An Outline and Benefit of Research Collaboration between NEES and E-Defense

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ABSTRACT :
Brief histories of the establishment of NEES and E-Defense are presented, followed by a summary of the preparation, initiation, and status of the NEES/E-Defense collaboration. The benefits obtained from the collaboration are discussed in the light of conspicuous differences in the organizational features of the two organizations, i.e., a single large facility approach versus a network testing environment. A few notable examples of collaboration are discussed, e.g., the use of both facilities for the same specimens in different scales, blind analysis competition for the prediction of responses involving serious damage, and development of a multipurpose TestBed for cost-effective and time-efficient shaking table tests.

KEYWORDS: Experiment, Large-Scale, Shaking Table, Network Testing, Collaboration

1. INTRODUCTION

Earthquake is inevitable, but their damaging effects on the built infrastructure are not. Although accurate hazard identification, early warning, land use policies, and robust emergency response are all vital elements of a comprehensive risk mitigation strategy, only the application of sound earthquake-engineering principles has the potential to limit loss of life, minimize property damage, and reduce downtimes for economic activity.

For the enhancement of science and engineering, experimentation is indispensable, because it offers us *real data* by which we can verify our theories and predictions and learn unknown realities, particularly when our theories and predictions are contradicted. Reliable *real data* can be obtained only from good experimentation, and it requires decent experimental facilities. Nearly simultaneously, two major efforts to establish good experimental facilities, one on each side of the Pacific, took place in the discipline of earthquake engineering.

2. DEVELOPMENT OF NEES

In the aftermath of the 1971 San Fernando Valley earthquake, it became obvious that a large investment was needed to limit loss of life and property due to this type of natural disaster in the USA. In the domain of research, it was realized that investment in the improvement of test laboratories owned by universities was seriously needed. Through the tireless work of a number of researchers, NSF officials, and other stakeholders, the idea of developing a national network of research laboratories grew in the early 1990s, and those efforts culminated in the development of the George E. Brown Network for Earthquake Engineering Simulation (NEES) in 1999 (George 2005). Integral to the development of the NEES collaboratory was the idea that advances in analytical capabilities and computational power made possible a synergistic marriage between physical simulation and virtual simulation.

The initial development of the NEES collaboration consisted of two main, parallel activities: (1) a Consortium Development grant (2000 to 2004) aimed at developing the collaboratory infrastructure; and (2) two rounds of facility proposals (2000 and 2001) aimed at funding the physical infrastructure of the

Consortium. Based on the facilities proposals, the following 15 sites were awarded for the installation of advanced experimental facilities (Figure 1).

- Three sites with shake table equipment, ranging from one large-scale unidirectional facility to two facilities with multiple smaller, 6-DOF shake tables, for testing building and bridge components.
- Six sites with large, multipurpose testing equipment addressed primarily to the testing of large structural components.
- Two sites with geotechnical centrifuges.
- Two sites with field testing capabilities, one primarily structural and the other geotechnical.
- One tsunami research basin.
- One ground motion monitoring site.

Since 2004, NSF organizes a research grant (NEESR) to fund projects that would make the maximum utilization of the NEES sites and facilities. As of July 2008, over fifty projects, including three large projects (Grand Challenge), have been awarded.

3. DEVELOPMENT OF E-DEFENSE

The 1995 Hyogoken-Nanbu (Kobe) earthquake taught serious lessons to the Japanese earthquake engineering community (Architectural 1995; Nakashima et al 1998). These lessons are: (1) cities and towns throughout Japan have large stocks of old buildings and infrastructural systems whose seismic capacity is insufficient; and (2) much larger shaking than that contemplated in current seismic design is possible. These lessons lead us the following strong needs: a) the characterization of the collapse margin, defined as the reserve capacity that the structure possesses for loads greater than those specified in seismic code up to collapse, and b) the evaluation of new technologies for the enhancement of the functionality, operability, and safety of structures. These needs inevitably require real data obtained by experimentation. Reliable real data can be obtained only from tests using specimens with realistic scales and loaded at realistic speeds.

