Illustration of Shake Table Experiments in Structural Engineering Curriculum

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ABSTRACT

The importance of understanding the effects of earthquakes on structures to the civil engineering community is apparent. Recent catastrophic earthquakes in Northridge, Kobe, Turkey, Taiwan and India have reminded us of the powerful and potentially deadly consequences of such natural events. The essential equipment for the study of structural dynamic behavior in earthquake engineering is an earthquake simulator, or shake table, that can reproduce the historical earthquake ground motion records. For the feasibility of classroom demonstration, small scale table-top shake tables, such as MTS T-TEQ, are used for illustration purposes in the structural analysis and design lecture courses. From observing the structural dynamic behavior of civil engineering prototype structures, students will have a better understanding of the seismic design concepts such as the nature of earthquake loading, the effectiveness of lateral bracing, structural damping and base isolation on structural control.

INTRODUCTION

Recent catastrophic earthquakes in Northridge, Kobe, Turkey, Taiwan and India have caused severe damage to buildings, bridges, and crucial lifeline infrastructures. During the Northridge earthquake, for example, about 12,500 structures were moderately to severely damaged including residential homes, businesses, and freeways (see Figure 1). Major freeway damage occurred up to 32 km from the epicenter. Collapses and other severe damage forced closure of portions of 11 major roads to downtown Los Angeles. On the first anniversary of the 6.7 magnitude 1994 Northridge earthquake, Kobe, Japan was struck by a 6.9 magnitude. Both earthquakes ruptured beneath densely populated areas, and both caused horrible damage (see Figure 2). Yet in Kobe there were many more deaths, financial losses than in Northridge. And the amount of destroyed structures and infrastructures were far worse in Kobe than in Northridge due to the different seismic engineering practices.

San Fernando Valley Apartment Damage

I-5 & Antelope Valley Freeway Damage

Figure 1. Structural Failures of Building and Bridge in the 1994 Northridge Earthquake

The most important lesson learned from both earthquakes is that structural engineers must possess the skills to significantly improve structures to resist earthquake damage and thereby avoid most of the deaths and financial losses. Past earthquakes have demonstrated that it usually costs less to prepare for earthquakes in advance than to repair the damage afterwards. It is urgent to train a new generation of civil engineers that possesses understanding of seismic engineering who are qualified in design of new buildings and retrofit of the existing structures.

It is particularly important in the state of California, located in high seismic region, that structural engineers have a good understanding of structural dynamics principles and failure modes in structures due to the heavy emphasis on designing and retrofitting of structures for earthquake loads**.** For the curriculum in Structural Engineering, new components on earthquake engineering need to be added to the curriculum so that students have an opportunity to learn about the earthquake engineering and seismic resistant design of structures.

Mid-height Collapse of a Mid-rise Commercial Building

Seismic Failure of Lifeline Components

Fire Following Earthquake

Figure 2. Various Types of Damages in 1995 Kobe Earthquake

INSTRUCTIONAL SHAKE TABLES

The essential equipment for the study of structural dynamic behavior in earthquake engineering is a shake table that can reproduce the historical earthquake ground motions records. For the purpose of classroom illustrations, small-scale instructional shake tables, such as table-top MTS T-TEQ earthquake simulator shown in Figure 3, is ideally suited for classroom demonstrations and hands on learning experiences. This tabletop earthquake system is capable of generating the historic earthquakes as well as random and sinusoidal excitation. The integrated controller of the system can provide up to 50 historical earthquakes and random time histories (such as the Northridge earthquake records shown in Figure 5), which can be selected and played out at adjustable scale factors. The shake table experiments are effective in demonstrations of dynamic loading concepts such as the effective of lateral bracing, structural damping, and modal coupling. Figure 4 showed the shake table with a test structure for illustrating the affects of earthquakes and vibrations on structures. Effective "hands on" learning exercises can be structured for undergraduate students with strong, visual feedback of results. MTS T-TEQ can extend the usefulness to more advanced undergraduate work and to graduate studies. The system costs $17,000, and this portable and user-friendly system is a great way to qualitatively investigate the dynamic response of structures to horizontal ground motions, both harmonic and recorded earthquake time histories.

