FRAMEWORKS FOR NCREE DATA MODEL AND INTERNET-BASED SIMULATIONS ON EARTHQUAKE ENGINEERING

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ABSTRACT :

This paper presents the latest development of collaborative experimental environment at Center for Research on Earthquake Engineering (NCREE). A collaborative hybrid simulation platform named Internet-based Simulation on Earthquake Engineering (ISEE) has been updated and can work with NEES UI-SimCor system. An experimental data management system has been developed for archiving NCREE's experimental data, sharing data with registered users in the world. The data management system is aimed to be able to exchange data with other data management systems.

KEYWORDS: Experimental data management system, NCREE Data Model, Hybrid Simulation, ISEE

1. INTRODUCTION

Collaboration and systematic data exchange have become important factors in the earthquake engineering researches. Different earthquake engineering laboratories and research centers all over the world are nowadays constructing and developing different experimental facilities and application areas. It is getting obvious that further improvement on earthquake engineering technology strongly relies on tight collaborations and research information exchange and sharing among laboratories and research centers around the world. This paper focuses on NCREE’s efforts on strengthening the software-based foundation on inter-laboratory collaborative hybrid simulation experiments and experiment data exchange and sharing.

2. A BRIDGING APPROACH BETWEEN ISEE AND UI-SIMCOR

As the scale and the complexity of modern earthquake engineering experiments increase, existing laboratories, often with limited resources, inevitably face difficulties to accommodate such experiments. To address this issue, the Hybrid Simulation (HS) approach is proposed and several networked HS Environments (N-HSEs), such as ISEE (Yang et al., 2007 and Wang et al., 2007), UI-SimCor (Kwon et al., 2005 and 2007), and OpenFresco (Takahashi and Fenves, 2006; Schellenberg and Mahin, 2006), have been developed recently. The sharing and integration of resources among laboratories further increase the capability of an HS to tackle large-scale and complex earthquake engineering experiments.

In the case where collaborative hybrid simulations are desired among laboratories using different N-HSEs, two solutions may be considered. The first one is to achieve agreement among all collaborating laboratories on adopting the same N-HSE. This may seem to be a straight-forward solution but it may not be an easy task to achieve the agreement and for a laboratory to adopt a new N-HSE. The second solution is to enable the communication and collaboration between different N-HSEs. This may seem to be a difficult task because different N-HSEs can not by default collaborate or share their resources with each other although they may employ similar software frameworks and simulation procedures. This solution is worth investigating because it allows each laboratory to use its own N-HSE that has been familiar to its members, and even optimized in term of reliability, robustness, and efficiency. The first part of this paper presents a bridging approach to enable communication and collaboration between two N-HSEs, namely NCREE-ISEEdb (Yang et al. 2007) developed at NCREE (Center for Research on Earthquake Engineering) and UI-SimCor (Kwon et al., 2005 and 2007).

A general bridging approach is prototyped based on an abstract framework of N-HSE. The abstract framework is a generalization model of NCREE-ISEEdb and UI-SimCor based on their similarity. The abstract framework includes four essential modules: Commander, Remote Sub-structure, Communication, and Executor.

A Commander runs dynamic time integration and computes the structural responses (typically, displacements) of each physical test specimen. The Main Routine in UI-SimCor or the Analysis Engine in NCREE-ISEEdb is a Commander. Typically there is only one Commander in a hybrid simulation.

A Remote Sub-structure represents a sub-structure settled on a remote site. The MDL_RF in UI-SimCor or the user-defined element class in NCREE-ISEEdb is a Remote Sub-structure. A Remote Sub-structure may represent a physical test specimen installed in a laboratory, or a part of a structure numerically simulated by a remote computer. In each time step, a Remote Sub-structure receives requests from the Commander and then forwards it to its corresponding Executor (which will be introduced later). It then receives the responses from the Executor and sends back to the Commander.

A Communication indicates what messages should be transferred and describes how to transfer the messages between Remote Sub-structures and Executors. Although the communication methods or protocols of networked hybrid simulation platforms are different, the essential messages between a Remote Sub-structure and an Executor are similar. The essential messages are mainly composed of displacements and reacting forces.