Figure 1 Development of NEES

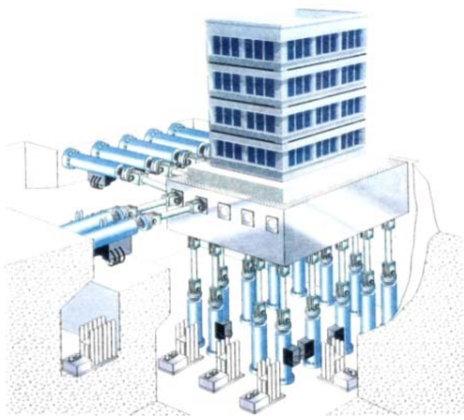

Figure 2 Development of E-Defense

To comply with these needs, the Government of Japan constructed a jumbo shaking table, named E-Defense, in the outskirts of Kobe. E-Defense was completed in 2004, and since that time it has been operated by the Hyogo Earthquake Engineering Research Center, administered by the National Research Institute for Earth Science and Disaster prevention (NIED) (Hyogo 2005). E-Defense has the unique capacity to experiment with life-size buildings and infrastructural systems in real earthquake conditions. The E-Defense table is attached to five actuators in each horizontal direction and supported by fourteen actuators installed vertically underneath the table (Figure 2). The table is 20 meters by 15 meters in the plan dimension, and can accommodate a specimen up to a weight of 12 MN (1,200 metric tons). The unique feature of the table is that it can produce shaking of a velocity of 2 m/s and a displacement of 1 m in the two horizontal directions simultaneously. Since the establishment of E-Defense, eight, eight, and nine projects, all of which included shaking table tests of either full-scale or large-scale test specimens, were conducted in fiscal 2005, 2006, and 2007, respectively.

4. NEES/E-DEFENCE COLLABORATION

4.1 Development of Collaboration

NEES and E-Defense began their operations in the fall of 2004 and the spring of 2005, respectively. Mitigation of earthquake disaster is a very critical problem in both countries. NEES and E-Defense facilities have similar missions and functions in research on the mitigation of earthquake disasters, and the two countries have a very long history of collaboration on earthquake engineering research and practices. A very natural outcome of this history is the research collaboration through complementary usage of the two facilities. Since the spring of 2004, the research communities in the USA and Japan have conducted extensive discussion regarding visible and close research collaboration. The two communities met several times, including three planning meetings held between 2004 and 2005 at Kobe and Washington D.C. To strengthen and formalize the collaboration, a memorandum of understanding (MOU) between NSF and MEXT (the Ministry of Education, Culture, Sports, Science, and Technologies) and another MOU between NEES and NIED were exchanged. As a result of the series of meetings, the parties reached an agreement that steel buildings and bridges would be the immediate targets of research collaboration. In addition, NEES and E-Defense have formalized collaboration on the advancement of cyber-infrastructure.

4.2 Ongoing Collaboration

To oversee the collaboration and expedite communication between researchers in the two countries, a Joint Technical Coordinating Committee (JTCC) was formed. Since 2004, the committee meets regularly with a frequency of approximately once a year. Through NEESR funds sponsored by NSF, the following projects have been awarded as having formal collaboration with E-Defense.

- NEESWood: Development of a Performance-Based Seismic Design Philosophy for Mid-Rise Woodframe Construction (PI: John van de Lindt)
- Controlled Rocking of Steel-Framed Buildings with Replaceable Energy Dissipating Fuses (PI: Gregory Deierlein)
- International Hybrid Simulation of Tomorrow's Braced Frame Systems (PI: Charles Roeder)
- TIPS - Tools to Facilitate Widespread Use of Isolation and Protective Systems (PI: Keri Ryan)
- Simulation of the Seismic Performance of Nonstructural Systems (PI: Emmanuel Maragakis)

On the Japanese side, NIED established a five-year project focused on the collaboration, and in compliance with the agreement, two theme projects shown below began in 2005. These projects serve as the direct counterpart of the NEESR projects listed above.

