AC 2011-2508: EXCHANGE – MULTI-DAY EARTHQUAKE ENGINEERING WORKSHOP FOR MIDDLE SCHOOL STUDENTS

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Exchange – Multi-day earthquake engineering workshop for middle school students

Abstract

A rigorous, two and a half day, curriculum developed for an earthquake engineering summer workshop is presented and its effectiveness is discussed with general observations from the faculty organizers, student mentors, students, and parents. Two workshops were organized in the Summer of 2010, enrolling 15 students, ages 11 to 15, in each workshop. The workshop presented basic topics in earthquake engineering and incorporated a relatively advanced analytical component linked to a series of shake-table experiments. The experiments demonstrated the influence of mass and stiffness on structural response while the analytical component introduced physics-based relationships engineers use to analyze seismic behavior. Overall, comments from the students and parents substantiate the effectiveness of an extended educational experience which will inform future activities on an NSF-funded project. Engaging students in a mix of enjoyable and rigorous engineering activities over the duration of several days is a novel approach not commonly used in the field of earthquake engineering, but should be disseminated and encouraged to increase excitement and promote diversity of the engineering workforce.

Introduction

The United States has experienced a decline in the number of technology and engineering college graduates, largely due to fewer students choosing to enter an engineering education and profession (Crawford et al, 1994). Furthermore, the performance of K-12 students in the Science, Technology, Engineering, and Mathematics (STEM) fields has decreased in overall achievement as reported by Weiss et al (2003) and others. Rightly so, government agencies and education researchers have made the link between a decreasing number of engineering college graduates, relative to demand, and the declining performance of K-12 students compared to other nations on STEM assessment exams. With the speed of technology change world-wide, these negative trends impede our nation's ability to compete internationally while also making it more difficult for US educators to reverse the trends in the presence of compounding effects.

In this light, a thrust of national funding agencies has been to improve the quality of technology education in K-12 classrooms and incorporate new, innovative strategies to bolster interest of pre-college students in STEM majors. While many of the funding strategies have a direct charge of focusing on K-12 technology education, agencies have also indirectly emphasized Education, Outreach and Technology Transfer (EOT) by mandating education components as part of larger research projects. One such research program is the George E. Brown Jr., Network for Earthquake Engineering Simulation (NEES), funded by the National Science Foundation (NSF) with the goal to reduce the effects of seismic events while also educating and disseminating cutting edge research on earthquakes to practitioners, stake holders and society.

Traditional EOT exercises conducted by earthquake engineering researchers typically focus on one-day activities and utilize building materials such as plastic K'Nex or light-weight wood (balsa, Popsicle sticks, etc.). The students often design and construct buildings or bridges which are tested on bench-top shaking tables programmed with scaled earthquake ground motions. While exciting for the students on the day of the exercise, and relatively easy to conduct, the long-term influence of such an event is questionable considering the brief exposure to engineering concepts. Furthermore, the students are rarely exposed to meaningful quantitative exercises, and even qualitative descriptions of behavior are difficult since the student-led designs often lack realistic structural geometry, stiffness, and strength properties. The true excitement of an engineering profession lies in the ability to describe the physical world with quantitative reasoning, employing mathematical models and relationships to improve designs.

Through a series of analytical and experimental exercises, the earthquake engineering workshop described in this paper exposes students, ranging from ages 11 to 15, to important relationships and characteristics which control structural stability during large earthquakes. With the assistance of undergraduate and graduate mentors, the students were asked to complete worksheets designed to challenge the students' mathematical skills and logical reasoning abilities. Fun activities were also incorporated into the workshop to demonstrate a variety of structural engineering principles, while also providing a hands-on component to the learning environment.

The workshop was conducted under the auspice of a 2009 NEES award to Stanford University (PI institution), State University of New York (SUNY), Buffalo, University of New Hampshire and California State University, Sacramento (CSUS). The research objectives of the NEES project include validating hybrid testing techniques to the point of structural collapse by comparing global and local responses with results from shake table testing previously performed by Lignos et al (2008). This validation experiments consider 1) hybrid simulations where the whole structure is physically tested and only dynamic effects are simulated in the computer and 2) substructure hybrid simulations in which portions of the structure are physically tested and others are simulated in the computer. Thus, considering the larger goals of the research project, the 3-day engineering workshop curriculum described herein incorporates the theme of studying the effects of earthquakes on steel structures to the point of collapse.

