George E. Brown, Jr.
(1920-1999)

NEES is formally known as the George E. Brown, Jr. Network for Earthquake Engineering Simulation.

Congressman Brown was elected to the House of Representatives in 1962 and re-elected to seventeen more terms until his passing in July 1999 at the age of 79. His career was prominent for several reasons, including strong advocacy for racial and ethnic equality, environmental pollution controls, efforts to end the Vietnam War, research in alternatives to fossil fuel energy use, and space exploration.

With respect to earthquake engineering, the late Congressman Brown was a strong supporter of Federal funding for earthquake engineering research. In particular, he had an impact on engineering research programs as planned by the Office of Science and Technology Policy, a new Executive Office entity whose creation in 1976 he supported, and the National Science Foundation. He was the ranking Democratic member of the House Science Committee and served as its Chair. He was a champion of numerous NEHRP (National Earthquake Hazard Reduction Act) re-authorizations. Of all the Senators and Members of Congress from California, his tenure in office has been the longest. In the 1980s he was a Congressional spokesperson for the drive to advance the educational, engineering, information technology, and international collaboration programs within NSF, a confluence of four themes that is strongly present in NEES.

His wife, Marta Macias Brown, carries on the goal of improving the quality of science education and offering it more widely to students and science teachers as President of the Brown Foundation. The Brown Foundation was established in the Riverside/San Bernardino County area of Southern California where the late Congressman Brown’s home district was located.
TABLE OF CONTENTS

- Program
- President’s Welcome
- Message from the Executive Director of the NEES Consortium
- Speaker Bios and Abstracts
- NEES Consortium Board of Directors Roster
- NEES Consortium Committees
- NEES Equipment Sites
- Meeting Registration List
- Hotel Floor Plans
- Meeting Polling Results
Acknowledgements

<table>
<thead>
<tr>
<th>Organizing Committee for the 2004 NEES Consortium Annual Meeting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bob Reitherman, CUREE, Chair</td>
</tr>
<tr>
<td>Anke Kamrath, San Diego Supercomputer Center</td>
</tr>
<tr>
<td>José Restrepo, University of California, San Diego</td>
</tr>
<tr>
<td>Solomon Yim, Oregon State University</td>
</tr>
<tr>
<td>Andrew Neitlich, Organizational Consultant</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CUREE Staff Providing Support for the 2004 NEES Consortium Annual Meeting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reed Helgens, Operations Manager</td>
</tr>
<tr>
<td>Darryl Wong, Media Production</td>
</tr>
<tr>
<td>Leah Radke, Administrative Assistant</td>
</tr>
<tr>
<td>Doron Serban, Computer Graphics</td>
</tr>
</tbody>
</table>

Thanks to Todd Shechter of Oregon State University for on-site wireless services and technical support.
Program
WEDNESDAY, MAY 19, 2004

6:00-8:00 pm  Hosted reception with hors d’oeuvres, sponsored by MTS Systems Corp. – Beach North
Equipment Sites and SI project personnel will be available to discuss usage of NEES
with potential researchers. Early check-in for the meeting will also be available.

THURSDAY, MAY 20, 2004

7:15-8:15 am  Continental Breakfast & Meeting check-in

All Plenary Sessions to be held in the Kon Tiki Ballroom, Second Floor

8:15-8:30  Opening of Meeting and Agenda Overview: Ian Buckle, President, NEES Consortium

8:30-8:45  Welcome by NEES Consortium, Inc. Executive Director: Clifford Roblee

8:45-9:15  Welcome from NSF: Joy Pauschke, NSF NEES Program Director

9:15-9:45  The Shared Cyberinfrastructure Program: Sangtae Kim, Director, Division of Shared
Cyberinfrastructure, Directorate of Computer and Information Sciences & Engineering, NSF

9:45-10:15  NEES Research Solicitations: Steven McCabe, NEESR Program Manager, NSF

10:15-10:30  NIED E-Defense: Toru Hayama, Executive Director, National Research Institute of Earth
Science and Disaster Prevention - NIED E-Defense Facility and Plan for its Future Use

10:30-11:00  Break – Foyer, Second Floor

11:00-noon  NEES Equipment Site “Travelogue,” Part I: Shake Tables (UB-SUNY, U.Nevada-Reno,
UCSD); Mobile and Field (BYU/UCSB, U. Texas - Austin, UCLA)

noon-1:30 pm  Lunch – Aviary Ballroom, Second Floor

Guest Speaker: Kenneth Stokoe, University of Texas at Austin
The NEES/IRIS/USGS Workshop: Exploring the Potential of a Multi-Facility Approach to
Solving Scientific and Engineering Problems.

1:30-2:30  NEES Committee Updates and Live Wireless Polling of Members: Andrew Neitlich
   Education, Outreach, and Training: Thalia Anagnos, Chair
   Finance: Craig Comartin, Chair
   Data Sharing and Archiving: Andrei Reinhorn, Chair
   IT: Cherri Pancake, Chair
   Site Operations: Roberto Leon, Chair

2:30-3:00  Break – Foyer, Second Floor

3:00-5:00  NEES Committee Meetings (as assigned)

6:00-7:30  Banquet – Aviary Ballroom, Second Floor

Guest Speaker: Luis Esteva, President, International Assoc. for Earthquake Engineering
A Spectrum of Earthquake Engineering Challenges Around the World

[Following the banquet, NSF will convene a meeting of the “NEES Awardees,” i.e., awardees in the current development
phase of NEES—the NEES Equipment Sites, System Integration Project, and Consortium Development Project. The meeting
is not related to any NSF awards anticipated as a result of the NEES Research solicitation.]
FRIDAY, MAY 21, 2004

7:30-8:00 am  Continental Breakfast – Foyer, Second Floor

All Plenary Sessions to be held in the Kon Tiki Ballroom, Second Floor

8:00-9:30  NEES Equipment Site “Travelogue,” Part II: Tsunami (OSU); Large-Scale Structures (U. Illinois - Urbana-Champaign, Lehigh, U. Minnesota, UC-Berkeley, U. Colorado - Boulder); Large-Scale Lifelines and Geotechnical (Cornell); Centrifuges (RPI, UC-Davis)

9:30-10:30  Early Research Usage of NEES Equipment Sites

Cathy French
Roberto Leon
John Wallace
Sharon Wood

10:30-11:00  Break (w/ group photo on Beach South)

11:00-11:45  Committee Reports

Education, Outreach, and Training: Thalia Anagnos, Chair
Data Sharing and Archiving: Andrei Reinhorn, Chair
IT: Cherri Pancake, Chair
Site Operations: Roberto Leon, Chair

11:45-1:15 pm  Lunch – Multi-Purpose Room, First Floor

Guest Speaker: James Malley, President of SEAOC and Principal Engineer at Degenkolb Engineers – Speculating on the Potential Benefits of NEES Facilities and Resources to Applications in Engineering Practice

1:15-1:50  Community Input: Andrew Neitlich

Discussion and live wireless polling of the audience: Prioritization of NEES Consortium membership services, reactions to the first round of NEESR Solicitations/proposals, evaluation of this annual meeting, preferences for future meetings

1:50-2:30  Demonstration of New NEES IT Capabilities

Bill Spencer, System Integration Project, Technology Showcase of NEESgrid - The Nation's Virtual Collaboratory for Earthquake Engineering
Tarek Abdoun, RPI – NEES Interactive 3D Viewer & Visualization Tools

2:30-3:00  Break – Foyer, Second Floor

3:00-4:00  Building Bridges Between NEES and the Geoscience Community

Chaitan Baru, GEON: GEON: The Geosciences Network
Thomas Jordan, SCEC: Opportunities for NEES/SCEC Collaboration
William Leith, USGS and ANSS: NEES and the Advanced National Seismic System
David Simpson, IRIS and Earthscope: Opportunities for Partnership and Interaction

4:00-4:15  Closing:  Ian Buckle, NEES Consortium, President

SATURDAY, MAY 22, 2004

8:30 am  Depart Hotel for Field Trip to UC San Diego Equipment Site

11:00 am  Bus arrives at San Diego airport; then after this brief stop, it continues to the hotel where it arrives by 11:30 am
President’s Welcome
President’s Welcome

Second Annual Meeting of the NEES Consortium
San Diego, California

Dear NEES Consortium Members:

Welcome to the Second Annual Meeting of the NEES Consortium. Much has happened since our first meeting a year ago in Park City.

The construction phase of NEES is almost over with many of the fifteen equipment sites now completed. NEESgrid products for telepresence are also nearing completion and version 3.0 will be released for beta testing late next month. Schema for archiving data in the NEES repository, and portals to simulation tools such as OpenSEES, have been developed and currently being refined. The NEES IT Service Center (NITSC) has been established at the San Diego Supercomputer Center and transition of the above System Integration products and services to NITSC has begun.

A Proposal for the Management, Operation and Maintenance of the Consortium for the period 2004 – 2014, has been prepared by the Consortium Development (CD) Team and submitted to NSF. This multi-million dollar proposal has since been under review by NSF using mail-in reviews, a blue-ribbon panel, an independent cost reviewer, and various levels of internal assessment within NSF. At the time of writing, the Proposal is on the agenda of the May meeting of the National Science Board for review and approval.

A national search for an Executive Director for the Consortium has been undertaken, and I pleased to announce that Dr Clifford Roblee was recently appointed to this important position. Although he will not be full time until July 1, Cliff is already hard at work on senior personnel issues and developing options for the location of NEES headquarters in Davis, California. Please take the opportunity during this meeting, to welcome Cliff to the NEES family.

Five directors completed their one-year terms a few weeks ago and I would like to recognize their extremely valuable contributions to the work of the Board and the wider membership during this last year. These five directors are Craig Comartin, Ricardo Dobry, Bruce Kutter, Robert Nigbor, and Jim Wight. Three new directors have since been elected, including Chris Rojahn, Charles Roeder, and Bill Spencer. And Bruce Kutter was re-elected to another term. The fifth new director is a Board-elected position and will be filled by at the May meeting of the Board.

Finally a word of sincere appreciation to the entire CD Team, and in particular to Bob Reitherman, Bob Nigbor and Reed Helgens, for not only organizing this meeting, but also getting the Consortium off to a flying start. We have a capacity attendance and a very full agenda before us. There is much to do and it will be both demanding and rewarding. I look forward to great meeting.

Sincerely

Ian G. Buckle
President
NEES Consortium, Inc.
Message from the Executive Director of the NEES Consortium
A Message from the Executive Director of NEES Consortium, Inc.

Second Annual Meeting of the NEES Consortium
San Diego, California

Dear NEES Colleagues:

With a great sense of anticipation and humility, I am genuinely thrilled to join you on the forthcoming NEES journey to revolutionize earthquake-engineering research. Of course, this journey would not be possible without the far-reaching vision of the National Science Foundation, the outstanding Consortium Development team effort led by CUREE, and the tremendous dedication of the NEES Board and its committees in capturing the collective will of the earthquake engineering research community. Together, you have created an unprecedented collaboratory framework that will indeed serve as a foundation for rapid advancement in earthquake risk mitigation for years to come.

Over roughly the same time period of time that NEES has been formed, I have been deeply involved in developing earthquake research collaborations through the industry-sponsored PEER-Lifelines program. This work has led to unprecedented coordination between private, state, federal, and international entities for the common pursuit of resolving key earthquake hazards-related issues. The PEER-Lifelines program has focused on performing the applied research needed to span the ‘implementation gap’ between fundamental research and leading engineering practice. In my new role as the Consortium Director, I will continue to nurture this vital relationship with ‘end users’ on behalf of NEES. Further, I will seek creative new ways to extend outreach efforts even further to better connect the research experience with a range of educators, policy makers, and the general public.

In just a few short months, we will pass the critical milestone from building new capabilities to their creative application. No doubt, we will experience some unanticipated obstacles as we undergo the transition to operations, but nothing that cannot be resolved by this dynamic community with its combination of professionalism, good will, patience, and healthy sense of humor. I firmly believe that a vital collaboratory depends not only upon wise use of our collective talents, but also upon our common sense of dedication to achieve real reductions in earthquake risk and the creation of truly earthquake resilient communities. Toward these ends, I intend to focus headquarters staff on the facilitation of research-to-resource coordination, the development of new partnered research opportunities, and connection of the great NEES enterprise to a broad range of current and new stakeholders. I truly look forward to this unprecedented adventure where this nation’s best minds and ideas are to be coupled with its best equipment to address truly significant challenges facing our profession and society. Let us begin our journey as a community and with a great sense of adventure and dedication.

Sincerely

Cliff Roblee
Executive Director
NEES Consortium, Inc.
Speaker Bios and Abstracts
NIED E-Defense Facility and Plan for its Future Use

Toru Hayama, Ph.D.
Executive Director
National Research Institute for Earth Science and Disaster Prevention

The Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan and The National Research Institute for Earth Science and Disaster Prevention (NIED), Tsukuba, Japan, are now constructing the World Largest Three Dimensional Full Scale Earthquake Testing Facilities (E-Defense) in Miki, Hyogo prefecture, Japan. The facilities are planned and designed on the basis of the learning from the Hanshin-Awaji Earthquake Disaster that it is not realistic to design structures to avoid any failure for any kind of earthquake, and that structures should collapse without harming human lives even if a failure occurs. For this purpose, E-Defense will have an ability to destruct full scale structures to investigate the behavior of fracture of structures.

The maximum payload is 1200 tons, and the size of the table is 20m by 15m, to perform collapse test of full-scale structures. The facilities will be able to generate a maximum acceleration of 0.9G, a maximum velocity of 2m/sec, and a maximum displacement of plus/minus 1m.

The construction of the facilities will be completed in the end of the fiscal year of 2004 (March 2005), and the E-Defense will become available for three dimensional dynamic collapse test of full scale structures.

Initial series of tests will, in principle, be performed by researchers of NIED, other research institutes, and universities in Japan, according to the program of “The Special project for Mitigation of Earthquake Disaster in Urban Area” (Dai-Dai-Toku), sponsored by MEXT, The Dai-Dai-Toku has already started in 2002, and includes preliminary research for the full scale experiments on wooden houses, reinforced concrete buildings, Foundation and soil structures, to be carried out in 2005 and 2006.

E-Defense will, however, be open to all researchers interested in the mitigation of earthquake disaster in Japan. We also expect E-Defense to be utilized by researchers of foreign countries as well. We have started the discussion on NEES/E-Defense Collaboration. We strongly believe that it will be useful to combine E-Defense and NEES Facilities to conduct a research project in earthquake engineering field. We also expect to have opportunities to cooperate in research and development of the collaboration network for earthquake engineering and numerical simulation of fracture of structures.

Since April 2001, Dr. Toru Hayama has been the Executive Director of National Research Institute for Earth Science and Disaster Prevention (NIED), Tsukuba, JAPAN. Dr. Hayama has also been the Director of Special Project Center of NIED, which involves the Project on Development and Construction of E-Defense and the Project on E-Defense Related Research. He has been responsible for promoting “The Special Project for Earthquake Disaster Mitigation in Urban Area (Dai-Dai-Toku) sponsored by Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan.

Prior to joining NIED, Dr. Hayama had been working for Hitachi Ltd. and its group company for 38 years in the field of Research and Development. He was the General Manager of Mechanical Engineering Research Laboratory of Hitachi Ltd. from 1989 through 1993, and was a Board Director of Hitachi Electronics Engineering Co. Ltd., from 1993 though 2001, taking charge of corporate research and development.

He was graduated from Keio University in Mechanical Engineering in 1963, and received Ph.D. from Keio University in 1974.
A Spectrum of Earthquake Engineering Challenges around the World

Luis Esteva
President, IAEE
Professor Emeritus, National University of Mexico (UNAM).

An overview is presented of the challenges faced in the development and application of modern Earthquake Engineering around the world. Some are of technical nature; others arise from socio-economic conditions. Both groups of problems are examined within the context of the different, but complementary, roles of NEES and IAEE in the pursuit of their solution.

A few lines are devoted to IAEE’s history, started about half a century ago, in response to an identified need for worldwide exchange of engineering knowledge about both recent advances and field experiences. The simple vision and methods of the first days in the development of our discipline are compared with the powerful tools and systems we have created for the prediction of seismic response and performance and for the assessment of seismic hazard and risk. The need for this evolution has largely resulted in response to lessons learned along the years from frequent experiences about seismic events that have produced severe damage at sites or regions which were earlier thought to offer less vulnerable conditions than those disclosed by the mentioned events. Specific comments are made about the earthquakes of 1985 in Mexico City and 1994 in Northridge. Research and implementation needs born from these events are briefly examined.

In some seismic prone regions in the world, many Earthquake Engineering challenges are grounded on socio-economic conditions and attitudes. A significant number of IAEE activities throughout the years have been oriented to providing professionals and leaders of the communities living in those regions with some basic tools for the development of simple design criteria and for the formulation of practical recommendations oriented to the improvement of construction practices of non-engineered construction in order to reduce its seismic vulnerability. Because any effective action for the reduction of seismic risk must emerge from within the affected country or community, for the formulation of strategies to stimulate actions along this line in developing countries IAEE has adopted the role of a motivator and a facilitator of programs adopted by local authorities and executed by local professionals, if necessary with the aid of international experts.

Born in Mexico City in 1935, he started research at the Institute of Engineering, UNAM, in 1959. From 1982 to 1991 he was Director of the Institute. From 1991 to 1993 he was Dean of Science of the University.

His research has been motivated by his interest in contributing to the solution of many problems faced by both individual structural engineers and bodies in charge of writing building codes, as well as in providing them with practical tools. His interest in the development of rational approaches to establish structural design requirements and safety margins led to his involvement in the probabilistic analysis of structural reliability and seismic hazard and risk.

He has served in many national and international committees and boards, including the President of Mexico’s Advisory Council on Science; UNESCO committees and missions to earthquake struck regions; ACI, ASCE-IABSE and IASPEI technical committees, among others. He is also an active participant in a vast number of Mexican, Latin American and international associations, academic and technical groups.

He is a Corresponding Member of several academies of Engineering in Latin America. In 2000 he was appointed as a Foreign Associate of the United States National Academy of Engineering.
Collaboratory Research:  
Behavior of Braced Steel Frames with Innovative Bracing Schemes

Roberto Leon  
President of CUREE  
Georgia Institute of Technology

The 1994 Northridge and 1995 Kobe earthquakes showed that new technologies and structural configurations are needed to limit damage to steel structures subjected to moderate and large ground motions. In this context, the need to provide additional stiffness to modern frame configurations is clear, leading to a renewed interest in braced frame configurations. Braced frames, however, are regarded as not being very ductile because buckling of individual braces quickly leads to formation of story mechanisms. The additional need for stiffness and ductility for modern structures is compounded by the trends towards lighter structures, more compact lateral-load resisting systems and the advent of performance-based design.

To solve the traditional problems associated with conventional braced frames, a new class of bracing systems, known as a zipper frames, will be developed and tested as part of this proposed work. This proposal represents the first phase of a two-phase collaborative approach to the problem. In the experimental portion of the first phase, four laboratories (Georgia Tech (GT), U. at Buffalo (UB), U. of California at Berkeley (UCB), and the U. of Colorado at Boulder (CU)) will conduct studies on the behavior of whole systems, subassemblages, and individual elements. These will be tested under a variety of load regimes, ranging from shake table tests to quasi-static ones, in order to provide comprehensive data on which to base design recommendations. In the analytical part of the first phase, the four universities listed above, plus Florida A&M (FAMU) and Imperial College-London (IC), will conduct extensive analytical studies to provide (1) a basis and a complement to the experimental work, (2) a testbed for the NEESgrid portion of the NEES Consortium, and (3) new, simplified and comprehensive models for use in design. As the final task for the first phase, GT and FAMU researchers will develop the proposal for the second phase, which will deal with the use of advanced materials and active controls in braced steel structures.

This research will provide a unique database of information on the behavior of zipper frames, and will provide results from proof-of-concept studies on a new class of bracing systems. In addition, the research will lead to the development of analytical models that can be implemented into existing seismic analysis programs. The research will develop analytical tools and methodologies to allow practicing engineers to determine potential benefits of a variety of applications of zipper frames.

The project also intends provide initial shakedown studies for the NEES Consortium and in particular to test the flexibility and robustness of the NEESgrid system. In addition, it will provide valuable lessons from both the logistical and technical standpoints for future NEES collaborations. The project will link three NEES sites, one well-established program (GT), one developing program (FAMU) and international partner (IC) as a test case for future grand challenge collaborations. The project has been divided into two phases so that two younger remote researchers (Dr. DesRoches from GT and Dr. Abdullah from FAMU) will benefit from the work on the first phase in order to develop the technical expertise in pseudo-dynamic and shake table testing that they will need for the second phase. This intends to be a model for future NEES projects in which researchers from remote sites will be able to gain valuable experience and mentoring from established researchers/sites.

Roberto T. Leon is professor in the School of Civil and Environmental Engineering at the Georgia Institute of Technology. His research interests center on dynamic behavior and design of structures with partially-restrained composite connections, composite floors and floor systems, bond of reinforcement under cyclic loads, testing of full-scale and model structures in the laboratory, and field instrumentation of structures. His research includes extensive experience with seismic performance of steel systems, with emphasis on bolted connections and flexible framing systems, and original research on performance of composite joist floor systems and trussed girder systems. He currently chairs the Building Seismic Safety Council (BSSC) TS11 (Composite Construction in Steel and Concrete) and the American Institute of Steel Construction (AISC) TC-5 Composite Design. He is also member of the AISC Specification Committee, the AISC Seismic Design Committee, the AISC Load, Analysis and Systems Committee, and the BSSC Provisions Update Committee. He is a registered professional engineer in Minnesota, the co-author of a book on composite construction, a non-technical book on bridges and tunnels, and is the author and co-author of over 50 articles in refereed journals.
James O. Malley is a Senior Principal with Degenkolb Engineers of San Francisco, California. He received both his Bachelors and Masters Degrees from the University of California at Berkeley. A registered Structural Engineer in California, Mr. Malley has over 20 years of experience in the seismic design, evaluation and rehabilitation of building structures. He has specialized in the seismic design of steel frame structures, especially for health care facilities. Mr. Malley served as the Project Director for Topical Investigations for the SAC Steel Program. In that position, he was responsible for directing data collection and interpretation of steel frame buildings damaged by the Northridge Earthquake and all of the analytical and testing investigations performed as part of the SAC Steel Project. In 2000, this work was recognized by AISC in presenting Mr. Malley its’ Special Achievement Award. Mr. Malley is a member of the AISC Specifications Committee and the Chair of the AISC Seismic Subcommittee that is responsible for developing the AISC Seismic Provisions that are the basis of the 2000 IBC. Mr. Malley is a member of the ASCE Committee on Steel Buildings and the ASCE Seismic Effects Committee. He was a member of the steel subcommittee of the ATC 33 project that developed FEMA 273/274, “NEHRP Guidelines for the Seismic Rehabilitation of Buildings”, and is the chair of the Building Seismic Safety Council TS 6 on Structural Steel Construction. Jim has served as a member of the SEAONC and SEAOC Board of Directors, and was President of SEAONC in 2000-2001. Mr. Malley is also a member of the AWS D1.1 Subcommittee on Seismic Welding Issues. He has made numerous presentations on the effects of the Northridge Earthquake on Steel Frame Buildings, as well as the seismic design of steel structures. The author of over forty technical papers, Mr. Malley was the Co-Recipient (with the late Egor Popov) of the 1986 ASCE Raymond C. Resse Research Prize ASCE for the paper "Shear Links in Eccentrically Braced Frames".
While most earthquake losses—both human and economic—result from damage to buildings and other structures, much can be done to mitigate urban earthquake risk. Accurate urban earthquake hazard maps, development of seismic design provisions and adoption of earthquake-resistant building codes, design of new earthquake-resistant structural systems, rehabilitation of older structures, and the implementation of structural damping elements and isolation all have contributed to improved performance in many earthquake-prone cities. Yet basic data and analysis is lacking for how buildings and other structures perform under the extreme loads produced by earthquakes. The situation can only be improved by greatly expanding accurate measurements and by developing analytical techniques for predicting the performance of the built environment. On-scale ground-motion recordings from instrumentation networks in regions of moderate to large earthquakes are essential for furthering understanding of the behavior of foundation, structural and non-structural elements when strongly or severely shaken. Two recent Federal efforts directly address the need for better understanding of the response of structures to earthquakes: The Advanced National Seismic System (ANSS) and the Network for Earthquake Engineering Simulation (NEES). ANSS, an initiative by the U.S. Geological Survey to broadly modernize and expand seismic monitoring in the U.S., would provide the needed shaking data by placing up to 6000 strong-ground-motion recording stations in U.S. urban areas. Half of these sensors would be placed in buildings and other vulnerable structures to capture the needed measurements. NEES, developed by the National Science Foundation, provides a distributed facility and communications infrastructure for earthquake engineering. NEES will provide new tools for modeling, simulation and visualization of site, structural and non-structural response to earthquakes. When supported by earthquake and engineering research, the combination of these two efforts, if fully implemented, would lead to significant progress toward the goal of building resiliency into the urban environment. Beyond improving earthquake safety, earthquake-resistant construction and structural monitoring can be linked to improved homeland security. Better understanding and reducing the earthquake threat to lifelines has obvious security implications. An earthquake-resistant structure is also a blast-resistant structure. In addition, modern seismic monitoring systems emplaced in structures could serve as warning systems, post-event indicators of building damage and state-of-health, and sources of forensic information.

Dr. Leith [Bill] is Coordinator of the Advanced National Seismic System, a USGS initiative to broadly expand and modernize seismic monitoring in the U.S. He also serves as Associate Program Coordinator for the Earthquake Hazards,Geomagnetic Hazards and Global Seismic Network Programs at USGS. Bill joined the USGS in 1986, after receiving a doctoral degree in seismology and geology from Columbia University, and a bachelor’s degree with honors from the University of California at Berkeley. He served as Chief of the USGS Military Geology/Special Geologic Studies Group from 1990-2000, and as Senior Technical Advisor to the Assistant Secretary of State for Verification and Compliance, from 2001-2003. In 1988, Bill was a member of the U.S. Delegation to the Geneva Nuclear Testing Talks, and was the first U.S. geologist visit to a Soviet nuclear test site. Between 1997 and 2000, he advised the Department of Defense on the dismantlement of the former Soviet Nuclear test site near Semipalatinsk, Kazakhstan, and in the implementation of a series of large-scale explosion experiments to calibrate global and regional seismic monitoring systems. While at the State Department, he advised the Assistant Secretary on technical and policy issues related to the verification of nuclear test limitation treaties and other nuclear treaty matters, including research. Bill is author of over 100 scientific publications, and is a member of the American Geophysical Union and Seismological Society of America.
NEES, IRIS and EarthScope: Opportunities for Partnerships and Interactions

David Simpson
IRIS Consortium and Earthscope

At the interface between the built environment and the solid Earth, there lie many opportunities for interactions between earthquake engineering and Earth science. As two major consortia funded by the National Science Foundation, IRIS and NEES have a special opportunity and responsibility to facilitate interdisciplinary research; collaborate in common endeavors in education and outreach; and encourage support for national and international programs in earthquake studies and risk reduction.

Observational seismology (whether for weak motions or strong) collects time series of vibrations of the Earth or engineered structures. Sensors and recording systems with enhanced bandwidth and dynamic range are helping erode many of the artificial boundaries between the historical territory of “engineering”, “earthquake” and “Earth structure” seismologists. Discipline-specific requirements still drive some aspects of the geometry and characteristics of individual elements in sensor grids, but there are many common aspects to the tools and techniques used for collection, distribution and analysis of earthquake time series. Advances in cyber technology and data management greatly facilitate the sharing and exploitation of data resources. The IRIS Data Management System and PASSCAL program for portable instrumentation complement a number of data and instrumentation activities at NEES facilities. While sharing of resources may be cost-effective in the collection and distribution of data, even greater benefits can derive from interactions in the development and execution of joint research projects and facility operations to help develop a common understanding of the research challenges at the interface between engineering and seismology.

David W. Simpson has served since 1991 as President of the Incorporated Research Institutions for Seismology (IRIS), a consortium of more than 100 U.S. universities with research programs in seismology.

IRIS is supported by the US National Science Foundation to develop and maintain facilities for seismological research. IRIS programs include the Global Seismographic Network (GSN, operated in cooperation with the US Geological Survey) of 138 stations worldwide; a pool of 1000 portable instruments (PASSCAL); a Data Management System and a program in Education and Outreach. IRIS resources are used to support university and government investigations in earthquake studies, research on Earth structure and dynamics, and applications in nuclear test ban monitoring. IRIS is also part of EarthScope, an new NSF project to develop an observatory of geophysical instrumentation for detailed investigations of the structure and evolution of North America. IRIS will be responsible for USArray, a network of more than 2000 portable and permanent stations that will form the core seismological component of EarthScope.

Dr. Simpson received his undergraduate training in seismology and oceanography at Dalhousie University, Halifax, Canada and PhD from the Australian National University in Canberra. From 1974 to 1991, he was at the Lamont-Doherty Earth Observatory of Columbia University where he was Senior Research Scientist and Associate Director for Seismology, Geology and Tectonophysics.

His research interests have included the study of earthquakes triggered by the filling of large reservoirs, velocity structure of the mantle transition zone, the tectonics and seismicity of the northeastern US and Central Asia, applications of satellite imagery and topographic data in tectonic studies, and the application of seismology in the monitoring of nuclear explosions. He has participated in field programs on all continents, including the establishment of earthquake monitoring networks in Australia, New York, Tadjikistan, Kyrgyzstan and Egypt. He participated in immediate post-earthquake studies in California, New York, Egypt, Armenia and Georgia.