An Executor executes all operations requested from its corresponding Remote Sub-structure and then replies with the outcome of the operations. For a Remote Sub-structure representing a physical test specimen in a laboratory, an Executor is responsible for controlling the equipment (e.g., hydraulic actuators).

In addition to controlling a physical test specimen, an Executor may simulate a part of a structure numerically for special purposes. Furthermore, there are some auxiliary modules other than the above essential modules in UI-SimCor or NCREE-ISEEdb, such as modules for data acquisitions, camera control and instant visualization. The auxiliary modules in UI-SimCor and NCREE-ISEEdb work in different ways. The data acquisition module in UI-SimCor (i.e., MDL_AUX) is passively triggered by the Commander, while that in NCREE-ISEEdb (i.e., DAQ module) actively monitors the progress of a hybrid simulation and triggers itself at proper time. The compatibility of these auxiliary modules across UI-SimCor and ISEE Database Approach has not implemented yet in this work.

Figure 1 depicts the basic idea of an approach on bridging NCREE-ISEEdb and UI-SimCor. In this case, the Analysis Engine of NCREE-ISEEdb is selected to carry the dynamic time integration of the hybrid simulation. A Translator module is designed to help message exchange between different Communication modules of different N-HSE. The Translator module for bridging NCREE-ISEEdb 2.0 and UI-SimCor 2.6 was developed in this work using MATLAB. The m-files of MATLAB for sending and receiving messages to and from both NCREE-ISEEdb and UI-SimCor were implemented. All these m-files of MATLAB are packaged and named ISEEdbSQL for MATLAB. They not only allow for bi-directional communication between NCREE-ISEEdb and UI-SimCor but also open the door for NCREE-ISEEdb to access the powerful functionalities of MATLAB.

Compared to the direct communication approach employed by UI-SimCor and OpenFresco (Schellenberg et al., 2007) that Communication modules of these two N-HSEs can communicates directly, the bridging approach aforementioned is indirect, which the Translator can be regarded as an additional level between Communication modules. Additional overhead of network operations is required in the bridging approach. To minimize the overhead, it is suggested to place the Translator on the same computer of one of the Communication modules.

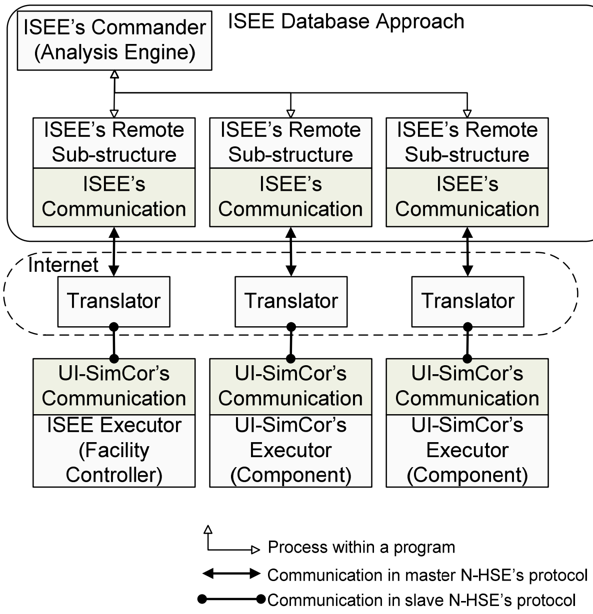

Figure 1: the basic concept of the bridging approach

The advantage of the bridging approach is that developers do not need to modify any original software of the N-HSEs if the bridging approach is employed. All procedures and technical details regarding to message translation and compatibility of the two N-HSEs are encapsulated in the Translator module. It eases the maintenance of the compatibility between different N-HSEs if the communication protocols or message contents is changed.

A software simulation of a networked hybrid simulation using NCREE-ISEEdb and UI-SimCor environments was performed to validate and demonstrate the bridging approach. A networked hybrid simulation of a bridge carried out among NCREE (in Taiwan), Taiwan University (in Taiwan) and Carleton University (in Canada) (Yang et al., 2006) was reproduced in a software manner. The bridge structure is divided into four parts: Pier 1 (P1), Pier 2 (P2), Pier 3 (P3) and the rest of the structure, as shown in Fig. 2. In this software simulation, the three Piers were simulated by three Components of UI-SimCor based on OpenSees models. Dynamic time integration and numerical simulation of the rest of the structure were carried out by the OpenSees-based Analysis Engine of NCREE-ISEEdb. A 10-second bi-directional ground motion with time increments of 0.02 seconds was used. There were 500 time steps in the networked hybrid simulation. The time sequence diagram of the networked hybrid simulation is shown in Fig. 3. The P3 part in Fig. 3 is the same as the P1 and P2, and was removed due to limited page width of this paper.

