ISSUES AND RESEARCH NEEDS
IN
SIMULATION DEVELOPMENT

A report of a Workshop held September 13, 2007
at the Chicago Hilton Hotel, O'Hare Airport.

INTRODUCTION

Purpose

This report summarizes the results of a one-day workshop held on September 13, 2007 in Chicago. The purpose of this meeting was to identify critical research and development needs that must be addressed to advance the experimental simulation capabilities of the 15 NEES Equipment Sites.

This report is intended to guide interested researchers in the kinds of research that the earthquake engineering research community needs, in order to ensure that the NEES Equipment Sites remain at the cutting edge of experimentation and simulation. A call for proposals to undertake such research is expected to be made in the forthcoming NSF Solicitation for NEES Research (NEESR), under the category of Simulation Development (NEESR SD). Such proposals may be submitted by researchers from both NEES and non-NEES sites and institutions.

NEESR-SD projects are intended to provide a mechanism for the development of tools to improve experimental and numerical simulation in the earthquake engineering community. These tools may have quite general applicability. It is anticipated that NEESR-SD projects will also

- enhance the efficiency, usability and performance of NEES equipment sites,
- improve the use, archiving and sharing of NEES data, and/or
- enable NEES sites to generate experimental data that can be more rigorously and effectively used to test and develop numerical simulation procedures.

Within the Operations and Maintenance budget for NEESinc, NEESit and the fifteen Equipment Sites, there are limited funds available for increasing capacity and enhancing existing NEES infrastructure. It is anticipated that NEESR-SD projects will support developments that are either too large to be supported within the O&M budgets, or involve projects that may be outside the expertise of personnel available at NEES sites

Background

The NEES Equipment Sites are state-of-the-art experimental facilities for conducting cutting-edge research in earthquake engineering. Supported by cyber-infrastructure tools, each equipment site provides unique opportunities to develop advanced experimental simulation techniques and instrumentation not previously possible. These techniques may require, for example, the development of advanced sensors, measurement devices, control algorithms, or robotic tools. Hybrid testing techniques in particular, are expected to progress well beyond their current limitations leading to new applications that are not currently feasible. Identification of these techniques and the steps to be taken to make them a reality, was the intent of this workshop. The meeting was sponsored by the National Science Foundation (NSF) and organized by the NEES Consortium, Inc. (NEESinc**).** About 28 researchers participated in this one-day meeting representing 21 universities and research organizations (Appendices B and C).

Focus Areas

The workshop focused on three critical areas for which research is needed to advance simulation development. These areas were identified by the Steering Committee after reviewing topics proposed by potential attendees when pre-registering for the meeting. The three areas were:

- Challenges in Hybrid Simulation
- Challenges in Data Measurement, Modeling, Visualization and Knowledge Generation
- Challenges in Integrated Computational and Physical Simulation

Format

Twenty-four short presentations were made in three plenary sessions, one for each of the above challenge areas. See Agenda in Appendix A. These plenaries were followed by three breakout groups, one for each area, during which time research needs were identified and reported back to the full meeting in a closing session at the end of the meeting. Written summaries of the group findings are given in the next section. Each summary was prepared by the Breakout Chair and circulated to members in that group for comment post-workshop.

Reports of Breakout Sessions

As noted above, three breakout sessions were held to identify issues, develop research needs and assign priorities to each need. These are summarized in the following section. The membership of each group was as follows:

1. **Challenges in hybrid simulation (Chair: Andrei M. Reinhorn)**
   *Participants***:** Cheng Chen (Lehigh U.), Richard Christenson (U. Connecticut), Shirley Dyke (Washington U.), Oh-Sung Kwon (U. Illinois Urbana-Champaign), Chris Pantelides (U. Utah), Gokhan Pekcan (U. Nevada Reno), Andrei Reinhorn (U. Buffalo), Jim Ricles (Lehigh U.), Victor Saouma (U. Colorado Boulder), Boza Stojadinovic (U. California Berkeley), Tony Yang (U. California Berkeley)

2. **Challenges in data measurement, modeling, visualization, and knowledge generation (Chair: Bruce Kutter)**
   Participants: Rigoberto Burgueno (Michigan State U.), Youseff Hashhash (U. Illinois Urbana-Champaign), Bruce Kutter (U. California Davis), Sri Sritharan (Iowa State U.)

