An Open Platform for Simulation of Earthquake Engineering Damage

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ABSTRACT :

The researches on earthquake engineering started in late 1900s. During the last 100 years of history, there has been a vast accumulation of knowledge, information and research results in earthquake engineering, which are scattered among different corners around the world. Experimental facilities have been gradually built at many locations on the globe. Over the last 20 years, there have been tremendous advances in information technology, especially in networking environment, hardware capability and open-source initiatives. Network for Earthquake Engineering Simulation (NEES) became a major initiative in NSF to deploy a network environment that connects 15 facilities on earthquake engineering in the US. Based on the above information, this paper proposes a new open platform for simulation of earthquake engineering damage, which is called Simulation of Earthquake Engineering Damage (SEED). There are three main components in the platform, the networked hardware environment, the numerical simulation and research, and the basic information repository. This open platform will act as an operating system for earthquake engineering researches in the future, trying to connect all the facilities, data, information, knowledge and people together to this distributed networked platform. NEES initiative will be a sample model for the networked hardware environment, OPENSEES will serve as the basis for the numerical simulation component, and data warehouse tools can be expanded to serve as the basic information repository. A detailed schematic graph and architectural design are provided to explain the components within the open platform and how each component interacts with each other. Latest information techniques are applied to design framework of the open platform. Finally, the plan and current status to build the platform are introduced with detailed information on the schedule and funding status

KEYWORDS: Open Platform, Earthquake Damage, Simulation, Platform Framework, Experimental Study

1. INTRODUCTION

Earthquake is the direct result of the continuous plate movement whose mechanism is still unknown to human being. Although the earthquake record in China can go back as early as 2000B.C. (Ziqun Min, 1995), the research on earthquake disaster reduction actually started with the forming of a committee in Japan for earthquake disaster preparedness in 1892 after the Nobi earthquake, which is a little over 100 years from today. During the last 100-plus years, researchers in earthquake engineering have accumulated a huge amount of data and research results. The earthquake engineering research in China started in early 1950s at Institute of Engineering Mechanics (IEM), China Earthquake Administration (then called Institute of Civil Engineering and Architecture, Chinese Academy of Sciences) with a history of over 50 years. Chinese researchers in earthquake engineering, working in parallel with their international counterparts, also piled a large amount of data and research results.

The economic expansion around the world in the last 20 years has helped to make good progress in both experimental and theoretical research. The traditionally isolated single experimental equipments have been gradually replaced by a variety of large-scale testing facilities. The structural experiment started from a sample testing to component testing until most recently the testing on full-scale structures. Geotechnical testing also evolved from an in-lab sample testing under cyclic loading to an in situ testing under complex loading conditions. The observation network at the same time was improved from analogue to digital. One of the striking characteristics is that similar systems are being built at many locations worldwide.

Starting from 1990s, the rapid progress made in networking and information technology has enabled an elevated and better means for scientific research in almost every area. Under the support from NSF in 2000, earthquake engineering community in the United States spent over 80million USDs to build NEES (Network for Earthquake Engineering Simulation) connecting 15 research centers in the US continent (Jiping Ru and Yan Xiao, 2002), which provided others around the world with a good example for future directions of experimental platforms. Afterwards, similar networks were built in Japan, Korea, JRC in Europe and Chinese Taiwan. In China mainland, with the support from Natural Science Foundation of China (NSFC), a few prototype systems were built as well.

In order to effectively reduce earthquake disasters, a large amount of different types of basic datasets are also important in addition to advanced experimental techniques and numerical simulation, such as the earthquake fault information, the historical earthquake catalogs, strong motion records, underground geologic structures, building characteristics, as well as other key economic and societal information. Similarly, these pieces of information are also scattered at different corners around the world.

Therefore, there is a high need for an open platform what can be used to share different pieces of information, integrate disperse experimental systems around the world, and assemble large-scale research team at discrete geographical locations. This paper based on the above understanding proposes an open platform for earthquake engineering research. Initial design and implementation have been completed within IEM, which will serve as a good starting project of this gigantic endeavor.

2. A Holistic View of the Open Platform

2.1 History and current status of earthquake engineering research

With a little over 100 years of history in earthquake engineering research, the activities in this area have been taken up by many countries around the world. According to the statistics of abstract submission to the upcoming 14th world conference on earthquake engineering to be held on October 12-17, 2008 in Beijing, China, the authors of the more than 4000 abstracts submitted are from around 80 countries and/or regions from all 5 continents, making it potentially the most attended conference in its 50-plus years of history. Therefore, it can be concluded that earthquake engineering research is conducted at many places around the world. It is imperative to start sharing information, integrate disperse systems to avoid further duplication and waste of time, money and human resources.

