Engaging Undergraduate Students into Advanced Earthquake Engineering Research

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Abstract

Preparing undergraduate students for advanced studies is critical to enhance engineering education for future American workforce. This paper presents the engagement of undergraduate students into a two-year BRIGE project funded by National Science Foundation. The research project aims to establish a reliability assessment approach for real-time hybrid simulation with the presence of actuator delay during the test. Real-time hybrid simulation has been widely considered the most effective and efficient alternative for shake table test to accommodate rate-dependent behavior within large-scale civil engineering infrastructures. Research is urgently needed for reliability assessment of experimental results of real-time hybrid simulations. A total of five undergraduate students were recruited with varying knowledge background in earthquake engineering. To involve these students into research activities, they were provided introductory lectures on structural dynamics and real-time hybrid simulation. Numerical model using Matlab and Simulink is created to emulate nonlinear structural behavior under selected ground motions. The students were instructed to conduct computational simulations of a nonlinear structure using recorded ground motions from PEER strong motion database and to interpret the simulation results to analyze the effect of actuator delay in real-time hybrid simulation. These engagement activities of undergraduate students have been demonstrated very effective preparing the undergraduate students for the further study to accomplish the project objectives.

Introduction

In 2010 the Committee to Assess the Capacity of the U.S. Engineering Research Enterprise published a report indicating that engaging students in engineering research is essential for our nation's competitiveness and long-term productivity in a global, knowledge-driven economy[1]. To achieve this objective, the National Science Foundation (NSF) provided the Broadening Participation Research Initiation Grants in Engineering (BRIGE) program which intends to increase the diversity of researchers in the engineering disciplines. The goal of the BRIGE program is to support innovative research and diversity plans that contribute to recruiting and retaining a broad representation of engineering researchers especially those from groups that are underrepresented in the engineering population[2]. In 2012, the project titled "Reliability Assessment of Real-Time Hybrid Simulation Results for Performance Evaluation of Structures under Earthquakes" led by first author was funded by NSF to develop a probabilistic approach to assess the reliability of experimental results using the real-time hybrid simulation technique for replicating actual structural responses during earthquakes. To accomplish the project objectives, a total of five undergraduate students are recruited at San Francisco State University (SFSU). This paper presents the engagement of these five undergraduate students into an on-going two-year BRIGE project.

SFSU is one of the 23 campuses of the California State University system and one of the nation's most ethnically and culturally diverse master's-granting universities. With a total enrollment of 29,718 in fall 2010, SFSU is the 51st largest university in the country[3] and ranks 14th in the nation in awarding undergraduate degrees to minorities[4]. Of the 29,718 enrolled students, who reported their ethnicity in fall 2010, 37.2% were from underrepresented minority (URM) groups including 21.5% Latino; 5.9 % African American; 0.8 % Pacific Islander and 0.4% Native Americans. The students in the School of Engineering are equally ethnically, culturally, academically, and economically diverse. About 15% of the School's students are women and 78% are students of color (33% Asian, 20% Filipinos and Pacific Islanders, 16% Hispanic, 8% Black, and 1% Native Americans). The diverse student body at SFSU provides an ideal environment to accomplish the goal of the NSF BRIGE program.

The research objectives of the funded BRIGE project are: 1) Analyze the effect of actuator delay on accuracy of real-time hybrid simulation involving single or multiple actuators. 2) Conduct correlation analysis between actuator delay and simulation accuracy based on numerical analysis results. 3) Incorporate the probability model to develop probability-based criteria for reliability assessment of real-time hybrid simulation results. 4) Validate the effectiveness of the reliability assessment approach by applying it to experiment results from real-time hybrid simulations. Along with these research objectives, this BRIGE project also aims to: 1) create a diverse research group at SFSU to provide student researchers with meaningful research experiences and prepare them for engineering careers; 2) develop learning modules on earthquake engineering and involve student researchers into state-of-the-art earthquake engineering research so as to prepare them for their future more advanced degrees; 3) provide student researchers opportunities to participate and present at engineering conferences.