He has served in an advisory role to numerous government agencies including the USGS, NSF, DOD and DOE. He has been a member of the National Research Council's Committee on Seismology and served on a number of its panels. He was Chair of the NSF Advisory Committee for the Geosciences. He has been a member of the US delegation to the Gore-Chernomyrdin Commission and chair of an International Science Foundation review panel. He currently serves on the National Steering Committee for the USGS Advanced National Seismic System and the Board of Directors of the Seismological Society of America. He is the author of more than 60 papers in scientific journals and books.
NEES Consortium
Board of Directors Roster
NEES Consortium, Inc.
2004 Board of Directors Roster

**Professor Thalia Anagnos**
San Jose State University
Dept. of Civil & Environmental Engineering
One Washington Square
San Jose, CA 95192-0083
Tel: 408-924-3861 / Fax: 408-924-2444
email: tanagnos@email.sjsu.edu
(2 year term) Term Expires: April 30, 2005

**Professor Ian Buckle - President**
University of Nevada, Reno
Dept. of Civil Engineering
MS 258
Reno, NV 89557
Tel: 775-784-1519 / Fax: 775-784-4213
email: igbuckle@unr.edu
(3 year term) Term Expires: April 30, 2006

**Mr. Craig Comartin - Treasurer**
Comartin-Reis
7683 Andrea Ave.
Stockton, CA 95207
Tel: 209-472-1221 / Fax: 209-472-7294
email: comartin@comartin-reis.com
(3 year term) Term Expires: April 30, 2007

**Professor Gregory Deierlein - Member, Executive Committee**
Stanford University
Dept. of Civil & Environmental Engineering
Blume Earthquake Engineering Center
Terman Engineering Center - MC 4020
Stanford, CA 94305-4020
Tel: 650-723-0453 / Fax: 650-723-9755
email: ggd@stanford.edu
(2 year term) Term Expires: April 30, 2005

**Professor Helmut Krawinkler**
Stanford University
Dept. of Civil & Environmental Engineering
Blume Earthquake Engineering Center
Terman Engineering Center - MC 4020
Stanford, CA 94305-4020
Tel: 650-723-4129 / Fax: 650-723-7514
email: krawinkler@stanford.edu
(3 year term) Term Expires: April 30, 2006

**Professor Bruce Kutter - Vice President**
University of California, Davis
Dept. of Civil & Environmental Engineering
213 Walker Drive
Davis, CA 95616
Tel: 530-752-7929 / Fax: 530-752-6758
email:blkutter@ucdavis.edu
(1 year term) Term Expires: April 30, 2004

**Professor Kyran D. Mish**
University of Oklahoma
Dept. of Civil Engineering & Environmental Science
Fears Structural Engineering Laboratory
303 East Cheasapeake
Norman, OK 73019
Tel: 405-325-1010 / Fax: 405-325-4077
email: kdmish@ou.edu
(2 year term) Term Expires: April 30, 2005

**Professor Andrei Reinhorn**
University at Buffalo - SUNY
Dept. of Civil, Structural and Environmental Engineering
231 Ketter Hall
Buffalo, NY 14260
Tel: 716-645-2114 / Fax: 716-645-3733
email: reinhorn@buffalo.edu
(2 year term) Term Expires: April 30, 2005

**Professor Charles Roeder**
University of Washington
Dept. of Civil and Environmental Engineering
233B More Hall
Box 352700
Seattle, WA 98195-2700
Tel: 206-543-6199 / Fax: 206-543-1543
email: croeder@u.washington.edu
(3 year term) Term Expires: April 30, 2007

**Mr. Christopher Rojahn**
Applied Technology Council (ATC)
201 Redwood Shores Parkway
Suite 240
Redwood City, CA 94065
Tel: 650-595-1542 / Fax: 415-593-2320
email: crojahn@atcouncil.org
(3 year term) Term Expires: April 30, 2007
Professor Billie F. Spencer  
University of Illinois at Urbana-Champaign  
Civil & Environmental Engineering  
2213 E. Newmark CE Lan, MC 250  
205 N. Mathews  
Urbana, IL 61820  
Tel: 217-333-8630 / Fax: 443-646-0675  
email: bfs@uiuc.edu  
(3 year term) Term Expires: April 30, 2007

Professor Sharon L. Wood  
University of Texas at Austin  
Ferguson Structural Engineering Laboratory  
10100 Burnet Road, Bldg. 177  
Austin, TX 78758  
Tel: 512-471-7298 / Fax: 512-471-1944  
email: swood@mail.utexas.edu  
(3 year term) Term Expires: April 30, 2006

Professor Kenneth H. Stokoe, II  
University of Texas at Austin  
Dept. of Civil Engineering  
One University Station C1792  
Austin, TX 78712-0280  
Tel: 512-232-3689 / Fax: 512-471-6548  
email: k.stokoe@mail.utexas.edu  
(3 year term) Term Expires: April 30, 2006

Professor Solomon C. Yim  
Oregon State University  
Dept. of Civil, Construction and Environmental Engineering  
202 Apperson Hall  
Corvallis, OR 97331-2302  
Tel: 541-737-6894 / Fax: 541-737-3052  
email: solomon.yim@orst.edu  
(2 year term) Term Expires: April 30, 2005

Mr. J. Carl Stepp  
COSMOS  
1301 S.46th Street  
Richmond, CA 94804  
Tel: 510-231-9436 / Fax: 510-231-471  
email: cstepp@moment.net  
(3 year term) Term Expires: April 30, 2006
NEES Consortium Committees
Site Operations Committee

Charge

The charge of the committee is to:

1. develop and maintain the NEES Facilities Users Guide, the basic document adopted by the Board of Directors governing the shared use of NEES Equipment Sites;
2. develop guidelines, through a consensus process, on how shared use should be defined and implemented for the different sites;
3. oversee the staff’s development and coordination of the assessment of the shared use of the NEES Equipment Sites, and report to the Board of Directors the level of shared use at each Equipment Site;
4. develop guidelines, through a consensus process, on maintenance and operation issues that should be addressed at the Equipment Sites;
5. review the annual Equipment Site maintenance and operation budget in conjunction with Consortium staff and make recommendations to the Finance Committee regarding this budget;
6. recommend to the Board of Directors any rewards or disincentives that should be put in place to encourage improved operations, maintenance and shared use at a particular Equipment Site;
7. assist the Consortium staff with coordination of projects at Equipment Sites by providing information to prospective users on the anticipated level of use in the future;
8. assist the Consortium staff with scheduling of projects at Equipment Sites when conflicts arise. Decisions will be based on an analysis of the risks of delays, potential payoffs, and technical priorities for individual projects;
9. oversee the staff’s monitoring of the progress of all research at NEES Equipment Sites to insure that schedules are maintained and to help plan ahead in case of expected delays;
10. develop mediation procedures and arbitration guidelines to address specific problems arising between NEES Equipment Sites and those who are funded by the National Science Foundation to benefit from shared usage of one or more Equipment Sites;
11. develop policies and procedures for extending shared use to experimental facilities other than the original 15 NEES Equipment Sites that may wish to participate in or collaborate with NEES;
12. provide input to the Education, Outreach, and Training Committee for the maintenance of information to be provided electronically via the Web with specific information on functionality and access tips for each Equipment Site, including Frequently Asked Questions and case histories; and
13. interface with other Standing Committees as required or needed.
Committee Members

Roberto Leon, Chair
Georgia Institute of Technology

Ross Boulanger
University of California at Davis

Shirley Dyke
Washington University in St. Louis

André Filiatrault
University at Buffalo - SUNY

Marc Eberhard
University of Washington

Danta Fratta
Louisiana State University

Stephen Mahin
University of California at Berkeley

David Sanders
University of Nevada, Reno

John Wallace
University of California at Los Angeles

Sharon Wood, Board Representative
University of Texas at Austin

Tarek Abdoun
Rensselaer Polytechnic Institute

JoAnn Browning
University of Kansas

Shirley Dyke
Washington University in St. Louis

Marc Eberhard
University of Washington

Danta Fratta
Louisiana State University

Stephen Mahin
University of California at Berkeley

David Sanders
University of Nevada, Reno

Sharon Wood, Board Representative
University of Texas at Austin
Information Technology Committee

Charge

The charge of the committee is to:

1. advise the Board on the operation and budgeting of the networking, collaboration, communication, data and simulation tools repositories, and computational resources of the NEES Consortium;
2. provide the Board with strategic plans to update the networking, collaboration, communication, and computational resources and capabilities of the NEES Consortium;
3. review the annual Information Technology budget in conjunction with Consortium staff and make recommendations to the Finance Committee regarding this budget;
4. advise the Education, Outreach, and Training Committee on effective ways to serve the NEES Consortium’s Members in advancing information technology knowledge and skills;
5. coordinate with the Data Sharing and Archiving Committee on overlapping issues;
6. assist the staff by providing expertise in information technology; and
7. interface with other Standing Committees as required or needed.
Committee Members

Cherri Pancake, Chair  
NACSE/Oregon State University

Kyran Mish, Board Representative  
University of Oklahoma

M. Pauline Baker  
Indiana University

Peter Beckman  
Argonne National Laboratory

Beverly Clayton  
Pittsburgh Supercomputer Center

Jerome Hajjar  
University of Minnesota

Barbara Horner-Miller  
Arctic Region Supercomputer Center

Loukas Kallivokas  
University of Texas at Austin

Anke Kamrath  
San Diego Supercomputer Center

Yi Long Mo  
University of Houston

Jamison Steidl  
University of California at Santa Barbara

Benny M. Vigil (Manuel)  
Los Alamos National Laboratory
Data Sharing and Archiving Committee

Charge

The charge of the Committee is to:

1. advise the Board on the operation of the data and simulation tools resources of the Consortium;
2. assist the Information Technology Committee with their advisory function related to operation and budgeting of the data and simulation tools repository resources of the Consortium;
3. recommend to the Board specific policies to encourage and require broad earthquake engineering community access to and use of these data and simulation tools repository resources;
4. provide recommendations to the Board for resolution of disputes with regard to data sharing;
5. assist the Consortium staff in the development of policies and procedures for quality assurance and curation of data and simulation tools;
6. investigate the feasibility of establishing an electronic journal and make a recommendation to the Board on that subject;
7. investigate ways to coordinate the NEES data and simulation tools repositories with other engineering and scientific data repositories;
8. review the annual Data Sharing and Archiving budget in conjunction with Consortium staff and make recommendations to the Finance Committee regarding this budget;
9. assist the Consortium staff by providing expertise on data sharing; and archiving and
10. interface with other Standing Committees as required or needed.

Committee Members

Andrei Reinhorn, Chair
Board Representative
University at Buffalo - SUNY

Jacobo Bielak
Carnegie Mellon University

Finley Charney
Virginia Tech

Catherine French
University of Minnesota

Jerome Hajjar
University of Minnesota

Philip Liu
Cornell University

Daniel Wilson
University of California at Davis
Education, Outreach, and Training Committee

Charge

The charge of the Committee is to:

1. advise the Board on education, outreach, and training programs and policies of the Consortium;
2. work with Consortium staff to achieve Consortium education, outreach, and training goals, including wide usage at different educational and age levels of NEES research and effective implementation of NEES research by practicing engineers and others in the design and construction industries to achieve NEES Consortium goals;
3. advise and coordinate with the Site Operations Committee, the Information Technology Committee, and the Data Sharing and Archiving Committee on educational opportunities and training requirements for serving the Consortium’s membership;
4. advise the Consortium staff on outreach to and coordination with the broad earthquake engineering and seismology community;
5. review the annual education, outreach, and training budget in conjunction with Consortium staff and make recommendations to the Finance Committee regarding this budget;
6. assist the Consortium staff by providing expertise in education, outreach, and training; and interface with other Standing Committees as required or needed.

Committee Members

Thalia Anagnos, Chair
Board Representative
San Jose State University

Scott Ashford
University of California at San Diego / PEER

Mark Benthien
SCEC

Phil Gould
Washington University

William Holmes
Rutherford & Chekene

Gerard Pardoen
University of California at Irvine

John Taber
IRIS Consortium

Sara Wadia-Fascetti
Northeastern University
Nominations Committee

Charge

The charge of the Committee is to:

1. nominate to the Members of the Corporation the candidates to be elected by the Members to fill positions on committees. In so doing, the Committee shall attempt to provide a balance among different disciplines and backgrounds, and between those who do and do not have interests closely allied with those of an Equipment Site;
2. nominate to the Individual Members of the Corporation the candidates to be elected by the Individual Members to fill positions on the Board of Directors. In so doing, the Committee shall attempt to provide a balance among different disciplines and backgrounds, and between those who do and do not have interests closely allied with that of an Equipment Site;
3. nominate to the Institutional Members of the Corporation the candidates to be elected by the Institutional Members to fill positions on the Board of Directors. In so doing, the Committee shall attempt to provide a balance among different disciplines and backgrounds, and between those who do and do not have interests closely allied with those of an Equipment Site;
4. nominate more candidates than there are open positions, to provide choices to the Members of the Consortium;
5. oversee a fair and open process whereby any Member of the Corporation who has appropriate qualifications to fill a Committee or Board seat, for whom at least five Members (or 5% of the number of Members if the total number of Members is greater than 100) have stated in a timely manner that they wish to nominate the Member for that position, shall be included with the Committee-nominated individuals on ballots and given the same opportunity to have statements distributed to the Members.
6. oversee the process of contacting prospective candidates to verify they are willing to serve if elected and oversee the process of compiling statements from the candidates that can be distributed to the Members of the Corporation with ballots in advance of elections.

Committee Members

William Holmes, Chair
Rutherford & Chekene

Thalia Anagnos, Board Representative
San Jose State University

Catherine French
University of Minnesota

Anke Kamrath
San Diego Supercomputer Center

Philip Liu
Cornell University

Susan Tubbesing
EERI
Finance Committee

Charge

The charge of the Committee is to:

1. recommend to the Board financial policies and procedures;
2. review the finances and budget of the Consortium and make reports to the Board;
3. propose a budget to the Board for its adoption, receiving recommendations from the following committees: Site Operations; Education, Outreach, and Training; Information Technology; and Data Sharing and Archiving. The recommendations of these Committees shall be forwarded by the Finance Committee to the Board along with the Finance Committee’s recommendation on the integration of these components into a total budget for the Consortium that is fiscally responsible and efficient;
4. make a recommendation to the Board on the selection of an independent auditor and make related recommendations for appropriate financial safeguards for the Consortium.

Committee Members

Craig Comartin, Chair
Board Representative
Comartin & Reis

Katy Schmoll
University Corporation for Atmospheric Research (UCAR)

James Wight
University of Michigan

J. Carl Stepp
COSMOS

Kenneth Stokoe, II
University of Texas at Austin
NEES Equipment Sites
The NEES Equipment Sites

1. Cornell University
2. Lehigh University
3. Oregon State University
4. Rensselaer Polytechnic Institute
5. University at Buffalo-SUNY
6. University of California at Berkeley
7. University of California at Davis
8. University of California at Los Angeles
9. University of California at San Diego
10. University of California at Santa Barbara
11. University of Colorado at Boulder
12. University of Illinois, Urbana-Champaign
13. University of Minnesota
14. University of Nevada, Reno
15. University of Texas at Austin

Extracted from the NEES Maintenance and Operation proposal submitted October 2003.

Proposal document available for download at www.nees.org
D.1 Cornell University

The Cornell Equipment Site focuses on lifeline testing, laboratory simulation of soil-structure interaction under large ground deformation, and database generation and model-based simulation of lifeline component response to large transient and permanent displacements induced by earthquakes. It will simulate large earthquake-induced displacements and evaluate the ramifications of such displacements with respect to the soil-structure interaction of underground facilities and the ductile performance of aboveground structures.

The facility will be equipped with large-stroke actuators, capable of 0.91-m cyclic and 1.82-m one-way displacements. High and low strong walls will provide reaction members for underground and above-ground lifeline experiments. Soil storage bins and a portable conveyor system will allow for rapid movement and placement of soil for large-scale experiments on underground lifelines subject to large permanent ground displacements.

Coordinated experiments with the RPI centrifuge and large-scale Cornell facility will cover the range of geometric characteristics, material properties, construction practices, and loading rates encountered in the field. Special split-box centrifuge containers will be housed at RPI and used to complement and refine the large-scale testing at Cornell.

The experimental facility is not only important for earthquake engineering simulations, but is well suited for evaluating the effects of locally severe deformations arising from adjacent construction, subsidence, undermining excavations, flooding, landslides, and offshore construction. It will be possible with the facility to evaluate many different types of pipelines, electric conduits, telecommunication cables, straight pipe sections, pipelines with elbows and tees, specialized joints, coatings, retrofitting techniques, as well as different soils, unit weights, moisture contents, and depths of burial.

Pipelines and conduits are frequently placed in trenches backfilled with soil that is different than the native soil. Currently, there are no guidelines for evaluating soil-pipe reaction to large ground displacements under these conditions. The experimental facility is ideally suited to clarify soil-pipe interaction for various trench geometries and properties of native soil and backfill. It can assess measures to reduce soil resistance to pipe and conduit movement with sloped trenches, high-density polyethylene (HDPE) sheets to promote sliding and lateral pipe movement, and the use of expanded polystyrene (EPS) or other crushable materials.

Soil-structure interaction problems involve locations where abrupt transitions from structure to soil create localized stresses and deformations. Examples include bridge abutments, underground vaults, and building basements where a number of different cables and conduits may transition from soil and penetrate structural walls and/or abutments. The experimental facility will have the ability to simulate complex interactions at these soil-structure interfaces.

Another problem that can be addressed involves the effects of near field transient displacements on base isolation elements. Large deformation across base isolation elements, as well as contemporaneous interaction with adjacent soil, can be simulated with the equipment, thus clarifying soil-structure interaction under conditions for which there is currently little information or guidance.

A predominant theme in earthquake-resistant design is ductility. The large-scale facility is designed for investigating the performance of highly ductile above-ground structures that can accommodate large lateral drift. For example, the experimental facility is well suited to investigate the performance of full-height columns, using post-tensioned advanced composite materials, such as highly ductile concrete with polymer fibers. New mix designs for ductile cement-based composites, which are needed to facilitate large-scale fabrication, will be developed and characterized before selection and subsequent use in the larger-scale experiments. Material tests and characterization are necessary for constitutive model development. Such models will be used to predict experimental results, develop the appropriate test series and test set-ups, and provide tools for design once the system behavior is understood and the materials and preparation procedures are ready for implementation in practice.

The project team consists of Harry E. Stewart (PI), Tarek Abdoun (Co-PI), Michael J. O’Rourke (Co-PI), and Thomas D. O’Rourke (Co-PI).

Website: http://nees.cornell.edu/
**Equipment Site Description**

The facility focuses on lifeline testing, laboratory simulation of soil-structure interaction under large ground deformation, and database generation and model-based simulation of lifeline component response to large transient and permanent displacements induced by earthquakes. The essential service that the experimental equipment provides for NEES is the capability to simulate large earthquake-induced displacements and to evaluate the ramifications of such displacements with respect to the soil-structure interaction of underground facilities and the ductile performance of aboveground structural components.

The facility will be equipped with large-stroke actuators, capable of 0.91-m cyclic and 1.82-m one-way displacements. High and low strong walls will provide reaction members for underground and aboveground lifeline experiments. Soil storage bins and a portable conveyor system will allow for rapid movement and placement of soil for large-scale experiments on underground lifelines subject to large permanent ground displacements. In addition, special split-box centrifuge containers will be housed at RPI for use in their geotechnical centrifuge. Centrifuge testing can be performed at RPI to complement and refine the large-scale testing performed at Cornell.

It should be recognized that the experimental facility is not only critically important for earthquake engineering simulations, but is well suited for evaluating the effects of locally severe deformations arising from adjacent construction, subsidence, undermining excavations, and other extreme events, such as flooding and high winds. Moreover, the experimental equipment will provide simulation capabilities for the effects of landslides, submarine instabilities, and offshore construction effects on oil and gas gathering and transmission systems.

**Potential Research Projects**

Three potential experimental projects are discussed below.

1. **Soil Structure Interaction Under Permanent Ground Deformation**

Some of the most serious damage to underground lifelines during an earthquake is caused by permanent ground deformation (PGD) [e.g., O’Rourke, 1998]. Figure D.1-1 illustrates the concept, which provides the basis for laboratory simulation of the most severe PGD effects associated with surface faulting, liquefaction-induced lateral spread, and landslides.

Relative displacement is generated along a moveable interface between two test basins, or boxes, containing soil and the buried lifeline. Soil is placed and compacted according to field construction practice. The scale of the experimental boxes is chosen by computation modeling and previous test experience such that the soil-lifeline interaction is unaffected by the boundaries of the test facility. The experimental facility also will have the capability of imposing simultaneous vertical and horizontal displacement, as well as modest amounts of extension or compression normal to the rupture plane.

Soil storage bins will be fabricated that are recessed within the structural column system of the Winter Laboratory. The bins are located within the lifeline testing area, and a moveable conveyor system has been chosen for rapid transfer of soil from bin to test boxes.

Large displacements will be generated with large stroke actuators. Two actuators will each provide ± 0.91 m of cyclic movement, and 1.82 m of one-way displacement. An additional actuator (a exact match to an existing actuator) will provide ± 0.63 m of cyclic and 1.26 m of one-way movement. By linking actuators in series, it will be possible to generate several meters of movement. The test boxes will slide on Teflon strips, having a coefficient of friction of about 0.05. Cornell experience with this sliding system has been very good (Yoshisaki, et al., 2002), and provides a sound basis for sizing both the actuator stroke and load capacity.

As shown in Figure D.1-1, it will be possible to evaluate many different conditions with the experimental facility, including different types of pipelines, electric conduits, and telecommunication cables. Straight pipe sections and pipelines with elbows and tees can also be investigated. Steel, plastic, ductile iron, reinforced concrete piping, as well as a variety of specialized joints, coatings, and retrofitting techniques are viable candidates for testing. Soil-lifeline interaction for different soils, unit weights, and moisture contents, depths of burial, and pipeline diameters can be investigated.

One of the most interesting conditions to investigate involves the effects of trench geometry and backfill. As illustrated in Figure D.1-1 (d) pipelines and conduits are frequently placed in trenches backfilled with soil that is different than the native soil. Currently, there are no guidelines for evaluating soil-pipe reaction under these
conditions. The experimental facility is ideally suited to clarify soil-pipe interaction for various trench geometries and properties of native soil and backfill.

Specialized trench geometries and advanced materials have been recommended for fault crossings to reduce soil pressures, as illustrated in Figure D.1-1 (d). Measures to reduce soil resistance to pipe and conduit movement include sloped trenches; high-density polyethylene (HDPE) sheets to promote sliding and lateral pipe movement, and the use of expanded polystyrene (EPS) or other crushable materials. The experimental facility is ideally suited to investigate these mitigation measures.

Coordinated experiments with the RPI centrifuge and large-scale Cornell facility will cover the range of geometric characteristics, material properties, construction practices, and loading rates encountered in the field. A centrifuge test can be performed more rapidly and at significantly less expense than a large-scale experiment. Hence, the centrifuge is used to define parameters for tests at full scale. It is important for deciding on the appropriate boundary conditions, trench configuration, backfill material, and protective measures to be investigated. Likewise, centrifuge tests extend the range and relevance of full-scale experiments. After a full-scale test has provided detailed information on soil-structure interaction for specific cases, the influence of key parameters can be explored in several centrifuge tests that follow the full-scale experiment and clarify the role of different parameters.

Figure D.1-1: PGD Effects on Buried Lifelines

Specialized trench geometries and advanced materials have been recommended for fault crossings to reduce soil pressures, as illustrated in Figure D.1-1 (d). Measures to reduce soil resistance to pipe and conduit movement include sloped trenches; high-density polyethylene (HDPE) sheets to promote sliding and lateral pipe movement, and the use of expanded polystyrene (EPS) or other crushable materials. The experimental facility is ideally suited to investigate these mitigation measures.

Coordinated experiments with the RPI centrifuge and large-scale Cornell facility will cover the range of geometric characteristics, material properties, construction practices, and loading rates encountered in the field. A centrifuge test can be performed more rapidly and at significantly less expense than a large-scale experiment. Hence, the centrifuge is used to define parameters for tests at full scale. It is important for deciding on the appropriate boundary conditions, trench configuration, backfill material, and protective measures to be investigated. Likewise, centrifuge tests extend the range and relevance of full-scale experiments. After a full-scale test has provided detailed information on soil-structure interaction for specific cases, the influence of key parameters can be explored in several centrifuge tests that follow the full-scale experiment and clarify the role of different parameters.
2. **Soil-Structure Interface Interactions**

Soil-structure interface problems involve locations where abrupt transitions from structure to soil create localized stresses and deformations. As illustrated in Figure D.1-2, examples include bridge abutments where a number of different cables and conduits may transition from soil through the abutment and/or other structural elements.

The experimental facility will have the ability to simulate complex interactions at soil-structure interfaces. The experimental concept is shown in Figure D.1-2 (d). An actuator can apply lateral displacements to a structural vault or bridge abutment element at the same time another actuator applies displacements to a test box with backfill soil and a buried conduit that penetrates the structural element. A special sliding connection can be fabricated to allow relative movement between the test box and structural element. As discussed with respect to the previous text example, Teflon strips will allow for low-friction sliding of the experimental members. Although not shown in the figure, vertical movement between the soil and structural element can be imposed to simulate the effects of soil settlement adjacent to the structure.

The experimental facility will be able to simulate and evaluate the effects of many different variables, including soil properties, pipe trench characteristics, pipe material properties, pipe diameter, depth, and characteristics of the pipe/conduit penetration. The cyclic displacements imposed by the actuators will be derived from computational simulations of the full-scale structure and surrounding ground conditions.

As illustrated in Figure D.1-2 (c), another problem that can be addressed with the experimental facility involves the effects of near field transient displacements on base isolation elements. Large deformation across base isolation elements, as well as contemporaneous interaction with adjacent soil, can be simulated with the equipment. The effects of such deformations and interactions with adjacent soil are largely unknown. Experimentation to quantify these conditions can improve base isolation design.

3. **Highly Ductile Structural Response**

The predominant emphasis in earthquake-resistant design practice is on ductility. In reinforced concrete, ductility traditionally has been achieved with monolithic construction and proper reinforcement detailing, such as adequate concrete confinement. With steel structures, moment-resisting frames with adequate connection details are a common approach to ductile design. In highway structures, innovative restrainers and isolation devices also are becoming more common. The limits of ductility are being pushed steadily, and further improvements in ductility will continue into the future.

An example of a highly ductile system is that of precast segmental concrete bridge piers with unbonded vertical post-tensioning and localized use of highly ductile fiber-reinforced concrete. One-fifth scale experiments on partial columns with unbonded post-tensioning and localized use of the ductile composites have proven the feasibility of this system (Yoon et al., 2002). As shown in Figures D.1-3 (a) and D.1-3 (b), it was found that the highly ductile concrete located in hinge regions maintains its integrity beyond drifts of 20% while the unbonded post-tensioning does not yield and thus minimizes any residual displacement after reaching such high drifts. The load-carrying capacity of the system was also maintained at these large drifts. Residual drifts were on the order of 2-3%.
Experiments now are needed on full-height columns (roughly half-scale will be feasible with the facility) due to the use of unbonded post-tensioning. Because the post-tensioning is unbonded, there is no localized yielding of the post-tensioned steel. Strain induced in the bridge columns is spread along the entire length of the post-tensioning. Therefore full bridge piers using the full length of strand are necessary for accurate investigation of such systems. Figure D.1.3 (c) illustrates the experimental concept. Full bridge pier experiments will require stroke capacities of 0.65-1.0 mm. The Cornell NEES facility will include a modular 1.2-m-high low reaction wall and a modular 7.2-m-high reaction wall. The experiments will be carried out on the upper surface of the low reaction wall and lateral load would be applied from the high portion of the strong wall. Equivalent gravity load would be applied using high capacity (force) actuators that would react off of the strong floor or from a stiff frame supported at the top of the reaction walls. This support system would be designed to allow the actuators to move with the specimen as it undergoes large drift cycles.
Cyclic experiments on large-scale specimens are necessary to understand the impact of segment size and fabrication techniques on potential energy dissipation in these highly ductile materials. Such tests would be a part of the above-mentioned project, for instance single or half-column tests, and would be carried out also on the surface of the low reaction wall, reacting laterally from the high reaction wall.

Finally, smaller-scale material characterization is necessary in the development of new ductile materials. In this example case, new mix designs for ductile cement-based composites, which are needed to facilitate large-scale fabrication, will be characterized before selection for use in the larger-scale experiments. It is also essential that such material characterization be carried out in conjunction with the large-scale system characterization tests to facilitate model-based simulation. The material tests are necessary for constitutive model development. Such models will be used to predict experimental results, develop the appropriate test series and test set-ups, and provide tools for design once the system behavior is understood and the materials and preparation procedures are ready for implementation in practice.

**Figure D.1-3: New Highly Ductile Materials and Example of a Highway Structure Needing Experimental Verification under Large-Displacement Cycles**

(a) Reinforced concrete hinge region after failure (14% drift)  
(b) Ductile fiber-reinforced concrete hinge region after 22% drift  
(c) Example bridge support system to be tested using proposed NEES equipment
D.2 Lehigh University

The Lehigh NEES Equipment Site features a real-time multidirectional testing (RTMD) facility with the capabilities to perform integrated experimental and analytical research in conjunction with real-time testing. The RTMD facility enables the effects of real time multidirectional ground motions on the structural response of buildings, bridges, and foundation systems to be investigated.

The Lehigh Equipment Site is housed in the ATLSS Center Multidirectional Testing Laboratory, which features a multidirectional reaction wall and strong floor. The primary component of the loading system is the hydraulic power system. The hydraulic system, combined with dynamic actuators and a real-time digital servo-control system, enables real-time strong ground motion effects to be sustained for up to 30 seconds. Testing methods include the effective force method, real-time pseudo-dynamic testing method, and the real-time pseudo-dynamic hybrid testing method. The facility also supports multi-site pseudo dynamic hybrid testing.

The Lehigh NEES Equipment Site also features a high speed data acquisition and advanced sensors, that include wireless MEMS-based accelerometers, piezoelectric transducers (strain and acceleration measurement), and fiber optic strain gages of Stimulated Brillouin Scattering principles. The Lehigh NEES Equipment Site is connected to the NEES network through the Mid-Atlantic GigaPop Internet 2 (MAGPI) connection, enabling various degrees of teleparticipation and shared-use access and training. Teleparticipation is supported by a teleobservation system that includes video cameras, a data server, and web servers.

A machine shop, material testing facilities, and scanning electron microscope equipment are available to support research projects conducted at the Lehigh Equipment Site.

The functional flexibility of the RTMD facility enables numerous possibilities for integrating analytical and experimental research. These include not only seismic testing but also testing to evaluate response to other types of loading conditions, including wind and bridge structures with moving traffic loads. Large-scale structural components, subassemblages, and superassemblages can be built and tested at the Lehigh Equipment Site. Some examples of research that can be performed at the Lehigh Equipment Site include: (1) large-scale testing to evaluate the seismic performance and behavior of structural systems with either passive, semi-active, or active controlled devices for wind or seismic hazard mitigation; (2) multidirectional earthquake testing of large-scale structural components such as reinforced concrete bridge cap beam - pier - foundation systems; (3) response of structural elements and connections to high strain rate of loading, including blast loading.

The teleobservation equipment at the Lehigh Equipment Site enables remote users to observe tests, or view visual data and measured response data from completed tests that are stored on an archive server. Hence, the response of structures tested at the RTMD facility can be observed, providing a powerful means of education though examining and comparing the response of different structural systems and components to earthquake loading.

The project team consists of James M. Ricles (PI), Clay Naito (Co-PI), Sibel Pamukcu (Co-PI), Richard Sause (Co-PI), and Yunfeng Zhang (Co-PI).