Within China, there are tens of universities and research institutes which are actively conducting earthquake engineering researches. Shaking tables and large composite testing facilities have been built in a few dozens of places. The recently completed national digital observation network for strong motion has installed more than 2000 observation units at 1000-plus stations, which can potentially provide fundamental strong motion datasets to support future research activities. The national conference on earthquake engineering which is held every 4 years has attracted hundreds of participants each time. The number of abstracts submitted to the upcoming world conference has surpassed 700, making China one of the leading top two countries in the number of abstracts submitted.

In Japan, most of the researchers on earthquake engineering traditionally belong to either the architectural engineering or civil engineering community. The annual meetings of both communities attract thousands of participants among those more than 1/3 are working on earthquake engineering related fields. The Japanese

Association for Earthquake Engineering (JAEE) was formed in 2001 with members mostly from 4 correlated associations. The annual meeting held by JAEE attracts close to 1000 participants every year.

In the United States, there are already 15 major research centers on earthquake engineering which are supported by NSF via NEES. In 2006, more than 3000 participants joined the international conference commemorating the 100th anniversary of 1906 San Francisco earthquake. The national conference of earthquake engineering held every 4 years is participated every time by close to 1000 people.

In addition, earthquake engineering researchers are also active in countries such as Iran, South Korea, Mexico, Spain, Greece, Italy, Chile, and Indonesian because they also face similar challenges from disastrous earthquakes.

Looking from the research perspective, in the engineering seismology community, ever since the first strong motion record which was obtained from the 1933 earthquake at Long Beach, every major improvement of theory and understanding has always been connected with the accumulation of valuable strong ground motion records. For example, the 1985 Mexican earthquake records demonstrated the effect of valleys on the long period components of strong ground motion records. Records from recent large earthquakes in Japan, Chinese Taiwan as well as the recent May 12, 2008 Wenchuan Earthquake all demonstrated the problems of a large vertical component. There are also cases where near-fault records show the effect of directivity, large impulse, long duration, and the larger amplification on the hanging wall side. These are all new phenomena observed recently which require further detailed study from which interesting breakthroughs are to be expected.

It is worthwhile to look at a small place called Turkey Flat in Parkfield of California. In 1980s, this place was expected to have a strong earthquake imminently. Many types of instruments were installed and deployed to the region, and an international blind prediction of strong ground motion at Turkey Flat was carried out under the leadership of IAEPEI and IAEE. The expected earthquake, though with a smaller than expected magnitude, finally came in September, 2004, which propelled another blind test at Turkey Flat with the support of USGS. Similarly in Japan, there was a blind test at Odawara south of Tokyo in 1992. I was fortunate at that time to be a graduate student at Earthquake Research Institute of The University of Tokyo, so I had the great chance to help Prof. Kazuyoshi Kudo participate in the blind test (Zifa Wang, Tadao Minami and G. Jeon, 1992; Kazuyoshi Kudo and Zifa Wang, 1992). These three blind tests provided us with a good opportunity to assess our current simulation models on strong ground motion, which encouraged the engineering seismology community to improve and refine their different types of simulation models.

In calculating the structural response, added mass method was initially used, which was later replaced by time history analysis, which was later added with the consideration of uncertainty and reliability. Recently performance based design has become a hot topic and there are authors who start to include the consequence consideration in the design process (Zifa Wang, 2006).

The experimental method also started from simple sample tests to complex full-scale tests on structures. Recently a hybrid method is gaining momentum, which combines the advantage of both experimental and analytical methods. The relative small and complex portion of a structure can be modeled by a testing model while the remaining can be simulated via a computer program. In this way, effective methods can be derived pretty easily and this direction has attracted a lot of attention worldwide.

Since 2005, the author and his team partnered with the famous risk modeling firm RMS, Inc. to develop China earthquake risk model (Zifa Wang, 2008). The model was calibrated and applied to estimate different types of earthquake in China including a number of scenario analysis. In May, 2007, right after the Pu'er earthquake in Yunnan Province, our model estimated the loss amount to be 850million RMB while the final loss from field investigation was reported to be close to 1billion. Similar, right after the May 12, 2008 Wenchuan Earthquake, the model estimated a loss and casualty number which was 10 times higher than any other estimates at that time. The estimate was still way below the final reported number, but it was good enough to help the Chinese government to make decisions to mobilize extra personnel for emergency response, search and rescue efforts (Zifa Wang, et al, 2008).