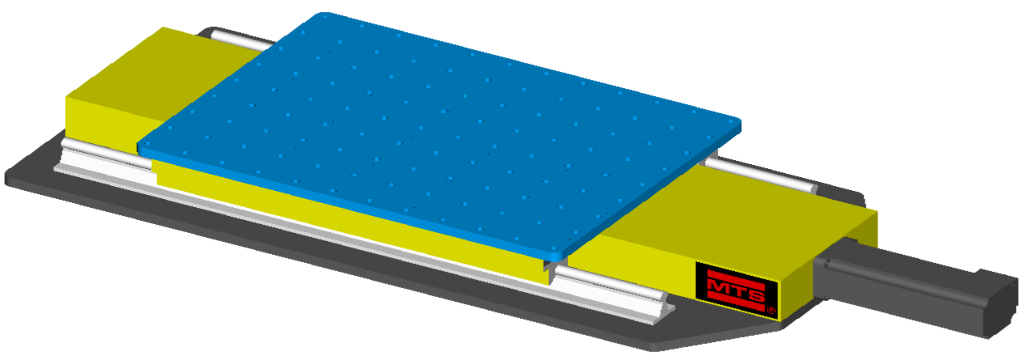

Figure 3. MTS Table-Top Earthquake Simulator

A series of multi-story prototype structures will be built for testing. This will be done through a senior design project. Various types of test structures will be constructed so that the students can compare the behavior of a variety of structures, and learn how mass and stiffness affect the dynamics of a structure.

In addition to learning about structural dynamics, students will also about data acquisition systems, sensors, actuators, and digital control systems. The knowledge gained through both the theoretical and experimental study on the structural dynamic behavior will be very beneficial to the students and prepare them for a better tomorrow.