Website: http://nees.atlss.lehigh.edu/
**Equipment Site Description**

In the past, few structural experiments have been performed at large-scale with load rates approaching those that occur in actual structures under earthquake loading. Although there is a long tradition of using structural tests to advance the state-of-the-art in seismic design and performance of structural systems in the US, experiments on large-scale (near real-scale) structural subassemblies, components and connections have become common only during the past two decades. This deficiency in existing experimental research capability is being overcome through the creation of the Lehigh NEES Equipment Site. The Lehigh NEES Equipment Site features a real-time multidirectional testing (RTMD) facility with the capabilities to perform integrated experimental and analytical research. The RTMD facility enables the effects of real time multidirectional ground motions on the structural response of buildings, bridges, and foundation systems to be investigated.

The centerpiece of the Lehigh NEES Equipment Site is the ATLSS Center’s multidirectional reaction wall and strong floor. A primary component of the loading system is the hydraulic power system. The hydraulic system, combined with dynamic actuators and a real-time digital servo-control system, enables real-time strong ground motion effects to be sustained for up to 30 seconds. Testing methods include the effective force method, real-time pseudo-dynamic testing method, and the real-time pseudo-dynamic hybrid testing method. The facility also supports multi-site pseudo dynamic hybrid testing.

**Equipment Capabilities**

The equipment for the RTMD facility is located and stored at the ATLSS Center at Lehigh University. A description of the facility and equipment is given below.

**Fixed installations:** The laboratory of the RTMD facility includes a strong floor that measures 31.1m x 15.2 m in plan, and multidirectional reaction wall up to 15.2 m in height. Anchor points are spaced on a 1.5-m grid along the floor and walls. Each anchor point can resist 1.33 MN tension force and 2.22 MN shear force. Additional steel framing is used in combination with the strong floor and reaction walls to create a wide variety of test configurations.

A 178-kN capacity overhead crane services the test area and an adjacent fabrication area. Additional smaller cranes with capacities of 45-kN and 27-kN also serve this area.

**NEES equipment performance specifications:** The equipment portfolio and resources of the Lehigh NEES equipment site include:

- Five channels of dynamic loading, with the system configured for up to 8 channels and control by using either displacement or force, consisting of two 2050 kN dynamic actuators ported for three 400 gpm servovalves, +/- 500 mm stroke, and three 1500 kN dynamic actuators ported for three 400 gpm servovalves, +/- 500 mm stroke.
- Ten three-stage 1500 liters/min high flow-rate servo-valves.
- Hydraulic distribution lines and service manifolds, with a low-pressure and high-pressure setting, to operate at 20.7 MPa with a maximum flow of 1500 liters/min.
- Surge tank and two banks of accumulators, when utilized in conjunction with existing 20.7 MPa 2270 liters/min hydraulic power system, will enable strong ground motion effects to be sustained for up to 30 seconds. Each bank consists of eight 190-liter accumulators, providing a total accumulated oil supply of 3040 liters.
- Hydraulic system modifications, to connect the accumulators to the pressure line of the existing system, with dedicated connections for the new, high-flow hydraulic service manifolds, and a new return line from these dedicated connections to the pump house area, along with a new hydraulic oil reservoir in the pump house area for the oil needed to fill the accumulators and to receive the return flow, as well as connections between this reservoir to the existing reservoirs, heat exchangers, and pumps.
• Digital 8-channel control system with real-time hybrid control packages, with each channel of the controller designed to follow an independent, random load, or displacement history.
• Digital video teleobservation system including a system of video cameras, video server, data server, restricted access web server, and a public access web server.
• Teleoperation equipment consisting of an application server that coordinates the data streams to/from the test process module, digital controller, and video server, synchronizes the time stamps between these with the time server, and allows a control client application to interact with these elements of the test scheme.
• High speed 256-channel data acquisition system, capable of acquiring data at 1000 Hz (1000 samples per second) per channel and expansion to 512 channels.
• Advanced sensors that include wireless MEMS-based accelerometers, piezoelectric transducers (strain and acceleration measurement), and fiber optic strain gages of Stimulated Brillouin Scattering principles.

Communications: The RTMD facility communication capabilities include the Internet, televideo conferencing, as well as traditional capabilities that include telephone and Fax machines.

Data acquisition, processing, and storage: The data acquisition includes a high speed 256-channel data acquisition system, capable of acquiring data at 1000 Hz (1000 samples per second) per channel and expansion to 512 channels. Data will be processed using LabView software. Storage includes a local data repository having a 1.3TB capacity, with a 2.5TB disc mirrored Fiberchannel RAID array. The storage has been configured as a redundant array attached to the local repository with an appropriate amount of tape based backup.

Teleobservation and teleoperation: Teleobservation capabilities include five Canon VCC4 cameras in conjunction with the NEESpop, telepresence manager, and video/image encoding storage servers.

Connection to high performance network: The equipment site will be connected to the NEES network through the Mid-Atlantic GigaPop Internet 2 (MAGPI) connection, with 155 Mb/sec Ethernet capabilities that can be scaled to 1 Gb/sec Ethernet capabilities when necessary. Like the other NEES equipment sites, the expanded lab will allow for shared-use access and training, the exchange of data in real time over the Internet, and telepresence and educational opportunities.

Examples Of Potential Research And Educational Uses

The functional flexibility of the RTMD facility enables numerous possibilities for integrating analytical and experimental research. These include not only seismic testing but also testing to evaluate response to other types of loading conditions, including wind and bridge structures with moving traffic loads. Large-scale structural components, subassemblages, and superassemblages can be built and tested at the Lehigh NEES Equipment Site, as illustrated in Figure D.2-2. Some examples of research that can be performed at the Lehigh NEES Equipment Site include: (1) large-scale testing to evaluate the seismic performance and behavior of structural systems with either passive, semi-active, or active controlled devices for wind or seismic hazard mitigation; (2) multidirectional earthquake testing of large-scale structural components such as a reinforced concrete bridge cap beam - pier - foundation system; (3) concurrent seismic testing of several components of a structural system using the hybrid testing method to couple the components; (4) response of structural elements and connections to high strain rate of loading, including blast loading.
The multidirectional earthquake testing of a reinforced concrete bridge cap-beam-pier foundation system is illustrated in Figure D.2-3. The objective of this test is to investigate the effects of soil-structure interaction on bridge structures subjected to realistic (4-DOF) seismic demands, and to acquire data for verifying analytical predictions. Using the multidirectional reaction wall, the structural test component is tied down to the strong floor and the dynamic actuators arranged to load the specimen, as illustrated in Figure 3. The bridge cap beam and pier are set on top of its pile foundation (which is placed in a soil box). Since the portion of the superstructure between bridge bents is known to remain elastic, it and other remaining parts of the bridge not appearing in the test structure are analytically modeled and coupled to the test structure. The top of the bridge pier is subjected to bi-directional earthquake loading (resulting in transverse, longitudinal, torsional, and rotational motions to the top of the bent with simultaneous gravity loading from static actuators), where the displacements are based on the real-time pseudo-dynamic hybrid testing method. In addition to conventional instrumentation, the structural and soil behavior are measured using a grid of MEMS accelerometers and continuous distributed fiber-optic sensors that are embedded in the soil and reinforced concrete. The data from the fiber-optic sensors are mapped digitally to obtain real-time evolution of strains over 2D or 3D configurations.
Figure D.2-3: Bridge System with Pile Foundation Setup

The teleobservation equipment at the Lehigh NEES Equipment Site enables remote users to observe tests, or observe visual data and measured response data from completed tests that are stored on an archive server. Hence, the response of several structures tested using the RTMD facility can be observed, providing a powerful means of education though examining and comparing the response of different structural systems and components to earthquake loading.
The Tsunami Wave Research Facility, located at the O. H. Hinsdale Wave Research Laboratory (WRL) at Oregon State University, consists of a three-dimensional (3-D) Tsunami Wave Basin (TWB) and a two-dimensional (2-D) Large Wave Flume (LWF). The WRL is located on the campus of Oregon State University in Corvallis, Oregon. It also hosts a circular wave basin for sediment transport and coastal processes studies, and a structure laboratory with strong floor and strong wall for large-scale structural testing. It is the only laboratory of its kind in the world with both large-scale fluid and structure testing capabilities connected through an information system network that allows remote observation and participation. The Tsunami Wave Research Facility is unique from three perspectives. First, it is the largest and most advanced tsunami testing facility. Second, it has a comprehensive Information Architecture (developed by experienced usability engineers) supporting remote users to ensure a positive impact on researcher effectiveness and productivity. Third, it has a Tsunami Experiment Databank so the broader research community can study the results of tsunami experiments, reducing the need for experimentation and providing data for validating analytical and numerical models.

The Tsunami Wave Research Facility consists of a three-dimensional (3-D) Tsunami Wave Basin (TWB) and a two-dimensional (2-D) Large Wave Flume (LWF). The tsunami wave basin is 48.8 m long, 26.5 m wide and 2.0 m deep and has a tsunami wave generator consisting of a 30-segment wave generator with each segment 0.88m wide and 2m high. The generator is capable of producing large multi-directional waves in arbitrary profiles. This tsunami wave basin is ideal to explore realistic three-dimensional effects of tsunami on coastal community and environment, as well as ports and harbors. The Large Wave flume is 104 m long, 3.66 m wide and 4.57 m deep. A hinged flap wave board, hydraulically driven with digital controls, generates large periodic and random waves up to 1.52 m high. This wave flume is one of six large flumes worldwide (two in Japan and three in Europe), and it is used to induce and measure wave forces on constructed and natural ocean features.

Network Connection Information Technology Support: A comprehensive information architecture has been developed and implemented, specifically engineered to enhance the effectiveness and productivity of tsunami researchers operating from remote sites. The system includes a large-scale repository of experimental data that makes it possible to replay experiments at a later date, and facilitates the exploration and identification of data on the basis of experimental characteristics, as well as extraction of results in a form suitable for validating the accuracy of numerical simulations of tsunamis. Tsunami experiments rely to a much greater extent on visual data and therefore requiring a greater degree of usability engineering to make results useful. Proven usability engineering methods applied throughout the development process ensure that the environment meets user needs and is easy to learn and use.

Research and Educational Uses: The Tsunami Wave Basin addresses all the requirements laid out by the tsunami research community. The basin dimensions and wave generation capabilities closely match the community’s vision of an “ideal basin.” Researchers can now measure the effects of tsunami runup, attenuation, and wave-impact using the facility for integration with tsunami simulation scenarios. Integration of research and education will be accomplished through graduate student training, research experiences for undergraduates, and K-12 outreach programs that specifically target groups under-represented in math and science. A majority of the outcomes from the tsunami experiments conducted at the facility will be presented in a visually enhanced form utilizing computer graphics technology. This realistic presentation of research results will be used proactively for the outreach programs.

The project team consists of Solomon Yim (PI), Daniel Cox (Co-PI), Cherri M. Pancake (Co-PI), Harry Yeh (Co-PI), and Charles K. Sollitt (Co-PI).

Website: http://nees.orst.edu/
Equipment Site Description

The Tsunami Wave Research Facility, located at the O. H. Hinsdale Wave Research Laboratory (WRL) at Oregon State University, consists of a three-dimensional (3-D) Tsunami Wave Basin (TWB) and a two-dimensional (2-D) Large Wave Flume (LWF). The WRL is located on the campus of Oregon State University (ORST) in Corvallis, Oregon, 100 miles south of the Portland International Airport. It operates on a cost-reimbursable basis and is accessible to clients, academic and commercial, worldwide. The WRL also hosts a circular wave basin for sediment transport and coastal processes studies, and a structure laboratory with strong floor and strong wall for large-scale structural testing. It is the only laboratory of its kind in the world with both large-scale fluid and structure testing capabilities connected through an information system network that allows remote observation and participation. The Tsunami Wave Research Facility is unique from three perspectives. First, it is the largest and most advanced tsunami testing facility. Second, it has a comprehensive Information Architecture (developed by experienced usability engineers) supporting remote users to ensure a positive impact on researcher effectiveness and productivity. Third, it has a Tsunami Experiment Databank so the broader research community can study the results of tsunami experiments, reducing the need for experimentation and providing data for validating numerical models.

The Building. The WRL is an open bay, steel building with surface area of approximately 5,800 m² and ceiling heights ranging from 7.6 m to 10 m. The building is T-shaped with the 2-D wave channel oriented N-S and located near the centerline of the top of the T. This wing of the building is approximately 114m long and 31m wide. Two commercial vehicle doors at each end of this wing provide access to the wave channel for mobile cranes and trucks. The circular and directional wave basins are located in the leg of the T, oriented E-W, which is approximately 72m long and 31m wide. The circular and 3-D basins are excavated 1.52 m below grade in this wing and 3m wide, 1:12 slope, ramps provide commercial vehicle access to the basins through doors in the building walls. Removable wave guides are constructed into the walls of the wave basins to provide continuity to the basin boundaries during testing. A band of 1.22m high windows surrounds the building at a height of 1.07m above the floor. In addition, the west side of the building has low-light transmission glass extending to the eaves and translucent panels are placed in the top half of all other exterior walls. Additional lighting is provided by 400 watt metal-halide fixtures, located at 7.6m centers. The broad spectrum lighting provides excellent video and film color coherency and fidelity. The elevated control room located at the intersection of the T shaped building has windows overlooking each of the three wave basins. Its dimensions are 7.6m wide by 22.9m long and the floor is elevated 4.3m above grade level. A false floor accommodates communication cables. The area is divided into thirds: computer workstations and data acquisition equipment; test coordination; and video logging and client workspace.

Tsunami Wave Research Facility. The Tsunami Wave Research Facility consists of a three-dimensional (3-D) Tsunami Wave Basin (TWB) and a two-dimensional (2-D) Large Wave Flume (LWF).

Tsunami Wave Basin (TWB). The 3-D wave basin is located in the east wing of the laboratory (indicated by “1” in Figure D.3-1) and is 48.8 m long, 26.5 m wide and 2.0 m deep (see Figure D.3-2). It is constructed as a reinforced
concrete reservoir, with a 15 cm wall and floor thickness. Uni-strut inserts are placed in rows at 2.1 m spacing to affix models, instrumentation and the wave generator throughout the basin. Two vehicle access ramps, 3m wide, allow equipment and materials to be transported conveniently into and out of the basin. A bridge crane with a capacity of 7.5 Tons spans the length and width of the TWB to position the models and to facilitate instrumentation. The edge-driven wave generator is designed and constructed by MTS Systems Corporation (MTS) of Minneapolis (see Figure D.3-2). Control of the wave board is achieved through displacement and velocity feedbacks. Displacement control is achieved by comparing the measured position of the wave board to a position algorithm, which creates solitary (tsunami) waves. Velocity control utilizes a wave profile measurement at the front of the wave board and compares it to the desired tsunami profile. The board velocity is adjusted via an algorithm that relates wave profile and board velocity. This velocity control cancels reflected waves in the basin and optimizes the wave shape beyond that available by means of the displacement constraint. The 30 wave generator segments are 0.88m wide and 2m high. To achieve the design wave conditions in 1 m water depth, each wave board must be capable of a 2 m displacement and a maximum velocity of 2 m/sec. Each digitally controlled wave board is powered by an AC electric motor with a peak power rating of approximately 20kW.

Figure D.3-2: View of Tsunami Wave Basin from control room (left). Detail of wavemaker (right).

Large Wave Flume (LWF) A dominant feature of the laboratory is a large wave flume in the west wing of the laboratory, indicated by a “3” in Figure D.3-1. The flume is 104m long, 3.66m wide and 4.57m deep. A hinged flap wave board, hydraulically driven with digital controls, generates periodic and random waves up to 1.52m high. A range of wavelengths can be modeled from short, deep water waves to long, shallow water waves as well as solitary and tsunami waves. Active reflected wave cancellation is provided by a wave profile measurement at the wave generator, serving as an input to wave board velocity control. This simulates the open boundary condition at sea, minimizing reflection off the wave generator and maintaining the quality of the incident wave environment. This wave flume is one of six large flumes worldwide (two in Japan and three in Europe). It is used to induce and measure wave forces on constructed and natural ocean features at large Reynolds numbers, providing high resolution wave structure interactions with minimum distortion due to viscous effects. Example applications include wave forces on marine pipelines and piles, stability of seabeds and breakwaters, runup on coastal margins, and floating structure response to wave excitation.

Figure D.3-3: View of Large Wave Flume from north end of the laboratory (left). Schematic of LWF (right).
Network Connection Information Technology Support:

Recent advances in computing and networking technology are leveraged to broaden the community that can benefit from large-scale tsunami experimentation. Our comprehensive Information Architecture uniquely supports the NEES vision of geographically-distributed use of experimental facilities. Sensor-based, visual, and audio data are harvested in real-time during tsunami tests and converted to formats suitable for transmission to remote sites and for long-term archival storage. Synchronized, multi-media data streams provide remote users with real-time observation and experiment steering capabilities. Web-based training materials are interactive, allowing users to “try out” different settings and observe the effects on simulated experiments. Proven usability engineering methods applied throughout the development process ensure that the environment meets user needs and is easy to learn and use.

The Tsunami Experiment Databank extends the lifespan of tsunami tests. Using special search interfaces, researchers are able to determine if the experiments they are planning replicate or overlap past tests conducted by other investigators. “Replay” capabilities allow researchers to re-visit experiments even years after they occurred. Extensive machine- and human-generated metadata make it possible to search, scan, and fast-forward through data streams to find the portions of greatest research interest. Computational modelers will be able to employ the databank exploration interfaces to identify and extract experimental results to validate the results of their simulations (Figure D.3-4).

![Figure D.3-4: TWB experimental notebook (left) and virtual TWB with sensor manipulation (right).](image)

Examples of Potential Research Uses:

Basin addresses all the requirements laid out by the tsunami research community. The basin dimensions and wave generation capabilities closely match the community’s vision of an “ideal basin.” The project builds on over two decades of experience operating related experimental facilities at the WRL. The upgraded wave basin allows repeatable, high resolution, large-scale experiments with very dense instrumentation. It enables researchers to test and validate advanced analytical and numerical models of tsunami-wave/structure interactions induced by sub-sea earthquakes, for a full range of ocean, coastal, and harbor studies. By controlling changes in bathymetry, surface permeability, roughness, and material erodibility, researchers can now measure the effects of tsunami runup and attenuation using the facility for integration with tsunami simulation scenarios (Figure D.3-5).
Examples of Potential Educational Uses:

The addition of the Tsunami Wave Basin makes it possible to expand Oregon State’s existing practice of involving students at both graduate and undergraduate levels in WRL projects. There is a significant number of scheduled courses in the Colleges of Engineering and of Oceanic and Atmospheric Sciences whose topics clearly relate to deterministic wave and tsunami loads, random waves and randomly generated tsunamis, nonlinear waves, and tsunami forces on coastal structures. We are developing Web-based materials to help faculty at other institutions to incorporate Tsunami Wave Basin experiences in their own courses.

Integration of Research and Education  The Wave Research Laboratory is an NSF REU (Research Experience for Undergraduates) site for nearshore science and hazard mitigation (wave.oregonstate.edu/ Education/REU/). Each summer, faculty mentors and their graduate students work with 10 talented undergraduate on active research projects with an overall goal of encouraging these students to consider graduate school. Half of the REU students are from under-represented groups, and half come from outside of OSU. Many of these students become involved in ongoing tsunami research (Figure D.3-6).
K-12 Education and Outreach  The WRL is actively engaged in K-12 education and outreach programs as part of its designation as an NSF-NEES site (Figure D.3-7). The WRL is currently working with the following people and programs to develop a comprehensive K-12 outreach program that will be used to highlight the tsunami projects:

- Ellen Momsen, Director, Women and Minorities Program at Oregon State University,
- Eda Davis-Butts, Director, Science and Math Investigative Learning Experiences (SMILE) program,
- Bill Hanshumaker, Public Marine Education Specialist, Hatfield Marine Science Center,
- Andrew Jackman, Vice President for Education, Oregon Museum of Science and Industry;
- Marta Marcia Brown, CEO, Brown Foundation (CA).

Figure D.3-7: Fourth and fifth grade student groups touring the facility.
The RPI 100 g-ton geotechnical centrifuge was commissioned in 1989 and started producing (1D) earthquake model simulation tests in 1991. By September 2004 it will have produced about 500 documented model experiments aimed at solving engineering problems, with a strong focus on earthquake engineering, extensive national and international collaborations, and results disseminated through more than 200 publications including 40 MS or PhD theses. This background is important because the accumulated experience of our research staff toward running excellent and repeatable tests is a significant part of the mode of operation of the RPI centrifuge. In the 2000-04 NEES construction project we are upgrading and integrating the centrifuge capability into the NEES grid. After 2004 our centrifuge model experiments will be more realistic than before thanks to the upgrading which includes: (i) increase in overall payload capacity from 100 g-ton to 150 g-ton; (ii) state-of-the-art in-flight 2D earthquake shaker and 2D laminar box; and (iii) 4-degree-of-freedom robot. Also, the models will now be instrumented with denser arrays of state-of-the-art sensors connected to our new Web-based data acquisition system, producing data suitable for storage in the NEES data repository as well as available for use in visualizations, teleparticipations, system identifications and model-based numerical simulations.

The centrifuge facility available to local and remote NEES users at RPI by Oct. 1, 2004 will include (see more details in www.nees.rpi.edu): (ii) 3m-radius, 150 g-ton capacity centrifuge; (ii) two 1D shakers capable of providing in-flight base excitation to several available rigid and laminar (flexible wall) model box containers; (iii) 2D shaker capable to provide in-flight excitation in the two prototype horizontal directions to the available 2D laminar box container; (iv) split box model container capable to simulate the effect of large ground displacement on buried pipes; (v) 4-degree-of-freedom robot capable of performing in-flight operations such as construction and excavation, pile driving, ground remediation, cone penetration, and model foundation loading tests without stopping the centrifuge and as directed by either local or remote users; (vi) in-flight soil reinforcement system; (vii) in-flight static and dynamic loading actuators; (viii) instrumented shallow and pile foundation models and quay wall models; (ix) LVDT, accelerometer, pore pressure, and earth pressure sensors as well as load cells and strain gages, other advanced sensors and a high speed camera and image processing software to monitor model response; (x) data acquisition system with 128+ channels and Internet capability; (xi) client-server data acquisition/control software for web-based observation and operation of centrifuge experiments; (xii) local area network connected to the high speed RPI network connection making it possible to share experimental data and other information in real time between the RPI research staff and outside parties; (xiii) a control/teleparticipation and a teleconference room; and (iv) model preparation, robot and electronic rooms and other equipment and peripheral facilities.

The added equipment versatility after upgrading plus availability of teleparticipation, will allow RPI together with other NEES and non-NEES researchers and facilities to investigate seismic soil and soil-structure problems in ways that were not possible before. This includes the large deformation behavior of soil deposits subjected to liquefaction and their interaction with port and highway structures, with buildings on shallow and deep foundations, and with buried pipes, which are some of the most complex and difficult problems to model numerically in earthquake engineering. Also, combined real-time soil-structure interaction experiments between the centrifuge and 1g structural facilities, comparisons between centrifuge and large 1g shaking table prototype experiments of soil or soil-structure systems in the US and/or Japan, and increased use of powerful numerical simulations before, during (hybrid testing mode), or after the centrifuge experiments, hold the highest promise of a new mode of research capable of solving some of the critical outstanding geotechnical earthquake engineering questions.

The project team consists of Ricardo Dobry (PI), Tarek H. Abdoun (Co-PI), Ahmed-W. M. Elgamal (Co-PI), Mourad Zeghal (Co-PI), and Thomas F. Zimmie (Co-PI).

Website: http://www.nees.rpi.edu/
Equipment Site Description

The 150 g-ton geotechnical centrifuge NEES facility is located in the basement of the Jonsson Engineering Center (JEC) of the RPI campus in Troy, NY. This building also contains the offices of essentially all personnel listed in this proposal, offices of graduate students conducting centrifuge and associated analytical research, and offices available for visiting users. The layout of the facility is shown in Fig. D.4-1 and is all in one level without interfering stairs. Main spaces shown in blue color in Fig. D.4-1 include the centrifuge itself and surrounding circular enclosure (Fig. D.4-2), as well as the connecting tunnel housing the variable speed motor controller and power electronics cabinets. Other main spaces of the centrifuge facility shown in blue in Fig. D.4-1 are: (i) two model preparation rooms; (ii) state-of-the-art control and teleparticipation room with four plasma screens and capacity for 6’ on-site operators/visitors; (iii) robot room; (iv) electronic development room; (v) state-of-the-art teleconference room; (vi) two rooms containing respectively the data acquisition (DAQ) and LAN servers; and (vi) geotechnical computer laboratory.

Figure D.4-1: Layout of RPI NEES geotechnical centrifuge facility (blue spaces) and other soil and structural research and educational facilities (yellow spaces)

The spaces included in the layout of Fig. D.4-1 contain the various centrifuge equipments, sensors, data acquisition and other hardware and software listed in Section A.1, with corresponding connections to the high speed RPI network, providing the physical infrastructure needed to support the NEES vision of high quality physical testing, shared use and combined real-time experiments with other facilities. More details are provided later in this proposal and can also be found for all pieces of equipment in www.nees.rpi.edu. Especially important for our aim of more realistic centrifuge models and for RPI’s contribution to the teleparticipation/shared use/model-based simulation NEES mode of research, are our new robot, new state-of-the-art 2D shaker, and advanced sensors and high speed camera, which are discussed below.
The in-flight 4-degree-of-freedom robot (Fig. D.4-3) allows for a stroke of 0.8 m in the x and y prototype directions, a stroke of 0.5 m in the y vertical prototype direction, and a 270° rotation around the vertical axis. It has a high degree of accuracy which makes it ideal for use in teleparticipation, and load capacities of +/- 1000 N and +/- 5000 N, respectively in the horizontal and vertical directions, as well as a torque capacity of +/- 5 NM around the vertical axis, applicable to uses such as static in situ cone penetration and loading tests of models of piles or shallow foundations. The robot will play a key role in teleparticipation, with remote users able to implement realistic simulations of construction and excavation operations, pile driving, ground remediation, cone penetration, and model foundation loading tests without stopping the centrifuge. The horizontal, vertical and torque loading capabilities of the robot will play a central role in combined real-time, soil-structure interaction tests involving other experimental facilities and/or feedback from simultaneous numerical simulations.
The in-flight 2D shaker servohydraulic multiactuator system (Fig. D.4-4) is capable of producing periodic or random motions in the two prototype horizontal directions as determined by the input signal. The nominal shaking force is 50 kN in each axis, capable of exciting a 965 x 660 x 711 mm payload at a centrifugal acceleration of 100 g with a nominal shaking frequency range of 0 to 350 Hz. The shaker excites the base of a 2D flexible wall laminar box container with the soil or soil-structure model; similarly to the 1D laminar box containers also available at RPI, the flexible walls of the 2D laminar box allow realistic simulation of the shear beam free field ground conditions during horizontal shaking. Two-dimensional shaking allows more realistic in-flight earthquake simulations for both soil and soil-structure models; available laboratory and field information indicates that two-dimensional shaking causes significantly higher densification in dry sands and excess pore pressures and liquefaction in saturated sands compared to 1D shaking. We also anticipate that this 2D shaking capability will play a key role in clarifying the relation between ground surface slope and topography, on the one hand, and direction of shaking on the other; for slope failure, flow failure and lateral spreading phenomena involving soft clays as well as saturated sand liquefaction.

Figure D.4-4: Two-dimensional in flight servohydraulic shaker (two prototype horizontal directions)

Figure D.4-5 illustrates some of the advanced monitoring and sensing technologies now being developed or under examination for centrifuge modeling at RPI. They include MEMS accelerometers (which we are exploring together with the UC Davis NEES experimental site), tactile pressure sensors and fiber optic shape tape, as well as our newly acquired Vantom 4 high-speed camera with associated image processing software. As new and extremely promising measurement technologies continue to appear in the market at a rapid rate, and evaluation (and in some cases, also some development) is needed before they can be reliably used in centrifuge tests, it is difficult to anticipate exactly which techniques will be available for shared users at the RPI centrifuge 2-3 years from now. However, it is clear that there will be continued improvement in the quantity and quality of the data, with greatly increased resolution (in space and time) of the model response. More and better soil (as well as foundation and structural) response data such as permanent and cyclic deformations, accelerations, pore water pressures, bending moments, etc., will become available. This is extremely important, as the centrifuge’s contribution to the NEES vision will be greatly enhanced by the use of dense arrays of advanced sensors and of high-speed cameras to provide high-resolution measured model response. This, in conjunction with our networked data-acquisition system and remote-access capability, will lead to a major advance in the use of the geotechnical centrifuge data at RPI, allowing better teleobservation, shared use of data, test visualizations, system identification, numerical computations, and development of model-based simulations. The RPI team has started to explore some of these possibilities and is getting ready to expand their use to the maximum in research applications, especially investigations on large deformation behavior of soil deposits which are both subject to liquefaction and interact with other structures. For example, in the current US-Japan research project involving some RPI researchers as well as UCSD, pile foundations in inclined soil deposits are subject to liquefaction and lateral spreading in the RPI centrifuge and in large prototype laminar boxes (as high as 6m) in shaking tables in San Diego and NIED in Japan. The size of the prototype experiments in the 1g shaking
tables allow extensive use of large amounts of sensors including dense arrays at critical locations, while both 1g and centrifuge experiments are instrumented with advanced sensors and the comparisons of experimental results make systematic use of system identification and visualization techniques, and numerical simulations are both calibrated by the measured results and are used in the planning of further tests and refinement of sensor locations. We expect to make these and other sensing technologies available to shared users of the RPI centrifuge as soon as their feasibility and reliability have been confirmed.

