Current Directions in Earthquake Engineering Education: The University Consortium on Instructional Shake Tables

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Abstract

Although considering the dynamic behavior of buildings and bridges is of fundamental importance in modern structural design, undergraduate civil engineering students seldom develop an understanding of the way that these structures respond when acted upon by time-varying loads. Because this topic is of great social and economical importance, there is a need in current civil engineering programs to provide more formal training in structural dynamics and earthquake hazard mitigation at the undergraduate level. Further, many students in non-engineering disciplines would gain from such exposure to basic concepts in earthquake engineering. The University Consortium on Instructional Shake Tables was formed to integrate earthquake engineering into the undergraduate civil engineering curriculum. The twenty-three universities forming the consortium are cooperating to develop a series of “hands-on” experiments for students at all levels. The experiments focus on the use of a bench-scale shake table. This program is expected to serve as a national (and international) model for integrating structural dynamics and earthquake engineering into the undergraduate curriculum.

1. Introduction

One of the most important challenges facing structural engineers of today is the development and implementation of effective techniques for minimizing the severe and often tragic consequences of earthquakes. To meet this challenge, future structural engineers must possess an understanding of the dynamic response of structures such as buildings, bridges, and towers to strong ground motion. Although considering the dynamic behavior of these structures is of fundamental importance in modern structural design worldwide, undergraduate civil engineering students seldom develop an understanding of the way that these structures respond when acted upon by time-varying loads. There is a need for integrating this important topic into the undergraduate curriculum.

Experiments are quite effective for demonstrating basic concepts in structural dynamics and earthquake engineering. Even at the undergraduate level, concepts in dynamics such as natural frequencies and mode shapes can clearly be portrayed during such experiments. To gain an understanding of the behavior of structures subjected to earthquakes, it is helpful to have the capabilities of modifying the dynamic characteristics of the test specimens, selecting different earthquake inputs, and measuring and analyzing structural responses. Students could learn these principles through the introduction of a series of “hands-on” experiments and classroom demonstrations throughout their coursework.

Earthquake simulator tables, or shake tables, are traditionally used for experimental research in earthquake engineering. These instruments are capable of reproducing the motion of the ground during an earthquake, allowing for controlled testing of structures subjected to earthquakes. New concepts and techniques are often tested on scaled structures using shake tables before implementation on actual structures. Shake tables have been used at several universities for educating students about earthquake engineering and structural dynamics. However, few universities have shake tables and due to testing schedules only a handful of these universtities have the freedom to provide students with access to these instruments. Moreover, “hands-on” experiments are not feasible due to the size of the equipment and the specialized training required to operate such systems safely.

Bench-scale shake tables are an ideal alternative to provide students access to such “hands-on” experiments. At this scale, students can observe earthquake responses, design and build model structures, modify their structures, measure structural responses, and reproduce several earthquake records. Further, bench-scale tables are mobile enough to bring into the classroom or even to local grade schools for demonstrations. Thus, it is desirable to introduce experiments based-on the use of bench-scale shake tables into the undergraduate curriculum.

The University Consortium on Instructional Shake Tables (UCIST) was formed to strategically integrate earthquake engineering and structural dynamics into the undergraduate curriculum. UCIST is a consortium of twenty three universities associated with the three national earthquake engineering centers – the Pacific Earthquake Engineering Research Center (PEER), the Multidisciplinary Center for Earthquake Engineering Research (MCEER), and the Mid-America Earthquake Center (MAE). In June of 1998 a task force was formed with representatives from each center, to develop a strategy to achieve this goal, identify equipment specifications, contact vendors to develop bench-scale shake tables, and select the equipment to purchase. This cooperative effort is expected to have a significant impact on the future direction of civil engineering education, and we anticipate that this nationwide effort will result in widespread adoption of this approach by civil engineering educators. As an indication of the potential of this program on the undergraduate civil engineering curriculum, twelve additional universities (beyond the original 23) have joined in the purchase of these shake tables since the UCIST task force selected the shake table.