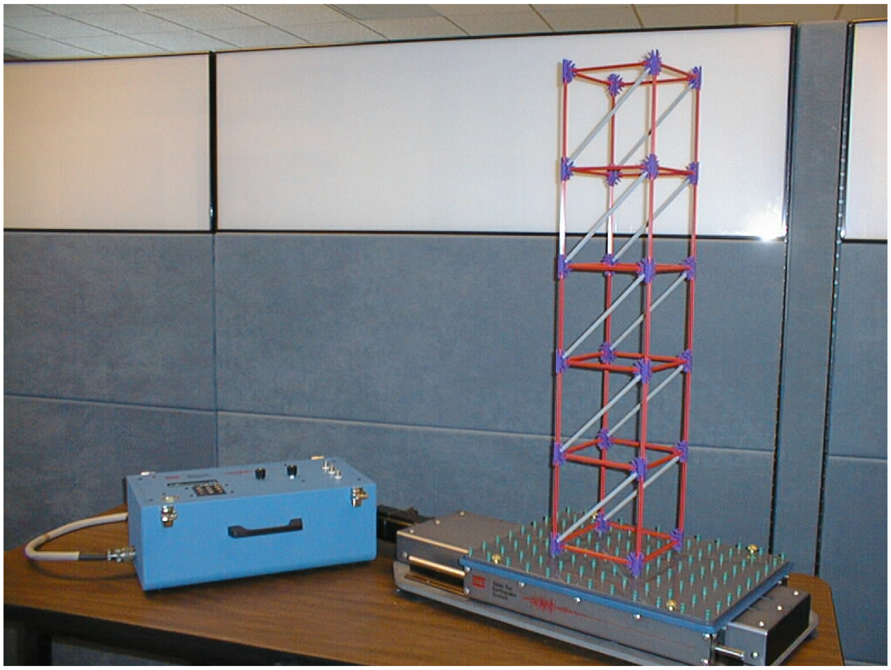

Figure 4. Instructional Shake Table with Test Prototype Structure

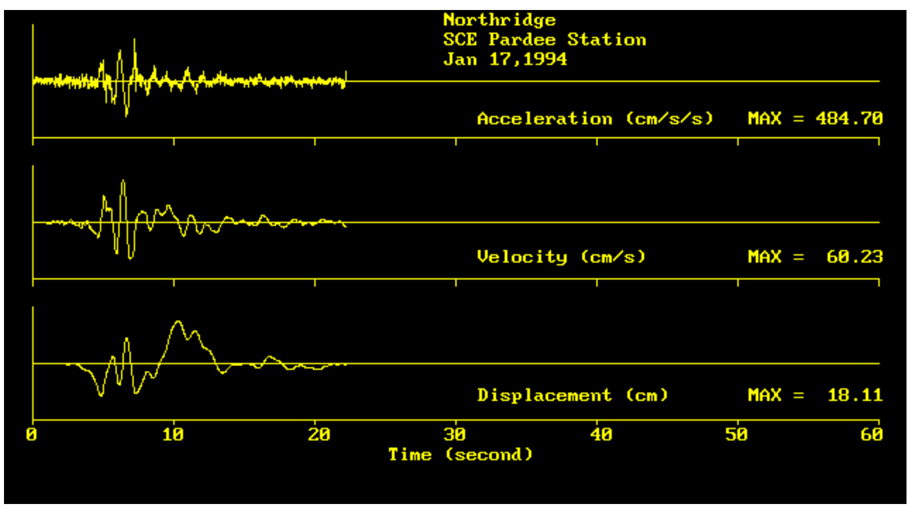

Figure 5. Seismographs of Northridge Earthquake recorded on Jan. 17, 1994

APPROPRIATE COURSES

The instructional shake tables are to be used to illustrate a series of hand-on experiments in Structural Dynamics and Earthquake Engineering. The experiments are designed to provide the students with a background in the basic principles of structural dynamics, and the implications of these principles in structural design.

To enhance student learning in the area of Structural and Earthquake Engineering, shake table experiments can be demonstrated in the classrooms for such courses Structural Analysis, Structural Steel Design, Structural Timber Design, and Aseismic Design. The equipment may be used in both undergraduate and graduate curriculums. Through effective comparative studies and classroom demonstrations, students will have a better understanding of the seismic design concepts such as nature of dynamic earthquake loading, the effectiveness of lateral bracing, structural damping and base isolation on structural control.

In the classes of Steel Design and Timber Design, a series of multi-story test structures (prototype) will be constructed for testing. Various masses and stiffnesses will be built so that the students can compare and contrast the behavior of a variety of structures, and learn how mass and stiffness affect the dynamic behavior of a structure.

In the classes of Structural Dynamics and Aseismic Design that are generally taken by a mixture of undergraduate and graduate students, experimental determination will be conducted on the following dynamic phenomena of prototype structures constructed of steel, aluminum, timber, and composite material (such as fiber reinforced plastics - FRP). The shaker tables and linear displacement gages will be used for these experiments. The following experimental results will be compared with analytical calculations:

- Natural frequency from free vibration tests.
- Resonant frequency.
- Response spectra.
- Mode shapes for MDOF systems.
- Damping ratio by a) logarithmic decrement and b) half-power bandwidth.
- Natural frequency and damping from a frequency-response curve.
- Comparison of structural response to earthquake record input for systems with and without special isolation features such as base isolators, shock suppressors, and tuned mass dampers.
- Comparison of structural response to earthquake record input of systems with and without lateral bracing.

OBJECTIVES

The objectives of the new curricula with experimental illustrations are:

- To systematically integrate hands-on experiments in structural dynamics and earthquake engineering and structural failure modes into the undergraduate civil engineering curriculum. This way students will enhance the understanding of principles in both the structural analysis and design courses. The objective is to tie the concepts covered in class to laboratory models and experimentation. Automatic data acquisition and display methods will be used during testing to illustrate these concepts.
- To help students develop a better understanding of structural design criteria. Students will observe the physical behavior of structural systems such as ductile moment resisting frames, buckling phenomena of columns, or the plastic hinging of beams.