Figure D.4-5: Advanced monitoring and sensing technologies (tactile pressure sensors, fiber optic shape tape, and high speed camera)

Figure D.4-6, presented by B. F. Spencer, Jr. of the U. of Illinois at the 8/7/03 Summit Meeting in Chicago (http://worktools.si.umich.edu), illustrates the vision of NEES for combined, pseudo-dynamic real-time soil-structure tests involving several 1g structural NEES experimental facilities for structural response, and a geotechnical centrifuge NEES facility such as RPI’s for the foundation and soil response. In this type of experiment, which is conducted with the foundation-soil centrifuge model always spinning, important roles should be played by our robot (which will apply the loading to the foundation-soil model), by our advanced sensors and data acquisition system, and, of course, by our teleparticipation capability. Figure D.4-6 shows very clearly the kind of research now made possible by NEES with the participation of the RPI centrifuge, which was not possible before.
Visualization tools, especially those that provide a real-time (or almost real time) picture of the response and behavior of the soil or soil-structure model during and after the shaking, are extremely important as part of our centrifuge contribution to NEES’ tasks and vision, including shared use, teleparticipation, and real-time experiments such as illustrated by Fig. D.4-6. At the most basic level, they are the answer to the question of how to integrate in a meaningful way the vast mass of data to be provided by the dense arrays of advanced sensors together with the high speed cameras. For real time teleparticipations and combined experiments such as that of Figure D.4-6, timely human decisions by the shared users may be needed that will depend on their understanding of how the model is responding, and this can only be obtained through automated routine visualizations of the model’s response. The RPI team will provide an increasing number of these visualization tools to the shared users as part of the capabilities available to them. Examples of visualization capabilities that are already available can be viewed in www.nees.rpi.edu. Figure D.4-7 is a frame – corresponding to one time instant during shaking – obtained from one such visualization. The visualization of Figure D.4-7 corresponds to the shaking and liquefaction of loose saturated sand behind a waterfront quay wall centrifuge model, which approximated the conditions at Port Island during the 1995 Kobe earthquake. In this visualization, blue = ocean, black = quay wall, red = liquefied sand with high positive pore water pressure, yellow = sand with some positive pore pressure, and green = sand with negative pore water pressure. The visualization clearly shows that the sand in the free field liquefied both behind the quay wall and under the ocean bottom, while a complicated soil-structure interaction pore pressure response was taking place near the quay wall, including the development of negative pore pressures under the quay wall as this structure both rocked under the shaking and slid toward the ocean.
The University at Buffalo’s (UB) Structural Engineering and Earthquake Simulation Laboratory (SEESL), which operates since 1982, one of the laboratories serving the Multidisciplinary Center for Earthquake Engineering Research (MCEER), was expanded to become a VERSATILE node of NEES. Equipped with two shake tables, a new reaction wall and a new strong floor located in an expansion to the exiting lab, the facility will be capable of conducting advanced testing of full or large-scale structures using static or dynamic loading. The use of modern techniques such as Pseudo-Dynamic, Effective Force, and a new Real-Time Dynamic/Pseudo-Dynamic Hybrid will be possible, along with conventional Static, Quasi-static, and Dynamic Force techniques. The new Real-Time Dynamic Hybrid Testing (RTDHT) developed and enhanced at UB is a form of substructure testing in which shake table and/or dynamic force experiments on substructures are combined with real-time computer simulations of the remainder of the structure. This provides a more complete picture of how earthquakes would affect large structures, including buildings and bridges, without the need to physically test the entire structure. Specifics of the expansion include:

(i) A testing area expanded from approximately 3,000 square feet to 13,000 square feet (including a greatly expanded strong floor), reaction walls, and a trench for the moveable shake tables.

(ii) A set of two high-performance, six degrees-of-freedom shake tables, which can be rapidly repositioned in a trench from directly adjacent to one another to positions up to 34 m apart (center-to-center). Together, the tables can host specimens of up to 100 metric tons and as long as 37 m

(iii) Next to the shake tables, a newly constructed large reaction wall equipped with external dynamic actuators will allow application of computer-simulated forces on shake table-mounted substructures, thus simulating the reaction of the entire structure (Real-Time Dynamic Hybrid Testing, or RTDHT).

(iv) An expanded strong floor totaling more than 600 square meters are equipped with high performance dynamic and static servo-actuators which allow implementing forces of up to 7800 tons

(v) Equipment required operating the shake tables and the high performance actuators, including a high-capacity, high-performance hydraulic supply and distribution system (up to 6000 lpm).

Networked tele-experimentation capabilities using modular and expandable teleobservation and teleoperation equipment, tied to the testing systems using discrete and global sensors, including high-resolution digital video and imaging capabilities, make it possible for remote collaborators to use the UB NEES facility, as well as for all to remotely observe these activities. A NEES collaboration room located adjacent to the laboratory is equipped with NEES-Grid enabled equipment to supports the NEES collaborative activities.

The project team consists of Michel Bruneau (PI-construction), Andrei Reinhorn (PI–operations), Michael Constantinou (Co-PI), Theva Thevanayagam (Co-PI-construction), Andrew Whittaker (Co-PI), André Filiatrault (Co-PI –operations), Mettupalayam Sivaselvan (Project Engineer), Zach Liang (Project Engineer), Mark Pitman (Lab Manager), and Tom Albrechcinski (Project Administrator)

Website: http://nees.buffalo.edu/
Equipment Site Description

The NEES laboratory at UB is capable of conducting testing of full or large-scale structures using static or dynamic loading. This is accomplished by combination of large-scale dynamic and static servo-controlled actuators that have a cumulative capacity to apply forces of up to 7800 tons, a strong floor, and a large reaction wall – all of which integrated with two shake tables that can be easily relocated in a 37-m long trench. To achieve the high loading rates required for seismic simulation, the test equipment is supported by a high-capacity, high-performance hydraulic supply and distribution system (capable of supplying up to 6000 lpm), and operated by numerous high-performance digital control systems. The facility is housed in the new NEES laboratory and is serviced by a 40-ton capacity crane.

The use of modern testing techniques, such as Pseudo-Dynamic and Real-Time Dynamic Hybrid Testing are possible, along with conventional Static, Quasi-static, and Dynamic Force techniques. A new form of dynamic substructure testing, Real-Time Dynamic Hybrid Testing, is being developed at UB with the new equipment in which shake table and/or dynamic force experiments of substructures are combined in real-time with computer simulations of the remainder of the structure. This provides a more complete picture of how earthquakes would affect large structures, including buildings and bridges, without the need to physically test the entire structure.

Networked tele-experimentation capabilities using modular and expandable teleobservation and teleoperation equipment, tied to the testing systems using discrete and global sensors, including high-resolution digital video and imaging capabilities, make it possible for remote collaborators to use the UB NEES facility, as well as for all to remotely observe these activities. A NEES collaboration room located adjacent to the laboratory is equipped with NEES-Grid enabled equipment to supports the NEES collaborative activities, such as real time tele-observations, tele-operations and group interactive consultations.

The NEES laboratory at the University at Buffalo is a part of the Structural Engineering and Earthquake Simulation Laboratory (SEESL) of the Department of Civil, Structural, and Environmental Engineering and one of the laboratories affiliated with the Multidisciplinary Center for Earthquake Engineering Research (MCEER).
Description of Testing Capabilities

The two shake tables of the UB NEES facility are six degrees-of-freedom simulators, which can be rapidly (within 3 days) repositioned, from directly adjacent to one another, or in various positions at 3.05 m c/c, up to 30.5 m apart (center-to-center of the tables). The nominal payload for each of the table is 20 tons, but specimens up to 50 tons can be tested on each table, albeit at reduced levels of shaking (maximum overturning moment capacity is 46 ton meter). Together the tables can support specimens of up to 100 metric tons and as long as 36 m. Table motion excitations can be fully in-phase or totally uncorrelated dynamic excitations.

Each shake table is 3.6 meters x 3.6 meters in plan. The maximum horizontal (2-axis) and vertical displacements are ±150 mm, ±150 mm, and ± 75 mm respectively, maximum velocities are 1250 mm/sec, 1250 mm/sec and 500 mm/sec, respectively, and maximum accelerations are ±1.15 g, ±1.15 g and ±1.15 g, respectively, for a 20-ton specimen. The maximum frequency of operation is 50 hertz at the nominal payload, and 100 hertz maximum.

Next to the shake tables, a large 9m tall reaction wall equipped with external dynamic actuators allows application of computer-simulated forces on shake table-mounted substructures, thus simulating the demands on an entire structure (Real-Time Dynamic Hybrid Testing). A high level of familiarity and experience with “on-line” testing procedures is required to use Real-Time Hybrid Testing, and but this capability allows the most experienced experimentalist to consider testing small specimens as part of complex structures integrated via numerical simulation, through substructuring and other strategies.

The close proximity of a 3200 square feet (40’x80’) strong floor to the reaction wall allows, with the use of dynamic or static actuators, testing of large-scale or full-scale specimens or components. Three 100 ton dynamic actuators are available for this purpose, each having ± 20 inches stroke, swivel heads (tilt angle ±8°, swivel angle +90°,-30°), and 3000 lpm servovalves, and capable of developing a load of approximately 150 kips (70 tons) at 1 meter/second. Additionally, each actuator has a custom port shut off valve assembly and a second low flow servovalve manifold that can be manually selected to allow low-flow operation. Furthermore, two 250 ton static actuators are also available, each having ± 20 inches stroke, swivel heads (swivel angle +90°,-80°), and 60 lpm servovalves.

Shake tables and actuators are driven by a high-capacity, high-performance hydraulic supply and distribution system (up to 1600 gpm), and numerous digital control systems. The hydraulic capacity is provided by a hydraulic power supply system (2800 lpm) and accumulators (2800 lpm). When the accumulators are fully mobilized, the peak hydraulic flow capacity can be sustained for approximately 30 seconds. Hydraulic ports are located along the shake table trench, as well as at distribution manifolds located at fixed locations on the strong floor.

Maximum pull-out capacity at any anchor points on the floor or reaction wall varies between 60 to 120 tons, depending on proximity to the perpendicular supports to the floor or wall. The laboratory area is serviced by a single 40 ton gantry crane.

Due to its proximity to the existing SEESL a large amount of additional actuators, dynamic instruments, rigging equipment, and tools can be made available to the new NEES facility for handling most complex experiments.

Description of Telepresence Capabilities

Telepresence gives the user the ability to observe and participate remotely in an experiment conducted physically at UB. The two primary tools used to participate in a remote experiment are the TelePresence Server and the WorkTools Site, both accessible through a standard web browser. With these tools one can view the lab space through 8 user controllable telerobotic video cameras placed throughout the lab in reconfigurable locations. The remote participant can pan, tilt, and zoom each camera to the area of their choosing. In addition to these video sources, one can choose to take a high resolution still image of an area of the remote lab space so more detail can be revealed. Microphones will be placed near the current experiment so the sounds of the experiment and voices of the people physically participating can be heard.

The data acquired from the sensors in the experiment will be streamed to the NEESpop and can be viewed live with the DataViewer in numerical and graphical form. This tool is fully configurable and allows one to choose what data
he/she wants to view and the format in which it is presented. Other data from the experiment, such as general notes and setup data, is stored in the Electronic Notebook and can be easily accessed by remote participants. Multi-site video conferences can be held ad-hoc to collaborate interactively with local and remote participants during an experiment. Through all of these tools one can observe and participate in many aspects of a remote experiment.

Networking Capabilities

The UB-NEES networked operations are shown in the block diagram. The LAN includes five basic components (subnets) for (1) basic testing control; (2) real time simulation and control; (3) data acquisition and storage; (4) audio/video information interface; and (5) numerical simulation. The LAN has an interface to the WAN and to the NEES GRID through NEES-POP.

The test control subnet includes a layered network of computer clusters that control the individual shake tables, experimentation stations individual actuators and internal data transfer. The testing network has (a) an internal non-routable subnet ensuring proper interconnection of instruments, (b) shared common RAM network interface and system (ScramNet™), and (c) an addressable subnet for running experiments.

The real-time hybrid simulation and control subnet includes a cluster of computers running Windows 2000 and real-time operating software from Matlab (Real-Time Workshop and Simulink), and stations for structural simulations, control reference generation and high-speed data acquisition. Similar to the test control subnet, the real-time hybrid subnet uses a shared common RAM network (ScramNet™) and an internal non-routable subnet.

The data acquisition subnet includes clusters of IP-addressable OPTIM / Megadac and Pacific Instruments multi-channel stations (325 channels) and several PC-based workstations using industry standard A/D and D/A interfaces connected directly to the data acquisition (DAC) subnet in the existing SEESL “FAULTLINE” domain. Data is acquired through distributed workstations, located on the laboratory floor, running Megadac/TCS proprietary software and equivalent. The data acquisition subnet is equipped with two Tera-bytes of local storage, which will be made part of the NEES Grid for distributed repository.

The video / audio subnet includes three separate functions: (a) the tele-observation equipment; (b) the tele-cooperation, tele-communication and display equipment using two workstations with real time “video-conferencing” equipment (using Polycom VS4000), (c) the tele-monitoring equipment with high-resolution high-speed cameras (EKTAPRO or equivalent).

The computational simulation and modeling subnet (or knowledge accumulator) is a cluster of workstations running various operating systems (Windows, Unix, Linux, or Sun-OS) that are networked to the local UB Supercomputer Center (CCR). The subnet provides the computational power required for test preparation/simulation, data interpretation, test visualization, analytical-model development, computational-platform development, and model and platform validation.

The interface of UB-NEES to the UB-WAN provides a link of the existing LAN in Ketter Hall through Gigabit fiber optics cables, connections and switches to the UB backbone that has OC3- (155MB) switched connections (OC12 by 10/04). The new LAN is connected to services of vBNS and Abilene.
Examples of potential research and educational uses

The hybrid testing capabilities of the UB NEES facility make it possible to conduct a class of tests considering structures as large as possible while only testing a key substructure. For example, it could be possible to investigate the behavior of a multi-story building retrofitted with passive energy dissipation systems (e.g. fluid-dampers) introduced only in the first two stories. A number of recent analyses have suggested that optimal implementation of this technology does not require dampers at all stories, and that implementations only at a few lower stories may be sufficient. Experimental validation of this concept under 6-dof excitation using a three-dimensional specimen will also make it possible to investigate: (i) whether torsional response is also effectively controlled; (ii), the adequacy of the dampers’ attachment points under out-of-plane excitation; (iii) the impact of severe non-linear response in the stories without dampers, and; (iv) various types of energy dissipation systems within the same experimental framework. To achieve this, a two-story three-dimensional frame with dampers would be in-stalled on the shake-table. Three horizontal high-capacity dynamic actuators connected to the top story would provide the ability to displace the story at any position in plan, to maintain the proper horizontal boundary conditions. Four vertical actuators connected to the top floor and distributing the load to each column using spreader-beams, would allow accounting for the gravity-load boundary conditions. The rest of the structure, considered though a substructure computer-model, is analyzed in real-time, using data from the shake-table and specimen to calculate and feedback to the actuators the new interface displacements that must be imposed to correctly account for dynamic action of these upper stories on the specimen.

Note that the substructure computer model need not be limited to elastic response, but may also include non-linear hysteretic models. In fact, with the ability to account for yielding elements, it then be-comes possible and attractive to introduce a valuable tele-experimental component to this test, with a remote site conducting a large-scale test of a yielding component that is part of the computer modeled substructure.

Tests would be web-cast to high-school science students, who would have prepared earlier by reading the K-12 primer on earthquake engineering located on the web site of the Multidisciplinary Center for Earthquake Engineering Research. During the test, earthquake-engineering students nationally and internationally would receive streaming data from instrumentation measuring the seismic performance of payload equipment located on the specimen, for the purpose of separate studies.
The broader impact of the proposed operation of the NEES Equipment Site at the University of California, Berkeley, nees@berkeley, is in that it enables NEES researchers to develop and use a new generation of hybrid simulation methods in their earthquake engineering research projects. Hybrid simulation smoothly integrates physical and numerical components. The fundamental premise of this simulation method family is that the effect of inertia forces on the structure can be computed numerically and simulated by applying appropriate actions using hydraulic actuators. The first advantage of this approach is the ability to impose the dynamic actions at a chosen rate thereby controlling the time scale of the experiment. The second advantage is the ability to divide the model into physical and numerical sub-structures and simulate their interaction thereby controlling the length scale of the experiment.

NEES researchers using the nees@berkeley equipment site can do hybrid simulation in both local and geographically-distributed modes. In the local mode, physical and numerical sub-structures are connected using a local shared-memory network. The speed of this network enables hybrid simulation at high rates: real-time tests are possible at actuator speeds up to 0.5 m/sec. The nees@berkeley equipment site supports digital control of up to 8 independent degrees of freedom on physical sub-structures (sufficient for two or three such sub-structures) and has one shared-memory connection for a computer dedicated to numerical sub-structures. To do more, NEES researchers can use the NEESgrid network to perform geographically distributed hybrid simulation by placing physical and numerical sub-structures of their models at the chosen NEES equipment and computer sites. The intellectual merit of the proposed operation of the nees@berkeley equipment site is that it supports geographically-distributed hybrid simulation by providing the algorithms for conducting such tests, Matlab models for pre-test simulation, implementing NEESgrid protocols enabling data exchange, and offering high-speed Ethernet connection to the NEESgrid network.

NEES researchers can also perform conventional earthquake engineering experiments at the nees@berkeley equipment site. A post-tensioned reconfigurable reaction wall, comprising 24 0.5m tall reaction blocks, a strong floor and an array of hydraulic actuators enable NEES researches to use a variety of specimen sizes, shapes and configurations. They can collect data using a new 128-channel data acquisition system for conventional deformation and force measuring instruments as well as a set of high-resolution video and still-image cameras. The nees@berkeley equipment site can host NEES researchers while they conduct their work on-site or let them participate from a remote location using teleconference equipment, telepresence cameras and a robot avatar. NEES SI tools for generating meta-data, documenting and archiving the test, and facilities for teleobservation required by NSF to conduct NEES research are provided and supported. A nees@berkeley 12-person team is ready to facilitate NEES-related work.

The project team consists of Jack Moehle (PI), John Canny (Co-PI), Don Clyde (Co-PI), Stephen Mahin (Co-PI), Sylvia Mazzoni (Co-PI), Khalid M. Mosalam (Co-PI), and Bozidar Stojadinovic (Co-PI).

Website: http://nees.berkeley.edu/
Equipment Site Description

The NEES Equipment Site at the University of California, Berkeley, nees@berkeley ES, is one of the 15 equipment site comprising the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES). nees@berkeley is designed to support the development and active research use of a new generation of geographically distributed hybrid testing methods. Given a fast and reliable NEESgrid network, the limits of laboratory size, computer location and geography virtually disappear, enabling hybrid and distributed simulations of structures at scales and levels of complexity not possible today. The structural testing methodology and hardware, information technology and operation components of the nees@berkeley ES are described in the following sections.

Hybrid Simulation Method

Response of a structure to an earthquake is the result of complex interaction of all elements of that structure. Today, our understanding of earthquake response of individual sub-structures is quite good. However, we do not fully understand how interactions among sub-structures define the response of the entire structure. The nees@berkeley ES is designed to enable modeling and simulation of the interaction among different sub-structures. A model in such hybrid simulation consists of sub-structures, many instantiated in powerful computers as finite element sub-models, and some instantiated as physical specimens in laboratories representing sub-assemblages of the prototype that are too complex to model numerically. Hybrid simulation is conducted using combined numerical analysis and test control procedures that smoothly integrate physical and computational sub-structures into a single model. The interaction among the sub-structures in a hybrid test occurs in the network that binds together the computers and laboratory facilities where the sub-structures are instantiated. Such simulation is rooted in the pseudo-dynamic testing method (PDTM) developed since the 1970’s at UC Berkeley and elsewhere. Even though the hybrid simulation test is happening on the Ethernet, PDTM integration procedures and dynamic testing similitude rules still apply. Our challenge was to build the technology to enable such hybrid testing and test result interpretation on the NEESgrid network.

The technology for geographically distributed hybrid testing is based on a three-loop hybrid test control architecture. The innermost loop is the conventional PID actuator control loop updated at a 1kHz rate. The outermost loop is the conventional time-step integrator used in PDTM updated at 0.1kHz rate. The intermediate loop, comprising a predictor and a corrector, acts as a buffer between the inner and outer loops. When a hybrid test is run in a local mode (with all sub-structures connected using a high-speed shared memory network at nees@berkeley ES), the three-loop control architecture enables fast testing at real-time rates. However, the principal advantage of the three-loop architecture is that it lends itself to implementation on the NEESgrid network. The fast-rate communication between the inner and intermediate loops must be done locally using a shared-memory network, but the slower-rate communication between the outer and the intermediate loop may be shifted to NEESgrid relying on 1Gb/sec Ethernet spanning the NEES Equipment Sites.

However, such control architecture is not sufficient to enable geographically distributed testing. The time-delays or unexpected outages on the Ethernet introduce a random element into the control loop. An event-based control strategy, based on a finite state machine, was develop to encapsulate the logic required to make the geographically distributed hybrid test robust enough to be completed on the Ethernet. A proof-of-concept test using the sub-structure configuration, network deployment and event logic shown in Figure D.6-1 was successfully accomplished during the May 2003 NEES Awardees Meeting at Park City, UT.
Structural Testing Equipment

The nees@berkeley equipment site leverages the capabilities of existing testing facilities located at the University of California, Berkeley Richmond Field Station. It builds on an existing 6.1x18.3m strong floor and an existing 4-million-pound axial compression-tension machine (Figure D.6-2a). A new reconfigurable strong wall, built using 24 0.5m-tall post-tensioned blocks, can be configured in three principal ways to enable: 1) multiply sub-structured testing (Figure D.6-2b); 2) high-axial-load testing (Figure D.6-2c), and 3) collapse mechanism testing (Figure D.6-2d). An array of dynamic and static actuators is provided to augment an existing set of static actuators. These
actuators are powered by a hydraulic pump system with a 2000 liter accumulator system and controlled by a hybrid simulation controller with 8 independent control channels enabling quasi-static, near-real-time and real-time hybrid simulation, or by a 4-channel MTS Flex-test system enabling conventional static and quasi-static testing. Matlab/Simulink models of the reaction wall and actuators are available for computer-only pre-test simulation of hybrid simulation tests. Conventional deformation and force measuring instruments is available to support data collection using a new 128-channel data acquisition system that features a hardware-based data ring buffer and a Matlab and LabView user interface. A video-as-data collection system is also available. This system comprises high-resolution cameras (6 video and 4 still cameras), image storage and editing facility, as well as time-stamping using a network time protocol server to synchronize images and test controller commands.

Figure D.6-2: nees@berkeley reaction floor and wall configurations.

Information Technology Equipment

The nees@berkeley ES is connected to the Ethernet using a 1Gb/sec fiber-optic network. A dedicated router located at the Richmond Field Station is at the outer edge of the UC Berkeley network and thus close to the Ethernet backbone, a feature crucial for minimizing the communication delays on NEESgrid. Behind the router, the nees@berkeley ES traffic is split into three sub-nets. One sub-net is hosting a wireless network for NEES research use during test preparation and local observation. The second subnet is dedicated to the video and telepresence equipment, while the third sub-net is dedicated to the hybrid test control and data collection (Figure D.6-3). By dividing the network in such way, the mission critical hybrid test control sub-net can be insulated from the bandwidth-hungry video sub-net and casual user traffic.
The hybrid simulation sub-net comprises the hybrid simulation controller and interfaces the controller local shared-memory network with the high-speed Ethernet and NEESgrid. The equipment on the telepresence sub-net enables remote researchers to interact with the staff at nees@berkeley before, during and after the test and remote users to observe a NEES test. The NEES-wide teleobservation system based on Axis/Broadware hardware and Chef workgroup software is provided for use by remote observers. NEES researcher can use a Polycom video conferencing system for interaction with the staff. Finally, a robot avatar provides the most direct method for remote interaction. This robot, a mobile teleconferencing station with a laser pointer, can move under control of a remote researcher and thus provide the remote user with a personal roaming presence at nees@berkeley.

The nees@berkeley local area network provides a 1TB mirrored RAID disk array for local data and video storage facilities. Both remote and local users can utilize the facilities provided by the NEES System Integrator and nees@berkeley staff to generate the meta-data appropriate for their test, describe the collected data, and upload it to the NEES data repository. Finally, secure and redundant connection to NEESgrid makes it possible to browse and download NEES data from the NEES data repository and store it locally.

**Operation of the nees@berkeley ES**

The nees@berkeley equipment site operation is lead by the PI, Professor Nicholas Sitar, and the co-PI, Professor Bozidar Stojadinovic. An organization chart showing the reporting hierarchy of the nees@berkeley staff is shown in Figure D.6-4. A potential NEES researcher will contact the NEES Operations Manager at nees@berkeley to prepare and submit a NEES proposal. When the proposals are funded, nees@berkeley facility manager will interact with the Consortium to schedule and organize the tests, while the remote NEES researchers and their students attend nees@berkeley training. Such training comprises a course on hybrid simulation methods, offered by the co-PIs, and lectures on safety and equipment usage at nees@berkeley provided by the staff.
The main component of the outreach and information effort at the nees@berkeley equipment site is our web page: http://nees.berkeley.edu. The web page contains the documentation and examples of use of the nees@berkeley ES. It is operational now: visit to start using the nees@berkeley equipment site.
D.7 University of California at Davis

The UC Davis centrifuge has the largest radius and platform area of any geotechnical centrifuge in the US; it is among the largest anywhere in the world. The centrifuge can carry 5 ton payloads to 75 g at its effective radius of 8.5 m. The large size and available resources allow researchers to perform detailed experiments of complete geotechnical engineering systems. NEES developments capitalized on the size of the centrifuge and revolutions in instrumentation and information technology to enable generation of higher resolution information (control, sensors, and images) and more realistic physical models, providing unambiguous experimental data for assessing Model Based Simulation theories. The centrifuge is a shared-use facility in the NEES laboratory. Researchers are invited to take advantage of the centrifuge facilities and centrifuge test data available at UC Davis.

A shaking table mounted on the centrifuge is used to simulate ground motions from microtremers to great earthquakes, in either biaxial (horizontal-vertical) or uniaxial (horizontal) shaking modes.

A distributed high-speed wireless data acquisition system records data from hundreds of MEMS accelerometers / inclinometers in a single test. The system consists of many miniature eight-channel high-speed data acquisition units that can be buried in the soil. The dense transducer arrays can be used to study spatial variability of wave propagation, or to quantify the internal deformations of the soil profile at resolutions that were previously impossible. A large inventory of wired transducers can also be used to monitor model behavior during an experiment using the updated data acquisition system. Arrays of pore pressure transducers, for example, can be used to monitor spatial variation of liquefaction.

A gantry robot with changeable manipulator tools and an on-board tool rack can be used to perform multiple tasks without stopping the centrifuge. Users can use the gripper tool to drive piles, apply load cycles to structures, and manipulate objects to simulate construction processes. The robot can also perform in-flight in-situ site characterization tests using geophysical testing methods. Soil strengths can be indexed using the cone penetrometer and vane shear robot tools. A needle probe tool may be used to deduce porosity variation at millimeter resolution. An ultrasound tool may used to measure the deformation of a submerged surface or subsurface. Users can inspect the exposed model surface with a stereo camera tool.

An array of high-speed video cameras can be used to image the surface of models and track deformations during shaking events. Bender element arrays may be used to measure shear-wave velocity distributions. An electrical resistivity tomography system can create images of internal resistivity distribution that can be correlated to porosity distribution. The various independent systems are interconnected in the data acquisition network. The network structure can easily accommodate future growth or custom data acquisition systems developed on a project-specific basis.

A new 470 m² building houses the visualization and control room, where we use 3-D software and our Geowall stereo display to explore data from hundreds of sensors collected in simulated earthquake events. The room is also outfitted with video conferencing and telecollaboration equipment so that remote researchers can interact with local staff during experiments.

The UC Davis NEES Operations team consists of - PI: Bruce Kutter (Center Director); Co-PIs: Dan Wilson (Facility Manager) and Ross Boulanger.

Website: http://nees.ucdavis.edu/
Equipment Site Description

The UC Davis centrifuge has the largest radius, and largest platform area of any geotechnical centrifuge in the US; it is one of the top few in these categories in the world. The centrifuge can carry 5 ton payloads and operate at 75 g (at the effective radius of 8.5 m). Typical geotechnical model testing in the past used very limited amounts of instrumentation that provide observations at selected points in a physical model. Progress in earthquake engineering was hindered by incomplete and ambiguous data sets that allow for subjective and potentially mistaken interpretation. The development of the NEES Centrifuge at UC Davis capitalized on the size of the facility and revolutions in instrumentation and information technology to enable researchers to enable generation of much higher resolution information (more control, sensors and images) and more realistic physical models that will provide unambiguous experimental data for assessments of Model Based Simulation theories.

UCD NEES Centrifuge

The 9-m radius centrifuge at UC Davis (Fig. D.7-1) is the largest in the US, and it can carry five-ton payloads to accelerations of 75 g. The large size and available resources allow researchers to perform detailed experiments of complete geotechnical engineering systems.

An earthquake simulator, mounted on the end of the centrifuge, is designed to operate in either a biaxial (horizontal-vertical) or uniaxial (horizontal) shaking mode (Fig. D.7-2). The servo-hydraulic shaking tables are capable of simulating broad-spectrum earthquake events as well as step- and sinusoidal-wave type motions, and can vary intensity from microtremors to extreme shaking events.

The 2-m long x 1-m wide uniaxial shaking table is the largest centrifuge-based shaking table in the US and is among the largest available anywhere in the world. Uniaxial models may be constructed, depending on the project priorities, using flexible shear beam containers - designed to deform with the soil profile during shaking, a rigid container - with clear side walls for observing below grade behavior with video cameras, or a hinged-plate container – which allows permanent lateral deformations among its advanced features. These containers are all on the order of 1.7-m long x 0.7-m wide x 0.7-m deep. The useable volumes are among the largest centrifuge model containers available in the world, and when testing at 75 g’s the models simulate a site that is approximately 130 m x 50 m x 50 m in size. A 1-m long x 0.5-m wide x 0.4-m high flexible shear beam container is available for biaxial shaking. While smaller than those available for the uniaxial shaker, it is still considered to be a large centrifuge container.

Figure D.7-1: The 9-m radius geotechnical centrifuge at UC Davis. NEES upgrades include streamlining and drivetrain improvements that increased centrifuge capacity from 40 g to 75 g.
A large inventory of transducers and signal conditioning equipment can be used to monitor model behavior during an experiment. Arrays of pore pressure transducers, for example, can be used to monitor spatial variation of liquefaction. Arrays of accelerometers can be used to study wave propagation. Many projects also include arrays of custom transducers, e.g. strain gauges on model structures. This data acquisition system was overhauled as part of NEES. It currently records up to 160 transducers, and can be expanded as need arises.

A distributed high-speed wireless data acquisition system can be used to record data from up 400 MEMS accelerometers / inclinometers in a single test. The system consists of 50 miniature eight-channel high-speed data acquisition systems that can be buried in the soil. As dense arrays of accelerometers the transducers can be used to study spatial variability of wave propagation. As inclinometer arrays the transducers can be used to quantify the internal deformations of the soil profile. For example, a closely spaced vertical array of these sensors would produce information to define the permanent shear strain distribution within a soil deposit. Assuming a smooth shear strain distribution, the shear strain could be integrated over the depth to accurately quantify the permanent displacements within the soil deposit.