Workshop Format

Participants

The workshop participants were enrolled on a first-come basis, solicited from Northern California home school distribution lists. An email explaining the objectives and format of the workshop was sent to parents with the notion that the workshop would attract students interested in technology and engineering careers. While future efforts by the research team may seek to reach students who have not considered STEM careers, it was desirable to assemble a captive audience for the first offering of the workshop. Furthermore, the home school aspect of the participants provided an opportunity to invite several parents with education backgrounds to observe the workshop and provide feedback (discussed later).

Two workshops were held during August 2010 with a week between each to alter the curriculum based on feedback and experience from the first session. Each workshop had approximately 15 students, divided by age into four groups and led by undergraduate and graduate civil engineering majors from CSUS and Stanford University, respectively. The undergraduate and graduate students served as mentors for their respective groups and were responsible for guiding the students during activities and answering specific questions during break-out sessions.

Curriculum Schedule, Overview and Learning Objectives

The overall schedule for the three day workshop is described in Tables 1-3. The general format consisted of a short lecture by the faculty member and an activity by the students in their respective groups. A similar learning style has been shown to be effective by Titcomb (2000) and many others. Also note the hands-on activities (e.g., paper columns, marshmallow/spaghetti structures) dispersed during each of the three days between the lectures/group learning exercises. Not only did these activities keep the energy level high throughout the day, but the activities also lend themselves well to explaining various concepts in structural engineering. For example, the students typically make circular paper columns due to the relative ease of constructability and the fewer imperfections as compared to square cross-sections. Moreover, the columns fail by wrinkling at the base or top, an opportunity to discuss imperfections and local buckling.

In addition to the teachable moments provided by the ice-breakers and energizers listed in Table 1, there were three primary learning objectives for the workshop –

1.) <u>Describe</u> and <u>validate</u> the relationship between effective structural mass, stiffness and period of vibration. Through the use of physical models and an Excel spreadsheet developed by the research team, and shown in Figure 1, the students experimented with the effects of stiffness and mass on the period of vibration. This section of the curriculum also gave the faculty an opportunity to discuss the relationship between physical and numerical modeling, while also providing the students an opportunity to intuitively reason through the effects of stiffness, k, and mass, m, on the period of vibration, T. For example, if a structure is very stiff (or rigid) one would expect faster shaking, or a decreased period of vibration. Of course, the opposite is true if the mass is increased. From this reasoning, and through several illustrative examples, the following equation can then be presented to the class –

$$T = 2\pi\sqrt{\frac{m}{k}} \qquad (1)$$

Table 1: Day 1 Workshop Schedule (see Appendix B for sample of student worksheet)

9:00-9:15	Welcome and general information	
9:15-9:30	Ice-breaker I (design of paper columns)	
9:30-10:00	Ice-breaker II (paired introductions)	
10:00-10:15	Introduction to civil engineering	Activity #1
10:15-10:30	Introduction to earthquake engineering	Activity #2
10:30-10:45	**Break: Concrete and structures lab tour**	
10:45-11:15	Earthquake engineering modeling I	Activity #3
11:15-12:00	Earthquake engineering modeling II[1]	Activity #4
12:00-1:00	**Lunch break**	
1:00-1:15	Energizer I (building demolition[2])	
1:15-2:00	Period/frequency of vibration	Activity #5
2:00-3:00	Stiffness measurement of structures	Activity #6
3:00-3:30	Mass measurement	Activity #7

