Earthquake Engineering Education: A Modern Approach

S.J. Dyke, B. Nepote, J.M. Caicedo, S.M. Johnson and E.A. Oware
Washington University in St. Louis

Abstract

Currently civil engineering undergraduates have limited opportunities to gain an understanding of the principles of structural dynamics or exposure to the innovative new structural control methods. “Hands-on” experiments seem to be particularly effective for teaching basic concepts in dynamics and control. The objective of the educational program described in this paper is to systematically integrate these topics into the undergraduate civil engineering curriculum. Three bench-scale seismic simulator tables are being used to integrate a series of “hands-on” experiments in structural dynamics and control throughout the civil engineering curriculum at Washington University. This paper discusses how structural dynamics and earthquake engineering are being integrated into the undergraduate program at Washington University. Additionally, outreach activities and undergraduate research experiences influenced by the equipment are discussed. Furthermore, an outgrowth of this program, the multi-institutional University Consortium on Instructional Shake Tables, is introduced.

1. Introduction

The importance of understanding the effect of earthquakes on structures to the civil engineering community is apparent. Recent catastrophic earthquakes in Northridge, Kobe, Turkey and Taiwan have reminded us of the powerful and potentially deadly consequences of such natural events. At the undergraduate level, few students have opportunities to gain experience with the behavior of structures subjected to earthquake loading. Even fewer students are exposed to the exciting possibilities that recently developed structural control techniques offer the civil engineer.

In the last two decades, the concept of using structural control systems to mitigate the potentially catastrophic effects of severe seismic events has attracted much attention in the civil engineering research community. These types of control systems, often termed protective systems, offer the advantage of being able to dynamically modify the responses of a structure to increase its safety, reliability, and serviceability. This technology has the potential to revolutionize earthquake engineering, especially in vulnerable existing buildings which are characteristically difficult and expensive to retrofit. The undergraduate students at Washington University are aware of these issues and have demonstrated a great deal of interest in earthquake resistant design.

The goal of the educational program described herein is to provide the undergraduate students at Washington University with an understanding of basic concepts in structural dynamics and exposure to the exciting new structural control techniques. This objective is being achieved by integrating a series of “hands-on” experiments into the civil engineering curriculum. The experiments have been designed to provide the students with a background in the basic principles of structural
dynamics, and the implications of these principles in structural design. Students are expected to tie the theoretical concepts discussed in class to their experimental observations. Moreover, students have an opportunity to investigate innovative techniques in earthquake hazard mitigation, including active, passive and semi-active techniques. Through these experiments they are introduced to the latest research results in structural control.

Although the program described herein was developed by the senior author, all of the student authors played a role in making this project a reality. They have been involved in various aspects of the program including the development and implementation of the experiments used in the undergraduate coursework. Additionally, they have been involved in the equipment installation and operation, system integration, and web page development. Furthermore, some of them are conducting undergraduate research projects using the equipment described herein.

The laboratory activities are based on the use of a bench-scale seismic simulator, or shake table. Creative utilization of the equipment has offered numerous opportunities to supplement the rather conventional content of several courses by integrating “hands-on” experiments in earthquake engineering. The plans are designed to provide exposure to structural dynamics and control in the freshman year, and then expand this knowledge through the senior year. Additionally, experiments in passive, active, and semi-active structural control will allow undergraduates to further explore the implications of various design and mitigation strategies. Moreover, students at all levels will learn the fundamentals of using modern equipment and instrumentation, including sensors, actuators, and data acquisition/analysis systems. Additionally, on-line exercises are under development to allow students to familiarize themselves with basic concepts in the use of such equipment before they enter the laboratory.

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2. Equipment

The essential equipment for classroom experiments in earthquake engineering is the bench-scale earthquake simulator, or shake table. This instrument, based on similar larger scale research facilities, has the capability to reproduce the motion of the ground during an earthquake, allowing for examination of structural behavior and of the performance of both conventional and innovative techniques under controlled conditions.