A gantry robot with changeable manipulator tools and an on-board tool rack can be used to perform multiple tasks without stopping the centrifuge (Fig. D.7-3). Onboard robotics, for example, allow more accurate simulation of construction processes, which can, for example, control effectiveness of soil improvement and influence behavior of geotechnical systems such as pile groups. Users can use the gripper tool to drive piles sequentially, apply load cycles to structures, and manipulate objects to simulate construction processes.

The robot can be used to perform in-flight in-situ site characterization tests using geophysical testing methods. These tests can help relate data in the centrifuge models to field conditions and can be used to study the evolution of material properties through a series of shaking events. Soil strengths can be indexed using the cone penetrometer (Fig. D.7-3) and vane shear robot tools. A needle probe tool may be used to measure porosity variation at millimeter resolution. An ultrasound tool may used to measure the deformation of a submerged surface or subsurface during flight based on sound waves. Users can also inspect the exposed model surface with a stereo camera tool.

The robot has a versatile tool interface to support future growth. A preliminary design for a new tool for soil improvement has been completed, pending funding through research projects. We will develop new tools on a project-specific basis as need and funding arises.

Various imaging techniques are used to monitor evolution of the surface and interior of centrifuge models during testing. An array of high-speed video cameras can be used to image the surface of models and track deformations during shaking events. An eight-channel array of bender element sources may be monitored using up to sixteen receivers, allowing interpretation of shear-wave velocity distributions by direct methods or tomographic inversion. An electrical resistivity tomography system uses 48 electrodes to monitor changes in electrical resistivity...
between any combination of electrodes. Inversion methods may also be used to create images of resistivity distribution that can be correlated to porosity distribution.

The various independent systems are interconnected in the data acquisition network and can share data and timing signals so that everything works together. The network structure can easily accommodate future growth or custom data acquisition systems developed on a project-specific basis.

A **470 m² building**, opened in 2003, houses the 42 m² **visualization room**, where we use 3-D software and our Geowall stereo display to explore data from hundreds of sensors collected in simulated earthquake events (Fig. D.7-4). The visualization room is also outfitted with video conferencing and telecollaboration equipment so that remote researchers can interact with local staff during experiments.

**NEES Research using the UCD NEES Centrifuge**

The UCD equipment portfolio is unique in that the size and available resources allow researchers to perform detailed experiments of complete geotechnical engineering systems. An example of an envisioned research project is to evaluate the efficiency of vibroflotation to mitigate liquefaction-induced lateral spreading. Hundreds of millions of dollars per year are spent in the US on **ground improvement to mitigate liquefaction hazards**. The fundamental effects of ground improvement by deep vibration, as just one example, are incompletely understood; deep vibration densifies the soil and increases the lateral confining pressures and the improvements are dependent on soil properties and the power of the tool. Quality control of improvement is usually monitored by before and after penetration resistance measurements. However, the changes due to ground treatment have different, time-dependent effects on the quality control measures used and on the triggering and consequences of liquefaction. Furthermore, ground improvement creates a heterogeneous distribution of soil properties in the ground, and engineers do not yet have established procedures to account for heterogeneity on the liquefaction behavior.

For this example the researcher might be interested in determining how to evaluate the composite behavior of a treated soil mass, and how far to extend treatment extend beyond a structure's edges to protect it from the effects of

---

Figure D.7-3: A 4 degree-of-freedom robot has been added to the centrifuge. An onboard tool rack holds up to five tools for use during in-flight inspection and construction. The robot is fully operational in conjunction with shaking table tests.
liquefaction in the surrounding soils. These and other issues can have large effects on the cost and reliability of ground improvement works.

The soil model might consist of a saturated layer of loose sand overlying dense sand, with the entire model sloping in the hinged-plate container, which will allow largely unrestrained lateral deformations (Fig. D.7-5). We would treat a portion of the loose sand with a robotic vibrating probe in flight. Measurements of pore pressures, accelerations, and geophysical properties around the vibrating probe would provide information on the treatment mechanism. The cone tool, needle probe tool, and/or electro resistivity tomography equipment, and bender element arrays would be used to characterize the extent and degree of treatment, as well as variations spatially within the treatment zone.

The model would be shaken to induce lateral spreading of the untreated zones. Spatial variations in accelerations and pore pressures within and adjacent to the treatment zone would provide data on the composite behavior of the treatment zone and its interaction with liquefied soils around it. Dense MEMS accelerometer / inclinometer arrays will provide the ability to study the physics of composite material behavior through measurements of the spatial variation in dynamic response, rather than inferring the physics from a few select measurement points. Post-shaking measurements would characterize changes in soil properties, and the robot stereo imaging equipment would scan the surface to map the surface manifestation of the zones of influence of the improvement.

This complicated model test would be performed by a team of researchers. Operating the shaker, the robot, and the tomography equipment requires specialized training, and a single researcher cannot efficiently and safely operate all of this equipment simultaneously. The overall experiment would be managed by the lead project engineer, a researcher working at UC Davis. This engineer would oversee the construction of the model and ensure all of the physical equipment is in place for testing. During the experiment the lead engineer would be responsible for gathering data during seismic tests. Another researcher would be responsible for operating the robot in-flight. A third researcher would operate the tomography and imaging equipment in-flight. These two engineers could be remote operators, collaborating via the high-performance network but performing their work independent of location.

The database from this experimental project would provide the basis for evaluating and developing Model Based Simulations for years to come because of the completeness of information obtained using the NEES equipment.

Research on the UC Davis NEES centrifuge will involve cross-disciplinary collaboration that will infuse student researchers with the latest advances from several fields, from earthquake engineering to robotics to MEMS to
networks to data management and visualization. This cross-disciplinary team environment will open opportunities for these students to envision other fruitful connections throughout their careers. Once the equipment is established, student researchers will become familiar with these advanced technologies and be better equipped to champion their application to other civil engineering applications.

Experimental data obtained with the new equipment will become increasingly attractive for use in case-study instruction of earthquake engineering at universities because of the completeness of the data. We already have used some experimental data as “cases studies” for use in our case-based instruction of geotechnical engineering. With the new equipment, we would increase the use of experimental data as cases because the students could watch the high-resolution high-speed videos, work with site characterization data (e.g., CPT, vane, geophysical methods), work with ground improvement data, and assess the performance during earthquakes over a range of shaking levels.

Figure D.7-5: Ground Improvement for mitigating Liquefaction Hazards. The robot could manipulate a vibroflot tool to improve a zone of soil. Resistivity tomography is used to characterize the porosity distribution in the soil before and after improvement and shaking. The Hinged Plate Container allows the liquefied soil to spread during shaking. The mesh of MEMS record the distribution of motions within the layer during shaking, and the permanent deformation patterns within the soil layer after shaking, for comparison to MBS. The stereo robot eyes are used to scan and inspect the model after shaking, looking for surface manifestations of liquefaction and spreading.
The nees@UCLA equipment site provides state-of-the-art equipment for forced vibration testing and seismic monitoring of full-scale structural and geotechnical systems. This equipment is useful for identifying system properties through system identification analyses of recorded data, studying the nonlinear responses of systems with limited mass, and evaluating the interactions of various system components for realistic sets of boundary conditions.

The nees@UCLA facility equipment portfolio includes the following major components:

(i) eccentric mass shakers for harmonic excitation of structural systems; (ii) linear inertial shaker for broadband realistic seismic structural simulation at low force levels; (iii) above-ground sensors for monitoring structural acceleration or displacement response; (iv) retrievable subsurface accelerometers to monitor subsurface vibrations; (v) wireless field data acquisition system that efficiently transfers data from test structure to the high performance mobile network; (vi) high performance mobile network that receives and locally stores data at a mobile command center deployed near the test site, transmits selected data in near real time via satellite to the UCLA global backbone, and broadcasts data via the NEESpop server into the NEESgrid for teleobservation of experiments.

We anticipate that the nees@UCLA mobile field laboratory can be used for several general categories of application. The data retrieved from these applications has the potential to significant impact our ability to effectively model complex geotechnical and structural systems, manage and interpret data collected from dense field sensor networks, which will ultimately lead to improved seismic design procedures and significant reductions in the public’s seismic hazard exposure. Example application areas include building or bridge structural response studies, seismic health monitoring and sensor networks, soil-foundation-structure interaction studies, and response studies for geo-structures or soil deposits.

The project team consists of John Wallace (PI), Joel P. Conte (Co-PI), Jonathan P. Stewart (Co-PI), Deborah Estrin (Co-PI), Daniel H. Whang (Project Manager), Eunjong Yu (Graduate Student Researcher), William Elmer (Engineering Aide), Colin Means (Engineering Aide), and Balaji Vasu (Webmaster)

Website: http://cee.ucla.edu/nees/
Observations of the field performance of full-scale structures has been and continues to be a principal driving force behind advances in earthquake engineering (EERI, 2003). However, previous studies of the field performance of full-scale structural systems have traditionally employed relatively sparse instrumentation that does not provide the detailed performance data that are needed to move the profession forward. For example, buildings permanently instrumented to record earthquakes typically have approximately 12 accelerometers. This level of instrumentation is sufficient to evaluate properties of low-order vibration modes, but is not sufficient to identify higher-order modal responses or component behavior. This is especially problematic for structures loaded into the nonlinear range, for which the data resolution is too low to aid in the development and verification of numerical models of nonlinear structural response, including damage localization and propagation effects.

Of course, engineers cannot always wait for earthquakes to provide excitation of structures from which measurements are needed. Thus, forced and ambient vibration testing has traditionally been used to investigate structural response at relatively low-level response amplitudes. This testing has suffered from three principal limitations. First, the level of detail in response measurements is limited by the use of cumbersome wired sensors (this effectively limits the number of instruments that can be installed). Second, traditional dynamic sources such as eccentric mass shakers are limited in their ability to provide excitation of sufficient amplitude and bandwidth to load a structure into the nonlinear range under conditions that simulate true earthquake effects. Third, very limited data has been obtained on system interactions, such as the interaction between different structural systems (e.g., lateral system and gravity system), structural and non-structural elements (e.g., structural framing and partitions/piping), and soil-foundation-structure. Given the aforementioned limitations, obtaining detailed performance data has remained almost exclusively within the domain of laboratory studies of small scale models of structural systems, or small-to-moderate scale models of individual structural components or sub-assemblages with idealized boundary conditions, subjected to quasi-static cyclic force or displacement histories.

The vision of the nees@UCLA equipment site is to fill this critical gap in engineering characterization of structural and foundation-soil performance by developing and implementing the next generation of forced-vibration testing and seismic structural monitoring equipment. Through the use of innovative sensors and wireless technology, it is now possible to rapidly install large arrays of sensors in structures, on the ground surface, and within foundation soils, to obtain high resolution measurements of system performance during forced vibration experiments or during earthquakes. Moreover, innovative systems for load application have been developed that enable either harmonic or broadband excitation across a wide range of force amplitudes, the upper bound of which is sufficient to bring small-to-moderate size structures into their nonlinear range.

The nees@UCLA equipment site was established to enable field vibration testing and monitoring of structural and geotechnical systems. The major equipment components of the site are illustrated in Fig. A.1 and include the following:

A. **Eccentric mass shakers** that can apply harmonic excitation across a wide frequency range in one or two horizontal directions. These shakers can induce weak to strong forced vibration of structures. For small structures, excitation into the nonlinear range is possible when the shakers are operated near their maximum force capacity. The shakers can be operated in a wired or wireless mode.

B. **Linear inertial shaker** that can apply broadband excitation at low force levels. These shakers can be programmed to approximately reproduce the seismic structural response that would have occurred for any specified base-level acceleration time history (assuming the properties of the structure are known). The shaker can be controlled in a wired or wireless mode.

C. **Above-ground sensors** that can be installed at the ground surface or on building, bridge, or geo-structures to record acceleration or deformation responses. Accelerations are recorded with uni-directional or triaxial accelerometers. Deformations (i.e., relative displacements between two points) are recorded with LVDTs or using fiber-optic sensors.

D. **Retrievable subsurface accelerometers** (RSAs) that can be deployed below-ground to record ground vibrations. The sensors and their housing are specially designed to be retrievable upon the completion of testing.

E. **Wireless field data acquisition system** that efficiently transmits data in wireless mode from the tested structure to the high performance mobile network (see following item).
F. **High performance mobile network** that (a) receives and locally stores data at a mobile command center deployed near the test site; (b) transmits selected data in near real time via satellite to the UCLA global backbone; and (c) broadcasts data via the NEESpop server into the NEESgrid for teleobservation of experiments.

As shown in Figure D.8-1, a typical application of the equipment would have shakers installed on or within a structure, a dense array of sensors throughout the structure and RSAs deployed below the ground surface. Data from the building sensors and RSAs are transmitted wireless via field data loggers to the mobile command center where all data are locally stored. Selected data channels and video streams could be transmitted via satellite to the UCLA global backbone for subsequent dissemination via NEESpop for teleobservation of the experiment.

One point that should be emphasized is that the nees@UCLA equipment can be utilized with several types of vibration sources. Obviously, the eccentric mass shakers and linear inertial shaker are two such types, but the equipment is also ideally suited for seismic monitoring of structural or geo-systems (i.e., aftershock or microtremor sources).

Figure D.8-1: Schematic illustration of deployed equipment from the NEES@UCLA equipment site.

We anticipate several general categories of application for the nees@UCLA equipment site. The data retrieved from these applications has the potential to significant impact our ability to effectively model complex geotechnical/structural systems and to manage and interpret data collected from dense field sensor networks, which will ultimately lead to improved seismic design procedures and significant reductions in the public’s seismic hazard exposure. Example application areas are described briefly in the following paragraphs:

**Building or bridge structural response/performance studies.** The equipment can be used to identify the modal responses of buildings (i.e., vibration periods, damping ratios, mode shapes), to evaluate the performance of non-
structural elements within tested structures (i.e., HVAC, partition walls, equipment, etc.), and to evaluate the
detailed response of structural components (e.g., beam-column connections, column-slab connections, etc.).
Experiments can be performed at low levels of excitation from ambient vibration, micro-tremors, or over a range of
excitation levels using the various shaker systems. For structures of small to modest size, eccentric mass shakers
can be utilized to excite structures into the nonlinear range. An important aspect of field testing is the ability to
capture structural response and interactions without the shortcomings of scale and boundary conditions that
commonly exist for laboratory testing. A unique feature of experiments performed using the nees@UCLA
equipment relative to previous field testing programs is the potential for installation of dense instrumentation arrays
that will provide more detailed insights into structural and non-structural response and performance characteristics.
Potentially the greatest benefit will be derived from forced-vibration studies of existing structures slated for
demolition, full-to-moderate scale structures or sub-systems constructed specifically for testing, or use of the sensors
and data acquisition system within structures during earthquake aftershocks.

**Seismic health monitoring and sensor networks.** A long-term vision for equipment use involves development of
robust sensor networks for real-time seismic structural health monitoring by collaborating with other disciplines
(e.g., computer science). Important issues to be addressed include: development of robust MEMS sensors,
application of network time protocols in field sensor deployments, efficient transmission of data (e.g., multi-hopping
or beam-forming), effective use of in-network processing, and development of efficient techniques for data
management and interpretation.

**Soil-foundation-structure interaction (SFSI) studies.** The equipment can be used to apply forces and moments to
foundation components, the response of which can be measured with acceleration and/or displacement sensors to
evaluate SFSI effects. Load application to foundations is a natural consequence of vibration testing of buildings and
bridges, so SFSI studies could be a component of any such experiment. Moreover, shakers can be directly installed
on model foundations or simple structures mounted on model foundations to generate cyclic responses.
Instrumentation would typically include an accelerometer array to record foundation motions and ground surface
motions near the foundation, as well as RSAs below the ground surface. Specific research objectives of such work
could include the evaluation of frequency-dependent stiffness and damping terms for foundation systems, as well as
foundation-soil-foundation interaction effects.

**Response/performance studies for geo-structures or soil deposits.** As with building or bridge structures, geo-
structures such as dams, embankments, and retaining wall systems can be tested through forced vibration or seismic
monitoring. Such studies would typically be performed to evaluate seismic response characteristics (i.e., vibration
periods, damping ratios, topographic amplification effects). Excitation at amplitudes that could induce soil shear
failure is expected to not generally be possible. RSAs would enable measurements of internal response and
deformations of geo-structures. Seismic monitoring of soil deposits is also possible with the RSAs. Monitoring of
soil deposits might be of interest following a major earthquake, as data recorded from aftershocks could provide
insight into wave propagation characteristics and soil pore water pressure generation.
D.9  University of California at San Diego

This outdoor shake table will be a 7.6 m x 12.2 m long single (horizontal) degree-of-freedom system. The table will have a peak horizontal velocity of 1.8 m/s, maximum stroke of +/-0.75 m, maximum gravity (vertical) payload of 20 MN, maximum overturning moment of 50 MN-m, force capacity of actuators of 6.8 MN, and a frequency bandwidth from 0-20 Hz. The major equipment for the LHP shake table facility consists of servocontrolled dynamically-rated actuators with large-servo valves, a large power supply, a vertical load/overturning moment bearing system, a digital three-variable real-time controller, concrete foundation and reaction mass, and weatherproofing system. The facility will be the only outdoor shake table in the U.S. and will enable large/full-scale testing of structural systems and soil-foundation-structure interaction that cannot be readily extrapolated from testing at smaller scale, or under quasi-static or pseudo-dynamic test conditions, as well as testing large-scale systems to observe their response under near source ground motion. The LHP outdoor shake table will be located 15 km from campus at the UCSD Camp Elliott field site. This two-acre site was selected so that the shake table could be used in conjunction with an adjacent soil pit and laminar shear soil box being provided by the California Department of Transportation. This site will allow room for multiple test specimens to be constructed and instrumented before placement on the shake table. A 177 kN rough terrain crane will be provided at Camp Elliott for loading, unloading, and everyday construction purposes. For heavier lifting capabilities, an 880 kN crane will be available on an as needed rental basis, with the individual experiment requiring the larger crane to cover this cost. This equipment will be operational by September 30, 2004, and will be managed as a national shared-use NEES equipment site, with teleobservation and teleoperation capabilities, to provide new earthquake engineering research testing capabilities through 2014. Shared-use access and training will be coordinated through the NEES Consortium.

The shake table, acting in combination with equipment and facilities separately funded by the California Department of Transportation (Caltrans), which include a large laminar soil shear box and a refillable soil pit, results in a one-of-a-kind worldwide seismic testing facility. The LHPOST has been developed at Camp Elliott, a field laboratory site located 15km East of the main UCSD campus, in concurrence with the development of the Caltrans SFSI facility at the same site. UCSD is convinced that this innovative piece of NSF equipment in conjunction with the field laboratory site adds unique testing capabilities to NEES and consolidates the leadership of the NEES collaboratory as the predominant earthquake testing consortium in the world.

The project team consists of José Restrepo (PI), Joel P. Conte (Co-PI), Enrique Luco (Co-PI), Frieder Seible (Co-PI), Lelli Van Den Einde (Co-PI and Project Manager), Paul Croft (Senior Project Consultant), Larry Berman (Principal Development Engineer) and James Batti (Systems Administrator).

Website: http://nees.ucsd.edu/
Equipment Site Description

Current United States research in earthquake engineering is lacking the capability to conduct real time shake table testing of full or large-scale structural systems including soil-foundation-structure interaction (SFSI). Also, experimental capabilities are required to simulate near source ground motions with large velocity and displacement pulses. Existing shake table systems in the U.S. are limited by payload capacity (base shear and/or overturning moment), pumping capacity, stroke, and overhead room to construct and test tall structural systems. The University of California, San Diego (UCSD) is providing the earthquake engineering community with a Large High Performance Outdoor Shake Table (LHPOST) within the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) collaboratory. This LHPOST, built as part of the Charles Lee Powell Structural Research Laboratories at UCSD, incorporates performance characteristics that allow the accurate reproduction of near source ground motions for the seismic testing of very large structural and SFSI systems.

The LHPOST is a 7.6m wide by 12.2m long single degree of freedom (DOF) system with the capability of uprating to 6-DOF. The current specifications consist of a stroke of ±0.75m, a peak horizontal velocity of 1.8 m/s, a horizontal force capacity of 6.8MN, an overturning moment capacity of 35MN-m (bare table) and 50MN-m (400 ton specimen), and a vertical payload capacity of 20MN. The testing frequency range is 0-20 Hz. Further specifications can be found at structures.ucsd.edu/NEES/. Figure 1 provides a schematic rendering showing the key components of the LHPOST facility.

Component 1 in Figure D.9-1 shows the steel platen, which consists of a 12.2 m long by 7.6 m wide structural steel box of variable depth up to 2.4m. Hold down connections will be provided at 610 mm on center for connecting test specimens to the platen. The reaction mass (component 2) consists of a ring structure using reinforced and mass concrete with hold down connections spaced at 610 mm on center for fastening loading frames, connecting temporary construction rigs and connecting actuators for testing in the adjacent soil pit. MTS Systems designed the hydraulic and mechanical systems for the LHPOST such as the two horizontal actuators (component 3), six vertical pressure balance bearings (component 4) with a force capacity of 8 MN each to react the vertical forces, two vertical tension cylinders (hold-down struts) for the overturning moment restraint system (component 5), and the components required for yaw restraint to prevent the platen from undesirable out-of-plane motions in the uniaxial configuration (component 6). A weatherproofing system (component 7) consisting of permanent and retractable prestressed concrete planks and pressurized with filtered, conditioned air running continuously will ensure that the environmentally sensitive parts of the hydraulic system will be protected from the elements by housing them in an essentially indoor environment. Detailed descriptions of the components are described in subsequent paragraphs.

The equipment will be operational by October 2004 and will be managed as a national shared-use NEES equipment site, with tele-observation and limited tele-operation capabilities. The facilities at Camp Elliott will be used to conduct large- and full-scale testing to investigate structural and geotechnical performance issues related to the area of Critical Infrastructure Protection (CIP) that cannot readily be extrapolated from testing at smaller scale, or under quasi-static or pseudo-dynamic conditions. Potential research that could be carried out include (a) the effects of passive and semi-active energy dissipating systems on building response, (b) large-scale testing of kinematic soil-foundation-structure interaction, (c) seismic response of nuclear waste dry storage casks, including the soil-structure interaction and the kinematic interaction between casks, (d) loss estimation of buildings, including the interaction between their components, (e) seismic response of full-scale wood-frame construction including school buildings (f) response of building diaphragms, where the presence of a distributed mass constrains the testing to be performed solely under dynamic conditions, (g) assessment of liquefaction mitigation mechanisms, (g) optimization of shallow foundations to maximize kinematic soil-foundation interaction, h) the study of the complex interaction between interconnected components of electrical substations, such as high-voltage transformer-bushing systems, and i)
The response of structural members to blast loading. Such experiments present unique opportunities to develop, calibrate, and validate computational tools.

**Description of Physical Facility**

The UCSD LHPOST was developed at the Field Station at Camp Elliott, a site located 15km away from the main UCSD campus (see Figure D.9-2). The shake table, acting in combination with a Soil-Foundation-Structure Interaction (SFSI) facility, funded by the California Department of Transportation (Caltrans) and an Explosive Loading Laboratory (ELL), funded by the Technical Support Working Group (TSWG), will result in one-of-a-kind worldwide real-time testing of structural components, assemblies, and systems such as nuclear casks, building structures, bridge abutments, and embankments and foundations that will be subjected to real-time earthquake or blast loading. UCSD is convinced that the LHPOST in conjunction with the field laboratory site adds unique testing capabilities to NEES and consolidates the leadership of the NEES collaboratory as the predominant earthquake testing consortium in the world. Camp Elliott is situated on the corner of Miramar/Pomerado Rd. and Interstate 15. It is on University property that currently houses an animal facility for the UCSD School of Medicine and a storage facility for Scripps Institute of Oceanography. Camp Elliott has restricted access and is a gated facility. The Structural Engineering field station is currently located on a 2-acre site on the Northwest corner of the University property. Hotel and dining services are within 1 mile of the site.

**LHPOST System and Component Specifications**

The design criteria and main specifications of the shake table system were dictated by consideration of a number of target research application examples consisting of large or full-scale shake table experiments. Design criteria and expected performance parameters of the shake table are summarized in Table D.9-1. Performance parameters consist of specifications for actuator stroke, velocity and force capacities, and frequency bandwidth of the earthquake simulator. Specifications for the various components of the LHPOST in its uniaxial configuration can be found on the project website (currently hosted at http://structures.ucsd.edu/NEES/). These components include the horizontal actuators, the vertical bearings, hold-down struts, and the hydraulic power supply. Detailed descriptions of the various components are provided in the following sections.

**Reaction Mass**

Extensive 2-D and 3-D finite element modeling of the reaction mass taking into consideration the surrounding soil properties that were based on the results from geotechnical investigations performed at Camp Elliott were conducted and led to a reaction mass design consisting of a ring structure using reinforced and mass concrete. Lumped mass concrete corners are connected with reinforced concrete tubes. The tubes are designed with potential hold down connections spaced at 610 mm on center for fastening loading frames, connecting temporary construction rigs.

![Figure D.9-2: Field Station at Camp Elliott](image)

<table>
<thead>
<tr>
<th>Table D.9-1: NEES LHPOST Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size</td>
</tr>
<tr>
<td>Peak velocity</td>
</tr>
<tr>
<td>Stroke</td>
</tr>
<tr>
<td>Maximum gravity (vertical) payload</td>
</tr>
<tr>
<td>Force capacity of actuators</td>
</tr>
<tr>
<td>Maximum overturning moment (bare table, 400 ton specimen)</td>
</tr>
<tr>
<td>Frequency bandwidth</td>
</tr>
</tbody>
</table>
connecting actuators for testing in the adjacent soil pit (see component 2 in Figure D.9-1). Openings in the tubes were required for distributing the hydraulic lines and for access to the main pit below the platen and to the tunnel that leads to the pump/accumulator house. The reaction mass was designed to transfer mainly by bending and shear, the forces resulting from the horizontal actuators acting along the longitudinal axis in the 1-DOF configuration. To maintain a constant flexural and shear stiffness, the beam was proportioned so that the maximum tensile stresses at maximum thrust were below the tensile strength of concrete. A thick slab was proportioned in the transverse tubes to act as a reaction element to the horizontal actuators. A massive concrete member was cast below the platen. This member was required for stiffness and to transfer the reasonably large forces developed from the combination of the prestressing action of the discrete vertical tension struts and those generated by the maximum overturning moment in the transverse and longitudinal direction of loading. The final design of the reaction mass removed portions of the corner concrete elements to reduce the overall amount of concrete and minimize costs. The reaction block was built using 25 MPa strength concrete. The lower parts of the reaction mass will be covered with an epoxy resin to contain any oil leakages that might occur and special pockets were provided to pump oil and water out when required.

Actuators and Servo-valves

In the current 1-DOF configuration, two horizontal actuators equipped with high flow servo-valves will power the shake table. These are single ended actuators ported to allow flows over 20,000 liter/min each. Dual 10,000 liter/min servo-valves (MTS Model 250.27) are mounted to each actuator. The technical specifications for the actuator are provided in Table D.9-2. For the servo-valves, at the pilot stage the rated flow is 19 liter/min @ 7 MPa servo-valve pressure drop. At the intermediate stage, the rated flow is 630 liter/min @ 7 MPa servo-valve pressure drop, the null leakage is less than 15 liter/min, and the drain flow is less than 0.25 liter/min. The technical specifications for the servo-valves are provided on the project website.

Table D.9-2: Actuator Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Force Compression</th>
<th>Force Tension</th>
<th>Combined Force on Table</th>
<th>Max. Velocity</th>
<th>Stroke</th>
</tr>
</thead>
<tbody>
<tr>
<td>Force Compression</td>
<td>4.2 MN</td>
<td>2.6 MN</td>
<td>± 6.8 MN</td>
<td>1.8 m/s</td>
<td>± 0.75 m</td>
</tr>
</tbody>
</table>

Platen Sliding System: Hydrostatic Pressure Balance Bearings

The LHPOST uses a set of 6 pressure balance bearings with a force capacity of 8 MN each to react the vertical forces imposed on the table by the platen (approximately 2.25 MN) and specimen weight (20 MN), the hold-down force (9.4 MN), additional gravity loads, and the overturning moments from the test specimen. To accommodate the very large LHPOST forces and consequently the high flow requirements, MTS Pressure Balance Bearings are used, which have a number of inherent features that can be used to enhance the LHPOST operation. These features are high-pressure capability, which allows for minimum size, seals that minimize leakage resulting in zero power required for flow, self-aligning capabilities up to 2 degrees, low friction, operational at high velocities and high strokes, uses servo-control, which allows height adjustment to provide alignment, and can also function as an actuator. In the pressure balance actuator, force applied to a piston area develops pressure. This pressure is transmitted to the bearing face. The pressure supports most of the force, and the result is a very low friction coefficient. UCSD has operation experience with these bearings in the Seismic Response Modification Device (SRMD) system.

Overturning Moment Restraint System: Discrete Tension Cylinder Prestressing System

A shake table for physically reproducing the effects of earthquake motions on structures must be capable of reacting all of the forces imposed by the test specimen on the table. The overturning moments are generally the dominant vertical force components that must be reacted, and generally add considerable complication to bearings or vertical actuator construction. The LHPOST uses a tension cylinder prestressing system that was used in the PWRI, Japanese Ministry of Construction (MOC) shake table designed by MTS in Japan and similar to the static tare weight compression passive actuators used on many MTS earthquake simulation shaking tables. In the 1DOF configuration, the table sits on six hydrostatic bearings and two vertical tension cylinders (hold-down struts). The downward or compressive movement of the table is taken by the hydrostatic bearings, while the tension-only struts resist any upward movement. The use of the discrete tension cylinder prestressing system allows for the bearings to be expanded to actuator-bearings for future upgrade to 6-DOF.
Platen

The UCSD-NEES project team has worked closely with MTS Systems on the design of the turnkey steel platen system. The platen is being fabricated in three pieces and will be assembled on-site using field welding and bolting. Figure D.9-3 shows a schematic of the platen, including attachments for the yaw-restraint and horizontal actuators. The platen consists of a 12.2 m long by 7.6 m wide structural steel box of variable depth up to 2.4 m. Hold down connections will be provided at 610 mm on center for connecting test specimens to the platen. This array of hold down connections is identical to that used in the Powell Laboratories at UCSD making it compatible with existing hardware and loading frames. The design weight of the platen is less than 1.5 MN. The stiffness requirements consist of ensuring a fundamental mode of vibration (lowest natural vibration frequency) greater than 65 Hz. For strength requirements, elastic response is expected throughout the entire operation with only localized yielding permitted upon impact of a collapsing body, and extensive yielding allowed upon unanticipated loss of control of the shake table. The latter requirement is to protect the reaction mass from irreparable damage. The stability requirements for the platen consist of providing a factor of safety against wall stability of 3.0, even for the case when a specimen that extends across the entire width of the table is post-tensioned to the table at 890 kN/tie-down. Detailed manufacturing specifications and tolerances were established for the platen.