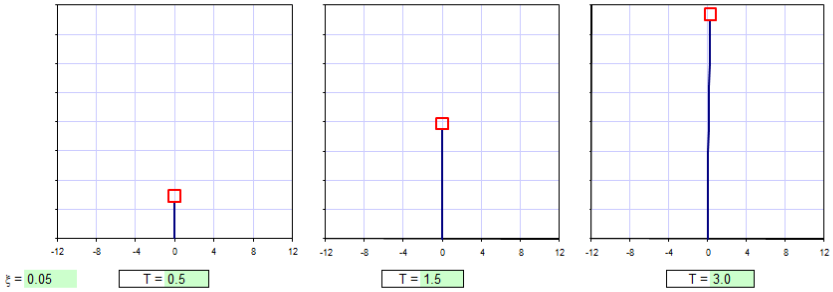
[1]http://sstl.cee.illinois.edu/java/mdof/index.html
[2]http://armorgames.com/play/4142/demolition-city

Table 2: Day 2 Schedule

9:00-9:30	Energizer II (marshmallow/spaghetti structure)	
9:30-10:30	Review Day 1 (+ summary worksheet)	
10:30-10:45	**Break: Group picture**	
10:45-11:00	Theoretical stiffness (advanced groups)	Activity #8
11:00-11:30	Present structures on board	Activity #9
11:30-12:00	Build structures for shake-table testing	Activity #10
12:00-1:00	**Lunch break**	
1:00-2:00	Test structures 1 and 2 on shake-table	
	Groups 3 and 4 in classroom – base isolation	
2:00-3:00	Test structures 3 and 4 on shake-table	
	Groups 1 and 2 in classroom – base isolation	
3:00-3:30	Finish remaining worksheet from morning	

Table 3: Day 3 Schedule

9:00-9:15	Energizer III (pizza order)	
9:15-9:45	Energizer IV (Lego structures)	
9:45-10:15	Watch/discuss day 2 experiments	
10:15-10:30	Elastic, brittle and ductile materials/behavior	Activity #11
10:30-11:20	Summary worksheet	
11:20-11:30	Graduation ceremony	
11:30-12:00	Campus tour	
12:00-1:00	**Lunch: Pizza party**	
12:20-12:45	Assessment with parents	
4:00-5:00	Assessment with faculty and mentors	



(a)

(b)

Figure 1: (a) Numerical (Excel) and (b) Physical demonstration of a structural period of vibration.

2.) <u>Relate</u> the period of a building to the expected deformations and accelerations during an earthquake event. Once students grasp the concept that structures have a period of vibration and behave differently during earthquakes, the remainder of the workshop becomes, in large-part, a reinforcement of this concept. The effects of displacements and accelerations on buildings were demonstrated experimentally by placing aluminum foil on the exterior of the structure to represent a deformation sensitive component, such as a partition wall, and an aluminum block on the roof of the structure to represent an acceleration sensitive component, such as a bookshelf. The experimental setup is shown in Figure 2. Referring to the figure, the mass of the structures is controlled with cast lead blocks held in a rigid pan. The stiffness of the structure is controlled by the length, or height, of the four steel columns. See Appendix A for the steel columns details. Since each group was given a predesigned structure with different mass and stiffness combinations, the students compared and contrasted the visual response of four structures with respect to the period of vibration.

(a) (b) (c)

Figure 2: Experimental structure with (a) Exposed steel columns and acceleration sensitive block, (b) Deformation induced foil tearing, and (c) Acceleration induced block falling.

3.) Distinguish between ductile and brittle structural collapse. The four experimental structures tested on the shake-table all illustrated ductile failures by reaching large inelastic deformations prior to collapse. Brittle failures were demonstrated in the classroom with online videos of earthquake induced collapse of unreinforced concrete and masonry structures. See Figure 3. A group activity (#11) required the students to differentiate between ductile and brittle materials, and encouraged the class to suggest methods to increase ductility of common materials (e.g., mixing ductile materials with non-ductile materials).

(a) (b)

Figure 3: (a) Ductile and (b) Brittle collapse of unreinforced concrete column

By design, the most rigorous day was the first day of the workshop. The material quickly progresses from an introductory discussion of 'what is civil and earthquake engineering?' to requiring the students to calculate the period of vibration of a Single Degree of Freedom (SDOF) oscillator. However, beginning the workshop with an intense first day allowed the faculty to discuss relatively complex behavior with sophisticated explanations for the rationale behind structural design, base isolation, and other questions students had regarding earthquake engineering.