A shake table lab station also consists of a 350 MHz Pentium II computer, a seismic simulator table, a multi-story structure, passive control devices, an active mass driver to control the structure, appropriate sensors, a data acquisition system, and a real-time control system. Thus, in addition to learning about structural dynamics and control, this lab station has been designed to facilitate learning the fundamentals of using data acquisition/analysis systems, sensors, actuators, and digital control systems.
The bench scale uniaxial shaking table has a 18”x18” plate, which slides on high precision linear bearings and is driven by a Kollmorgen Silverline Model H-344-H-0600 motor fitted with a 1000 LPR IP 40 encoder. The earthquake simulator uses unit gain displacement feedback, and control is achieved using the MultiQ Board digital controller from Quanser Consulting Inc. The MultiQ board is a general purpose data acquisition and control board which has 8 single ended analog inputs, 8 analog outputs, 16 bits of digital input, 16 bits of digital outputs, 3 programmable timers and up to 8 encoder inputs decoded in quadrature. The system is addressed through the PC bus. The operational range of the simulator is 0–20 Hz.

A series of multi-story test structures have been constructed for testing (see Fig. 1). Various masses and stiffnesses have been built so that the students can compare and contrast the behavior of a variety of structures, and learn how mass and stiffness affect the dynamics of a structure.

The lab station also includes a Siglab 20-42 PC-based spectrum analyzer manufactured by DSP Technology Inc. This analyzer has 4 input and 2 outputs supported by the 18-bit sigma delta converters. The dynamic range is 84 dB, and the real bandwidth is 20kHz. The system has the function generator which can output periodic signals, random signals as well as user defined signals. Interfacing with the Siglab hardware is done through MATLAB. The structures tested are instrumented with PCB accelerometers.

The laboratory stations also include various control devices for the structures. A passive damper was developed for the small scale structures. The damper itself is the shock absorber from a remote control stunt car. The device is attached to the structure through a plexiglass tube. Undergraduate students in civil engineering have an opportunity to test this device and observe the behavior of a dampered structure.

* Quanser Consulting, 102 George Street Hamilton, Ontario, CANADA.
† DSP Technology Inc., Signal Analysis Group, 48500 Kato Road, Fremont, California 94538 USA.
** PCB Piezotronics, Inc., 3425 Walden Avenue, Depew, New York 14043 USA.
In senior/graduate level courses, an active mass driver (AMD) is used for experiments. This device, shown in Figure 3, consists of a moving cart, designed by Quanser Consulting Inc., driven by a DC motor. The maximum stroke is $\pm 15$ cm with a nominal maximum acceleration of 5g’s.

3. Overview of the Educational Program

Curriculum Development

At the undergraduate level, experiments have been introduced into existing courses and new courses. Four courses are currently utilizing the shake tables to do “hands-on” experiments, including one freshman level course (Introduction to Civil Engineering), one junior level course (Mechanics of Materials Laboratory), and two senior/graduate level courses (Structural Dynamics, and Experimental Methods in Structural Dynamics). The integration of structural dynamics and control experiments is discussed in this section.

In the Spring of 1999, a new freshman level survey course, Introduction to Civil Engineering, was developed. The course introduces students to various aspects of civil engineering, including structures, environmental engineering, and transportation systems. A portion of this course is devoted to introducing the students to basic concepts in structural vibrations and dynamic hazard mitigation. Students in this course use the shake tables to examine the effects of mass and stiffness on the natural frequency of a number of single story structures. Additionally, they are introduced to torsional motion of structures as well as passive control systems. All students are required to submit a written report on the results of their experiments.

In the Fall of 1998 an experiment in structural dynamics was added to Mechanics of Materials Laboratory, typically taken during the junior year. This experiment was designed to reinforce and build upon the student’s previous experience with the dynamic behavior of structures, and familiarize them with the instrumentation used in vibration testing. Students construct a structure for testing on the earthquake simulator, with the goal of developing an understanding of natural frequencies, mode shapes, and damping ratios. Additionally, students employ various equipment typically used in vibration testing including sensors (e.g., accelerometers, LVDT’s), actuators, data acquisition systems, and spectrum analyzers. Furthermore, passive and active control systems are discussed and demonstrated for the students.

In Structural Dynamics, generally taken by a mixture of undergraduate and graduate students, students now have an opportunity to relate the mathematical models that they are studying in class to the experimental structures they test in the lab. For example, in one experiment the students will be expected develop a mathematical model for a test structure and compare the predicted results to the experimentally obtained response in a written report or a presentation. They will be expected to explain the differences and similarities between the model and the experimental structure.
In addition a new course, Experimental Methods in Structural Dynamics, has been created. This course provides students with a background in topics such as modal analysis, structural control, system identification, experimental determination of transfer functions, and the behavior of non-linear dynamic systems. A series of illustrative experiments will be performed throughout the course in the earthquake engineering laboratory in which the students will utilize the material learned in class to analyze, identify, model, and control dynamic systems. In addition, these students would gain a thorough understanding of sensors, actuators, and data acquisition/analysis equipment and techniques.