Challenges for Engaging Students into Research Activities

Laboratory experiments play a critical role in earthquake engineering research. Devastating structural damages and loss of human lives in recent earthquakes in Christchurch New Zealand[5] and Tohoku Japan[6] call for advances in research on seismic resilient infrastructures. Numerical simulations have inherent limitations due to the simplification of complicated force-deformation relationships within engineering structures. Laboratory experiments therefore play a critical role by enabling immediate evaluation of structures under simulated earthquake loading and by providing data to calibrate numerical models. Findings from laboratory experiments not only replicate the damage and failure of structures during earthquakes, but also provide the most effective means for the earthquake engineering profession to understand and utilize new technologies to engineer structures that withstand earthquakes. Real-time hybrid simulation technique[7~10] divides the simulated structure into: (i) experimental substructures to be physically tested in laboratory, and (ii) analytical substructures to be numerically modeled. Typically, although not always, not well understood key components of the structure are physically tested as experimental substructures in the laboratories, while well-behaved parts are numerically simulated as analytically substructure in computer programs. A numerical algorithm is used to integrate the substructures and solve the structural dynamics in a step-by-step manner. The dynamic response of civil engineering structures, especially those in which complex nonlinear behavior is expected to occur in only a few locations, can therefore be simulated realistically and cost-effectively at large- or full-scale in the size limited laboratories. Figure 1 depicts a typical application of the real-time hybrid simulation technique, in which the energy dissipating devices are isolated as experimental substructures, and the steel moment resisting frame (MRF) is modeled analytically. Real-time hybrid simulation therefore represents the state-of-the-art research activities in earthquake engineering. The funded BRIGE project therefore provides a unique opportunity for students at SFSU to have meaningful research experience in the field of advanced earthquake engineering. Along with this also come the challenges to engage students at SFSU to understand the technical background and to produce meaningful results.

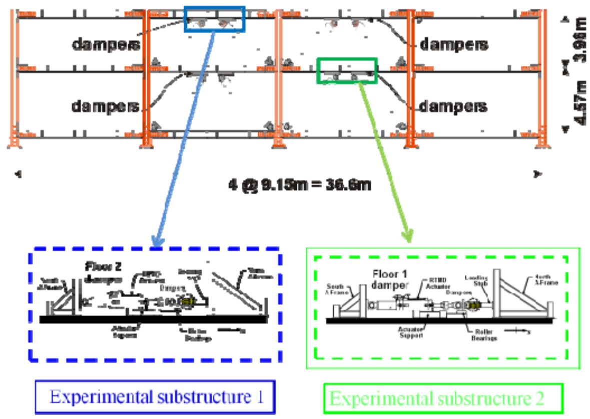

Figure 1. Real-time hybrid simulation of MRF with energy dissipating devices

With the support of NSF funding, a total of five undergraduate students at SFSU were recruited for the BRIGE project. Three of them are seniors and the other two are juniors. One is female and three of them are Hispanic students. As to the academic background, two of the five student researchers have finished the fundamental engineering course on structural dynamics and vibration, while another two were taking the course concurrently during the previous spring semester. During the first few weeks, the PI met the students twice a week to provide introductory lectures to the student researchers. These lectures focus on fundamentals of the BRIGE project including MATLAB[11] programming, structural dynamics and nonlinear structural behavior. For example, the nonlinear behavior considered in this project is emulated using the Bouc-Wen model[12], which is mathematically expressed by several differential equations. To help the students to understand and to be able to simulate nonlinear single-degree-of-freedom structure when subjected to selected ground motion, a Simulink model is developed as shown in Figure 2. After each lecture, the student researchers were required to make slight modifications to the MATLAB script to incorporate the varieties in ground motions, properties of SDOF structure and time delays. After four-week lectures, the students researchers started to understand the concept of real-time hybrid simulation, nonlinear structural behavior and computational simulation using MATLAB and Simulink[11].