2.2 The objective of the open platform

From the above description, it can be inferred that a lot has happened in the earthquake engineering research community in its 100-plus years of history. There is a lot of progress made and there are numerous achievements as well. Whereas, fundamentally there exist two problems. The first is the scattered distribution of different types of resources. As previously stated, there are at least 80 countries with earthquake research activities and there is a wide distribution of similar research programs and similar experimental facilities. This heterogeneous thin distribution makes it difficult to tackle large and complex problems in earthquake engineering. The second is the lack of effective communication and information exchange, which results in duplicate work and a great waste of time, money and other resources.

To solve the above mentioned two problems, there appears to be an urgent need to build an open platform that can help share the resources and improve the communication and information exchange. Specifically, there are four objectives for this open platform, 1) to aggregate and integrate all the results achieved in the past research activities; 2) with the help of the integration to lead future research activities and guide future research directions; 3) to share the information and knowledge; and 4) to form an effective and geographically distributed team.

2.3 Major components in the open platform

There are essentially three key components in the open platform: 1) research methods and theory; 2) experiment and observational system; 3) basic information system.

The research methods and theory part looks like an application platform where past research results are integrated and assembled. It functions like a special operating system for earthquake engineering in which past results are assembled as modules which serve as the basic element for future application programs. To some extent packages such as OPENSEES serve as a good starting point to implement this component.

The experimental and observational system part looks like a combination of NEES and other observation networks. All the nodes are connected with the latest networking technology and the network acts like a collaborated experimental facility that can be shared around the world.

The base information system contains mostly the basic data needed for earthquake engineering research. It is a huge database that encapsulates all pieces of information needed for conducting researches in earthquake engineering.

The center underlying layer that connects the above three components is the information technology infrastructure, which is composed of hardware and software. The hardware component is the networked environment including servers (computation and storage), connecting nodes, routers, audio and video equipments, etc. The software component consists of an active, distributed and dynamic information platform that is open-source, network enabled and highly integrated system.

2.4 Relationships among the three components

It should be noted that the three components in this open platform are not independent; rather they are interrelated with a high degree of interaction among themselves. Because of the modular design, a future application can assemble different modules from different sources to fulfill its requirement. For example, in simulating strong motion there can be multiple choices. For one, we can potentially use the earthquake source module and the empirical attenuation module. For two, we can use the module of Green’s function combining with earthquake source module, and lastly we can also use the source module with FEM modeling to calculate strong motion. Furthermore, the flexibility of modular assembling can enable new combinations including the inclusion of experimental module into the simulation process. It can be expected that after the completion of the platform, many new ideas and trials can be developed because of the information sharing and modular integration of all the relevant theory and research results.

3. Design of the Open Platform

3.1 The overall structure of the open platform

From the software architectural design point of view, the overall design of the open platform can be expressed in Figure 1.