Undergraduate Research Opportunities

In addition to educating students through classroom activities, the establishment of the laboratory stations offers numerous opportunities for undergraduate students to contribute to research projects that will have a significant impact on the future of structural engineering. Often, undergraduate research opportunities inspire students to further their education by pursuing graduate degrees. At Washington University, research conducted on the larger scale shake table located in the Earthquake Engineering and Structural Control Lab has already attracted a great deal of attention from both the undergraduate and graduate student populations. For example, the following quotations from undergraduate researchers in the lab indicate the influence that such undergraduate research experiences have had on Washington University students.

Euridice Oware, a senior in civil engineering, discovered the challenges in earthquake engineering by working as a research assistant. “I had never done anything with earthquakes before,” Oware says. “I know now I definitely want to go ahead and get my master’s degree in civil engineering, and I probably will study a topic related to earthquakes. That’s definitely a change because that was something I never wanted to touch before.”

Scott Johnson, currently a senior in civil engineering, has been working on the development of a safety circuit for the small shake tables that will cut power to the equipment if there is a system failure. Scott says “Working on this project really broadened my perspective on what civil engineers can do. I’ve always been interested in how you could control structures, but working in the lab has really helped me to understand what it means to do research.”
Undergraduates have been involved in the development of the shake table laboratory stations. A visiting undergraduate researcher, Barbara Nepote, conducted a research project to develop a control algorithm for the shake table. The goal of this project was to develop a procedure for controlling the shake table to reproduce historical earthquake records. After implementing this technique on the bench-scale table, she then proceeded to implement this technique on the larger scale shake table. In future structural control experiments this technique will be used to control the shake table. Additionally, as mentioned previously, Scott Johnson has augmented the bench-scale shake table with a safety circuit attached to limit switches at the ends of the table rails to protect against instabilities. In the course of this project he was responsible for development and construction of the circuit.

**Internet Activities**

The Internet is an exciting new arena for educational activities. The web page for the laboratory ([http://www.seas.wustl.edu/research/quake/](http://www.seas.wustl.edu/research/quake/)) contains interactive exercises and videos focused on earthquake engineering, structural dynamics, and structural control. Many videos are currently available for demonstrations of structural control using the shake tables. The interactive exercises will be used in the classroom to introduce students to basic concepts, and prepare students for the laboratory experiments discussed previously. As they are gradually developed, these on-line exercises will be made available through the web page.

**Outreach Efforts**

The establishment of the laboratory also provides additional opportunities for educating the local community. Because of the close proximity of the New Madrid fault, earthquake drills have recently become mandatory in all schools in the St. Louis area. In fact, New Madrid, Missouri is the site of the largest recorded seismic events in the continental U.S. (1811 & 1812), which flattened thousands of acres of forests, formed new lakes, and even changed the course of the Mississippi River. Since then, there have been other damaging earthquakes in the vicinity. Demonstrations will be provided to groups from local school districts to provide these students with an opportunity to learn how civil structures respond to earthquake events. In addition, the general public would be made aware of the existence and benefits of utilizing protective control systems in structures.

Collaboration in the outreach activities is ongoing with both the Earthquake Engineering Committee of the St. Louis Section of ASCE, and the New Madrid Chapter of Earthquake Engineering Research Institute, who have an interest in educating school children about earthquakes. The equipment has already been used for numerous outreach activities in the St. Louis area including
Earthquake Awareness Weekend (see Figure 5), the Washington University Chapter of the Society of Women in Engineering’s Women in Engineering Day, and ACCESS to Engineering Programs.

4. Evaluation

To assess the effectiveness of this program, evaluations are being performed during each course and through the internet site. Evaluations for the relevant courses will be extended to ask the student’s views of these experiences. In addition, students will be asked questions to determine in what ways they benefited from these exercises, and how these experiences may have influenced their career goals. Furthermore, evaluations will be made available on the web page to allow students to submit comments on the courses and others to submit suggestions/questions. Feedback provided by these sources will indicate directions for improvements in both the coursework and the web page.