- E-Defense Steel: Advancement of Steel Building Structures and Innovative Systems (PI: Kazuhiko Kasai)
- E-Defense Bridge: Performance Evaluation and Upgrading of RC Bridge Structures (PI: Kazuhiko Kawashima)

Among the five NEESR projects in explicit collaboration with E-Defense, two teams will come to E-Defense for their final verification tests. In the summer of 2009, the NEESWood team plans shaking-table tests of a full-scale five-story wood frame system in E-Defense. The Rocking System team plans a three-story rocking-frame test using the E-Defense TestBed (whose detail will be noted later) also in the summer of 2009. The E-Defense Steel team plans a series of tests using a multi-story model frame combined with various passive damping and base-isolation devices to validate the performance of these devices. The TIPS and Nonstructural System teams plan to install some of their devices and components in the model frame. The Braced Frame team also seeks a possibility of using the TestBed in their verification tests.

4.3 Benefit of Collaboration

Throughout the NEES/E-Defense collaboration over the past three years (2005 to 2008), numerous tangible benefits have been confirmed. Sharing the experimental data and exchange of researchers, particularly young ones including graduate students, are no doubt the heart of the collaboration.

In the early days (1990s) of discussion about the improvement of experimental facilities, the following two issues were seriously argued.

- Whether there ought to be one central location where most of the equipment should be housed or whether a large distributed network was more desirable.
- Whether the main investment should be in one large shake table or in a series of smaller pieces of equipment.

Each option had pros and cons, and we all knew it was impractical to satisfy all requirements. The selection was naturally not easy.

As evidenced from the established facilities, NEES adopted a combination of “a large distributed network” and “a series of (relatively) smaller pieces of equipment,” while E-Defense was the product of a combination of “central location” and “one large facility (shaking table)”. The NEES/E-Defense collaboration has become an excellent baseline on which we can quantify the genuine advantages and inevitable drawbacks of the two types of facilities, and we can develop a synergy through carefully tailored and complementary efforts. The E-Defense shaking table, the largest in the world, indeed serves as a tool for ultimate verification of new theories and technologies developed in individual research projects, providing us with unprecedented data never obtained anywhere before. The NEES distributed network is a challenge that is leading us to a revolution of the earthquake engineering research environment. Concepts of laboratory sharing, remote participation, and data sharing are indeed changing the culture of the researchers involved, and it is notable that many more researchers than before share a positive sense of participation under the common NEES umbrella.

5. NOTABLE COLLABORATION TO DATE

A few unique examples of the NEES/E-Defense collaboration are introduced.

5.1 Bridge Pier Tests at NEES and E-Defense

The E-Defense Bridge examines the existing performance of old RC bridge piers and the development of effective seismic retrofit of those piers. A series of large-scale single-pier specimens (height = 7.5 m and diameter = 1.8 m), with different reinforcing details and retrofit techniques, are being tested using E-Defense. Prior to the large-scale shaking tests, reduced scale specimens that would represent the large-scale specimens were tested in 2006 at the NEES site at UC Berkeley, and validity of the specimen design was checked. The test data was reflected in the final design of the large-scale specimens. Once the data of the large-scale specimens are made available, cross-comparison of the two sets of data will provide us with quantitative information on the scale effects with respect to both the size and time. The first specimen was tested in 2007 (Figure 3), and a few more specimens are planned to be tested in the fall of 2008. The details of the E-Defense Bridge are to be presented in a special session (S17-2): E-Defense Bridge – Verification of Seismic Performance of Bridge Structures Utilizing Large-Scale Shaking Table, during the 14WCEE.

Figure 3 RC Bridge Pier Test in E-Defense

Figure 4 Collapse Test of Four-Story Steel Moment Frame

5.2 Blind Analysis Competition on E-Defense Steel Collapse Test

In the fall of 2007, the E-Defense Steel conducted a shaking test to reproduce a collapse of a full-scale four-story steel moment frame (Figure 4). In the test, four levels of ground motion were adopted: Level 1 (for serviceability under small/medium motions), Level 2 (for safety under large motions), Level 3 (for incipient collapse under very large motions), and Level 4 (for complete collapse under extreme large motions). The structure sustained severe damage at Level 3, and exhibited a collapse in the first-story failure mode in Level 4. The detail of E-Defense Steel is to be presented in a special session (S17-1): E-Defense Steel – Full-Scale Shake Table Tests and Analyses on Conventional, Value-Added, and Innovative Multi-Story Steel Buildings, during the 14WCEE.