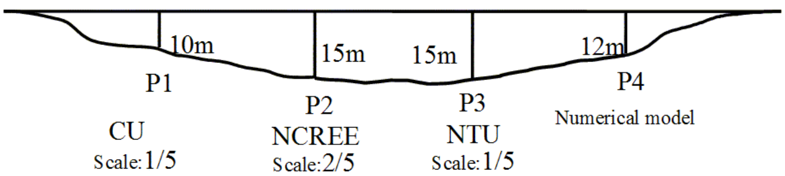

Figure 2: elevation of the bridge system in the networked hybrid simulation

The software simulation validates and demonstrates the feasibility of the bridging approach. The dynamic response of the bridge of the software simulation is very close to a pure numerical simulation. The slight differences come from different nonlinear analyses (i.e., the pure numerical simulation adopts Newton-based iteration method, while the software simulation of the hybrid simulation uses a non-iterative method as a typical hybrid simulation does). The software simulation was performed on a laptop computer with a 2.0GHz CPU and 2GB main memory. Each of the Translators, UI-SimCor Components, the Analysis Engine and the Data Center runs as an independent process. All the network operations were performed virtually within the operating system. Because there is no physical network transmission, the time cost of the network operations in the test represents the software performance.

Table 1 lists the timing statistics of the software simulation. The timing statistics was measured by a Translator. Each time step in average cost 0.369 seconds. About half of them (52.9%) were on querying displacement data from the Data Center, which includes the time cost on repeatedly checking the displacement data availability in the Data Center. The remaining time was almost on waiting the responses from UI-SimCor's Component, which includes OpenSees numerical simulation time cost of each pier. Compared to querying time, a Translator spends little time cost (only 3%) on sending data. By assuming that the communication overhead is about the same on the four network operations, it is estimated that the overhead induced by the Translator is only a small portion of the overall communication time in the test.

Table 1: timing statistics of the demonstration example

Translator's work	Average time cost per time step (sec.)	Percentage
Translator querying displacements from ISEE Data Center (including repeatedly checking the database, Analysis Engine's time integration, etc.)	0.1953	52.9%
Translator sending displacements to UI-SimCor Component	0.0013	0.4%
Translator querying resisting forces from UI-SimCor Component (including Component's numerical simulation)	0.1630	44.1%
Translator sending resisting forces to ISEE Data Center	0.0096	2.6%
Total time	0.3692	100%