3. **Challenges in integrated computational and physical simulation (Chair: Greg Deierlein)**
   Participants: Greg Deierlein (Stanford U.), Robert Fleischman (U. Arizona), Larry Fahnestock (U. Illinois Urbana-Champaign), Tasnim Hassan (North Carolina State U.), Scott Olson (U. Illinois Urbana-Champaign), Ganesh Thiagarajan (U. Missouri, Kansas City), Tony Yang (U. California Berkeley), Solomon Yim (Oregon State U.), Julie Young (Princeton U.), Qiuhong Zhao(U. Tennessee Knoxville)

CHALLENGES AND RESEARCH NEEDS IN SIMULATION DEVELOPMENT

1. HYBRID SIMULATION

A group consensus was reached in respect to future development needs at Equipment Sites: ***Real-time hybrid simulation*** is the most advanced solution to address the *rate effects* in large-structures in our limited size laboratories. Real-time simulation is sufficiently complex and can address the simpler issues that we have with the current techniques (static, pseudo-dynamic) and current numerical simulations. Real-time hybrid simulation developments within NEES will have an impact in other fields of engineering. It is noted that basic challenges were addressed by the NEES Workshop on Hybrid Simulation, Chicago, May 11, 2007.

The following subjects are to be addressed by the Equipment Sites (ES) to allow for wider use of Hybrid Simulation (HS) systems at ES.

Challenges and Needs:

1.1 **Introduce and include real time** *at the rate of the earthquake in the hybrid simulation* (currently static or quasi-static, with minor exceptions). **(Priority: High)**
- Develop simulation tools for large linear and nonlinear models using distributed computing in real time at the rate-of-earthquake or other fast excitations (at excitation, network, or other rates)
- Develop numerical procedures to solve computing-structures-actuation interactions (error tracking and compensation procedures – see below)
- Develop platform for integrated computing and control using synchronous – asynchronous operations
- Include off-the-shelf (OTS) FEM and Inelastic Analysis Procedures
- Validate simulation procedures through benchmark studies (see below)

1.2 **Develop numerical tools**, validated experimentally, that can lead to full numerical simulation of systems. **(Priority: Medium-High)**
- Develop simulation tools for large models (in- and out-of-real-time) for fast excitations
- Include off-the-shelf (OTS) FEM and Inelastic Analysis Procedures
- Expand capabilities of SIMCOR and Open-FRESCO
- Validate simulation procedures through benchmark studies (see below)

1.3 **Develop benchmark studies**: Determine usability and demonstrate capabilities of hybrid simulations **(Priority: High)**
- Design and develop benchmark physical models and set-ups at different scales suitable for multiple installations
- Develop set-ups suitable to all current testing techniques (dynamic, pseudo-dynamic, quasi-static, static)
- Characterize current equipment performance including two or more of the following: actuating systems, shake tables, computational platforms and computational networks)
- Determine scalability of hybrid simulation (testing-computing) procedures
- Develop series of tests to be run for validation of old systems when new developments are made

1.4 **Identify current limitations** of hybrid testing equipment and procedures, and **expand boundaries (Priority: Medium-High**)
- Develop numerical models of local equipment – including computational simulators
- Identify errors and establish a reliable error tracking system with feedback to the simulation procedure – for qualification and control
- Develop compensation procedures based on error tracking and optimization techniques

1.5 **Develop more advanced testing control** techniques needed for hybrid simulation either in-real-time or off-real-time (**Priority: Medium-High**)
- Integrate force control in hybrid simulations
- Develop multi-state controllers (displacement, acceleration, force, etc.)
- Develop nonlinear adaptive procedures for current hardware-inelastic models interactions
- Develop control compensation procedures for hardware-models-computer interactions

1.6 **Develop visualization** platform for hybrid simulation needed to provide the insight in the simulations and guidelines of use of the hybrid simulation procedures (**Priority: Medium**)
- Develop visual interfaces for modeling and evaluation
- Develop real time tracking of simulations (both computational and physical)
- Develop global picture tracking of combined computational and physical simulations (the big picture)
- Develop NEES guidelines for use of real-time hybrid simulation

- Address current state of knowledge to characterize available technologies, accuracies and usability.