Workshop Assessment and Feedback

A formal assessment strategy was not designed for the workshop. However, comments and suggestions were solicited from the faculty, student mentors and parents after each of the two workshops. A student mentor took notes during each session; the synthesized comments are listed below such that if there was consensus between the faculty, mentors and parents, the comment is shown.

1.) Day 1 certainly had the steepest learning curve as compared to Days 2 and 3. However, it was viewed as a necessity to setup the discussions for Days 2 and 3.
2.) The feedback from the students and parents highlighted the positive impact the undergraduate and graduate student mentors had on the participants. Furthermore, the 4:1 student to mentor ratio was ideal.
3.) From the wide range of age groups who attended the workshop, it was found that 13 and 14 year old students benefited the most from the curriculum.
4.) The curriculum should have emphasized experimental error on Day 3.
5.) Equation (1), used to calculate the structural period of vibration, may have been too advanced for the younger students in the class (ages 11-12).
6.) One of the more captivating discussions was on Day 3 during the base isolation section. Illustrating base isolated structures and other modern energy dissipation schemes generated wide-spread discussion and novel ideas from the students.
7.) Very rare to find an experience for this age group that goes into such great depth with a particular subject. Students seemed to appreciate using critical thinking abilities and assigning quantitative values to discover relationships and describe physical behavior.

Finally, several direct comments from parents are listed below, sent in emails several weeks after the workshop –

“Sam and David are still giving your workshop rave reviews when asked how they enjoyed it…the workshop was truly inspiring to Sam and it’s rare that younger children get a taste of something as sophisticated as what you presented. Thanks again to you and all the assistants.”

“Just wanted to give you a follow up to the effect your workshop had on Liam. He is in a competitive speech club and had already started to prepare his speech for the year before the workshop. Well, he enjoyed what he learned with you so much that he is changing his whole direction and will be speaking on what it takes to become a structural engineer! Thanks for inspiring both my kids and making the 3 days so interesting for them.”

Summary

This paper describes an education and outreach workshop designed to introduce middle school students to possible careers in the science or engineering fields. A multi-day experience was chosen to allow for an adequate presentation of physics-based relationships used to predict the response of buildings and other structures to earthquake loading. The curriculum was designed as short, interactive lecture periods, followed by group work to continually reinforce the concepts of the workshop. Fun, yet informative activities were dispersed throughout the technical presentations to energize the class and provide illustrative examples related to engineering.

From general observations and feedback, the workshop was viewed as a great success. The participants were excited and intrigued by the curriculum, especially the experimental study and base isolation discussion. Furthermore, the author continues to receive positive feedback from the parents and students, noting a continued interest in studying engineering topics, especially related to the material discussed during the workshop.

Acknowledgements

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Appendix A: Required Materials

Shake-table testing

- Steel columns (4x12"x0.1625", 4x10"x0.1625", 0.25" diameter holes at hinge locations)
- Video camera
- Aluminum foil
- Block of aluminum
- Colored sharpie markers

Cantilever experiment (see Appendix B)

- 4 C-clamps
- 4 pieces of wood (to measure from)
- Weights (nuts, washers, etc.)
- Wire Hooks
- Digital scale

Energizers and Ice-breakers

- Marshmallows, pasta
- 4 Lego structures
- 4x20 pieces of paper
- 4 rolls of masking tape

Elastic, brittle, ductile exercise

- Rubber bands
- Chalk
- Paper-clips

Miscellaneous

- Graduation certificates
- Candy
- Group 1-4 signs
- Roster for each group (check spelling for certificates)

Appendix B: Day 1 Student Worksheet

Ice-breaker 1

How tall was your paper column? ________ (inches)

How much weight did it hold? ________ (lbs)

Ice-breaker 2

Where is your teammate from?

What is their favorite subject?