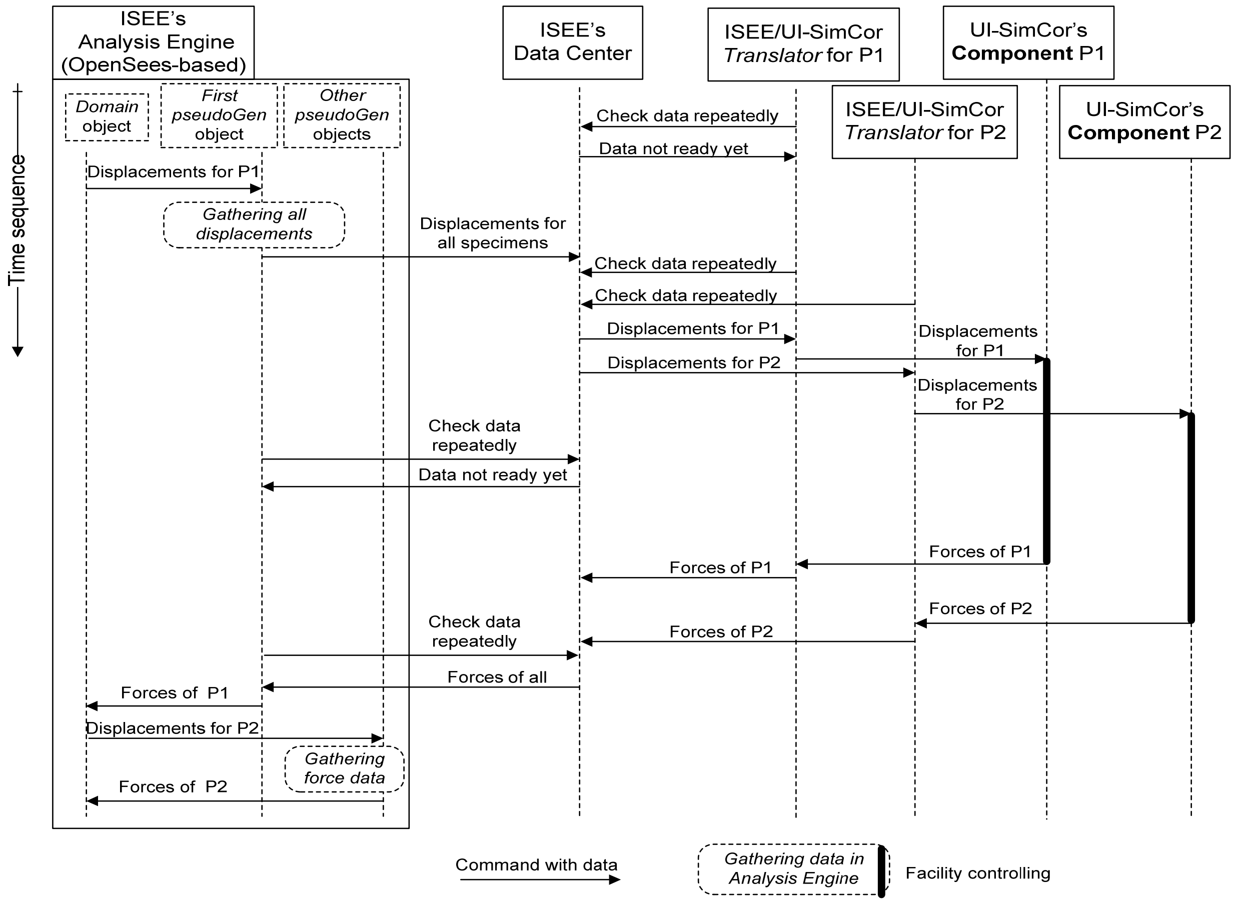

Figure 3: the time sequence diagram of the networked hybrid simulation

3. A PROTOTYPE OF NCREE EXPERIMENTAL DATA MANAGEMENT SYSTEM

Evaluation of a researcher's achievement is usually based on the citation or impact factor of a researcher's papers. From the perspective of NCREE, besides the valuable papers, the experimental data and research data from every earthquake engineering research activity have also contributed many outstanding achievements in the domain of earthquake engineering. However, due to there are many kinds of the experiments which produce different types of digital data, in earthquake engineering domain, there is still not a sufficient and systematic way to preserve these heterogeneous data effectively. At NCREE, for example, Even if many researchers manage their experimental data by storing them into a large number of digital data files that are organized in computer folders. It has been found that other researchers or even the original researchers after some period of time cannot easily reuse former experimental data if the meanings of and the relationships among data files were not well described and documented. Due to the inconvenience for research exchange, it is generally agreed by the researchers and common users that there should be a reliable and acknowledged way to manage the experimental data. Unfortunately, it is not always understood how a reliable and acknowledged way should be.

It is found that several researchers have paid attention to the issue about the preservation and management of the experimental data in recent years. NEES (Network for Earthquake Engineering Simulation) has been addressing the data preservation issue since 2002 or even early. The preliminary research of NEES data preservation is called NEESit data curation (Warnock et al., 2005). Data curation can be regarded as the actions needed to maintain digital research data and other digital materials over their entire life-cycle and over time for current and future generations of users. In addition, a harmonization workshop held by ISAMCO (International Structural Assessment, Monitoring and COntrol) initiated the collaboration in harmonization of data (Wenzel, 2004) and a data model named BRIMOS data model was developed to support a bridge monitoring system called BRIMOS (BRIdge MOnitoring System) by VCE (Vienna Consulting Engineers).