1.7 **Develop and package "canned systems"** of hardware and software for hybrid simulations, which can be used at existing and new equipment sites. This task requires cooperation and involvement of hardware-software manufacturers. The task will not deal with commercialization, but only with technical developmental issues. This task may provide the edge of US developments in international markets (**Priority: Medium**)

- Develop versatile, scalable and expandable architecture of hybrid simulation systems
- Integrate commercial controllers in hybrid simulations
- Integrate test control with distributed computing and experimentation

1.8 **Education**: Educate the community on the capabilities and challenges of hybrid simulation, in particular real-time, through webinars, demonstration projects and associated documentation. Update continuously the community through Users Groups. (**Priority: Medium-High, must follow some of previous issues**)

- Develop documentation for hybrid simulation, to be placed in the repositories for self instruction and development seminars.
- Develop demonstration projects using the benchmark testing capabilities (see above). Benchmark studies used for calibrations may be prepared for remote demonstration and self instruction
- Develop seminars and webinars for promotion of the new simulation techniques. Benchmark studies may serve the base for such instructions and dissemination of capability and usability of ES.
- Develop technical workgroups (of ES and Users) to meet periodically to identify practical problems, payload possibilities, exchange open information on latest developments – membership voluntary with support from NEES

Many similar topics were also discussed in the NEES Workshop on Hybrid Simulation (HS) on May 11, 2007 in Chicago, but the specific topics indicated above seemed to be of greater interest to the participating Equipment Sites (ES) representatives and users, and are intended to bring the ES to a higher level, never achieved by the profession in any comparable field of engineering.

2. DATA MEASUREMENT, MODELING, VISUALIZATION AND KNOWLEDGE GENERATION

This group proceeded on the basis of the assumption that "data" is of paramount importance to NEES. Data generated by experiments must be archived, interpreted, shared, visualized and used for validation of numerical simulations. The quality and limitations of NEES experimental data should be assessed, understood and continuously enhanced. Improved visualization of data to aid in its interpretation is fundamental of the research goal of developing further understanding of earthquake behavior and the development of improved design criteria. Furthermore, validated and shared numerical simulation software is evidence of knowledge that is generated through NEES research and evidence of the impact or potential of NEES on the profession. Thus the use of NEES data for development and testing of numerical simulations should be made more efficient.

Challenges and Needs:

2.1 **Data archiving**

Archiving and sharing experimental data is one of the core goals of the NEES consortium. NEESit has established the NEESCentral repository as the central location, where the data must be archived with appropriate metadata such that published data can be accessed easily and efficiently by the community. NEESR-SD projects that are related to data archiving and retrieval must use NEES data repository as the basis, but may extend the existing capabilities. NEESR-SD projects that speed the process of archiving and sharing of data as well as those improve the accessibility of information in the repository are encouraged. NEESR-SD projects could also be directed toward development of protocols for assimilation of relevant data from NEESR and non-NEESR research into the repository.

Development of new techniques and acquisition of tools for automated ingestion of experimental metadata would enable efficient and rapid documentation of NEES data. Smart sensors and data acquisition systems that automatically generate metadata such as serial number, calibration data, and other specifications are just one potential example. Tools that allow researchers to generate and render metadata describing the geometry of an experiment are also needed, for example, 3-D scanners that output data that may be rendered in CAD and solid models. User friendly tools and procedures to automatically generate numerical models of NEES experiments directly from the central repository would enable more rapid integration of experiment and numerical simulation.

2.2 Learning from data and knowledge generation.

Tools that enable more rapid comprehension of complex data sets produced by major NEES experiment and numerical simulations will facilitate sharing of and learning from NEES data. Comprehension is difficult due to the wide variety of sensor types, specifications, and trial and error adoption of new data intensive technologies. High speed video, close range photogrammetry, 3-D scanners, and proprietary technologies to measure displacements at multiple locations promise to enable greatly enhanced resolution, but require efficient schemes for synchronizing, storing and processing large quantities of data. Software to process large quantities of raw data to produce more meaningful information (e.g., converting arrays of displacement measurements to strain fields) and enabling this information to be compared with data from numerical simulations is needed. The tools and capabilities that will improve interpretation and comparison of data in real-time are encouraged.

