational period, it is hoped that knowledge of how large-scale systems, and their components, respond to earthquake excitation will be significantly increased. The goal is to greatly expand knowledge and to significantly impact the state of the art in design of systems to resist earthquake excitation.

Figure 1. NEES Awards to SUNY Buffalo, UC San Diego and UN Reno

Figure 2. NEES Awards to UC Davis, Rensselaer, Oregon State and UC Berkeley

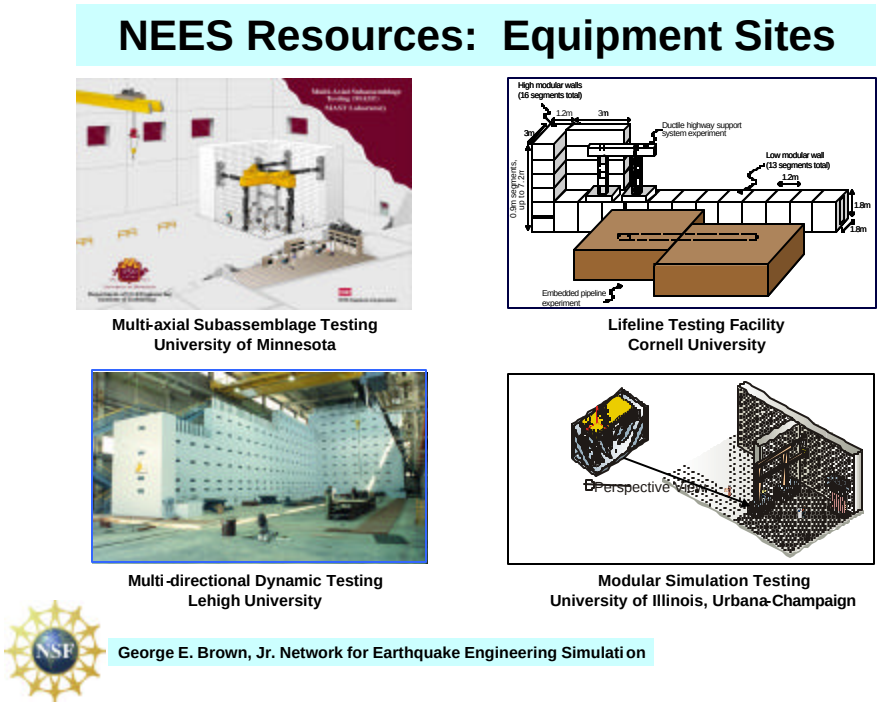

Figure 3. NEES Awards to Minnesota, Cornell, Lehigh and Illinois

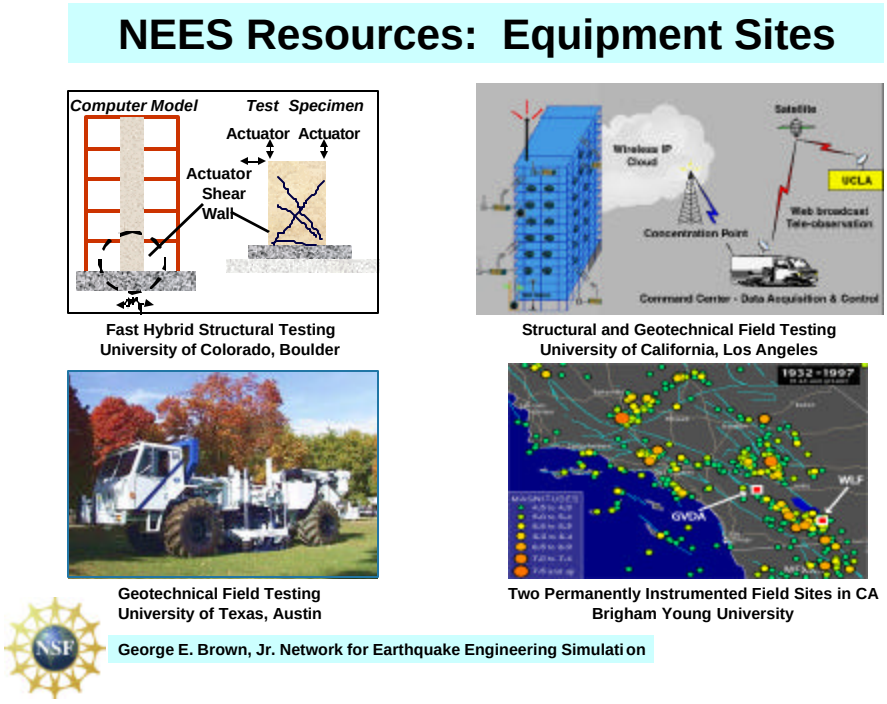

Figure 4. NEES Awards to Colorado, UCLA, UT Austin and BYU

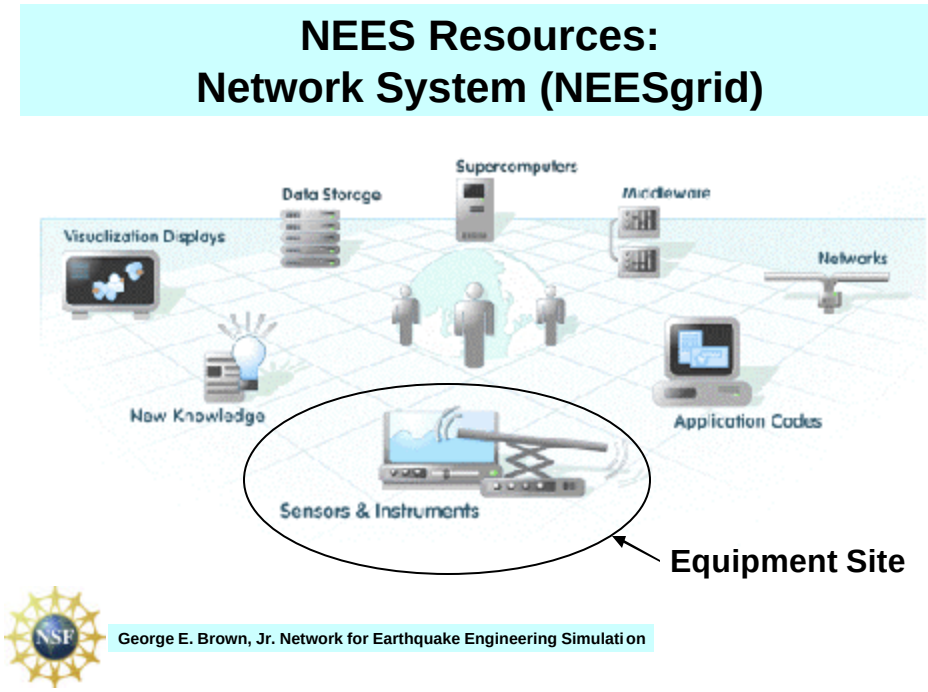

Figure 5. NEESgrid System

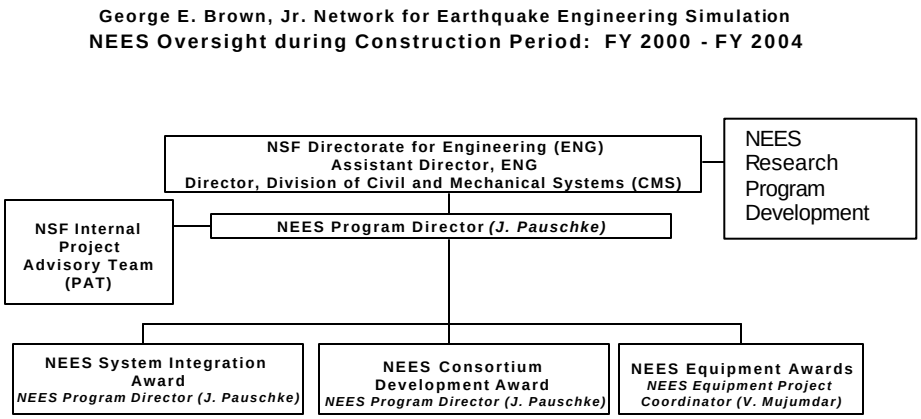

Figure 6. NSF Management Structure for NEES

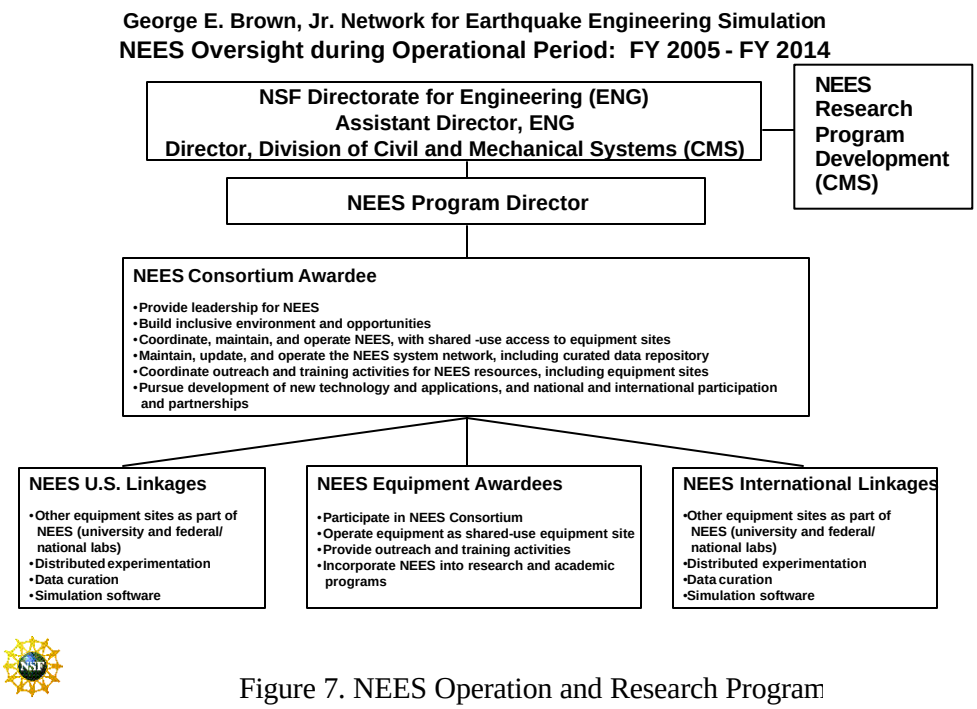

Figure 7. NEES Operation and Research Program