Data modeling is a process of designing a suitable data model for representing the scope of the data management. It provides a method and representation for describing the researchers' specific information requirements and the manner when conducting an experiment. A data model can be regarded as a graphic representation which provides a structured way of viewing a set of data and the relationship among them. A practical data model should capture sufficient information for data description and is effective enough to support data management for the development of related software tools. From NCREE's experience, it is usually not easy to design a complete data model in one-time work, because it is difficult for researchers' to express their requirements definitely. Under these constraints, an iterative and incremental approach was employed to identify the scope of preliminary NCREE data model (Hsieh, 2005).

The Object-Oriented approaches are employed in the design of the NCREE data model. Figure 4 shows the overview of the NCREE data model without detailed depiction. Every rectangle depicted on the model is called an object. The object is defined to represent a specific and abstract existence. For example, an earthquake engineering experiment could be regard as an object. From the perspective of NCREE, the major activities in an earthquake engineering research goal are further extended and named Project, Experiment, Test and Repetition objects on the data model. The Project is defined to represent a research activity which includes a series of experiments and is devoted to achieve a specific goal. The Experiment is defined to represent an experiment activity which includes a series of tests and has a specific specimen. The Test is defined to represent a single run of an experimental test or a numerical simulation. The Repetition is defined to represent a single run of a test and produces the output data. Every Repetition in a Test has the same setup and the input data except the output data.

It is found that both the reference NEESgrid data model proposed by Peng and Law (2004) and the NEES data model (2007) are similar to the NCREE data model in details. This implies that the concept of the modeling for the management of experimental data in earthquake engineering domain is not divergent. It is also possible to carry out the data exchange between different data models without too much difficulty.

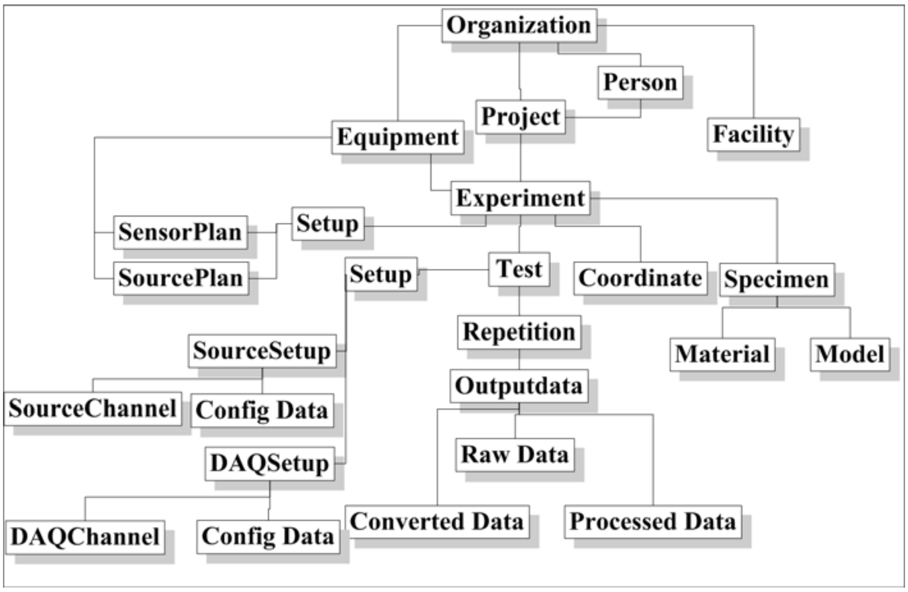

Figure 4: the time sequence diagram of the networked hybrid simulation

NCREE not only focus on the development of a suitable data model but also devotes to constructing a robust information environment to preserve and manage the experimental data. A management system named NCREE data center based on the NCREE data model is developed. NCREE data center is a web-based central environment for storing, managing, and sharing a large amount of experimental data and their description (or metadata). Considering the advantage of modeling and extensibility, three-tier architecture is employed on the development of the NCREE data center. Three-tier architecture is a popular approach for splitting a system's components into suitable single logical tier according to their functionalities. The presentation tier is employed as a guide in browsing and arranging experimental data based on the data model and shows the metadata as detailed information for each object defined in data model, as show in figure. The business tier is responsible for dealing with various jobs, such as establishing a connection to database or create an object defined by the data model. The data tier contains database system and data repository. The data repository is employed as a file system in storing the experimental data. The database system is employed in storing the metadata and the relationship of experimental data based on the NCREE data model.