The NEES data repository and data model now enable data in NEEScentral to be browsed with useful data viewers. RDV (Real Time Data Viewer) allows users to simultaneously view synchronized video and sensor data (-not yet available) either as it is gathered or in a playback mode from the NEEScentral repository. Open source data viewers such as N3DV (NEES 3D Data Viewer), integrated with NEES central, and available at NEESforge, can be used to animate sensor data superimposed on 3-D geometry of an experiment. These tools demonstrate a benefit of archiving structured data in the NEES data repository; the open source data viewers invite community enhancement or may inspire development of the next generation of visualization tools, possibly supported in versatile open source NEES visualization framework.

2.3 Quality and Information Content of NEES Data

The quality of NEES data should be quantified and understood. Numerical studies should quantify the importance of the interaction between the test specimen and test apparatus (e.g., actuators, servo-valves, and control systems) on the quality of a comparison between numerical and experimental simulation. Nonlinear models of the actuators, servo-valves, and control systems implemented in OpenSees and other analysis packages are needed to evaluate this interaction.

Inverse analysis procedures that enable generation of fundamental information about material properties and behavior based on measurements of experiments offer potential for extracting new and more fundamental kinds of information from experimental data. This information or knowledge can be used to develop enhanced numerical simulation codes. Development of off-line and on-line inverse analysis platforms is desirable. Off-line algorithms are useful for learning after the experiment is conducted. On-line algorithms can be used to continuously update information while an experiment is underway. This requires major development of fast, near real time simulation capabilities.

An assumption of the hybrid modeling technique is that the majority of the hybrid test article has properties that can be accurately modeled numerically. A single or small number of components with uncertain properties are tested in a physical experiment that is coupled with the numerical model of the rest of the hybrid test article. This assumption is questionable when the test article contains many unknown nonlinear components such as a building with multiple yielding columns which are kept with the original assumed properties in the numerical model and not updated based on the new information gained from the physical experiment(s). Hybrid simulation promises potential for producing experimental data on large scale systems that do not fit or may be too expensive to test using NEES equipment. However, the errors associated with this technique should be tested to document the quality of data generated by this technique. The ability to verify and improve the analytical model of seismic systems during hybrid testing is encouraged.

2.4 New Sensor and Data Acquisition Technology

Data from NEES experiments could be greatly enhanced by taking advantage of emerging sensor and data acquisition technologies and by developing specific sensors needed by the community. Specific sensor development projects funded through NEESR-SD should be coordinated with multiple NEES equipment sites to produce outcomes that have general utility by a large number of researchers. Examples of emerging sensor technologies include but are not limited to:

- Non-contact sensors that generate arrays of displacement data
- Wireless sensors, sensor networks, and wireless data acquisition systems
- Wireless transmission of data from the subsurface would be valuable, but may require advanced energy harvesting technology
- Methods for quantifying subsurface displacements, strains and stresses
- Fiberoptic strain sensors
- Rapidly deployable arrays of inexpensive sensors
- Sensors targeted to multiphase fluid, soil, structure problems such as hydrodynamic loading and scour are needed
- Methods to monitor the evolution of material properties (e.g., shear wave velocity) during an experiment.

3. INTEGRATED COMPUTATIONAL AND PHYSICAL SIMULATION

Physical simulation (i.e., physical testing) plays an important role in earthquake engineering to improve understanding the behavior of structural/geotechnical systems and to provide data for developing, calibrating and validating computational models that are essential to modern engineering research and practice. By permitting more realistic testing and extensive measurements and data archiving, the NEES lab facilities and cyber-infrastructure offer tremendous capabilities to develop and validate computational models. While the connection between physical and computational simulation is obvious, research is needed to realize the full benefits that physical testing offers to computational simulation methods. Thus, the focus of this breakout group is to examine issues and needs for advancing the development of computational methods by greater integration with physical simulation (testing). Summarized below are the issues and needs which were identified and prioritized by the breakout group.

Challenges and Needs:

3.1 Tools to facilitate accurate numerical simulations of experiments (Priority: High). Databases, guidelines (best practice documents), and other modular (object-oriented) tools are needed that will facilitate collection and manipulation of data from tests to improve computational models. The specific needs include the following:

- High fidelity characterization of constitutive material models, including inelastic cyclic response, high strain rates, and temperature effects. Incentives should be provided to encourage researchers to mine information from existing test data as well as new tests.
- High fidelity characterization of fatigue and damage models for materials and components.
- Methods and tools to facilitate the solving of inverse problems, whereby computational model parameters can be determined from test data.
- Guidelines to identify and illustrate appropriate techniques for validating computational models.