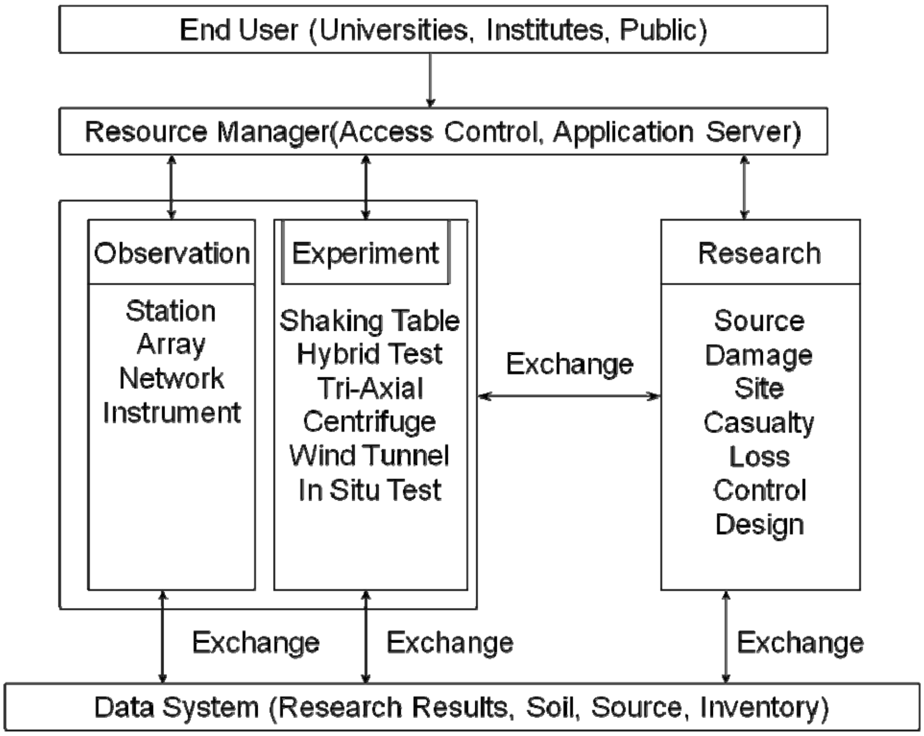

Figure 1 Major Components of the Open Platform

From Figure 1 we can see that the open platform is somehow similar to a generic information platform. For implementation, we can certainly expand the current NEES functionality to include both experimental and observational networks. We can also learn from OPENSEES to design our simulation and theoretical research component.

3.2 Technical Design of the Open Platform

To implement the idea proposed in Figure 1, we need to have a high-level design of the software structures. A simplified version of the software structure is illustrated in Figure 2. There are three main characters for this structural design. The first is the layered structure. The advantage of the layered structure is that it is not only good for maintenance, but also for future upgrades. We can replace any layer in the system instead of the whole system to save money, time and labor. The second is the modular design. The advantage of a modular design is easy to maintain, to use and to upgrade. Any independent function can be packaged as a modular for future assembling. The third is an independent server for management. This independence is very important for security, reliability and efficiency.

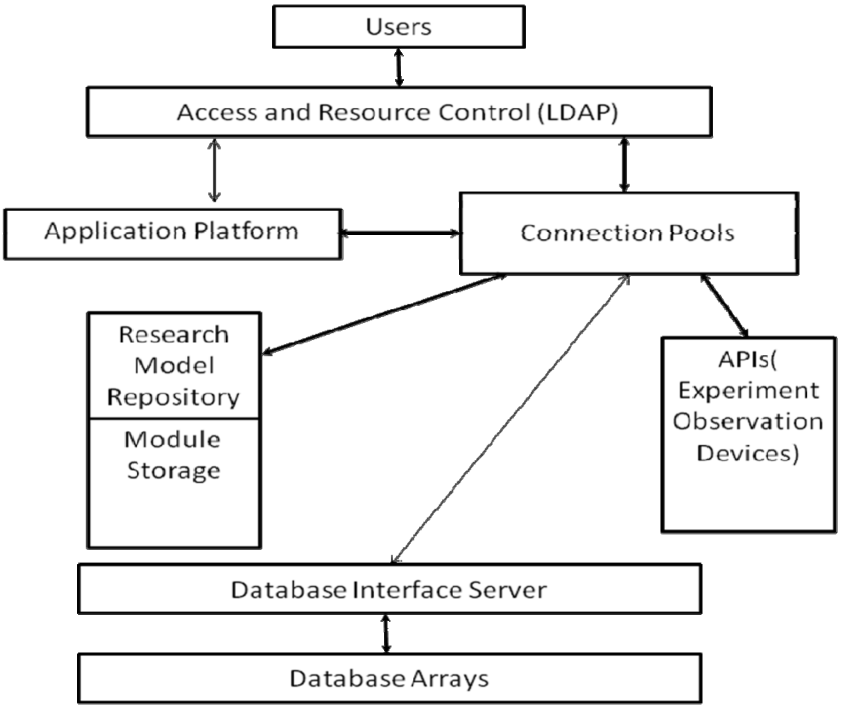

Figure 2 Software Structural Design of the Open Platform

To accommodate the need from the software structural design, the hardware layout will be relatively easy, which is shown in Figure 3.