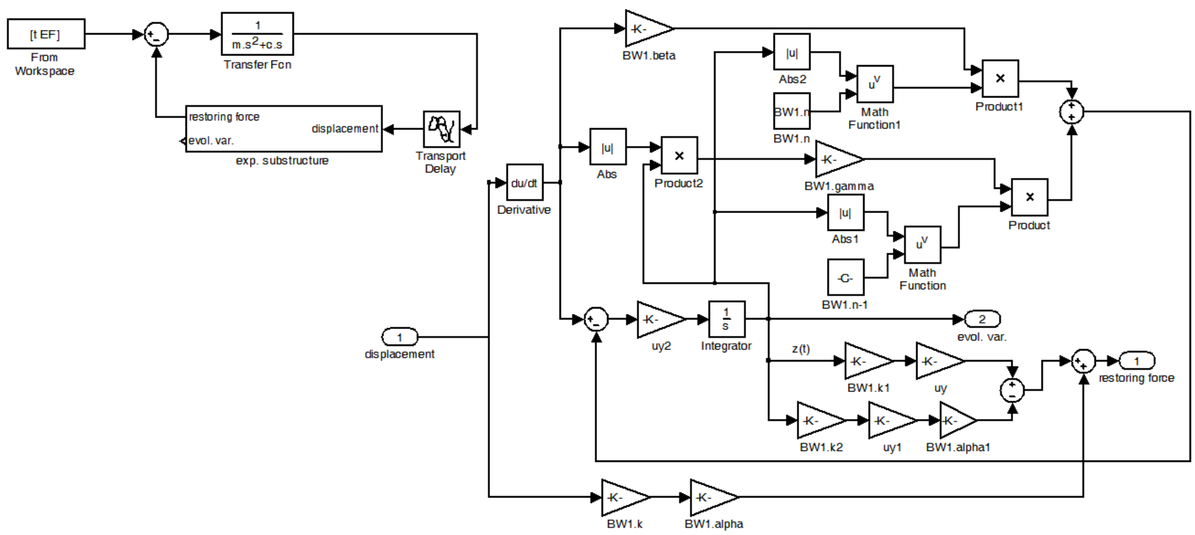

Figure 2. Simulink model for computational simulation of structural response under earthquakes

Another challenge is how to actively involve the recruited students into the research activities. All the student researchers have taken the PI's class in the past and the recruitment is based on academic standing and motivation. Around ten students have contacted PI for research opportunities and five of them are finally selected. To facilitate discussion, the students are divided into several groups working on different research topics. During the first semester, it has been shown that it is quite difficult to motivate all the recruited to devote themselves to the project. Two major issues exist: 1) Time management. During the junior and senior years, the students often take fourteen to sixteen units classes and also have part-time jobs ranging from 10 to 15 hours per week. It is difficult to have the students finish the assigned research tasks in time. 2) Financial support. The NSF funding provides an hourly rate of $11 for student researchers and a maximum of 20 hours per week. This is not comparable with internship payment. It is difficult provide enough financial support to students researchers to concentrate on the project.

Project Research Outcome

The research experience during the first semester (September to December 2012) enabled the student researchers to develop fundamental concepts about the BRIGE project, involve in state-of-the-art earthquake engineering research for the first time during their undergraduate study. Student researchers meet weekly with their supervisor to discuss their progress on their research and provide feedback on what they can achieve. The student researchers will need to balance between their course work and research task which helps them develop time management capability for their future career. The research activities have led to a peer-reviewed conference paper in Structures Congress[13] and two other publications are being submitted.

Figure 3 shows the computational simulation results for the effect of different ground motion inputs on the accuracy of real-time hybrid simulations with actuator delay including the ground motions recorded during the 1994 Northridge and 1995 Kobe earthquakes. The SDOF structure is assumed to be linear elastic. It can be observed that for the same amount of delay, different ground motions will lead to different values of maximum error. The student researchers are guided to conduct for computational analysis which further demonstrated that the actuator delay for given accuracy measure in terms of maximum error varies for different ground motions.

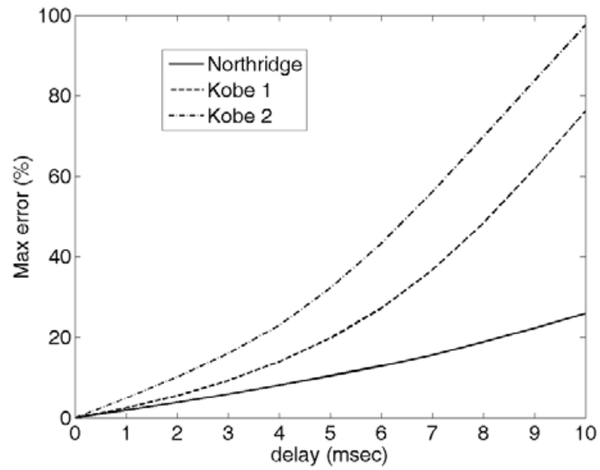

Figure 3. Effect of actuator delay on real-time simulations with different ground motions[13]

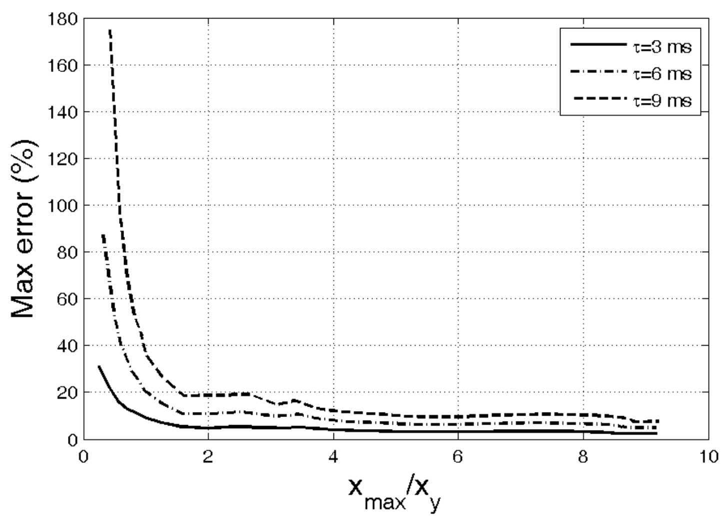

Figure 4. Effect of actuator delay for different ductility demands[13]