3.2 Realistic representation of boundary conditions in physical experiments (Priority: High). Equipment and techniques are needed to enable more realistic physical simulation of boundary conditions in lab tests. For example, in structural component tests it is often difficult to represent constraint associated with floor diaphragms, bridge abutments, etc. For geotechnical tests, and to a lesser extent structural tests, methods are needed to capture environmental factors such as temperature, which may have a significant effect on behavior. Finally, in tsunami tests further work is needed to improve equipment, control algorithms and techniques for multi-scale wave generation, fluid/beach interaction, and fluid/structure interaction.

3.3 Development of computational and physical simulation models and techniques for varying length scales (Priority: High). One of the important frontiers in both computational and physical simulation relates to accurate and convenient representation of length scales that can vary by many orders of magnitude in a given problem. For example, tsunami phenomena involve length scales that range from deep ocean phenomena measured in length scales of 10^{+6} meters down to fluid/solid interaction at scales of 10^{-6} meters. In structural and geotechnical systems and materials, length scales may range from simulating overall systems that are measured in 10^{+2} meters down to characteristic lengths for material damage on the order of 10^{-6} meters. In reduced scale physical testing, challenges arise from differences in similitude laws for different materials, e.g., such as arises in beach studies of tsunamis. Improved methods are needed for multi-scale characterization and spatial variability of material properties, loads, and boundary conditions. On the computational side are needs for multi-scale modeling techniques and software.

3. 4 Quantification and assessment of uncertainty (Priority: High). Due to the relatively high cost of physical testing (particularly at large scales), there are few testing programs that have evaluated nominally identical specimens to quantify uncertainties in the behavior of components and systems. Characterization of the inherent uncertainties in physical tests is particularly important for calibration and validation studies, so as to distinguish between modeling uncertainties (differences between the physical tests and mathematical models) and the inherent uncertainties in the physical tests. Therefore, it is recommended that replicate testing be given a priority when deemed appropriate. A related research need is to establish good practices for ensuring statistical rigor and making effective use of pre-test parameter sensitivity analyses when evaluating modeling uncertainties.

3.5 Quantification/representation of damping (structural/material, hydrodynamic) (Priority: High). With the increased use of inelastic time history analyses in research and practice, there is a need for improved understanding of damping and appropriate ways to model it. Damping presents unique challenges in several respects. First and foremost is the fact that the characterization and quantification of damping depends to a large extent on how one chooses to model damping, i.e., whereas the decay of a measured dynamic motion is unique, the representation of the decay in computational models is not unique (viscous versus hysteretic damping with multiple ways to represent each as either linear or nonlinear functions). Second, damping is amplitude and velocity dependent, which presents additional challenges in measurement and characterization. In addition to basic research on characterizing damping and its effects on structures, there is a need to devise physical tests that will improve our understanding of damping and ways to measure and model it.

3.6 Improved Sensors (Priority: High). As computational models become more refined, there is a need for improved sensors to make measurements that are high in spatial and signal resolution and are less intrusive. Specific desirable attributes are (a) non-contact sensors, (b) sensors that can be embedded in structural and geotechnical materials, (c) sensors to model fluid velocity while in flight in a geotechnical centrifuge, (d) small non-intrusive and multifunction sensors (e.g., for centrifuge application), and (e) sensors for modeling pressures and displacements in soils and soil-fluid composites.

3.7 Technical transfer of simulation technology to practice (Priority: Medium). More emphasis should be placed on finding effective ways to expedite the transfer of advanced computational simulation technology to the broad engineering research and practicing communities. One method to engage interest and participation in validation of computational methods is through blind prediction contests and studies in which the broad community is invited to participate in making pre-test predictions of response. Effective engagement of the community in integrating physical and computational simulation also depends strongly on making NEES data readily accessible to earthquake engineering community.