Hydraulic Power System

The LHPOST hydraulic power supply design is very similar to the existing power supply at UCSD for the SRMD facility. It consists of two pumps, a blow-down system, a cooling system, accumulator banks, and a surge tank. The hydraulic power is supplied to the actuators by an accumulator bank through a blow-down valve. The accumulator bank provides the high flow needed to simulate an earthquake, and the blow-down valve converts the high-pressure oil from the accumulators to constant 21 MPa pressure for controlling the actuators. MTS Hydraulic Power Units (HPUs) are provided to pump oil into the accumulator bank. Return flow is directed to an auxiliary reservoir or surge tank. One pump has a charging flow of 431 liter/min and is responsible for charging the 9,500 liters of oil in the accumulators. The second pump’s function is for direct pumping and has a charging flow of 718 liter/min. The accumulator bank, when supplemented with the two hydraulic power units, satisfies the design requirement of providing 2,720 liter at 21 MPa or above in order to simulate the design earthquake records. With this configuration, the expected time to charge the accumulator banks is 6 min and the flow from the accumulator banks could produce a swept displacement on the table of 7.5 m. The power system construction will allow for increasing flow for the targeted future upgrade to a 6-DOF system. The technical specifications for the hydraulic power supply are summarized in Table D.9-3.

<table>
<thead>
<tr>
<th>Component</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accumulator bank</td>
<td>Volume of 9,500 liters and pressure at 35MPa</td>
</tr>
<tr>
<td>Blow-down valve(s)</td>
<td>Peak flow of 38,000 liter/min</td>
</tr>
<tr>
<td>Hydraulic power units (2)</td>
<td>One pump flow of 718 liter/min for pilot pressure at 21 MPa and blow down assist, and one pump flow of 431 liter/min for accumulator charge at 35 MPa: power at 450 kVA each</td>
</tr>
<tr>
<td>Surge Tank</td>
<td>Volume of 10,000 liter</td>
</tr>
</tbody>
</table>
Weatherproofing System

A feature of the shake table system is that it is located outside so that normal construction techniques can be used in building and mounting specimens on the table. San Diego is an ideal location since it has one of the most temperate climates in the world. Since a significant number of components within the hydraulic system are sensitive to the environment, particularly UV radiation, dust, debris and moisture, in order to have the system operate reliably outdoors, various techniques must be used to prevent the elements from affecting the system. The LHPOST weatherproofing system ensures that all accessible portions of the LHPOST will be covered and pressurized with filtered, conditioned air running continuously (see component 7 in Figure D.9-1). The cover consists of enclosing the space between the platen and the surrounding reaction block with permanent and retractable prestressed concrete planks that can support the weight of equipment and foot traffic necessary to construct the specimen. During operation of the table, the planks are retracted and bellows will be attached to protect components from dust and debris. Therefore, the environmentally sensitive parts of the hydraulic system will be protected from the elements by housing them in an essentially indoor environment. Additionally, all electrical control cables that connect to the valves of the actuators will be high quality weather rated connections.

Digital Table Control System

The LHPOST will be controlled by the proven and advanced technology digital control systems MTS 469D. The MTS 469D is an integrated control solution including all computer hardware, software, transducers, data acquisition electronics, and cabling necessary for system operation. The system will provide for shake table tuning, system operation, and test execution in real time. MTS Seismic Digital Control Software provides an advanced graphical user interface (GUI). Full functionality is provided through the GUI for system tuning, test setup and operation, table data acquisition, and advanced high-level adaptive control for high fidelity earthquake waveform reproduction. The control software includes three-variable control, delta pressure stabilization, servo-valve flow linearization, resonance canceling non-linear notch filters, amplitude phase control, adaptive harmonic cancellation, adaptive inverse control, and on-line iteration.

Performance Envelopes of LHPOST

Based on the specifications of the servo-hydraulic components described in the previous sections, the performance envelopes of the LHPOST in a four-way logarithmic plot are as shown in Figure 4. It is noted that the table performance envelopes for a bare table condition, a table loaded with a 4 MN rigid payload (equivalent to a 2 MN flexible payload with a dynamic amplification of two), and a table loaded with a 20 MN rigid payload are provided. These performance curves were generated assuming a platen weight of 2.25MN rather than the actual platen, which is less than 1.5MN, making these curves conservative. Figure D.9-4 shows that the maximum acceleration input of the LHPOST is a function of the vertical payload on the table. For a bare table the performance curve indicates an acceleration of 3g, which reduces with increasing payload. For a 4 MN payload, the maximum acceleration is anticipated to be 2g, while for a maximum 20 MN payload it reduces to 0.3g. An overturning moment of 20 MN-m can be resisted by the system with the bare platen. Such moment of resistance is mainly due to the presence of the two vertical discrete tension cylinders. As gravity load is increased, by placing a specimen on the platen, the overturning moment of resistance is increased to a maximum of 50 MN-m. Weight in excess of 6.5 MN will not result in an increase in the overturning moment of resistance since the outermost pressure balance hydrostatic bearings will reach their allowable compressive force.
D.10 University of California at Santa Barbara

A goal of earthquake engineering research within a future NEES is to generate analytical and empirical models for accurate simulation of ground response and ground deformation and to understand how these ground motion predictions affect the built environment. A required element for the development of these models is well-instrumented field sites where actual ground response and deformation, and the interaction with the foundation and structure, can be monitored during earthquake shaking to provide benchmark case histories for model development and verification. In addition, the use of active methods to shake the structures and field sites can also provide benchmarks that can be compared with actual earthquake motions.

While we must still rely primarily on single point observations of ground motion and deformation at the surface due to the high cost of array instrumentation, geotechnical and structural arrays provide critical constraints for our methods of interpreting observed ground motions and failures. While previous efforts have been rather segregated into the seismological, geotechnical, and structural sub-disciplines of engineering, the NEES program, with its shared-use and tele-participation concepts provides an excellent opportunity to combine the efforts and talents of these disciplines into this single research experiment.

This project will provide NEES with two field laboratories for the study of SFSI, liquefaction, and ground deformation. The project is enhancing existing, well-studied, and well-characterized seismic array sites: Wildlife and Garner Valley. The enhanced NEES sites will be capable of both active and passive experiments, including an SFSI test structure with shaker and structural instrumentation at Garner Valley.

Permanently instrumented field sites for the study of soil-foundation-structure-interaction (SFSI) and soil failure address one of the identified research needs for earthquake engineering equipment sites. There is need to further study SFSI in real structures under seismic input, but there are always complexities with real structures that can mask understanding of the SFSI phenomena. Study of soil failure is also complicated in urban or geologically-complex settings. Simple, well-characterized test sites are needed to increase understanding of the physics behind SFSI and soil failure in earthquakes.

This project adds to the NEES program a unique pair of permanently instrumented sites that address these research needs. In particular, two simple sites in the seismically active Southern California region have been enhanced and brought into the NEES equipment portfolio, linked by next-generation wireless communications to the NEESgrid. The Wildlife site will provide a test facility for active and passive measurement of soil response and soil failure under dynamic loading. The Garner Valley site will provide a simple site with a simple structure for active and passive study of SFSI and soil response. The two field sites will provide research opportunities for those developing tools for site characterization and for the evaluation of soil properties and how they change with time during and after seismic disturbance. The project will provide unique research opportunities for studying the physics of SFSI. The field sites will also have an impact on undergraduate and graduate teaching programs in earthquake engineering, geotechnical engineering and engineering seismology. Students will be able to participate in the active experiments through teleparticipation as well as on-site workshops.

The project team consists of Jamison Steidl (PI), T. Leslie Youd (Co-PI), and Robert Nigbor (Co-PI). (Note: In the MREFC phase, Brigham Young University was the awardee and the PI was T. Leslie Youd.)

Website: http://nees.crustal.ucsb.edu/Index.php
**Equipment Site Description**

This project will provide NEES with two field laboratories for the study of SFSI, liquefaction, and ground deformation. The project is enhancing existing, well-studied, and well-characterized seismic array sites: Wildlife and Garner Valley. The enhanced NEES sites will be capable of both active and passive experiments, including an SFSI test structure with shaker and structural instrumentation at Garner Valley. As well as becoming part of NEES, both sites will interact with ANSS.

A goal of earthquake engineering research within a future NEES is to generate analytical and empirical models for accurate prediction of ground response and ground deformation and to understand how these ground motion predictions affect the built environment. A required element for the development of these models is well-instrumented field sites where actual ground response and deformation, and the interaction with the foundation and structure, can be monitored during earthquake shaking to provide benchmark case histories for model development and verification. In addition the use of active methods to shake the structures and field sites can also provide benchmarks that can be compared with actual earthquake motions.

Permanently instrumented field sites for the study of soil-foundation-structure-interaction (SFSI) and soil failure address one of the identified research needs for earthquake engineering equipment sites. There is need to further study SFSI in real structures under seismic input, but there are always complexities with real structures that can mask understanding of the SFSI phenomena. Study of soil failure is also complicated in urban or geologically-complex settings. Simple, well-characterized test sites are needed to increase understanding of the physics behind SFSI and soil failure in earthquakes.

While we must still rely primarily on single point observations of ground motion and deformation at the surface due to the high cost of array instrumentation, geotechnical and structural arrays provide critical constraints for our methods of interpreting observed ground motions and failures. These constraints are then used for development, validation, and calibration of improved physical and numerical models to predict ground motions and failures from future damaging earthquakes. While previous efforts have been rather segregated into the seismological, geotechnical, and structural sub-disciplines of engineering, the NEES program, with its shared-use and tele-participation concepts is an excellent opportunity to combine the efforts and talents of these disciplines into a single research experiment.

This project adds to the NEES program a unique pair of permanently instrumented sites that address these research needs. In particular, two simple sites in the seismically active Southern California region (Figure 1) will be enhanced and brought into the NEES equipment portfolio, linked by next-generation wireless communications to the NEESgrid. The Wildlife site will provide a test facility for active and passive measurement of soil response and soil failure under dynamic loading. The Garner Valley site will provide a simple site with a simple structure for active and passive study of SFSI and soil response. The two field sites will provide research opportunities for those developing tools for site characterization and for the evaluation of soil properties and how they change with time after seismic disturbance. The project will provide unique research opportunities for studying the physics of SFSI. The sites will be an excellent test bed for new in-situ site characterization techniques, and new sensor technologies. The field sites will also have an impact on undergraduate and graduate teaching programs in earthquake engineering, geotechnical engineering and engineering seismology. Students will be able to participate in the active experiments through teleparticipation as well as on-site workshops.
Vision

The purpose of this project is to augment and enhance the instrumentation at two carefully chosen field sites, Wildlife and GVDA (Figure D.10-1). Both of these sites are on soft and/or liquefiable soils where improved predictive models are urgently needed. At Wildlife, the focus will be on soil failure (liquefaction and lateral spreading). At GVDA, a small test SFSI test structure (a square 4mx4mx4m re-configurable steel frame structure with an substantial concrete slab foundation and roof) with active shaking capability will focus this site on SFSI physics. In addition, GVDA has nearby (within ~3 km) outcrop and borehole sensors located on/in bedrock to provide additional constraints on the reference input motion to the soil localities, and information on the response of the near-surface weathered bedrock materials.

Both sites will be instrumented with next-generation, high dynamic range (24-bit) systems to precisely measure ground accelerations from earthquakes and active sources. At GVDA, the structure will be instrumented as well with a variety of sensors. Both sites will have extra recording channels for use with innovative sensors brought by NEES users. The instrumentation at these field sites will be made part of the NEESgrid through wireless, 45Mb/s connections to the NSF-funded HPWREN system, allowing real-time data as well as teleparticipation and teleoperation from both sites.

The primary purpose of permanently instrumented sites is to provide real field data for development and verification of analytical and empirical models. Testing of models for prediction of ground response, SFSI, and soil failure at simple sites will be one of the major research uses of these permanently instrumented sites. The intent is to record both active shaking experiments and motions from some earthquakes that can drive the sites into the larger strain, nonlinear range. Such records will be widely used by modelers to test, modify and verify the simulation capability of the various models. Similarly, any recorded transient increase of pore pressure will be extremely useful to modelers of pore pressure response.

Should the liquefaction sites be shaken strongly enough to generate large pore pressures, liquefy the sites, and generate significant ground deformations, the recorded data would be invaluable to modelers of liquefaction behavior and ground failure. No adequately verified and widely accepted models have been developed to model this behavior. Potential records from this project will provide considerably more in-situ information than any previous
experiment because of the greater amounts of ground motion and pore pressure data that will be recorded. Many researchers will be able use these records in model development because of the shared-use and tele-participation involved in the NEES program.

Examples of three Possible Future Research Projects:

1. **Passive study of the effect of a structure upon ground shaking.** The existing GVDA array has recorded over 1000 small to moderate earthquakes, allowing detailed characterization of the site with no building. After addition of the 50-ton test building, it will be possible to study how the simple structure affects the earthquake ground motions at this simple site. Differences will be due to SFSI effects.

2. **Active study of liquefaction.** Both the Wildlife and GVDA sites are on liquefiable soils. At both sites we will be able to use the large shakers from the NEES University of Texas mobile shakers. These shakers should be powerful enough to cause localized liquefaction. Data from such an experiment could then be used to verify predictive models of both liquefaction and ground shaking.

3. **Active study of SFSI physics.** At GVDA, the reconfigurable test structure and its instrumentation can be used to measure structure and soil motion, soil pressures, and pore water pressures during active shaking of the structure. Such data will be invaluable for verification of predictive physics-based models of SFSI.

4. **Active study of soil property changes with time after disturbance.** At both sites, experiments could be performed using open cased boreholes, for solenoid and sensor strings to be installed for cross-hole wave propagation studies. Understanding how the strength of a soil column is changed with seismic disturbances, and how it recovers with time is an interesting future research project.

### Liquefaction Potential

The two field sites will provide unique instrumentation at locations where the liquefaction potential has been documented both by previous records and by simulation. An example of the site characterization details and liquefaction potential simulation that is available at both sites is shown in Figure D.10-2 below.

![Figure D.10-2: Geotechnical Soil Profile from CPT logs (left) and Liquefaction Potential (right).](image)

### SFSI Experiment

In the past the instrumented field sites have focused primarily on seismology, with some overlap into geotechnical earthquake engineering with the addition of pore pressure sensor arrays to monitor for liquefaction. The addition of the re-configurable SFSI experimental structure at Garner Valley broadens the scope of the instrumented field sites more into the geotechnical engineering arena and into the structural engineering discipline. This addition highlights the cross-disciplinary nature of the earthquake engineering problem.

A web-based simulation tool has been developed to assist the design of SFSI experiments at GVDA. The primary purpose of the simulation tool is to provide users with a simple JAVA-based interface to perform finite element analyses of the SFSI structure. The simulation tool is a web-based application with the finite element analyses (Figure D.10-3) performed on the server side by implementing the JAVA SERVLET technology. The results will be displayed for the remote user via a TCP/IP protocol through a web browser. This simulation tool will eventually
will be used to verify the structural configurations and the shaker parameters for experiments to be conducted at the NEES-sponsored Garner Valley SFSI test facility.

Teleobservation and Teleoperation Vision

The GVDA and WLA sites will have video capability over the HPWREN system for remote users to observe experiments and activities at the site, and for video conferencing during projects. The data acquisition systems are also remotely configurable and controllable via the HPWREN link. The shaker system installed inside the SFSI building will also be controllable remotely. This will be available from any networked classroom in the nation where the instructor has been trained and provided NEESgrid access privileges at the sites.

Education Outreach

It is anticipated that the data from these field sites will be heavily used at the graduate level for training of the next generation of earthquake engineers and seismologists. Workshops will be offered annually to provide students with field experience in seismology, geotechnical, and structural engineering sub-disciplines of earthquake engineering. The ability to remotely configure the data acquisition systems and the real-time telemetry capabilities of the networked field sites will give students and researchers unique access to experimental facilities.

A highlight of the educational aspect of the permanent field sites is an extensive undergraduate level education program that will utilize the teleoperational capabilities of the SFSI experiment at the GVDA site. This system will be especially useful for instructional/educational use in the classroom as students learn hands-on about modal analysis and structural dynamics. This will include a web-based training module for both the instructors and students. These capabilities will be advertised to the earthquake engineering and seismology communities.

The Brown Foundation operates several programs to encourage young K-12 students to enter into the fields of engineering and science. As the field sites are in the backyard of late George E. Brown Jr. congressional district, and one of the sites located just a few miles from where he was raised, the Brown Foundation has agreed to assist us in our outreach efforts to these local children. Web-casts and field visits to the sites from local schools will provide young students in the region with a unique glimpse into the field of earthquake engineering.
D.11 University of Colorado at Boulder

The NEES Site at the University of Colorado at Boulder (CU) has a unique Fast Hybrid Test (FHT) system that combines physical testing with model-based simulation. The FHT system is a shared-use facility that utilizes high-performance servo-hydraulic loading apparatus, modern digital control technologies, the state-of-the-art model-based simulation techniques, high-performance information network, and Internet-based information technologies to allow a most realistic and efficient assessment of the performance of large-scale structural systems, subassemblies, and components, and response mitigation devices under earthquake loads.

Traditionally, the most common means to evaluate the performance of a structural system under earthquake loads is either the pseudodynamic or shake table test method. While pseudodynamic tests can be applied to large-scale structures, the rate of loading in such a test can be more than 100 times slower than the real-time earthquake response of a structure. Since the inelastic behavior of most structures is, to a certain extent, sensitive to the rate of loading, the slow loading rate in such tests has raised some concerns as to whether the test results reflect the real behavior of a structure during an earthquake. Furthermore, the performance of many earthquake response mitigation devices is highly sensitive to the rate of loading. Testing such devices requires real-time loading. A shake table can apply a realistic excitation rate. Nevertheless, the size of a structure that can be tested is most often limited by the size and payload capacity of existing tables. Furthermore, one cannot easily test a structural component or subassemblage on a shake table due to difficulties in imposing proper boundary conditions on a subsystem in such a setup.

The FHT system at CU is built on a substructure pseudodynamic test concept. The main distinction is, however, that the system can deliver 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. During such a test, the actuators are in continuous motion. With this system, one can test the most critical structural subassembly, where severe inelastic deformation or damage is expected to develop, and model the rest of the structure in a computer. In general, the method can be applied to full-scale structural systems and subassemblies depending on the size and capacities of the reaction-wall facility and the high-speed, high-performance hydraulic actuators available. Furthermore, with a slower rate, it can be used to conduct geographically distributed tests, where different components and subassemblies of a structure can be tested in different laboratories with the synchronization and data exchange controlled by a computation model of the entire structure via the Internet. The system has a flexible software and hardware architecture to allow researchers to develop and implement new analytical models and computation techniques into its computational platform for hybrid testing.

The system consists of three high-speed actuators, one with a 100-ton (220-Kip) load capacity in tension and compression, and two with a 50-ton (110-Kip) load capacity. The actuators are controlled by a digital control system that is linked to a network of computers for on-fly simulations and data streaming. The system is accessible by remote users via the Internet for teleparticipation in experiments. It is connected to the NEESgrid, which provides capabilities for streaming live videos and numerical data from experiments and simulations.

The equipment is located in the Structures Laboratory of the University of Colorado. The strong floor area in the laboratory is 12 m by 21 m (40 ft. by 70 ft). The strong floor is 0.6-m (2-ft.) thick with 76-mm (3-in.) diameter holes spaced at a center-to-center distance of 0.91 m (3 ft.) in each direction for anchoring structural specimens. The testing bay has a vertical clearance of about 6 m (20 ft.) with a 5-ton overhead crane that covers the entire Structures Laboratory and can move all the way out of the loading dock. The vertical distance for crane lifting is about 3 m (10 ft.).

The project team consists of P. Benson Shing (PI) and Enrico Spacone (Co-PI).

Website: http://ceae.colorado.edu/nees/
**Equipment Site Description**

The NEES Site at the University of Colorado at Boulder (CU) has a unique Fast Hybrid Test (FHT) system that combines physical testing with model-based simulation. The FHT system is a shared-use facility that utilizes high-performance servo-hydraulic loading apparatus, modern digital control technologies, the state-of-the-art model-based simulation techniques, high-performance information network, and Internet-based information technologies to allow a most realistic and efficient assessment of the performance of large-scale structural systems, subassemblies, and components, and response mitigation devices under earthquake loads.

Traditionally, the most common means to evaluate the performance of a structural system under earthquake loads is either the pseudodynamic or shake table test method. While pseudodynamic tests can be applied to large-scale structures, the rate of loading in such a test can be more than 100 times slower than the real-time earthquake response of a structure. Since the inelastic behavior of most structures is, to a certain extent, sensitive to the rate of loading, the slow loading rate in such tests has raised some concerns as to whether the test results reflect the real behavior of a structure during an earthquake. Furthermore, the performance of many earthquake response mitigation devices is highly sensitive to the rate of loading. Testing such devices requires real-time loading. A shake table can apply a realistic excitation rate. Nevertheless, the size of a structure that can be tested is most often limited by the size and payload capacity of existing tables. Furthermore, one cannot easily test a structural component or subassembly on a shake table due to difficulties in imposing proper boundary conditions on a subsystem in such a setup.

The FHT system at CU is built on a substructure pseudodynamic test concept. The main distinction is, however, that the system can deliver 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. During such a test, the actuators are in continuous motion. With this system, one can test the most critical structural subassembly, where severe inelastic deformation or damage is expected to develop, and model the rest of the structure in a computer. In general, the method can be applied to full-scale structural systems and subassemblies depending on the size and capacities of the reaction-wall facility and the high-speed, high-performance hydraulic actuators available. Furthermore, with a slower rate, it can be used to conduct geographically distributed tests, where different components and subassemblies of a structure can be tested in different laboratories with the synchronization and data exchange controlled by a computation model of the entire structure via the Internet.

The system consists of three high-speed actuators, one with a 100-ton (220-Kip) load capacity in tension and compression, and two with a 50-ton (110-Kip) load capacity. The actuators are controlled by a digital control system that is linked to a network of computers for on-fly simulations and data streaming. The system is accessible by remote users via the Internet for teleparticipation in experiments. It is connected to the NEESgrid, which provides capabilities for streaming live videos and numerical data from experiments and simulations. The basic configuration of the FHT system is shown in Figure D.11-1.
The system is operated and maintained by a team of professional laboratory personnel to keep both the software and hardware up-to-date and in good operational conditions. The laboratory staff will assist on-site and off-site researchers in experiment planning, preparation, and execution, and data collection. The system has a flexible software and hardware architecture to allow researchers to develop and implement new analytical models and computation techniques into its computational platform for hybrid testing.

Experiments Envisioned

Three sample experiments are described below to illustrate potential applications of the FHT system.

Shear Wall Tests

Shear-wall structures have been tested on shake tables and with reaction wall facilities. Because of the capacity limitations of existing shake tables, only scaled models of multi-story shear-wall structures are allowed in such tests. In testing reinforced concrete structures, questions are often raised with regard to the scalability of the aggregates, reinforcing bars, and the bonds between the concrete and steel. Furthermore, because of the scaling, these tests were often conducted in a significantly compressed time scale. This leads to the issue of strain-rate effects. Because of the scarcity of large reaction wall facilities, quasi-static tests of full-size shear walls were often restricted to one or two stories. The overturning moments introduced by the upper stories of a structure often had to be ignored or approximately accounted for by fixing the effective shear span ratio. For this reason, results of these tests might not truly reflect the actual behavior of a wall under earthquake excitation, even though they may still be useful for the comparison of different design details under a consistent loading condition.

As shown in Figure D.11-2, the FHT method is especially useful for the evaluation of shear walls. With this method, one can only test the bottom story wall where most of the damage is expected to concentrate in a multi-story building, and model the rest of the building using a mathematical model. The wall specimen in such a test is controlled by three actuators to simulate the response under in-plane earthquake loads. One actuator is to control the
horizontal displacement, and the other two to control the vertical displacement and rotation at the top. In such a test, the effective shear-span ratio can vary depending on the response of the entire structure that is modeled.

**Bridge Column Tests**

During an earthquake, long bridge structures can be subject to multiple-support excitations. This can be simulated in a laboratory using multiple shake tables. The FHT method provides an efficient alternative to multiple-shake-table tests. As shown in Figure D.11-3, one can test individual bridge columns and model the rest of the bridge structure using the FHT method. The columns can be tested in a single laboratory or in separate laboratories using a high-performance Internet connection and multi-site test protocols.

Asynchronous ground excitations, soil-structure interaction, and other capabilities can be built into the current software platform to suit one’s research needs.

![Figure D.11-2: Shear Wall Tests](image)
Base-Isolation Systems

Base-isolation systems such as rubber bearings have been used to isolate and protect a structure from earthquake ground motions. With this kind of systems, the structural response is often expected to remain within the elastic range. Hence, to evaluate the effectiveness and nonlinear response characteristics of these devices, one can test the devices alone and model the structure mathematically as shown in Figure D.11-4.

This system can be applied to test the effectiveness of other passive and active response mitigation devices. Real-time loading is essential for these tests as the load-response properties of these devices can be highly rate sensitive.
The primary objective of the “Multi-Axial Full-Scale Sub-Structured Testing and Simulation” facility (MUST-SIM) is to develop a physical-analytical simulation environment whereby full scale structure-foundation-soil systems are subjected to complex loading and boundary conditions representing earthquake ground motion effects and the ensuing actions and deformations captured by state-of-the-art sensors are processed and visualized by local and remote users. MUST-SIM has the following features:

(i) 6-DOF load and position control at 3 connection points
(ii) Three dense non-contact measurement systems
(iii) Advanced geotechnical and structural analysis tools
(iv) Data fusion and high-end visualization capabilities
(v) A full array of telepresence equipment

The MUST-SIM facility realizes the above features through the development of three six-DOF Loading and Boundary Condition Boxes (LBCB) that allow for precise application of complex load and boundary conditions. The LBCBs will be able to impose motions on the test structures that are determined from the results of concurrently running numerical models of the test specimen and the surrounding structure/foundation/soil system employing pseudo-dynamic testing methods. Dense arrays of state-of-the-art, non-contact instrumentation, will allow near real-time model updating for the model-based simulation. Additionally, this facility and its telepresence capabilities will be enhanced by development of multi-function data visualization and knowledge interpretation tools in cooperation with the Automated Learning Group of NCSA.

Examples of how the results obtained from experiments carried out in the MUST-SIM facility will be useful to the research community include:

(a) the reliable establishment of performance limit states that take into account the structure, foundation and soil characteristics will aid in the accurate assessment of existing structures, as well as in the development of a new generation of performance-based design guidelines,
(b) the refinement and updating of existing analytical models and the establishment of new models can be facilitated through knowledge-based concepts derived from test results,
(c) experience gained through the use of the three advanced dense instrumentation will be valuable to other NEES sites, and
(d) the visualization modules developed may be extended in the future to include loss assessment models, hence can be used to portray overall loss scenarios before and after the application of remedial measures for seismic loss reduction.

The MUST-SIM NEES facility will stimulate new and unique approaches to experimental research to address earthquake engineering issues through a collaborative shared-use testing environment, ultimately leading to improved seismic performance of infrastructure, reduced economic losses in natural disasters, and more reliable structures and foundation systems.

The project team consists of Amr Elnashai (PI), Andrew G. Alleyne (Co-PI), Jamshid Ghaboussi (Co-PI), Daniel A. Kuchma (Co-PI), and Bill F. Spencer (Co-PI)

Website: http://cee.uiuc.edu/research/nees/


**Equipment Site Description**

The primary objective of this project is to create a facility in which a full-scale subassembly can be subjected to complex loading and imposed deformation states at multiple connection points on the subassembly, including the connection between the structure and its foundation. The MUST-SIM facility will have the following unique features: (i) 6-DOF load and position control at multiple connection points, (ii) system modularity to allow for easy expansion and low-cost maintenance/operation, (iii) multiple dense arrays of non-contact measurement devices, and (iv) advanced visualization and data mining capabilities for integrated teleoperation and teleobservation (telepresence), as shown in Figure D.12-1. The facility will realize the above features through the development of six-DOF Loading and Boundary Condition Boxes (LBCB) that allow for precise application of complex load and boundary conditions. The LBCBs will be able to impose motions on the test structures that are determined from the results of concurrently running numerical models of the test specimen and the surrounding structure/foundation/soil system employing pseudo-dynamic testing methods. Dense arrays of state-of-the-art, non-contact instrumentation, will allow near real-time model updating for the model-based simulation. In addition, this facility and its teleoperation capabilities will be enhanced by development of multi-function data visualization and knowledge interpretation tools in cooperation with the Automated Learning Group of the National Center for Supercomputing Applications (NCSA).

![Figure D.12-1: Principal components and information flow in the MUST-SIM Facility](image-url)

The distributed simulation and control software developed by the MUST-SIM team enables not only the utilization of the best available geotechnical and structural testing sites regardless of their geographical location, but also avails of the opportunity to deploy the best features of a number of analytical tools in one ‘system analysis’. The current version of this software controls four stations which could be physical or analytical simulation sites. In Figure D.12-2, a three-site simulation is depicted, where Sites A and B are physical and Site C is analytical. This schema is currently being applied to a multi-site test in collaboration with the System Integration (SI) team, and the University of Colorado.
The three loading and boundary condition boxes (LBCBs), shown in Figure D.12-3, have 3000, 1500 and 4500 kN load capacities in the two horizontal and one vertical directions. The corresponding deformation capabilities are 125mm, 250mm and 12-16 degrees rotation. The boxes can be anchored at any of 3 sides to either wall or floor, thus providing a versatile and adaptable experimental set up. The individual depicted next to the boxes is to give an indication of scale.

An L-shaped reaction structure is an integral part of the facility. Its location with respect to the strong floor in the Newmark Laboratory is shown in Figure D.12-4. The wall is 50x29 feet, and has a height of 23 feet. It is designed to resist the maximum force from the LBCB when placed at the top left corner and can also support all three LBCBs reacting against the wall at the same time.
The development, calibration, and validation of comprehensive numerical models require a density of experimental test data that is similar to the density of elements used in numerical simulation models. While conventional instruments such as strain gauges and displacement transducers have been the mainstay in structural research, the effort, expense, and space required by each of these gauges limits their usefulness in collecting the detailed data that is necessary for model validation and verification. Over the last few years, there has been a tremendous growth in the capabilities of non-contact instrumentation methods for measuring displacements and strains at a very large numbers of individual points. The three non-contact measurement technologies that have been identified for use in the MUST-SIM Facility are summarized below.