The focus of this paper is to provide a detailed description of the UCIST program objectives and strategy. The bench-scale shake table selected for this program is described in detail. The program outcomes and products, including experimental lab manuals, design competitions, outreach activities, and undergraduate research possibilities will be discussed. A comprehensive evaluation plan is described that is designed to determine the effect the program has on the UCIST institution students, as well as the extent to which these experiments are implemented nationwide. Further, an internet-based approach is used to disseminate the outcomes of this program to a broader audience. This program is expected to serve as a national (and international) model for integrating structural dynamics and earthquake engineering into the undergraduate curriculum, a recognized need within civil engineering. The program is funded by the National Science Foundation (NSF Grant No. DUE-9950340) headquartered and managed at Washington University in St. Louis. The most up-to-date details on the program can be found on the UCIST web page: *http://ucist.cive.wustl.edu/*.

Table 1: Universities Forming the UCIST.

University	University
University of Illinois	San Jose State University
MIT	University of Alaska–Fairbanks
Stanford University	University of Hawaii
University of California – Berkeley	University of Nevada – Las Vegas
University of California – Davis	University of Nevada – Reno
Oregon State University	University of California – San Diego
University of California – Los Angeles	Southern Illinois University – Edwardsville
Virginia Tech	Pennsylvania State University
University of Utah	Florida A & M
California Polytechnic State University	Washington State University
University of Notre Dame	Washington University
University of California – Irvine	

2. Equipment

Table 2: Specifications for Seismic Simulator.

Specification	Value
Design Payload	25 lbf
Peak Acceleration	1 *g*
Operational Frequency Range	0–20 Hz
Peak Velocity	20 in/sec
Sliding Table Dimensions	18 in x 18 in
Stroke	6 in (+/- 3 in)
Weight of Shake Table	< 100 lbf

The experiments to be developed for the UCIST program are based around the bench-scale shake table. Each institution involved in the program has purchased the shake table selected by the Task Force and the price was negotiated on a volume basis. To ensure that the shake table would be useful for a variety of experiments, the UCIST Task Force developed the design specifications given to the vendors. Additionally, the specifications included a requirement that the shake table is computer-controlled with a straightforward interface, is portable for off-site demonstrations, has maintenance-free operation (for at least 10 years), is "student–proof" to prevent injury or damage, and is reasonably priced. Further, the goal is to obtain an instrument that can be easily assembled and requires minimal start-up time before experimentation can begin.

Three vendors participated in developing prototype units and bidding on the project. The bench scale shaking table selected by the UCIST Task Force is produced by Quanser Consulting, Inc*. This instrument, shown in Figure 1 has a 18"x18" plate, which slides on high precision linear bearings and is driven by a Kollmorgan 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 a MultiQ board. The MultiQ board is a general purpose data acquisition and

*. Quanser Consulting, 102 George Street Hamilton, Ontario, CANADA.

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.

The shake table is controlled by a Pentium computer using Wincon software. The package comes with several historical earthquake records. Time and amplitude scaling is readily implemented using the provided software. In addition to the shake table, the laboratory package purchased includes a two story test structure and three accelerometer to measure the excitation and system responses. The package also includes a stand-alone function generator for off-site demonstrations.

The complete package allows students to reproduce earthquakes, observe structural behavior, measure structural responses, and utilize sensors and modern computer control systems. Further the system purchased facilitates off-site demonstrations and other outreach activities.

Additionally, several institutions opted to purchase an active mass driver (AMD) for the structure. The AMD (shown at the top of the structure in Figure 1) consists of a moving cart that is driven horizontally at the top of the structure to reduce structural vibrations. This equipments allows educators to introduce the concept of active controllers for buildings.

Figure 1. Bench-Scale Shake Table with Model Building and Active Mass Driver.

3. UCIST Program Description

The primary goal of the UCIST program is to develop a series of experiments that will be capable of providing undergraduate students with an understanding of structural dynamics, while being affordable for the institutions. The outcomes of this cooperative effort will include drawings of the scaled models, a set of laboratory manuals, experimental results, video-tapes, and a CD-ROM containing drawings and manuals to allow for the reproduction of all of the experiments. This section will provide a detailed description of the program goals and objectives, strategy to achieve these goals, outcomes and products, and supplemental activities.

3.1 Goals and Objectives

The primary goal of the program is to instruct undergraduate students in concepts in structural dynamics and earthquake resistant design. This goal will be achieved through the introduction of experiments in earthquake engineering throughout the civil engineering undergraduate curriculum. The experiments will focus on the use of “hands-on” seismic simulation experiments which will offer students opportunities to operate the shake table, excite scaled models of various civil engineering structures (e.g., buildings, bridges, towers, etc.) with typical earthquake loads, learn basic concepts in structural dynamics, and utilize sensors to measure responses of the structures.