Every object defined in the NCREE data model could be distinct as data object and information object. The data object is defined to exist as real digital file. For example, it could be JPG, PDF, DWG file, and so on. The information object is defined to contain the information which is used to interpret the object. In the NCREE data center, for example, a Project object is a kind of information object which provides the name, description and period of a project. Besides, it also includes a number of Experiment objects and project-related data objects. Both the data repository and database system are responsible for the storage of the objects defined in the NCREE data model. Figure 5 shows the hierarchy of the data repository which all the data objects stored in. The schema of the database system is based on the NCREE data center and all the information objects are stored in the database system. In addition, researchers could also describe the data object, so the description becomes the metadata of the data object.

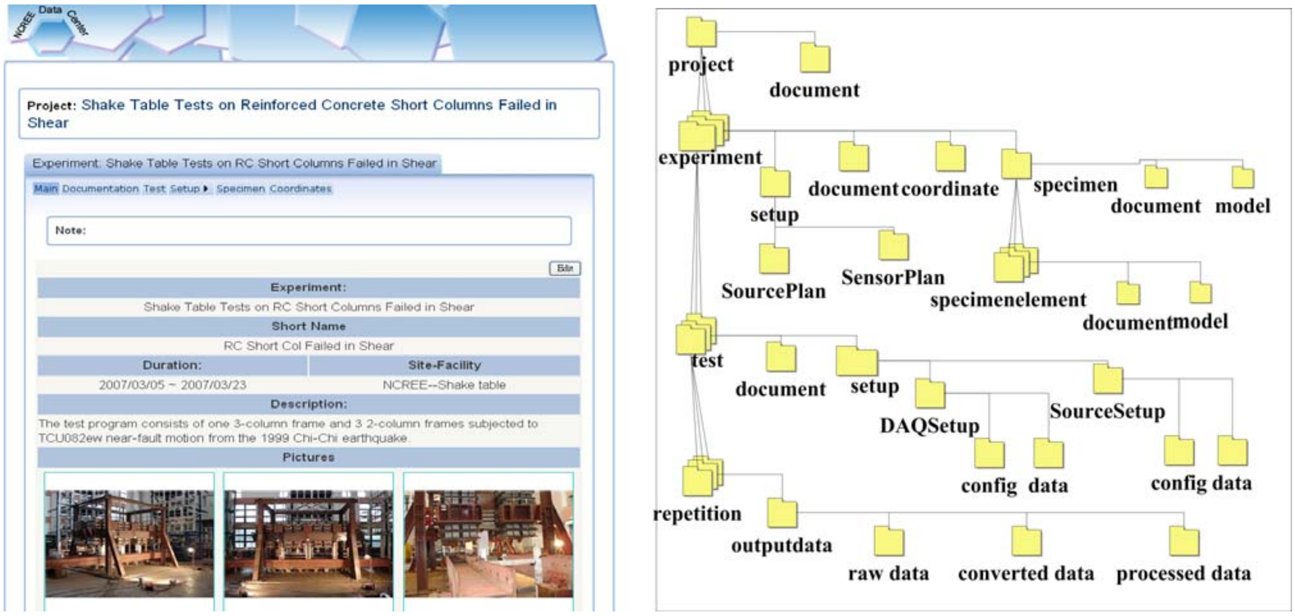

Figure 5: user interface and file hierarchy of the experimental data management system

4. SUMMARY

An approach for bridging two different hybrid earthquake engineering simulation environments has been introduced and demonstrated in this paper. The approach allows NCREE-ISEEdb and UI-SimCor to complete a collaborative networked hybrid simulation. More validation tests on the approach using more complicated realistic examples with more careful timing statistics and performance studies are currently being conducted by the authors.

Although the approach presented here focuses on bridging the NCREE-ISEEdb and UI-SimCor environments, the authors believe that it can be generalized to bridge any two different networked hybrid earthquake engineering environments. Research for a generalized bridging approach is currently underway at NCREE and its outcomes can be expected in the near future.

As to the experimental data management, sharing and systematic exchange, further efforts are still needed. Systematic experimental data management, sharing and exchange require a generally accepted data model and an accessing protocol.