The Krypton’s RODYM Dynamic Measurement Machine is able to measure the position of up to 256 small (8 gram and 8 mm diameter) light emitting diode markers in three-dimensional space to an accuracy of plus/minus 0.02 mm at a sampling rate of up to 3000 individual readings per second. The “Krypton” system consists of a portable housing containing three 2048 CCD line-element cameras. The camera system has an effective measurement volume of 17 m³. No calibration of the system is required by external researchers.

The Stress Photonics Gray Field Polariscope (GFP-1200) is a full field non-contact stress/strain measurement system that is based on the principles of photoelasticity. To use Stress Photonics’ Grey-Field Polariscope, an application of a thin (0.25 mm) plastic coating (photoelastic material/epoxy) is applied to the surface of the test specimen. A light source is then used to emit circular polarized light and a digital camera is used to measure the fringe patterns. Unlike with traditional photoelasticity, the GFP-1200 system measures small variations in patterns of circular light. As a result, reliable sub-fringe level accuracy can be obtained with high resolution in the stress/strain levels being resolved. A three-color system enables the system to compensate for variations in the thickness of the coating. The plastic coating does not creep; hence it is possible to stop a test for multiple days without a concern for loss of accuracy.

Close-Range Digital Photogrammetry is used as a third non-contact measurement methodology. Widely used in aerial mapping, this methodology has recently become increasingly popular for other applications in the field of engineering and solid modeling. In a structural engineering application, the system can be used to measure the movements of targets placed on the surface of the test specimen from which strains, crack widths, and other features can be determined. High accuracies can be obtained by capturing subsequent images through conventional and digital cameras. Over the last few years there has been a major increase in the quality of digital cameras and image analysis tool while there has been a significant decrease in the cost of these tools.

State-of-the-art software for structural and geotechnical analysis is being assembled from the work of the Project Team and also work within other NEES facilities. The software is being integrated with the testing and control...
software to deliver capabilities of modeling complex structures and materials alongside foundation materials, as well as deformation and failure of the foundation. This will drive the test in an online computer-controlled manner using recent development in algorithms that take into account the characteristics of the loading system (actuators, servo-valves, etc.). Current developments are based on a dual approach of utilizing simple MatLab analysis software for simple frame analysis whilst developments of control algorithms fully integral with the finite element analysis package ABAQUS is nearing completion. Figure D.12-5 shows the MUST-SIM development of a 3-site distributed simulation based on Matlab, and intended for use in the SI-UIUC-Colorado collaborative test.

Multi-function data visualization and knowledge interpretation tools are being developed for the NEES site with the Automated Learning Group of the National Center for Supercomputing Applications (NCSA). This will be accomplished in four stages: (i) visualization, (ii) integration and interpretation of multiple-source test data, (iii) integration of test and analysis information, and (iv) model adjustment and optimization. Teaming with NCSA in developing visualization tools ensures the efficacy of the project. Finally, the control and telepresence system does a three-level algorithm comprising network (supervisory), link, and servo levels, affording full teleobservation and teleoperation capabilities in an open, easy-to-modify architecture. The three-level control system provides high levels of safety in terms of teleoperation of such large facility. The PIs and the Project Team have an established record in all aspects outlined above (online dynamic testing, instrumentation, analysis, visualization, and control).

Education and training is a vital component of the MUST-SIM vision. Towards this end, an interactive web site is under development where users can access a kinematic simulator of the LBCBs, shown in Figure D.12-6, and can run virtual experiments. A second stage in the educational learning curve is use of a fully-functional 5:1 scale LBCB (Figure D.12-6) where testing scenarios may be played whilst providing an analytical representation of the rest of the structure-foundation-soil system. The above-mentioned two-stage approach is not only for engineering students and other groups, but is also part of the advanced user-training program of the Facility.
The MUST-SIM facility provides a total testing-analysis-visualization-display environment that combines the ability to test portions of structures under complex and continuously changing boundary and loading conditions with the ability to either model or indeed test the SSI feature of response. This is achieved through high precision application of six degrees of freedom with very high precision in both forces and displacements. Therefore, it is a NEES asset that has hitherto not been available. From the instrumentation viewpoint, there is a serious and clearly identified gap between the level of information obtained from advanced analysis and that from laboratory testing. This gap has hindered convincing and intensive calibration of software where only one or two response parameters, usually displacements, are compared to test results. The instrumentation component of this facility bridges this gap and provides, in addition to high resolution control of the test, detailed information on structural performance that enables the real calibration and enhancement of analysis software. The density of the instrumentation program for a test specimen will be comparable to that of a finite element idealization. The integration of the test with the analysis software, through extensive instrumentation using new non-contact technologies alongside traditional strain gauging and LVDTs, renders the facility novel in this respect too.

The MUST-SIM NEES facility will stimulate new and unique approaches to research to address earthquake engineering issues through a collaborative shared-use testing environment, ultimately leading to improved seismic performance of our infrastructure, reduced economic losses in natural disasters, and more reliable structures. Moreover, the MUST-SIM NEES facility, with its state-of-the-art components, will be fully integrated with the undergraduate and graduate programs of the Department of Civil and Environmental Engineering at the University of Illinois at Urbana-Champaign and will feature in demonstrations to minority and under-represented groups of potential students. Therefore, the wider impacts of this NEES facility are in developing advanced and reliable criteria for upgrading the existing infrastructure systems and the design of new systems, and in educating engineers and engineering students in earthquake testing, analysis, instrumentation, visualization and ultimately, in seismic risk assessment and reduction.
D.13 University of Minnesota

The Multi-Axial Subassemblage Testing (MAST) System at the University of Minnesota is one of the large-scale structural testing facilities awarded through the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program, funded by the National Science Foundation under Grant No. CMS-0086602. The MAST system is unique in size and scope and greatly expands large-scale earthquake experimentation capabilities both nationally and internationally.

Large-scale testing of structures or their components (e.g., beam-column frames, walls and bridge piers) can deliver engineering insight into structural behavior that cannot be realized by any other means. However, the boundary effects where the specimen couples to the reaction structure are often reduced to simple uniaxial loading configurations not necessarily representing the physical boundary conditions experienced in practice. Furthermore, the difficulty of imposing multiple-degree-of-freedom states of deformation and load using conventional structural testing means can be expensive, time-consuming, and difficult to achieve. The MAST system concept, as conceived by the University of Minnesota, advances the current state of technology by allowing the experimental simulation of complex boundary effects through its multi-axial capabilities.

With the MAST system, six-degree-of-freedom-control technology is employed in the operation of a series of eight large-capacity hydraulic actuators attached to a stiff steel crosshead that can apply up to 5900 kN (1.3 million pounds) of load in the vertical direction and up to 3900 kN (880,000 pounds) in the horizontal orthogonal directions. Maximum deformations of up to ±400 mm (±16 in.) can be applied in the horizontal directions. Structural subassemblages as large as 6.1 m by 6.1 m (20 ft. by 20 ft.) in plan and 7.6 m (25 ft.) in height can be accommodated. The multi-degree-of-freedom states of load and deformation applied to the test specimen through the crosshead are resisted by a strong wall – strong floor reaction system. The MAST system also features mixed-mode control such that different degrees-of-freedom can be controlled simultaneously in displacement or load control. This feature enables, application of horizontal deformations to a structural system while applying a specified axial load in the vertical direction for example. Structural subassemblages that can be tested within the MAST system will greatly enhance the earthquake engineering community’s understanding of complex failure states.

As part of a networked system of facilities, MAST fits into an integrated data-centric approach for experimentation, computation, theory, databases, and model-based simulation. A key feature of the MAST system is the state-of-the-art telepresence capabilities that facilitate collaboration among the research community. Remote teleparticipation and transmission of collected sensor data, still camera images, streaming video and audio data is enabled through Internet2.

The University of Minnesota has constructed a brand new structural engineering laboratory to house the MAST system. The laboratory features an 11m (35 ft.) high L-shaped reaction wall in the testing bay, a staging area for construction of test specimen, a control room featuring state-of-the-art control and data acquisition equipment and equipment to facilitate the unique telepresence capabilities of NEES through Internet2. The laboratory also features a conference space and offices to house visiting researchers. With the inherent ease of test setup, overall flexibility, and the incorporation of telepresence, the testing community at large will greatly benefit from the MAST system.

The project team consists of Catherine French (PI), Jerome Hajjar (Co-PI), Carol Shield (Co-PI), Arturo Schultz (Co-PI), Robert Dexter (Co-PI), Steven Olson (Research Associate), Drew Daugherty (Research Coordinator), Chen When (Research Fellow), Doug Ernie (Co-PI), and David Du (Co-PI)

Website: http://nees.umn.edu/
Equipment Site Description

The Multi-Axial Subassemblage Testing (MAST) System at the University of Minnesota is one of the large-scale structural testing facilities awarded through the George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) program, funded by the National Science Foundation under Grant No. CMS-0086602. The MAST system, shown in Figure D.13-1, is unique in size and scope and greatly expands large-scale earthquake experimentation capabilities both nationally and internationally. University of Minnesota co-investigators involved in the development and implementation of the MAST facility include Catherine W. French, Arturo E. Schultz, Jerome F. Hajjar, Carol K. Shield, and Robert J. Dexter, Steven A. Olson, Drew J. Daugherty, and Chen P. Wan from the Department of Civil Engineering (CE), Douglas W. Ernie from the Department of Electrical and Computer Engineering (ECE), and David H.-C. Du from the Department of Computer Science and Engineering (CSE).

Large-scale testing of structures or their components can deliver engineering insight into structural behavior that cannot be realized by any other means. However, the boundary effects where the specimen couples to the reaction structure are often reduced to simple uniaxial loading configurations not necessarily representing the physical boundary conditions experienced in practice. Furthermore, the difficulty of imposing multiple-degree-of-freedom states of deformation and load using conventional structural testing means can be expensive, time-consuming, and difficult to achieve. The MAST system concept, as conceived by the University of Minnesota, advances the current state of technology by allowing the experimental simulation of complex boundary effects through its multi-axial capabilities.

MAST System Concept

There are two key features of the MAST system. The first is the implementation of a sophisticated six-degree-of-freedom control system to enable application of complex multi-directional deformation or loading schemes to structural subassemblages. The second key feature of the MAST system is the ability to apply large loads and deformations to enable testing of large-scale structural subassemblages including portions of beam-column frame systems, walls, tanks, and bridge piers.

In the (MAST) system installation, shown schematically in Figure D.13-1, a stiff steel crosshead in the shape of a cruciform is controlled with six-degree-of-freedom (6-DOF) control technology. Two sets of actuator pairs with strokes of ±400 mm (±16 in.) provide lateral loads up to ±3910 kN (±880 kips) in the orthogonal directions. These actuator pairs are secured to an L-shaped strong wall with universal swivels. Four ±1470 kN (±330 kip) vertical
actuators, capable of applying a total force of ±5870 kN (±1320 kips) with strokes of ±510 mm (±20 in.), connect the crosshead and the strong floor. Hydrostatic bearings are used in conjunction with the vertical actuators to reduce friction loads. Vertical spacers can be mounted between the bearings and the vertical actuators for gross height clearance adjustment. The vertical clearance extends up to approximately 7.6 m (25 ft.), and can be varied by repositioning the lateral and longitudinal actuator attachments to the reaction wall. Horizontal clear distance between the vertical actuators can accommodate specimens up to approximately 6.1 m (20 ft.) in length in the two primary orthogonal directions.

With the MAST system, any degree-of-freedom may be programmed in either displacement control or load control, and degrees-of-freedom may be constrained in a master-slave relation to be a linear combination of the values of other degrees-of-freedom. For example, using the mixed-mode control capabilities of the MAST, it is possible to program any lateral displacement history, and at the same time specify overturning moment as a constant times the lateral force, while simultaneously maintaining an independent history of axial load on the test specimen. Another advantage of the MAST system is that it enables control of a plane in space rather than just a point in space. This feature, for example, enables application of pure planar translations, as well as the possibility of applying gradients to simulate overturning (e.g., axial load gradient in the columns of a multi-bay frame, or wall rocking). In addition, the system will be equipped with four ancillary actuators (not shown), which can be used to apply lateral loads at intermediate story levels, gravity loads, or simulated specimen boundary conditions.

The University of Minnesota has constructed a brand new structural engineering laboratory to house the MAST system. The laboratory features an 11m (35 ft.) high L-shaped reaction wall in the testing bay, a staging area for construction of test specimen, a control room featuring state-of-the-art control and data acquisition equipment and equipment to facilitate the unique telepresence capabilities of NEES through Internet2. The laboratory also features a conference space and offices to house visiting researchers. With the inherent ease of test setup, overall flexibility, and the incorporation of telepresence, the testing community at large will greatly benefit from the MAST system.

Example Structural Specimen to be Tested within the MAST System

The possibilities for structural testing within the MAST system are broad in scope. The following represent examples of types of structural configurations and variations on those concepts that could be tested with the MAST. The loading history, described below as “user-defined,” represents a multitude of options, including using an input from a multi-directional pseudo-dynamic testing system. In the case of pseudo-dynamic testing, the tests described below might represent one component of a structural system that is tested simultaneously at a number of NEES sites.

Example 1 – Flanged Wall (Multidirectional Test) Post-earthquake reconnaissance often identifies building corners formed by intersecting concrete or masonry walls as vulnerable to seismic damage, and biaxial loading effects are often cited as one of the reasons for this damage. However, little has been done to quantify the biaxial loading and wall resistance characteristics at these corners, nor to systematically verify details to mitigate this damage. The MAST system would enable full biaxial testing of full-scale or near full-scale subassemblage tests of wall sections. The sample reinforced concrete core wall shown in Figure D.13-2, typical of an elevator core, represents the lower two stories of a multi-story wall. To control the loading imposed on the wall through the boundaries, it is envisioned that rigid concrete blocks would be cast on the top and bottom of the wall to transfer the load from the cruciform-shaped crossheads to the flanged wall cross section. The 3/4 scale demands listed in Table 1 were scaled from a 10-story prototype with 3.7 m (12 ft. stories). Concrete strengths of 27.6 MPa (4000 psi) were assumed, along with a vertical reinforcement ratio of 2%, uniformly distributed throughout the cross section. Assuming a moderate amount of inelastic
behavior in the prototype structure, the centroid of the total lateral force distribution at maximum base shear is assumed at mid-height of the wall, resulting in a moment-to-shear \((M/V)\) ratio of \(H/2\), where \(H\) is the height of the wall. Testing of this system could proceed with a prescribed lateral drift applied along each horizontal direction to define the biaxial load pattern (e.g., either from a user-defined source or from pseudo-dynamic input). At the same time, mixed-mode control could be employed to impose the desired moment-to-shear ratio at the boundaries in the two orthogonal directions. The procedure might be as follows: A prescribed lateral drift is imposed simultaneously in the two orthogonal horizontal directions. The resulting moment vectors in the two orthogonal directions, caused by the actuators applying longitudinal and lateral loads, apply overturning moments to the structure. The distribution of lateral, longitudinal, and vertical loads would be controlled via the 6-DOF controller to ensure that the desired \(M/V\) ratio is maintained. The two remaining world DOF's (e.g., a twisting moment about the vertical axis and the resultant vertical force or axial load) may be suppressed or controlled as well. As an example, the vertical force might be specified as either constant or cyclically varying, and either independent or synchronous with the longitudinal/lateral drift histories.

Example 2- Beam-to-Column Subassemblage (Multidirectional Test) A typical beam-to-column subassemblage is shown in Figure D.13-3. The test specimen represents a portion of a structure modeled between inflection points assumed to occur at midheight of the columns and midspan of the floors. To represent the boundary conditions, movement of the top of the column would be controlled by the MAST top crosshead, and the bottom end of the column would be attached to the strong floor with a universal joint. Four ancillary actuators would maintain the story elevation of the beam ends as the column is subjected to a user-defined displacement history. The MAST 6-DOF controller enables complex biaxial displacement histories, while through mixed-mode control, the axial load on the column can be controlled as well. Table D.13-1 shows the required load and displacement demands to test a biaxially loaded subassemblage that would be similar in concept to one of the beam-to-column connections in the NSF Precast Seismic Simulation Systems (PRESSS) Phase 2A project, in which case the lateral load resistance was assumed to be provided by perimeter frames. The demands listed in Table D.13-1 are envisioned to be near the anticipated maximum limit for a large-scale biaxial subassemblage test. The lateral/longitudinal loads and ancillary actuator loads are based on the assumption that a beam-hinging mechanism develops. Maximum displacements are associated with extreme drifts (up to 8%). The axial load represents the gravity load on a lower story subassemblage in a 15-story building.
Example 3 – Multi-Story, Multi-Bay Frame (Unidirectional Test) The third example is a two-bay, two-story steel structure shown in the schematic view of the MAST system in Figure D.13-1, and in more detail in Figure D.13-4. The bottom of the columns would be fixed to the strong floor. The top of the test structure, representing inflection points at midheight of the column story, would be attached to the top of the MAST crosshead with pinned connections. The columns could be loaded initially to simulate gravity loading in the lower stories of the structure. As the structure is displaced under cyclic lateral loads, a proportional amount of overturning moment could be applied via the 6-DOF control. The out-of-plane degrees-of-freedom would be constrained against displacement and twist at the top of the columns. Ancillary actuators (shown as arrows in Figure D.13-4) may be used to apply supplemental lateral loads (or displacements) at the individual story levels. The loads (or displacements) applied by the ancillary actuators may be scaled from the MAST crosshead. Another use of the ancillary actuators could be in the application of gravity loads to the test structure floor system.

With the 6.1 m (20 ft.) clear distance between the vertical actuators of the MAST system, the multi-bay structure as shown is limited to ½ scale [1:1 scale would correlate with W14x311 (50) columns and W33x150 (50) girders for a steel structure]. Typical loading requirements are highlighted in Table D.13-1. These concepts could be expanded to include multidirectional testing capabilities.

<table>
<thead>
<tr>
<th>Specimen Type</th>
<th>Dimensions</th>
<th>Longitudinal</th>
<th>Lateral</th>
<th>Axial</th>
<th>Ancillary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Column</td>
<td>Beam</td>
<td>Load (kN)</td>
<td>Stroke (mm)</td>
<td>Load (kN)</td>
</tr>
<tr>
<td>MAST Capacity</td>
<td>6.1x6.1m in plan, vertical 7.6m (var.)</td>
<td>±3,910</td>
<td>±400</td>
<td>±3,910</td>
<td>±400</td>
</tr>
<tr>
<td>EX. #1 Scale 3:4</td>
<td>4.6x4.6m in plan, 230mm thick</td>
<td>±2,890</td>
<td></td>
<td>to web</td>
<td>±670</td>
</tr>
<tr>
<td>EX. #2 Scale 1:1</td>
<td>1x1.1m</td>
<td>0.5x1m</td>
<td>±1,510</td>
<td>±330</td>
<td>±1,510</td>
</tr>
<tr>
<td>EX. #3 Scale 1:2</td>
<td>W8x67</td>
<td>W16x31</td>
<td>±670</td>
<td>±380</td>
<td>optiona</td>
</tr>
</tbody>
</table>

1Each actuator will be calibrated at three ranges 10%, 25% and 100% for both stroke and load.
2Flanged wall dimensions are 4.6x4.6m in plan, 230mm thick, with longitudinal loading parallel to the web, and lateral loading normal to the web.

The MAST system is not limited to particular types of building materials. The example specimens described above might feature reinforced concrete, precast concrete, steel, and masonry, or combinations of these materials. There may also be new building materials or structural configurations, not yet envisioned, that could be tested within the MAST facility.
Shared-Use Telepresence Enabling Model-Based Simulation and Education Enhancement

As part of a networked system of facilities, MAST fits into an integrated data-centric approach for experimentation, computation, theory, databases, and model-based simulation that will promote collaboration through information sharing and cross-facility research. A key feature of the MAST system is the state-of-the-art telepresence capabilities that facilitate increased participation and collaboration among the research community and enable the achievement of broad educational and outreach activities. As an example, the telepresence features make available the tremendous experimental resources of the MAST system to schools that do not have direct physical access to laboratory resources. The remote teleparticipation and immediate access of collected sensor data, still camera images, streaming video and audio data is enabled through Internet2. Video and still cameras on robotic arms create a visual and audio record of the experiments. Sensor, visual, and audio data, interfaced with a web-based graphical visualization and control system, allow researchers both at the facility and at remote locations to be actively involved in MAST experiments and computational simulation projects. The integration of a networked series of laboratories and schools enables collaborative investigations of model-based computational simulation combined with experimental testing that will provide a comprehensive assessment of the performance of structural systems to advance the earthquake-resistance of the nation’s infrastructure and the education of its future engineers and academicians.
D.14 University of Nevada, 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.

The main test floor of the LSSL is a heavily reinforced concrete slab providing 780 sq m of useable test area. This area is serviced by two 222 kN overhead cranes with a clear height of 11 m. The strong floor measures, 46 x 17 x 0.91 m (length x width x thickness), and has about 1325 tie down holes on a 0.61 x 0.61 m grid. Significant testing is conducted in the LSSL using independent actuators. For this purpose, the laboratory has several MTS servo-controlled static as well as fatigue-rated actuators ranging in size from 250 kN to 3.1 MN, with stroke capacities ranging from ±75 mm to ±600 mm. These are routinely used for large-scale experiments on structural components that are too large or unsuitable for shake table execution. Hydraulic hardlines feed the Laboratory and provide 945 l/min at 21 MPa. Four ports along the centerline of the Laboratory floor provide access to feed, return, and drain lines. The same distribution system can supply up to 1,890 l/min depending on the pump capacity. At present, the Laboratory’s pumping capacity is 1000 l/min, which is boosted up to 6,056 l/min with blowdown accumulators for short durations.

A major upgrade and expansion of the LSSL is well under way 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. A shake table / telepresence demonstration was performed for the November, 2002 meeting of NEES Awardees and NSF program managers.

The equipment obtained has upgraded the two existing tables from uniaxial to biaxial motion, and the purchase, installation, and commissioning of a third biaxial table is also included. Manufactured by MTS, each table measures 4.35 x 4.50 m, has a stroke of ±300 mm, and can reach a peak velocity of 1 m/sec and an acceleration of ±1g under the full 450 kN payload in both directions. All three shake tables will be relocatable with the same characteristics in both directions. To achieve these maxima, banks of blowdown accumulators are used. Currently, LSSL has two such accumulators and will purchase a third for the new table.

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.

The project team consists of Ian Buckle (PI), Ahmad Itani (Co-PI), Emmanuel Maragakis (Co-PI), Mehdi Saiidi (Co-PI), and David H. Sanders (Co-PI).

Website: http://nees.unr.edu/
Equipment Site Description

The NEES Equipment Site at the University of Nevada Reno is a biaxial, multiple-shake-table facility that is suitable for conducting research on long, spatially distributed, structural and geotechnical systems. 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.

The Site is housed within the Large-Scale Structures Laboratory on the university’s main campus in downtown Reno. This high-bay laboratory has a 780 m² (8,400 sq ft) strong floor that measures 45.7 x 17.1 m (150 x 56 ft). Major equipment includes three shake tables, seven stand-alone servo-controlled hydraulic actuators and three data acquisition systems for the simulation and observation of earthquake loads and their effects. The NEES facility comprises the three shake tables, and each of these tables is:

- biaxial, with two degrees of freedom, the x- and y- displacements in the horizontal plane
- 4.25 m (14 ft) square, has 445 kN (50-ton) payload capacity at 1.0g acceleration, and ± 300 mm (12 inch) displacement capacity in the x- and y- directions simultaneously
- mounted on the strong floor of the Laboratory using tie-downs at 600 mm (2 ft) centers
- serviced by two, 222 kN (25 ton) overhead cranes with 9.4 m (31 ft) clearance, and
- relocatable, so that a variety of table configurations may be assembled to meet variety of research needs.

Each table may be operated

- independently of the other two tables, each with a payload of 445 kN (50 tons)
- in-phase with the other two tables, thus forming a single large table for specimens weighing up to 1335 kN (150 tons), or
- differentially with the other two tables for the application of spatially varying ground motion to distributed structural and geotechnical systems with a total weight up to 1335 kN (150 tons).

Within certain limits, table payloads may be increased if the maximum table acceleration is reduced. For example, if the peak table acceleration is limited to 0.5g, the payload may be increased to 890 kN (100 tons). The upper limit on the payload is governed by either the capacity of the table actuators (730 kN (165,000 Lbs) each) to generate the required base shear, or the capacity of the slide bearings to support the weight of the table and specimen and resist overturning moments.

Two of the three tables were installed in 1997 and the third table was added in 2002 under the University’s Cooperative Agreement with the National Science Foundation (NEES). Laboratory personnel have experience in using multiple tables for research purposes, and are skilled in experiment design, table operation, maintenance, and laboratory safety.

Such a facility is believed to be the only one of its kind in the United States and is suitable for a wide range of different kinds of large-scale experiments. These include studies on the effect of spatial variation in earthquake ground motions on lifeline systems, the biaxial response of long structural systems and their components, and the behavior of very large-scale systems which are either physically too large for existing, single-table, facilities or too heavy, or both.

In summary, these tables may be used to study:

- dynamic load distribution between walls and floors in a shear-wall building with simultaneous in-plane and out-of-plane inertia loads on the walls that develop material and geometric nonlinearities
- dynamic interaction between secondary components in buildings (mechanical systems) and the structural frame
• dynamic response of buried pipelines at shallow depths in liquefiable and other unstable soils
• dynamic loads on piled foundations due to lateral spreading in liquefiable soils
• biaxial response of nonlinear components and systems such as seismic isolators, columns, restrainers and beam-column joints in buildings, bridges and lifelines, and
• response of long structural systems such as bridges and pipelines to spatial variation in the ground motion using differential input motions at discrete supports.

Three of the above examples are described in greater detail below:

<table>
<thead>
<tr>
<th>Example</th>
<th>Table Configuration</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3 biaxial tables, spatially separate, same in-phase biaxial motion to all tables.</td>
<td>Performance of multi-span steel-girder bridges with simply-supported spans</td>
</tr>
<tr>
<td>2</td>
<td>3 biaxial tables, spatially separate, differential biaxial motion to tables.</td>
<td>Performance of jointed pipelines subject to differential motion</td>
</tr>
<tr>
<td>3</td>
<td>one large table assembled from 3 biaxial tables (1 in uniaxial mode), adjacent to each other.</td>
<td>Liquefaction-induced displacements and forces on bridge foundations</td>
</tr>
</tbody>
</table>

**Example 1: Performance of multi-span steel-girder bridges with simply-supported spans**

Steel-girder superstructures are commonly used in bridges in the central and eastern United States. Many are located in moderate seismic zones and yet design provisions for these structures are almost non-existent in the AASHTO and Caltrans Seismic Design Specifications. There is considerable uncertainty about the ability of a steel superstructure to adequately distribute seismic loads from the deck to its piers and foundations. The influence of in-plane flexibility on load distribution has not been studied in any detail and experiments have been limited to small specimens or low-amplitude field-testing. This gap in our knowledge could be addressed by performing large-scale experiments on a 2-span steel bridge supported on 3 shake tables. Dynamic load distribution to the bearings might explain why so many steel bearings fail during earthquakes and identification of the load path through the superstructure would enable a more rational design to be achieved. Improving the performance of these bridges might well be possible by embedding simple structural control devices into the superstructure and taking advantage of their flexibility to dissipate energy and dampen response. Such experiments would have particular credibility if conducted at a large scale (0.4 or larger) and using input motions at three independent supports.

In this experiment, the tables would be operated in-phase, as if they were a single table, but each one will be a span length from its neighbor. Separation up to 18 m (60 ft) will be possible for a 2-span bridge model.
**Example 2: Performance of jointed pipelines subject to differential motion**

Pipelines transporting water, gas, or volatile fuels are classified as ‘lifeline’ systems and are critical to the viability and safety of communities. Disruption to these lifelines can have disastrous results, either through the release of hazardous materials, or the loss of water required to fight fires and for domestic use. Most pipelines are buried at shallow depths and their failure is strongly correlated to the performance of the surrounding soil. In many cases it is the pipe joint which is the weak link and current research is examining the dynamic performance of single joints without the soil effect. Ideally the next step is to study buried pipelines and obtain insight into the soil-pipe-joint interaction problem.

This is a complex problem but one that is amenable to large shake table experiments. Not only could differential motions due to different soil types be simulated, but also the effects of spatial variation in the ground motion could be studied. The movement of one joint in a pipeline relative to another is a key parameter in the fragility of these systems. Experimental determination of fracture rates for pipes and joints due to this phenomena will advance-the-state-of the art immeasurably.

In this experiment, the tables would be operated differentially and separated along the length of the pipeline to uniformly support the soil mass and buried pipe.

**Example 3: Liquefaction-induced displacements and forces on bridge foundations.**

A soil-filled laminar box placed on a shake table can be used to realistically study many aspects of soil-structure interaction (SSI) phenomena. There are many important problems that fall under this category, and one of the most critical involves liquefaction-induced flow (lateral spread). Widespread lateral spreading has occurred in recent earthquakes with disastrous consequences for bridge foundations and other buried structures. Substantial forces are presumed to be imparted to these foundations, but so far laboratory confirmation has been elusive. To date centrifuge testing on bridge-soil systems has been undertaken at a very small scale, dictated by the limited size of the in-flight shake tables. On the other hand, a large capacity shake table could carry a sufficient depth of soil and be of adequate width to simulate pore pressure and boundary condition effects with improved accuracy. Experimental confirmation of induced forces on buried foundations could have a significant impact on the seismic design and retrofitting of new and existing bridge foundations.

In this experiment, the three tables would be operated as a single table (i.e. with in-phase motion) and will probably be located as close to one another as possible to carry the soil box and the bridge foundations.