The basic strategy behind the program described herein is to work collaboratively to achieve the project objectives, resulting in a well-integrated series of experiments that are geared for undergraduate students at all levels. Experiments will be developed for students at all levels – from freshman level introductory courses through senior/graduate level courses.

The specific objectives of these activities are: i) to develop an understanding and an intuition regarding the dynamic nature of structures in undergraduate students; ii) to reinforce theoretical concepts through the use of "hands-on" laboratory experiments; iii) to provide experience in the use of modern engineering tools including sensors, actuators, and data acquisition/analysis equipment; iv) to provide non-engineering students with exposure to the potential consequences of earthquakes and the dynamic behavior of civil engineering structures; v) to provide exposure to emerging technologies and modern methods in seismic resistant design; and vi) to improve technical communication abilities through written reports and oral presentations. These objectives will be achieved through the development of a series of illustrative structural dynamics experiments, and the integration of these experiments into the undergraduate curriculum.

Furthermore, experiments will be developed for non-engineering students that will benefit from such exposure (e.g. architects and geo-scientists). Additional activities include plans for developing two nationwide competitions in earthquake resistant design, one for undergraduates and one for elementary school children.

3.2 Outcomes and Products

The primary outcome of the UCIST program will be a series of experiments for students at all levels. These experiments are designed to introduce students to relevant topics such as: introductory concepts in structural dynamics; general behavior/response of structural systems (buildings, bridges, towers, and dams); design aspects of such structures; liquefaction; application of new materials in civil engineering; response of non-structural components; and, introduction to emerging technologies.

In addition, many students in non-engineering disciplines would benefit from an introduction to basic concepts in earthquake engineering. For instance, government officials responsible for making decisions regarding building codes, and corporate managers responsible for making decisions on upgrading facilities to make them earthquake resistant, would gain from exposure to the potential consequences of earthquakes, the uncertainty in predicting structural responses, and the techniques available to mitigate these hazards.

To provide information to encourage duplication of these experiments, as well as introduce a mechanism to distribute this information widely, the following products will result.

- Designers of each experiment will develop a laboratory manual containing: 1) plans for the test specimen, 2) relevant theory, 3) experimental setup, 4) required exercises, 5) any in-house software designed for the experiment, and 6) anticipated results for comparison. The laboratory manual will be provided in a web-based format for direct insertion into the program web site.
- Video tapes will be produced to give students exposure to various experiments. For instance freshman engineering students at one institution focusing on a building model can see a video containing a series of experiments on bridges, towers, and liquefaction, at the freshman level.

- The final product will be a CD-ROM which will contain all laboratory manuals, photographs of the experiments, software, and video-clips. This CD will be made available to the academic community.
- As a result of the outreach activities, the program will produce a set of Seismic Resistant Design Student Competition Guidelines for student competitions. These will be provided to any institution that is interested in holding such competitions.

The UCIST program is designed to be a cooperative effort. Each university has selected a specific task (experiment, design competition, video, outreach activity, etc.). These tasks will be performed at the respective universities and the final products will be made available on the web site. Once all of the experiments are developed, each of participating universities will select and integrate at least three experiments into their curriculum in a way that most effectively achieves the goals of that institution's educational program.

3.3 Additional Activities

Although the primary focus of the requested equipment is the systematic integration of earthquake engineering into the undergraduate curriculum, there are many other exciting opportunities to use this equipment for educational purposes. These plans are described in the following paragraphs.

Nationwide Student Design Competition. Introducing a diverse group of students to the challenges of seismic resistant design at an early age may encourage these bright students to consider a career in civil engineering. Thus, the three earthquake centers are proposing to develop rules and regulations, and hold a nationwide competition for school children. One university will be selected to be responsible for developing the rules for such a design competition. This institution will select the goals of the competition and formulate the design criteria, and then each university participating in this proposal will hold a competition among local school children. Undergraduates and graduate students will be involved by assisting in setting up experiments and operating equipment. This effort will provide a means to encourage young students to develop an interest in science and engineering. *Collaboration* in this activity would be sought with regional Earthquake Engineering Committees of ASCE, regional Earthquake Engineering Research Institute chapters, earthquake engineering centers (CERI, CES) who have an interest in increasing earthquake hazard awareness.

Design Competition for University Students. A second more advanced design competition will be developed that is appropriate for undergraduates. This activity has the potential to generate as much interest as the ASCE Concrete Canoe and ASCE Steel Bridge Competitions. After a few successful competitions we will seek sponsorship from ASCE for the competition.