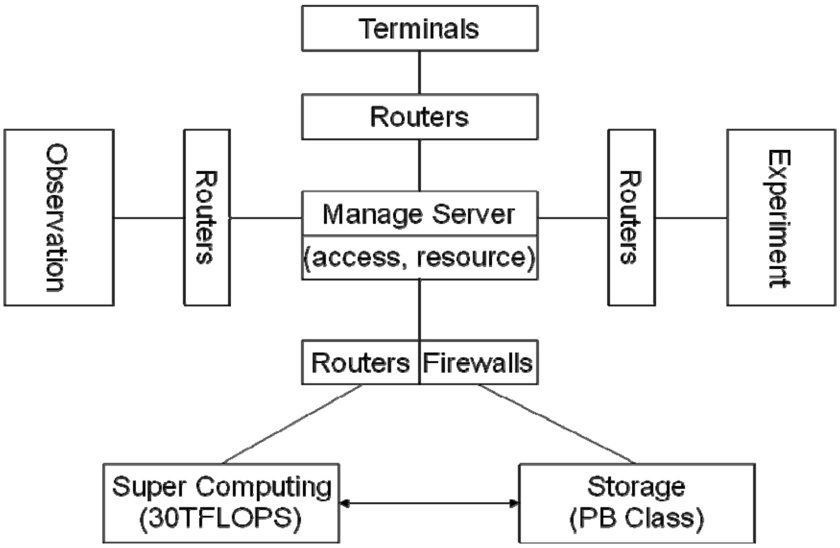

Figure 3 The Hardware Design of the Open Platform

From Figure 3 we can see that there are again three hardware components, the super-computing center, the storage and the networking connection and peripherals. It should be noted that the experimental and observational network can be an independent and separate sub-system, which is connected to the system via its own version of APIs.

3.3 Technical specifications for the open platform

The proposed open platform is a highly integrated and complex system. It is very difficult to give a single specification value to describe the current status of the system. We try to summarize a few specifications from four different angles, the functionality, stability, security and usability.

The technical specifications required for functionality can be summarized as follows:

- Extensibility: This is very important for future upgrades and repairmen.
- Computation speed: TFLOPS is a necessity because of the highly complex configuration and high demand in computing.
- Storage at PB class: With the accumulation of audio and video files, the demand for large storage is inevitable.
- High network bandwidth: A collaborated network for real time testing requires at least GB level bandwidth.
- A modularized parallel system: Modular and parallel are the two key words here and they are required for efficient high-computing system.
- Open source: Open source is a must in any effort for dynamic information sharing.

The specifications required for stability can be described in the following.

- Hardware online time: 99.99%. A higher demand is put on hardware because of its support for the whole system. This can be achieved with a racked parallel system.
- Software online time: 99.9%. Requirement for software system can be relaxed because in this disperse environment, most processes are parallel, therefore, a problem in one application is not easy to propagate within the system.

The specifications required for security are summarized as in the following.

- A layered management system: This is essential for different roles of accessing and managing the system.
- Separation of data and programs: This is designed for the security of the data in the system.
- Multiple authorizations: It is possible to process multiple authorizations given the layered structure.

The specifications required for usability are summarized as follows:

- Ease of information sharing.
- Remote access
- Ease of assembling new modules
- Ease of establishing diversified team
- Self adapting capability

4. Implementation Plan of the Open Platform

4.1 Plan for the hardware installation

Hardware installation includes the content of construction, the schedule and the financial support. On the super-computing side, IEM has procured a 384-node 8-CPU per node system with a theoretical top speed up to 32 TFLOPS. The PB class storage design is also approved with financial support for the first 200TB storage. The observational network for strong ground motion is already completed and in operation. The experimental facility and its networked environment design have been approved with funding to build a 16-meter high reaction, a shaking table array, a centrifuge and a structural lab in IEM. The construction schedule is also well planned and it is expected to be put into first-phase operation at the end of 2008. It is hopeful that a field trip be arranged during this 14WCEE for interested participants to visit the site of the construction. The financial support has been steady and continuous. So far, IEM itself has secured close to 100million RMB for improving the networked environment and procuring the super-computing and high-storage system.

4.2 Plan for software implementation

Parallel with another key research project led by the author, the design of this open platform has been finished. It is expected to up and running by the end of 2009. In terms of facilitating the research budget needs, there are already a number of projects approved that can support the research on this platform. Furthermore, there is continuous support for IEM to conduct its research at its own discretion and it is relatively easy these days to obtain research funds even on a competitive basis.

5. Conclusions

This paper summarizes the recent challenges faced by earthquake engineers based on which the author proposed an open platform to fully integrate and connect the community worldwide in the field of earthquake engineering. The rapid economic growth in China has provided IEM with a unique chance to realize and implement such a gigantic project with a grand vision. The initial result of the implementation seems to be promising and China is on track to catch up with its peers from other parts of the world.

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