3.8 Documenting fabrication and initial conditions of test specimen and sensors (Priority: Medium). Increased emphasis should be placed on documenting in the NEES repository the test specimen construction and characterization of uncertainties that arise in specimen construction as related to future model validation studies. For example, careful documentation of how soil is placed in tsunami beach/run-up specimens or centrifuge specimens can help explain variations in response that are detected later. Another example is that of fracture critical welds, where the welding sequence and resulting residual stresses may have a significant effect on response.

3.9 Multiphase simulation (Priority: Medium). For situations where the behavior is significantly influenced by interaction between multiple phases of material (e.g. soil and fluid in ground liquefaction), there is a need for improved computational simulation models that can capture the multi-phase behavior.

3.10 More realistic construction of centrifuge test specimens (Priority: Medium). Improved robot devices are needed to permit more realistic experimental simulation of in-situ conditions that result from construction operations in centrifuge specimens that should ideally be conducted in-flight centrifuge specimens (e.g., driving of piles in pre-consolidated soils).

3.11 Multi-scale hybrid simulation (Priority: Low). Most applications of hybrid testing have been conducted within or between like type of facilities, i.e., between two large-scale structural testing labs. Opportunities should be explored to investigate hybrid tests between tsunami, centrifuge, and/or structural test facilities.

3.12 Simulation of full testing rigs (virtual test) (Priority: Low). Where boundary conditions between a physical test specimen and test rig are not well defined, or where there is nonlinear interaction between the test rig and the specimen, it is useful to consider modeling the entire specimen and test rig within the computational simulation. Research in this area could undertake a trial study of a test where the loading apparatus is integral with the specimen including comparative interpretation through computational analyses with idealized boundary/loading conditions on the specimen versus simulation of the entire test specimen and loading rig.

Other discussion points included:

A **Technical education/training on advanced experimental and computer simulation.** The breakout group also discussed the need for continuing education and training on advanced experimental and computer simulation for researchers (graduate students and faculty) and practicing engineers. Some NEES-sponsored workshops already exist, such as the annual OpenSees users/developers workshop, run by UC Berkeley and NEESit. Other types of opportunities should be encouraged, such as student/faculty internships to participate in active projects to learn about specific experimental NEES facilities and/or computational facilities. NEES sites and NEESit should continue to emphasize activities and the development/dissemination of written guidelines and user/developer guides on advanced simulation capabilities.

B **State of computational simulation tools.** To a large extent, future advancements in computational simulation will depend on continued advancements in simulation software, including a mix of proprietary and open-source platforms. Particularly since earthquake engineering occupies a small niche in a much larger realm of computational analysis/mechanics, it is essential for the earthquake engineering research community to maintain research-oriented software frameworks that can serve as a testbed for new approaches and ideas. While there are many research software codes developed and maintained by small user groups, there is a need to support research software codes that have large developer/user bases. There was a strong endorsement from the breakout group to continue NEESit support for OpenSees (Open System for Earthquake Engineering Simulation, http://opensees.berkeley.edu/) which has versatile capabilities for both structural and geotechnical simulations and is widely used. Other research-oriented software mentioned by working group participants were: Tsunamos (for tsunami modeling) http://ceprofs.tamu.edu/plynett/TSUNAMOS/index.html and OpenFOAM (for computational fluids and solids modeling) http://www.opencfd.co.uk/openfoam/. Commercial codes identified as the breakout group to be used in earthquake engineering research and practice include: ABAQUS, LS_DYNA, ANSYS, FLAC, Plaxis, SAP/ETABS, PERFORM, FLUENT (fluids), MSC-NASTRAN, DYTRAN.

ACKNOWLEDGMENTS

Grateful acknowledgement is made of the encouragement and financial support provided by Joy Pauschke, Program Director, Division of Civil, Mechanical and Manufacturing Innovation, National Science Foundation, and Cliff Roblee, Executive Director, NEESinc, Davis, CA.

The members of the Workshop Steering Committee were:

- Ian Buckle, University of Nevada Reno, igbuckle@unr.edu, (Chair)
- Greg Deierlein, Stanford University ggd@stanford.edu
- Bruce Kutter, University of California Davis, blkutter@ucdavis.edu
- Andrei Reinhorn, University at Buffalo, reinhorn@buffalo.edu

The logistical support provided by Sara Moody, Executive Assistant, NEESinc, is also gratefully acknowledged.