- To promote the understanding and use of composite materials. In the future these materials will be used in addition to or in place of conventional materials for various structural components. Composite materials such as fiber reinforced plastics (FRP), are increasingly used in the rehabilitation, repair, and retrofit of the civil infrastructure—including, for example, as replacement bridge decks and wrapping for concrete columns. It is important to give "hands on" experience in composites to our current engineering students.
- To prepare students for those situations in which the design of a structural member or component is not covered by one of the design codes. Such situations often arise in practice and require testing to qualify the design. A web page will be created with training materials to teach students how to use the various test and data acquisition systems in the testing.
- To have students involved in the equipment installation and operation, system integration, and web page development. The Internet is an exciting new arena for educational activities. A web page for the laboratory will be created, which contains interactive exercises and videos focused on structural dynamics and earthquake engineering. The videos are for demonstrations of the structural response using the shake tables. The interactive exercises will be used inside and outside the classroom to introduce students to basic concepts, and prepare students for the future laboratory experiments.

UPGRADING OF EXISTING CURRICULA

In order to include the basic concepts of structural dynamics in the undergraduate curriculum, an introduction to this subject need to be integrated into undergraduate curriculum, specifically the Structural Analysis course. To effect this change, the course material in this course will be revised so that there will be time for the introduction of Structural Dynamics. The goal of this change is to provide undergraduate students with an introductory understanding of dynamic structural behavior. A set of illustrative experiments will be demonstrated to students in the classroom/lab. Students are expected to tie the theoretical concepts discussed in class to their experimental observations.

For graduate students, they are required to take Structural Dynamics, Earthquake Engineering, and Aseismic Design. They possess a more advanced knowledge of seismic structural response. A series of experiments will be performed throughout the course in which the students will utilize the material learned in class to analyze, identify, model, and control dynamic systems. They will be expected to explain the differences and similarities between the model and the experimental structure. The graduate students will be provided with a background in topics such as modal analysis, structural control, system identification, and the behavior of nonlinear dynamic systems. In addition, these students will gain a through understanding of sensors, actuators, and data acquisition equipment and techniques.

OUTCOMES

Through effective experimental illustrations of instructional shake tables, students especially undergraduate students will be exposed to the topics of Seismic Engineering. The experiments will provide the students with a background in the basic principles of structural dynamics, and the implications of these principles in structural design. Students will be able to broaden their perspective on what civil engineers can do, and this will lead them to be interested in how they could control structures. In addition, with the new curriculum designed to combine experimental activities, students will be able to achieve an improved understanding about structural behavior. The resulting curriculum and strategies are to increase student learning. Furthermore, more undergraduate students will be motivated to attend the graduate program in Structural Engineering to learn about earthquake resistant design and seismic retrofit.

BIBLIOGRAPHIC INFORMATION

1. A.R. Kukreti and B.J. Wallace "Teaching Dynamic Behavior of Structures Using Small-Scale Structural Dynamics Laboratory," Proceedings of the 31st Midwest Section ASEE Conference, Tulsa, Oklahoma, April 10-12, 1996.
2. Dyke, S.J., "Experiences in Integrating Research and Education after the Engineering Education Scholars Workshoop," Proceedings of the ASEE/IEEE Frontiers in Education Conference, Pittsburgh, PA, November 5-8, 1997.

BIOGRAPHICAL INFORMATION

Dr. Wang is an assistant professor in Civil Engineering Department at California State Polytechnic University, Pomona (Cal Poly Pomona). Before she joined Cal Poly in 1999, she worked with an engineering consulting firm in the area of Structural and Earthquake Engineering. Dr. Wang received her Ph.D. in Structural Engineering from the University of California, Irvine, her M.S. in Geotechnical Engineering from China Academy of Railway Sciences, and her B.S. in Civil Engineering from Southwest Jiaotong University. She teaches classes at undergraduate and graduate levels in Structural Engineering at Cal Poly Pomona. Her professional interests are: earthquake engineering, structural dynamics, liquid-structure interaction on liquid storage structures, and design of buildings and bridges for earthquake and wind loading.