The students were further guided to analyze the effect of nonlinear behavior on the accuracy of real-time hybrid simulation results. Figure 4 shows that the maximum error for real-time hybrid simulations of a SDOF structure decreases with the increase of the ductility demand when the time delay is 3 ms, 6 ms and 9 ms, respectively. The yield displacement of the SDOF structure is 24.8 mm. The scale of the ground motion is gradually increased to achieve larger values of x_{max}/x_y. For the case of time delay equal to 3 ms, the maximum error in simulated response decreases from 9.37% for x_{max}/x_y equal to 1.0 to 4.22% for x_{max}/x_y equal to 3.2. Similar observation can also be made for the cases of time delay equal to 6 ms and 9 ms. Figure 4 reveals that for the same actuator delay, the maximum error of a real-time hybrid simulation involving nonlinear behavior could be estimated based on that for corresponding linear elastic structure by considering the ductility demand imposed on the SDOF structure.

Figure 5 shows an exploratory study by a student researcher on smart hybrid simulation [#]. Modeling errors are introduced into the analytical substructure parameters. The simulated response with modeling error is compared in Figure 5(a) with the exact structural response to demonstrate the detrimental effect. The error in simulated response in Figure 5(b) could reach 25% of maximum structural response. Figures 5(c) to 5(d) show the synchronized subspace plot between the restoring forces from the experimental and analytical substructures. Figures 5(f) to 5(h) demonstrate the effectiveness of modeling accuracy indicator (MAI) for assessing the accumulative error in restoring force due to the modeling error.

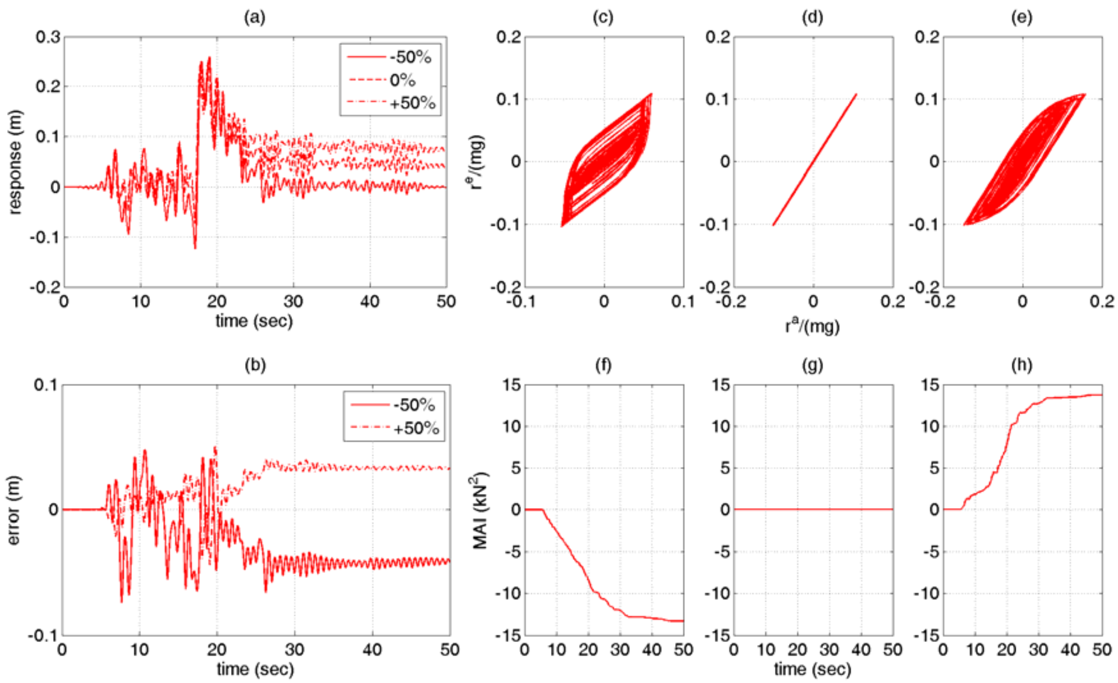

Figure 5. MAI for effect of error in yield displacement[14]

Summary and Conclusion

The NSF funded BRIGE project has been successful in engaging five undergraduate students at SFSU into state-of-the-art earthquake engineering research on real-time hybrid simulation. During the first semester, the project has helped the student researchers understand earthquake engineering topics. Under the supervision, the students have contributed to two peer-reviewed conference publications to demonstrate the success of this project engaging undergraduate students into engineering research.

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