5. Expansion of the Education Program

This program provided inspiration for the University Consortium on Instructional Shake Tables program (UCIST). The main goal of the UCIST project is develop a set of undergraduate-level, “hands-on” earthquake engineering experiments for a better understanding of earthquake related phenomena. Twenty-three universities across the U.S. are cooperating in the UCIST program. Each university has purchased the same base system to develop earthquake related experiments. This equipment consists of an electronically-driven, bench-scale shake table, a test structure, accelerometers and a computer to record data and control the shake table. Once an experiment is developed for one university, complete information of the experiment is shared with other universities using electronic media as the UCIST program web page (see http://ucist.cive.wustl.edu). The experiments developed in the UCIST project cover different topics as geotechnics, dynamics of structures, K-12 education, earthquake hazard mitigation and many more. This program is expected to serve as a national model for integrating structural dynamics into the undergraduate civil engineering curriculum. The UCIST program is described in detail in Ref. 2.

6. Summary

An educational program has been developed at Washington University in St. Louis to familiarize undergraduates with concepts in structural dynamics and with new approaches in structural control. The students gain an understanding of structural dynamics and control through “hands-on” experiments. The experiments are designed to be performed using a bench-scale shake table. This equipment allows one to simulate an earthquake and study dynamic behavior of structures. Additionally, students have access to experiments to examine the performance of innovative structural control techniques. At Washington University there are already four classes that utilize these shake tables in the classroom.

Additionally, activities such as undergraduate research opportunities using the bench-scale shake table are available for the students at Washington University. Several students, including the co-authors of this paper, have participated in such activities. These projects have had an impact on the students, introducing them to research and motivating them to attend graduate school. Outreach activities in the local community, conducted in cooperation with the St. Louis Section of the
American Society of Civil Engineers and the Mid-America Earthquake Center, have also had an impact on earthquake awareness regionally.

For further information on these educational efforts, see the web page: http://www.seas.wustl.edu/research/quake/.

These efforts have provided inspiration for the three national earthquake centers. The three centers have developed a strategy to incorporate earthquake engineering topics into the civil engineering curriculum through the effective use of bench-scale shake tables. This program, developed by the University Consortium on Instructional Shake Tables, already involves more than 23 universities and is described in detail in Ref. 2 (also see: http://ucist.cive.wustl.edu/).

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Bibliography

SHIRLEY J. DYKE
Shirley Dyke is an Assistant Professor of Civil Engineering at Washington University in St. Louis. She is the Director of the Washington University Structural Control and Earthquake Engineering Lab. Dr. Dyke received her B.S. degree in Aeronautical Engineering from the University of Illinois in 1991, and her PhD in Civil Engineering from the University of Notre Dame in 1996. Dr. Dyke was a recipient of the 1997 Presidential Career Award for Scientists and Engineers. Her current research interests are: structural dynamics and control, earthquake engineering, health monitoring, and system identification. Dr. Dyke teaches courses in structural dynamics, probability and statistics, and experimental methods.

BARBARA NEPOTE
Barbara Nepote is a visiting researcher in the Department of Civil Engineering at Washington University in St. Louis. She received her bachelor degree in December 1999 from the Department of Civil Engineering at the Politecnico di Torino, in Torino, Italy. She plans to continue working in the areas of structural dynamics and control through graduate level research.
JUAN MARTIN CAICEDO
Juan Martin Caicedo is currently a doctoral student in the Department of Civil Engineering at Washington University in St. Louis. Mr. Caicedo received his bachelor degree from the Universidad del Valle, Colombia. His current research interests include structural dynamics and control, earthquake engineering, health monitoring, and system identification. Mr. Caicedo is currently the President of the Washington University Chapter of the Earthquake Engineering Research Institute, and the Washington University graduate representative to the Mid-America Earthquake Center Student Leadership Council.

SCOTT JOHNSON
Scott Johnson is an undergraduate researcher in the Department of Civil Engineering at Washington University in St. Louis. Mr. Johnson will receive his B.S. in Civil Engineering in December of 2000. He then plans to attend graduate school. Mr. Johnson has been an undergraduate research assistant in the Earthquake Engineering and Structural Control Lab since January 1999. He is currently the undergraduate representative to the Mid-America Earthquake Center Student Leadership Council, and holds positions in the Washington University Student Chapter of the American Society of Civil Engineers, the Earthquake Engineering Research Institute, and the Civil Engineering Honor Society.

EURIDICE OWARE
Euridice Oware is an undergraduate researcher in the Department of Civil Engineering at Washington University in St. Louis. Ms. Oware will receive her B.S. in Civil Engineering in December of 2000. She then plans to attend graduate school. Ms. Oware has been an undergraduate research assistant in the Earthquake Engineering and Structural Control Lab since March 1999. Ms. Oware currently works for Army Corps of Engineers and is active on campus in organizations such as the Society of American Military Engineers.