APPENDIX A

PROGRAM

WORKSHOP ON SIMULATION DEVELOPMENT

September 13, 2007
Chicago Hilton Hotel O'Hare Airport
(773) 686-8000
8:00 am - 4:30 pm

Sponsored by the National Science Foundation through NEES Consortium, Inc.

8:00 Welcome and Opening Remarks (Chair: Ian Buckle)
Joy Pauschke, National Science Foundation
Cliff Roblee, NEES Consortium
Bruce Kutter, UC Davis

8:15 Plenary Session 1: Challenges in hybrid simulation (Chair: Andrei Reinhorn)
All presentations are 10 minutes duration.

Presenter	Title
Chen, Cheng	Hybrid testing algorithm
Christenson, Richard	Real-time hybrid testing
Dyke, Shirley	Hybrid testing visualization needs
Kwon, Oh-Sung	Hybrid simulation with UI-SimCor
Pantelides, Chris	Research needs: field testing hybrid capability
Pekcan, Gokhan	Potential research areas in hybrid testing/simulation
Reinhorn, Andrei	Hybrid simulation
Ricles, Jim	Hybrid real-time testing: stability under actuator delay and delay compensation; actuator tracking error
Stojadinovic, Boza	Hybrid simulation development needs: nees@berkeley view

9:55 Break (15 mins)

10:10 Plenary Session 2: Challenges in data measurement, modeling, visualization, and knowledge generation (Chair: Bruce Kutter)
All presentations are 10 minutes except those indicated by * which are 5 minutes duration.

Presenter	Title
Burgueno, Rigoberto	Non-contact instrumentation
Burgueno, Rigoberto*	Data processing and visualization*
Hashash, Youssef	Inverse analysis and learning from instruments
Ricles, Jim*	Data modeling*
Stojadinovic, Boza*	Quality of simulation measures*

10:55 Plenary Session 3: Challenges in integrated computational and physical simulation (Chair: Greg Deierlein)

All presentations are 10 minutes duration.

Presenter	Title
Fleischman, Robert	Testing considerations for system-level evaluations for structural components
Hassan, Tasnim	Research needs in understanding seismic damage of welded steel structures
Olson, Scott	Geotechnical earthquake engineering needs for transportation structures/bridges
Sri Sritharan	Capabilities needed to study seasonal temperature effects on SFSI and seismic response of structures
Thiagarajan, Ganesh	Numerical simulation of test structures subjected to seismic loading
Yang, Tony	Using nonlinear control algorithm to improve response of shaking tables
Yim, Solomon	Computational model calibration and validation
Young, Julie	Physical and numerical modeling of tsunami erosion and deposition
Zhao, Qiuhong	Simulation of connections in steel shear wall structures

12:25 Lunch (50 mins)

1:15 Breakout Sessions:

A. Hybrid Simulation (Leader: Andrei Reinhorn)
B. Data et. al. (Leader: Bruce Kutter)
C. Computational and Physical Modeling (Leader: Greg Deierlein)

3:15 Break (10 mins)

3:25 Plenary Session 4 (Chair: Ian Buckle)

Reports from breakout sessions.
Development of report outline, findings and conclusions.

4:25 Closing Remarks

Joy Pauschke, NSF
Cliff Roblee, NEESinc

4:30 Workshop Ends

APPENDIX B

LIST OF WORKSHOP ATTENDEES

Name	Title	Affiliation	Email address
Buckle, Ian	Professor	University of Nevada Reno	igbuckle@unr.edu
Burgueno, Rigoberto	Assoc. Professor	Michigan State University	burgueno@msu.edu
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Zhao, Qiuhong	Assist. Professor	University of Tennessee, Knoxville	qzhao@utk.edu

APPENDIX C

PARTICIPANT PRESENTATIONS.

OPENING SESSION

SESSION 1. CHALLENGES IN HYBRID SIMULATION

SESSION 2. CHALLENGES IN DATA MEASUREMENT, MODELING, VISUALIZATION, AND KNOWLEDGE GENERATION

SESSION 3. CHALLENGES IN INTEGRATED COMPUTATIONAL AND PHYSICAL SIMULATION

Pages 15 – 80 of Appendix C

have been intentionally omitted from this short version of the Workshop Report.

The full version is available on the nees.org website.