**Table Specifications**

The three tables are post-tensioned to the strong floor of the Laboratory and are relocatable within the following constraints:

- maximum spatial separation between tables is approximately 36.5 m (120 ft)
- minimum spatial separation between tables is approximately 6.1 m (20 ft)
- tie-downs are at 600 mm (2ft) centers
- max clearance from table platform to raised hook of overhead crane hook is 9.4 m (31 ft), and
- total lifting capacity of two overhead cranes is $2 \times 222 \text{ kN} = 445 \text{ kN}$ (50 tons)
Key performance parameters for the three tables are summarized below:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of identical biaxial tables</td>
<td>3</td>
</tr>
<tr>
<td>Degrees of freedom each table</td>
<td>2 (x- and y- displacements in horizontal plane)</td>
</tr>
<tr>
<td>Table size</td>
<td>4.25 m square (14 x 14.5 ft)</td>
</tr>
<tr>
<td>Max specimen weight at 1g acceleration</td>
<td>445 kN (100,000 Lb, 50 ton)</td>
</tr>
<tr>
<td>Max specimen weight at 0.5g acceleration</td>
<td>890 kN (200,000 Lb, 100 ton)*</td>
</tr>
<tr>
<td>Max acceleration with 445 kN (50 ton payload)</td>
<td>±1.0 g (both long. and lateral directions)</td>
</tr>
<tr>
<td>Max acceleration with 890 kN (100 ton payload)</td>
<td>±0.5 g (both long. and lateral directions)</td>
</tr>
<tr>
<td>Max velocity during blowdown cycle</td>
<td>1 m/sec (40 in/sec)</td>
</tr>
<tr>
<td>Max velocity after blowdown cycle</td>
<td>750 mm/sec (30 in/sec)</td>
</tr>
<tr>
<td>Max displacement</td>
<td>±300 mm (12 in) (long and lat simultaneously)</td>
</tr>
<tr>
<td>Dynamic vertical load</td>
<td>±135 kN (30,000 Lb)</td>
</tr>
<tr>
<td>Max overturning moment (pitch)</td>
<td>±542.5 kNm (400,000 Lb-ft)</td>
</tr>
<tr>
<td>Max overturning moment (roll)</td>
<td>±542.5 kNm (400,000 Lb-ft)</td>
</tr>
<tr>
<td>Max overturning moment (yaw)</td>
<td>±542.5 kNm (400,000 Lb-ft)</td>
</tr>
<tr>
<td>Dynamic force rating of actuators</td>
<td>667kN (150,000 Lb)</td>
</tr>
</tbody>
</table>

* Assumes payload center of gravity less than 1.83 m (6 ft) directly above center-point of table.

Data Acquisition and Telepresence

The Laboratory has three data acquisition systems with a total, nominal, capacity of 416 channels. Transducers include accelerometers, displacement transducers, and load cells. Strain gages are purchased as required. Data quality assurance protocols meet NEES system-wide standards, and on-line access to local and national data repositories is offered. Telepresence facilities are supported in the Laboratory, enabling both passive and active observation by remote participants. Numerical and video data streaming is available using NEESgrid services, which are based on standard web-based browser technologies. To provide this service, the Laboratory is equipped with a telepresence server (NEES POP), a data storage server with a 1TB disk array, and an SGI Origin 2200 server for large-scale numerical simulation as shown in Figure D.14-2.

Twelve telerobotic cameras and 4 high-resolution cameras are available, with a selection of cameras online 24/7. Video/audio hardware is shown in Figure 3. State-of-the-art video conferencing is also provided to enable seamless telepresence.
Figure D.14-2: Local Area Network for Large-Scale Structures Laboratory

Figure D.14-3: Video/audio hardware in Large-Scale Structures Laboratory (tentative)
The NEES equipment site at the University of Texas at Austin (nees@UTexas) is an equipment site that is aimed at advancing the state-of-the-art in in-situ dynamic material property characterization and field testing of geotechnical deposits and soil-structure systems. The nees@UTexas equipment includes: (1) three mobile shakers that have diverse force and frequency capabilities, (2) a tractor-trailer rig to move the two largest shakers around the United States, (3) an instrumentation van that houses state-of-the-art data acquisition systems and a satellite link-up, and (4) a large collection of field instrumentation that includes wired and wireless sensors that measure vibrational motions and dynamic pore-water pressures. The primary goal of nees@UTexas is to load real geotechnical and structural systems dynamically in their actual settings.

The three mobile shakers are called (top to bottom): (1) T-Rex, (2) Liquidator, and (3) Thumper. T-Rex is capable of generating large dynamic forces in any of three directions (X, Y, or Z directions). The shaking system is placed on an off-road vehicle so that it can be operated in difficult geologic environments. Liquidator is a lower-frequency shaker than T-Rex. It is also carried on an off-road vehicle. The shaking system is shop orientable in either the vertical or horizontal direction. Liquidator’s shaking system is specially designed to give a maximum dynamic output in the low frequency range, defined as 0.5 to 4.0 Hz. Thumper is the smallest shaker which has the lowest output but operates at the highest frequencies. Thumper is well suited for urban usage where larger vibration levels could disturb and/or damage existing structures and infrastructure.

A field instrumentation van houses the control systems and instrumentation for the mobile shaking equipment. The van carries data acquisition systems, waveform processing equipment, computer workstations, sensors, and teleparticipation equipment. There are two state-of-the-art data acquisition systems installed in the instrumentation van. These systems are: (1) a Sercel 408XL System which is capable of collecting up to 2000 channels of data (wired or wireless), and (2) a VXI Technology System which is a 48-channel dynamic signal analyzer. Sensors include 3-D, 1-Hz geophones, additional smaller geophones, accelerometers, and pore-water pressure transducers. The mobile field shakers and instrumentation van are connected to the NEESgrid via a satellite modem. Telepresence allows remote researchers to interact with field personnel and view results from field testing “on the fly”.

Natural geotechnical materials represent the largest fraction of all materials that impact the performance of the built environment during earthquakes. However, these materials are the least investigated, most variable, and least controlled of all materials in the built environment. The field equipment at nees@UTexas will improve our ability to characterize the subsurface more fully and will significantly advance our fundamental understanding of earthquake effects associated with geomaterials.

The project team consists of Kenneth Stokoe II (PI), Ellen M. Rathje (Co-PI), and Clark R. Wilson (Co-PI).

Website: http://www.geo.utexas.edu/nees/
Equipment Site Description

Functional Overview of the Equipment Site

The George E. Brown, Jr. Network for Earthquake Engineering Simulation (NEES) is a collection of next-generation, shared-use experimental sites for earthquake engineering that are geographically-distributed throughout the country, but networked together via the NEESgrid computational infrastructure. The NEESgrid links researchers together via the high-speed internet and provides tools for remote participation, teleobservation, and collaboration.

The NEES equipment site at the University of Texas at Austin (nees@UTexas) is an equipment site that specializes in dynamic field testing using large-scale shakers. The nees@UTexas equipment includes: (1) three mobile shakers that have diverse force and frequency capabilities, (2) a tractor-trailer rig to move the two largest shakers around the United States, (3) an instrumentation van that houses state-of-the-art data acquisition systems and a satellite link-up, and (4) a large collection of field instrumentation that includes wired and wireless sensors that measure vibrational motions. The primary goal of nees@UTexas is to load geotechnical and structural systems dynamically.

The three mobile shakers of nees@UTexas are called: (1) T-Rex, (2) Liquidator, and (3) Thumper. T-Rex was introduced by Industrial Vehicles International, Inc. (IVI) in 1999 and is capable of generating large dynamic forces in any of three directions (X, Y, or Z directions). Figure D.15-1 shows a picture of T-Rex. The shaking system is placed on an off-road vehicle so that it can be operated in difficult geologic environments. Some important specifications of the T-Rex are: buggy-mounted off-road vibrator; total weight of 29,030 kg; length equal to 9.8 m and width equal to 2.4 m; hydraulic drive system (offroad speed <5 m/sec); articulated body; 3 vibration orientations: vertical, horizontal in-line, horizontal cross-line; push-button transformation of shaking orientation; vegetable-based hydraulic oil (Mobil EAL 224H); vibrator pump flow – 756 l/m. These special characteristics make T-Rex an excellent vibrational source for subsurface seismic exploration and earthquake motion simulation. The theoretical performance of T-Rex (the force output of the vibrator is site dependent) in both the vertical and horizontal modes is shown in Figure D.15-2. As shown in the figure, the force output in the vertical mode is about 267 kN and decreases as frequency decreases below 12 Hz. On the other hand, in the horizontal mode, the force output only decreases with decreasing frequency below 5 Hz. The maximum force output in the horizontal mode is about 133 kN, about one-half of the maximum force output in the vertical mode.

Liquidator is designed to be a lower frequency vibrator. A photograph of liquidator during preliminary field trials in July, 2003 is shown in Figure D.15-3. As can be seen in the photograph, Liquidator has a similar overall design as T-Rex, but the shaking system is specially designed to give a higher force output in the low frequency range defined herein as 0.5 to 4.0 Hz. The important characteristics of Liquidator are: buggy-mounted off-road vibrator; total weight of 27,200 kg; length equal to 9.8 m and width equal to 2.4 m; hydraulic drive system (offroad speed <5 m/sec); articulated body; 2 vibration orientations (shop transformable): vertical or horizontal transverse; vegetable-based hydraulic oil (Mobil EAL 224H); vibrator pump flow – 530 l/m.
The comparison of vertical force outputs between T-Rex and Liquidator in the low frequency range are shown in Figure D.15-4. As can be seen in the figure, the force output of the liquidator surpasses that of T-Rex as frequency decreases below 4 Hz. The force output of Liquidator only becomes stroke limited and begins to decrease at frequencies below 1.3 Hz. Liquidator has a force output of about 89 kN at 2 Hz and about 44.5 kN at 1 Hz.
The third mobile shaker is called Thumper. Thumper is the smallest shaker and is placed on a Ford F650 pickup truck. Therefore, thumper can be moved along the highway with its support platform (the Ford F650 truck) which T-Rex and Liquidator need to be moved along the highway with the tractor-trailer rig shown in Figure D.15-5. A photograph of Thumper is shown in Figure D.15-6. Some important characteristics of the Thumper are: built on a Ford F650 Truck; built for use in urban environments; total weight = 5900 kg; 2 vibration orientations (shop transformable); vegetable-based hydraulic oil; vibrator pump flow = 150 l/m. The theoretical force output of
Thumper is shown in Figure D.15-7. As can be seen in the figure, the maximum force output is about 18 kN, which is about an order of magnitude lower than that of T-Rex (267 kN).

There are three state-of-the-art data acquisition systems installed in the instrumentation van. These three systems are: (1) Sercel 408XL System, which is capable of collecting data up to 2000 channels, (2) VXI Technology system which is a 48-channel dynamic signal analyzer system, and (3) Agilent 4-channel Dynamic Signal Analyzer. This equipment is connected to the NEESgrid via a satellite modem. The nees@UTexas field equipment can be used in a variety of applications, including shear wave velocity characterization, liquefaction testing, geophysical testing, and dynamic testing of structures. A photograph of the instrumentation van is shown in Figure D.15-8.
Figure D.15-7: Theoretical Force Output of Thumper

Figure D.15-8: Photograph of the Instrumentation Van during Preliminary Field Trials at J.J. Pickle Research Campus (PRC) of the University of Texas at Austin
Meeting Registration List
<table>
<thead>
<tr>
<th>Name</th>
<th>Name</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abdoun, Tarek</td>
<td>Eng, Jim</td>
<td>Kim, Sangtae</td>
</tr>
<tr>
<td>Anagnos, Thalia</td>
<td>Esteva, Luis</td>
<td>Konopnicki, Thad</td>
</tr>
<tr>
<td>Anderson, Thomas</td>
<td>Fenves, Gregory</td>
<td>Kuchma, Daniel A.</td>
</tr>
<tr>
<td>Asghari, Ali</td>
<td>Finholt, Thomas</td>
<td>Kutter, Bruce</td>
</tr>
<tr>
<td>Ashford, Scott</td>
<td>French, Catherine</td>
<td>Leith, William</td>
</tr>
<tr>
<td>Baker, Polly</td>
<td>Garlock, Maria</td>
<td>Leon, Roberto T.</td>
</tr>
<tr>
<td>Baru, Chaitan</td>
<td>Giraldo, Diego</td>
<td>Liu, Judy</td>
</tr>
<tr>
<td>Beldica, Cristina</td>
<td>Goel, Subhash</td>
<td>Malley, James</td>
</tr>
<tr>
<td>Benthien, Mark</td>
<td>Hajjar, Jerome F.</td>
<td>Mayes, Ronald</td>
</tr>
<tr>
<td>Bielak, Jacobo</td>
<td>Hanley, Jason</td>
<td>McCabe, Steven</td>
</tr>
<tr>
<td>Billington, Sarah L.</td>
<td>Hart, David</td>
<td>McKenna, Frank</td>
</tr>
<tr>
<td>Boulanger, Ross</td>
<td>Haupt, Tomasz</td>
<td>Medina, Ricardo</td>
</tr>
<tr>
<td>Brena, Sergio</td>
<td>Hayama, Toru</td>
<td>Memari, Ali M.</td>
</tr>
<tr>
<td>Bruneau, Michel</td>
<td>Hubbard, Paul</td>
<td>Menq, Farn-Yuh</td>
</tr>
<tr>
<td>Buckle, Ian</td>
<td>Johal, Paul</td>
<td>Mish, Kyran</td>
</tr>
<tr>
<td>Christenson, Richard</td>
<td>Johnson, Erik</td>
<td>Mo, Yi-Lung</td>
</tr>
<tr>
<td>Comartin, Craig</td>
<td>Jordan, Thomas</td>
<td>Moehle, Jack</td>
</tr>
<tr>
<td>Conte, Joel</td>
<td>Kagawa, Takaaki</td>
<td>Mujumdar, Vilas</td>
</tr>
<tr>
<td>DeJong, Jason</td>
<td>Kallivokas, Loukas F.</td>
<td>Nakagawa, Hiroyuki</td>
</tr>
<tr>
<td>Deng, Wei</td>
<td>Kalyanasundaram, Anand</td>
<td>Nastar, Navid</td>
</tr>
<tr>
<td>Dyke, Shirley</td>
<td>Kamrath, Anke</td>
<td>Neitlich, Andrew</td>
</tr>
<tr>
<td>Elnashai, Amr S.</td>
<td>Kasdorf, James</td>
<td>O’Rourke, Thomas D.</td>
</tr>
</tbody>
</table>
Ohtani, Keiichi
Olson, Steve
Pancake, Cherri
Pauschke, Joy M.
Pekcan, Gokhan
Peng, Jun
Phillippi, Don
Pincheira, José
Pitman, Mark
Ramirez, Julio
Ratzesberger, Hank
Reinhorn, Andrei
Reitherman, Robert
Restrepo, José I.
Rix, Glenn
Roblee, Clifford
Roeder, Charles W.
Rojahn, Christopher
Rollins, Kyle
Saiidi, Mehdi Saiid
Sasani, Mehrdad
Schachter, Macarena
Sereci, Angel Mark
Severance, Charles
Sezen, Halil
Shao, Xiaoyun
Shing, P. Benson
Silva, Pedro
Simpson, David
Sitar, Nicholas
Sivaselvan, Mettupalayam
Somerville, Paul G.
Spencer, Billie F.
Stanton, Christopher
Steidl, Jamison
Stepp, J. Carl
Stewart, Jonathan
Stokoe, Kenneth
Sture, Stein
Sydeski, Ray
Symans, Michael D.
Ting, Francis
Tsai, Keh-Chyuan
Van de Lindt, John
Wallace, John
Wehbe, Nadim
Whang, Daniel
Whitmore, Shannon
Wight, James K.
Willam, Kaspar
Wilson, Clark
Wilson, Daniel
Wood, Sharon L.
Wussow, Bill
Yeh, Harry
Yim, Solomon
Youd, T. Leslie
Zerva, Aspasia
Zhang, Jian
Zimmie, Thomas
Meeting Event Location Guide
Meeting Event / Location Guide

Wednesday – May 19, 2004

The Outdoor Evening Reception will be held from 6-8:00 PM on Beach North, behind the hotel, near the bay.

Thursday – May 20, 2004

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting Registration</td>
<td>7:30 AM</td>
<td>2nd Floor</td>
<td>Foyer</td>
</tr>
<tr>
<td>General Session</td>
<td>8:30 AM</td>
<td>2nd Floor</td>
<td>Kon Tiki Ballroom</td>
</tr>
<tr>
<td>Lunch</td>
<td>12:1-30 PM</td>
<td>2nd Floor</td>
<td>Aviary Ballroom</td>
</tr>
<tr>
<td>Site Operations Committee Meeting</td>
<td>3 - 5 PM</td>
<td>1st Floor</td>
<td>Rousseau Center</td>
</tr>
<tr>
<td>Finance Committee Meeting</td>
<td>3 - 5 PM</td>
<td>5 PM Closed Session</td>
<td>Marquesas Suite 308</td>
</tr>
<tr>
<td>Education, Outreach, and Training Committee Meeting</td>
<td>3 - 5 PM</td>
<td>1st Floor</td>
<td>Rousseau East</td>
</tr>
<tr>
<td>IT Committee Meeting</td>
<td>3 - 5 PM</td>
<td>2nd Floor</td>
<td>Cockatoo</td>
</tr>
<tr>
<td>Data Sharing and Archiving Committee Meeting</td>
<td>3 - 5 PM</td>
<td>1st Floor</td>
<td>Rousseau West</td>
</tr>
<tr>
<td>Resource Room / System Integration Demos</td>
<td>8 AM - 5 PM</td>
<td>2nd Floor</td>
<td>Boardroom West</td>
</tr>
<tr>
<td>Dinner Banquet</td>
<td>6 - 7:30 PM</td>
<td>2nd Floor</td>
<td>Aviary Ballroom</td>
</tr>
<tr>
<td>NEES Awardees Meeting</td>
<td>8:30 - 10 PM</td>
<td>2nd Floor</td>
<td>Cockatoo</td>
</tr>
</tbody>
</table>

Reminder: The Annual Group photo will be taken during the first break in the patio area. Remember to wear your NEES shirt.

Friday – May 21, 2004

<table>
<thead>
<tr>
<th>Event</th>
<th>Time</th>
<th>Location</th>
<th>Room</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meeting Registration</td>
<td>7:30 AM</td>
<td>2nd Floor</td>
<td>Foyer</td>
</tr>
<tr>
<td>General Session</td>
<td>8:15 AM</td>
<td>2nd Floor</td>
<td>Kon Tiki Ballroom</td>
</tr>
<tr>
<td>Lunch</td>
<td>11:45 - 1:15 PM</td>
<td>2nd Floor</td>
<td>Multi-Purpose Room</td>
</tr>
<tr>
<td>Resource Room / System Integration Demos</td>
<td>8 AM - 5 PM</td>
<td>2nd Floor</td>
<td>Boardroom West</td>
</tr>
</tbody>
</table>

Saturday – May 22, 2004

Field trip to the UC San Diego Shake Table Equipment Site (located at the UCSD Camp Elliot facility) will depart at 8:00 AM from the front lobby area. The bus will return from the airport to the hotel around noon.
Meeting Polling Results
Data Archiving and Sharing Committee Polling Questions

Which will be the best timing for data release to the public?

1. Immediately as recorded
   - 2%
2. Upon data check and initial processing
   - 14%
3. Upon data evaluation, check, and processing
   - 34%
4. Upon completion of initial research and publication of a report
   - 50%
5. Never
   - 0%
What will be the preferred data repository?

1. Data stored locally as recorded and transferred later to a central repository for archival/release - 54%
2. Data stored in a central repository as recorded and archived in the same location - 18%
3. Data stored and archived in a local repository with central services for access to archives - 28%

What is more important: quality assurance or time to release of data?

1. Thorough data quality evaluation before archiving at expense of longer time to release - 55%
2. Immediate archiving and release followed by a quality evaluation and corrections at later stage at risk of lower data quality/reliability - 9%
3. Immediate brief data evaluation following by archiving and release followed by further data check and release of corrected versions - 36%
How important is having a NEES publication system?

How would you rank order the following three?

Indicate your first choice:

1. Laboratory Report Series curated by NEES Consortium
   -- traditional reports with links to the archived data
   - 36%

2. Automated Laboratory Report series based on Data and Metadata (Data Documentation) from the repository
   -- requires special IT tools
   - 27%

3. Electronic Journal, peer reviewed and curated by NEES Consortium
   - 37%

How important is having a NEES publication system?

Indicate your second choice:

1. Laboratory Report Series curated by NEES Consortium
   -- traditional reports with links to the archived data
   - 42%

2. Automated Laboratory Report series based on Data and Metadata (Data Documentation) from the repository
   -- requires special IT tools
   - 25%

3. Electronic Journal, peer reviewed and curated by NEES Consortium
   - 33%
How important is having a NEES publication system? Indicate your third choice:

1. Laboratory Report Series curated by NEES Consortium -- traditional reports with links to the archived data
   - 22%

2. Automated Laboratory Report series based on Data and Metadata (Data Documentation) from the repository -- requires special IT tools
   - 54%

3. Electronic Journal, peer reviewed and curated by NEES Consortium
   - 24%

IT Committee Polling Questions
Over the next year, how often will you be visiting the nees.org website?

1. More than once a month - 41%
2. Every month or so - 33%
3. A couple of times a year - 12%
4. Only when I get an email giving me a reason to check - 14%
5. Won’t visit the website at all - 0%

Over the next year, what Equipment Site websites will you be visiting?

1. Several or all Equipment Sites - 55%
2. A couple of Equipment Sites - 29%
3. Probably only one Equipment Site - 6%
4. Only if I'm part of a scheduled experiment - 5%
5. Won’t visit their websites at all - 5%
Who should be involved in evaluating the performance of CENTRALIZED IT services?

1. Equipment Site staff 3%
2. Researchers using Equipment Sites 14%
3. All Consortium members 12%
4. 1 and 2 43%
5. All of the above 28%

Who should be involved in evaluating the performance of ON-SITE IT services?

1. Central IT staff 2%
2. Researchers using Equipment Sites 18%
3. All Consortium members 2%
4. 1 and 2 72%
5. All of the above 6%
To establish future IT priorities, who should be surveyed/interviewed?

1. Equipment Site staff
   - 2%
2. Researchers using Equipment Sites
   - 4%
3. All Consortium members
   - 18%
4. 1 and 2
   - 30%
5. All of the above
   - 46%

Site Operations Committee Polling Questions
Intro to Next Question:
The current NEES User Guidelines define a “shared use project” as any project that is sponsored through the NSF NEESR program. In addition, it allows the SOC and NEES Board to grant this status on a case-by-case basis to any project that meets some minimum NEES policies (data sharing and archiving mostly) currently under development.

Given the situation described on the previous slide, I believe that:

1. This is the correct approach as it provides good flexibility. Specific policies can be developed as needed, as the target shared used %’s (50% for most Sites) will need a major ramp up period.

2. The definition of shared use needs to be broadened now to include other projects such that the target %’s of shared use can be achieved immediately.

3. The definition needs to be revamped completely.
Intro to Next Question:
The current NEES User Guidelines propose the very careful planning be done both at the proposal stage and at the early award stage for the experimental portion of a project.

Given the situation described on the previous slide, I believe that:

1. This is over-restrictive and the process needs to be liberalized.
   - 27%

2. This is the correct approach in order to have fair competition and efficient operations.
   - 73%
The current NEES User Guidelines propose a series of conflict resolution procedures to handle disagreements between the sites and PIs. I believe that:

1. These are too elaborate and more power should be delegated to the NEES Executive Director to make final decisions. 9%
2. The approach is correct and should be revisited periodically. 20%
3. The process needs to be revamped completely. 2%
4. I am not familiar enough with this part of the User Guidelines to say for sure. 69%

The level of maintenance and support provided to the sites has raised concerns that this puts the sites at an advantage in competing for other laboratory work (e.g., non-seismic work on bridges). Is this a real concern to you?

1. Yes 32%
2. No 47%
3. Don’t know / Had not thought about it 21%
Day Two Polling Questions

Demographic Questions for Cross-Tab Analysis
Please choose which category describes your age bracket:

1. 35 and under (26%)
2. Over 35 (74%)

Please choose which category describes your sex:

1. Female (17%)
2. Male (83%)
Please choose which category BEST describes your engineering specialty:

1. Structural engineering
   - 71%

2. Geotechnical
   - 18%

3. Geoscience
   - 8%

4. Tsunamis
   - 3%

Please choose which category BEST describes you:

1. Equipment Site
   - 50%

2. Not Affiliated with Equipment Site
   - 50%
Polling Questions

The INITIAL impact of the NEES.org homepage should be:

1. General info on importance of EQ Engineering - 15%
2. Source of EQ Engineering educational materials - 3%
3. Organizational info for Consortium members - 4%
4. Info on NEES and sites for EQ Engineering researchers - 61%
5. Info on NEES and sites for non-researchers - 17%
Where would you like next year's meeting to be held?

1. Coastal California (e.g., like this year, San Diego) 27%
2. Rocky Mountains (e.g., like last year, Park City) 9%
3. Midwest (e.g., Chicago) 10%
4. East Coast (e.g., New York) 11%
5. Hawaii 43%

How long would you like next year's Annual Meeting to be?

1. Two days (like this year's) 59%
2. One day 18%
3. Three days 23%
When would you like the Annual Meeting to be held?

1. Mid-May: 47%
2. Early June: 23%
3. Late June: 27%
4. July: 3%

Do you feel you have ample opportunity to stay abreast of Committee activities?

1. Yes: 33%
2. Somewhat: 50%
3. No: 17%
Do you feel you have ample opportunity to stay abreast of Board activities?

1. Yes
   - 13%
2. Somewhat
   - 31%
3. No
   - 56%

What NEES Consortium service do you value most?

1. Access to Equipment Site information for proposal preparation
   - 43%
2. Input on Consortium Committee and Board policies
   - 10%
3. Annual Meeting
   - 15%
4. IT services provided remotely via website or email
   - 29%
5. Other
   - 3%
For next year's Annual Meeting (or a web forum), name your highest priority:

1. Profiles of funded NEES research projects 44%
2. Bulletin board/other interactive workspace for matchmaking among proposers 14%
3. Details on equipment site capabilities 3%
4. Strategic plans on obtaining NEES research funds beyond NSF 39%

What's your overall rating of this year's Annual Meeting?

1. Excellent 33%
2. Okay 65%
3. Poor 2%
What was your favorite part of the Annual Meeting Program?

1. Equipment Site presentations 12%
2. Committee presentations and meetings 7%
3. Early research project presentations 30%
4. Demonstration of new IT capabilities 24%
5. Automated Polling 27%

Were you part of a NEESR proposal submitted this year?

1. Yes 49%
2. No 51%
If so, how did you find the experience?

1. More challenging than a typical NSF proposal, but worthwhile - 41%
2. About the same as a typical NSF proposal - 37%
3. Frustrating, much more difficult than a typical NSF proposal - 22%

Which one of the following would most improve the NEESR process?

1. More online info about Equip. Site capabilities - 11%
2. More online info about Equip. Site costs - 20%
3. Bulletin Board postings of NEES member research interests - 9%
4. All three of the above - 33%
5. Nothing in particular to suggest - 27%
What is the single most important priority for the NEES Consortium?

1. Administration of the Equipment Site operating budgets 19%
2. Developing new sources of research funding 42%
3. Administration of the IT services 21%
4. Facilitating educational use of NEES research 8%
5. Providing a central spokesperson/PR person for NEES 10%

How satisfied are you with the progress the NEES Consortium is making in achieving its mission?

1. Very or somewhat dissatisfied 16%
2. Neutral 46%
3. Satisfied or very satisfied 38%
How satisfied are you with the efforts of the NEES Consortium to reach out to more junior researchers?

1. Very or somewhat dissatisfied: 38%
2. Neutral: 52%
3. Satisfied or very satisfied: 10%

How satisfied are you with the efforts of the NEES Consortium to reach out to women and ethnic minorities in the engineering community?

1. Very or somewhat dissatisfied: 33%
2. Neutral: 48%
3. Satisfied or very satisfied: 19%
What's your overall rating of this year's Annual Meeting?

- **Excellent**: 35% (Equipment Site), 33% (Not Affiliated with Equipment Site)
- **Okay**: 62% (Equipment Site), 64% (Not Affiliated with Equipment Site)
- **Poor**: 3% (Equipment Site), 3% (Not Affiliated with Equipment Site)
What's your overall rating of this year's Annual Meeting?

1. Excellent
   - Structural engineering: 30%
   - Geotechnical: 40%
   - Geoscience: 20%
   - Tsunamis: 10%

2. Okay
   - Structural engineering: 65%
   - Geotechnical: 50%
   - Geoscience: 60%
   - Tsunamis: 80%

3. Poor
   - Structural engineering: 0%
   - Geotechnical: 0%
   - Geoscience: 0%
   - Tsunamis: 0%

---

What's your overall rating of this year's Annual Meeting?

1. Excellent
   - Female: 33%
   - Male: 50%

2. Okay
   - Female: 42%
   - Male: 65%

3. Poor
   - Female: 8%
   - Male: 2%
What's your overall rating of this year's Annual Meeting?

1. Excellent
   - 25% (35 and under)
   - 42% (Over 35)

2. Okay
   - 75% (35 and under)
   - 54% (Over 35)

3. Poor
   - 0% (35 and under)
   - 4% (Over 35)

How satisfied are you with the progress the NEES Consortium is making in achieving its mission?

1. Very or somewhat dissatisfied
   - 11% (Equipment Site)
   - 19% (Not Affiliated with Equipment Site)

2. Neutral
   - 37% (Equipment Site)
   - 55% (Not Affiliated with Equipment Site)

3. Satisfied or very satisfied
   - 52% (Equipment Site)
   - 26% (Not Affiliated with Equipment Site)
How satisfied are you with the progress the NEES Consortium is making in achieving its mission?

1. Very or somewhat dissatisfied
   - Female: 14%
   - Male: 10%

2. Neutral
   - Female: 47%
   - Male: 40%

3. Satisfied or very satisfied
   - Female: 39%
   - Male: 40%

Consortium is making in achieving its mission?

How satisfied are you with the progress the NEES Consortium is making in achieving its mission?

1. Very or somewhat dissatisfied
   - Female: 9%
   - Male: 17%

2. Neutral
   - Female: 36%
   - Male: 46%

3. Satisfied or very satisfied
   - Female: 37%
   - Male: 55%
How satisfied are you with the progress the NEES Consortium is making in achieving its mission?

1. Very or somewhat dissatisfied
   - 0% (35 and under)
   - 20% (Over 35)

2. Neutral
   - 38% (35 and under)
   - 60% (Over 35)

3. Satisfied or very satisfied
   - 42% (35 and under)
   - 40% (Over 35)

How satisfied are you with the efforts of the NEES Consortium to reach out to more junior researchers?

1. Very or somewhat dissatisfied
   - 33% (35 and under)
   - 44% (Over 35)

2. Neutral
   - 50% (35 and under)
   - 58% (Over 35)

3. Satisfied or very satisfied
   - 6% (35 and under)
   - 9% (Over 35)
How satisfied are you with the efforts of the NEES Consortium to reach out to women and ethnic minorities in the engineering community?

1. Very or somewhat dissatisfied
- Female: 31%
- Male: 59%

2. Neutral
- Female: 33%
- Male: 46%

3. Satisfied or very satisfied
- Female: 8%
- Male: 23%

How useful have you found instant polling?

1. Very useful (use it at next year’s Annual Meeting)
- Female: 61%

2. Somewhat useful (could dispense with it)
- Female: 33%

3. Not useful at all (don’t use it at next year’s Annual Meeting)
- Female: 6%