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REFERENCES

Filip CF & Margarita C (2004), FEDEASLab Getting Started Guide and Simulation Examples, Technical Report NEESgrid-2004-22, NEESgrid. Available at http://it.nees.org/

Hsieh SH, Tu WH, Yang YS & Cheng WC. (2005), Progress on Management of Earthquake Engineering Experimental Data at NCREE, *Proceedings of the Seventh Japan-Taiwan-Korea Joint Seminar on Earthquake Engineering for Building Structures* (SEEBUS 2005), Seoul, Korea, October 21-22, 2005, 207-214.

Kwon OS, Nakata N, Elnashai AS, & Spencer B. (2005), A Framework for Multi-site Distributed Simulation and Application to Complex Structural Systems, *Journal of Earthquake Engineering*, **9**(5): 741-753.
Kwon OS, Nakata N, Park KS, Elnashai AS, & Spence B (2007), UI-SimCor Users Manual and Examples for UI-SimCor v2.6 and NEES-SAM v2.0, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Urbana, Illinois, February 2007.
Lin BZ & Tsai KC (2003), "Development of an Object-oriented Nonlinear Static and Dynamic 3D Structural Analysis Program," Report No. CEER/R92-04, Center for Earthquake Engineering Research, College of Engineering, Taiwan University, Taiwan.
OpenSees official web page. http://opensees.berkeley.edu/
Pearlman L, D'Arcy M, Johnson E, Kesselman C, & Plaszczak P (2004), NEESgrid Teleoperation Control Protocol (NTCP), Technical Report NEESgrid-2004-23, NEES Inc. Available at http://it.nees.org/
Peng J & Law KH (2004), Reference NEESgrid Data Model, Technical Report NEESgrid-2004-40. Available at http://it.nees.org/.
NEES Inc. (2006), "Soliciting Feedback on NEES Data Model," available at http://it.nees.org/documentation/pdf/nees-data-model-handout.pdf.
Schellenberg A & Mahin S (2006), Integration of Hybrid Simulation with the General-purpose Computational Framework OpenSees, *Proceedings of the 8th US National Conference on Earthquake Engineering* (in CD-ROM), Paper No. 1378, April 18-22, 2006, San Francisco, CA, U.S.A.
Schellenberg A, Kim HK, Takahashi Y, Fenves GL, & Mahin SA (2007), OpenFresco Framework for Hybrid Simulation: LabVIEW Experimental Control Example, Technical Report, NEES Inc. Available at http://neesforge.nees.it/projects/openfresco.
Takahashi Y & Fenves GL (2006), Software Framework for Distributed Experimental-computational Simulation of Structural Systems, *Earthquake Engineering & Structural Dynamics*, **35**(3): 267-394.
Yang YS, Hsieh HS, Tsai KC, Wang SJ, Wang KJ, Cheng WC, and Hsu CW (2007), ISEE: Internet-based Simulation for Earthquake Engineering Part I: Database Approach, *Earthquake Engineering and Structural Dynamics*, **36**(15): 2291-2306.
Yang YS, Wang SJ, Wang KJ, Lin ML, Weng YT, Cheng WC, Chang YY, Tsai KC, Lau DT, Hsieh SH, Lin FP & Lin SY (2006), Network System for A Transnational Collaborative Pseudo-dynamic Experiment on A DSCFT-pier Bridge System, *Proceedings of the 8th National Conference on Earthquake Engineering* (in CD-ROM), Paper No. 810, April 17-21, 2006, San Francisco, CA, USA.
Wang KJ ,Tsai KC, Wang SJ, Cheng WC, & Yang YS (2007), ISEE: Internet-based Simulation for Earthquake Engineering Part II: the Application Protocol Approach, *Earthquake Engineering & Structural Dynamics*, **36**(15): 2307-2323.
Warnock T, Van Dan Einde L, Moore R. (2005). NEESit Data Curation Roadmap. Technical Report NEESgrid-2005-046, NEES Inc. Available at http://it.nees.org/
Wenzel H (2004). International SAMCO I-SAMCO launched. *SAMCO Newsletter*, Issue **13**, January, 2004. Available at http://www.samco.org/
ZEUS-NL official web page: http://mae.ce.uiuc.edu/software_and_tools/