Undergraduate Research Experiences. Further educational opportunities stem from student participation in advanced interdisciplinary research projects. Undergraduate research experiences challenge and motivate students, encouraging them to pursue graduate degrees. Involving undergraduate researchers in state-of-the-art projects associated with the earthquake centers is a fundamental goal of the education programs of the three centers. Students will utilize the experimental

facilities to complete individual research projects that contribute to the overall goals of the ongoing research programs within the centers.

4. Evaluation and Assessment

To clearly identify the impact of this program, a thorough evaluation and assessment plan has been developed. Both formative and summative assessments will be performed. Undergraduate students, graduate assistants, K-12 faculty and university faculty will be included in this process. The program will be considered successful if it can be shown to benefit the undergraduate participants, demonstration audiences, K-12 faculty, university faculty and the civil engineering profession. Therefore, each constituency will be asked to critique the experiments, manuals, videos, CD-ROMs and presentations as appropriate. Our primary interest is to provide each university with a spectrum of informative, age or class appropriate experiments, demonstrations, and media so the participants can sample and explore structural dynamics from basic to advanced concepts using a "hands-on" approach. These shake tables must provide some overall, measurable contribution through outreach to the general public and young students, through instruction to undergraduate classes and through collaborative efforts of multiple universities' development of the experiments.

Distribution of surveys to conduct the program evaluation will be performed through the internet. The web page is designed to insert all relevant information into a database for direct compilation and quantitative analysis of the responses. Qualitative analysis will also be conducted through the use of short response questions in the surveys. A description of the types of surveys on the web site are described in the following paragraphs.

4.1 Formative Assessment

The involvement of each university in the program will be assessed at the end of each semester, culminating in a final report (survey) which will submitted through the web site. The survey responses from each university will be synthesized in a report reflecting each university's and each center's participation and use of their shake table. Each university will report quantitative statistics including: students in each class utilizing the shake tables (civil engineers and non-civil engineers), underrepresented groups, K-12 students exposed to a shake table demonstration, classes using the shake table (plus their titles), faculty involved in the use of the shake table, experiments in each class, new experiments/demonstrations developed, experiments developed by collaborating universities used in their classes and demonstrations, participants in any regional design competitions, and general public demonstrations made with the shake table. In addition, the report will be used to explore several qualitative issues surrounding the shake tables.

The university coordinators will be asked to provide their opinions on the use of collaborative university developed experiments and media, the impacts on undergraduate students, K-12 students, the general public, and their curriculum, and how specific products could be improved. The information from each report will reflect the student, faculty and administrative evaluations of the importance of having a shake table for classroom demonstrations, the experiments and the public demonstrations. This process will occur each semester throughout the project and the final year-end report will reflect the evaluations and recommendations by all universities involved in the

program. The final report will also reflect any implementation of the recommendations for the improvement of the program.

4.2 Summative Assessment

The year-end reports will be distributed to each of the universities for final comments. Once the final comments have been received, the assessment coordinators and other interested parties will convene to discuss the report and possible improvements to the program for the coming year and to discuss any potential new experiments and outreach activities. The final report will be forwarded to each of the universities with additional recommendations to achieve the objectives of this project. These year end reports will continue for several years beyond the life of the funding to assess the successes and shortcomings of the program and to document the impact that the project has made in engineering education, K-12 education, and public awareness.

5. Summary

Because of increased earthquake awareness in certain regions of the country as well as stricter design codes nationwide, civil engineering departments are interested in increasing the understanding of the dynamic behavior of structures at the undergraduate level. The interest generated within departments associated with the earthquake centers is indicative of what is expected nationwide. The UCIST has developed a strategic plan for integrating earthquake engineering and structural dynamics into the undergraduate civil engineering curriculum. The program is based on the use of bench-scale instructional shake tables which the students will use to perform "hands-on" experiments. The experiments developed within this program will be made available on the internet. Further, all universities would have access to video demonstrations of the experiments, and nationwide competitions at various levels would generate additional interest in earthquake engineering. Thus, the proposed program will have a significant impact on the future of civil engineering curricula nationwide.

For further information on the UCIST program, contact Dr. S.J. Dyke at *sdyke@seas.wustl.edu*, or see the web page: *http://ucist.cive.wustl.edu/*.

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