A blind analysis contest was conducted in conjunction with the collapse test, with the aim of stimulating the improvement of current computational methods and the enhancement of efficient modeling techniques for accurate prediction of seismic behavior of steel frames sustaining large damage including collapse. The contest was classified according to the type of analysis method and the type of participant. The analysis methods are classified as “3D Analysis” and “2D Analysis”, and the participants are classified as “Researchers/Students” and “Practicing Engineers”. The behavior/response to be predicted was taken as that obtained for Level 3. A total of 47 teams from seven countries participated in this completion, with the statistics of 30 and 17 teams for 3D-Analysis and 2D-Analysis, respectively, and 30 and 17 teams for Researchers/Students and Practicing Engineers, respectively. Four winners, one for each combination of the two categories, were announced in December 2007. Figure 5 shows a winner’s displacement time history, plotted together with the corresponding observed history. The details of the blind analysis competition are to be presented in a special session (S17-3): International Collaboration – Experiences and Challenges for Sharing Large-Scale Testing Facilities and Sharing and Disseminating Experimental Information, during the 14WCEE.

5.3 Development of Multpurpose “TestBed”

Large-scale tests are naturally expensive, and preparing the test is time-consuming. To reduce the cost and time of fabrication and the installation of test specimens, E-Defense has developed a facility named

"TestBed". The concept of this facility is to provide inertia to the specimen without interfering with the motion of the specimen, by which the specimen does not have to contain the actual mass in itself. TestBed is a frame consisting of multiple units as shown in Figure 6. Each unit is made of steel truss boxes with a plan of 6 m × 4.5 m and a height of 2.7 m. The unit carries a concrete slab with dimensions of 3 m × 4 m to add mass. In the case of unidirectional movement, one unit of the TestBed is supported by two unidirectional linear sliders and two bidirectional linear sliders. The inertial forces are transferred to the test frame through load-cell units that can automatically measure the shear forces exerted in each floor. The story drift between each floor is measured by LVDTs placed between each layer of units.

In 2007, two TestBed units were constructed, and several types of trial shaking-table tests were conducted using plane steel frames with damper systems. In 2008, an additional six units are planned to be constructed, and shaking-table tests will become available for up to a four-story frame. TestBed is planned to be used to verify innovative structural systems incorporating dampers as part of the D-Defense Steel.

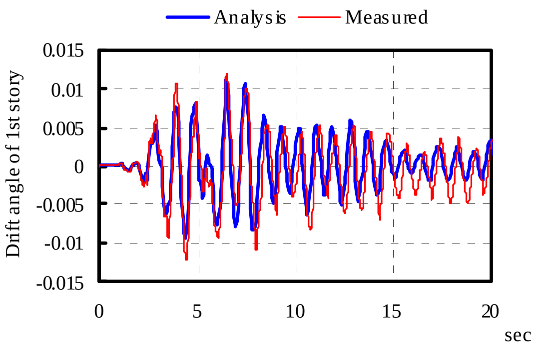

Figure 5 Example Prediction in Blind Analysis Competition

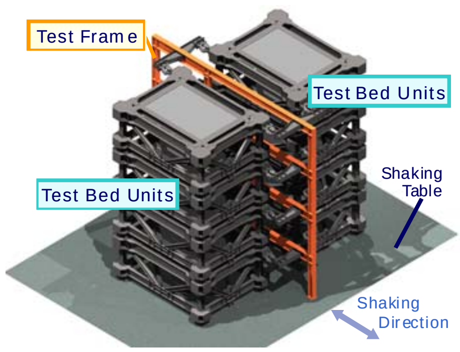

Figure 6 Multipurpose TestBed in E-Defense

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