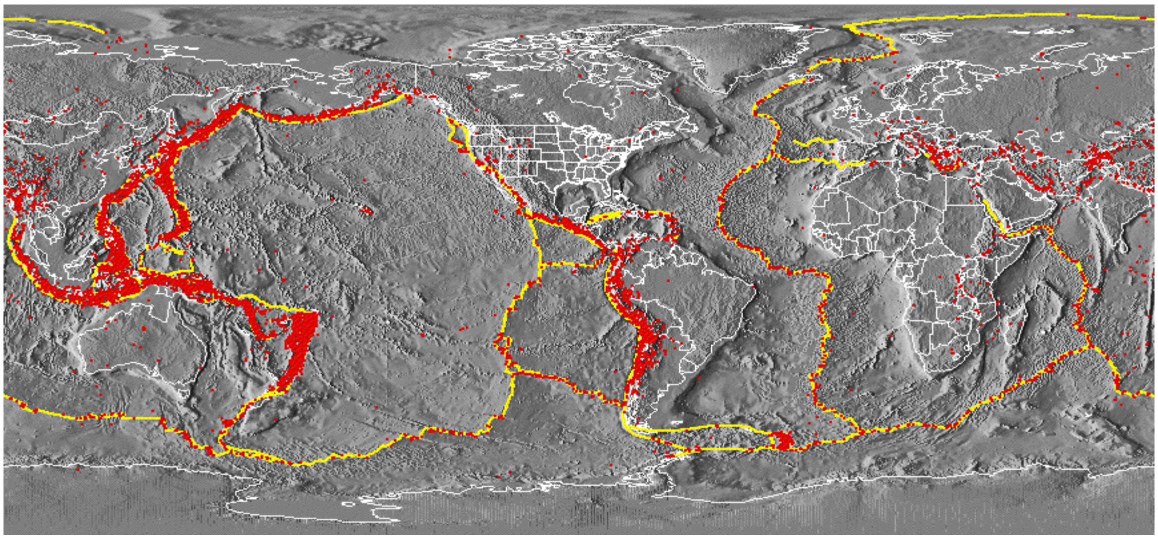
What has been the best part of the summer so far?

What is one funny thing about the person?

Activity #1

Picture	Types of Civil Engineering?	Structure Name and Location
		
		
		
		
		

Activity #2



Activity #3

If you were to mimic (or predict) how much a buildings shakes during an earthquake, what information about the building would you need?

Unit Conversion **Example #1:** Convert 53 quarters to dollars

Unit Conversion **Example #2:** Convert 185 pounds (lbs) to kilo-Newtons (kN)

Unit Conversion **Example #3:** Convert 3 inches (in) to meters (m)

Unit Conversion **Example #4:** A structure is pushed with a force of 1000 lbs and moves approximately 1.25 inches. What is the stiffness in lbs/in and kN/m?

Activity #4:

Convert 50 lbs to tons:

$$50 \text{ lbs x} \left(\frac{\quad}{\quad} \right) = \underline{\qquad\qquad} \text{tons}$$

Convert 15 lbs/in to kN/m:

$$\left(\frac{15 \text{ lbs}}{1 \text{ in}} \right) \text{x} \left(\frac{\quad}{\quad} \right) \text{x} \left(\frac{\quad}{\quad} \right) = \underline{\qquad\qquad} \frac{\text{kN}}{\text{m}}$$

Scale the El Centro Earthquake to 50% (Full strength is 0.3495g):

Change the damping to make sure damping ratio is approximately 2.0%

Activity #5:

Period (s)	Frequency (Hz)	Mass (tons)	Stiffness (kN/m)	Displacement (m)	Velocity (m/s)	Acceleration (g)
0.05	20			0	0	0.35
0.5	2.0					
1.0	1.0					
1.5						
2.0						

**Keep damping ratio at approximately 2.0%!

Circle the correct answer:

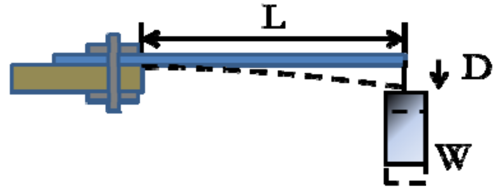
If the mass doesn't change, as stiffness increases, the period increase/decreases

…as the period decreases, the building shakes faster/slower

…as the period decrease, the building moves more/less

Remember: $\text{Period} = 2\pi\sqrt{\frac{\text{Mass}}{\text{Stiffness}}}$

Activity #6:



L = in

Measurement	W (lb)	D (in)	β (lb-in^2) $= \frac{WL^3}{3D}$
1			
2			
3			
Average:			