An Early Start to Studying Shaky Ground: Teaching Seismic Soil-Structure Interaction Topics in a Sophomore-Level Dynamics Course

Fatih Oncul, Ph.D.[1]

Abstract - Many structural engineers have limited experience concerning the dynamic behavior of structures subjected to strong shaking. Most building code seismic design provisions are prescriptive in nature and provide little or no insight into actual structural performance. [11] At the undergraduate level, few students have opportunities to gain experience with the behavior of structures subjected to earthquake loading [10]. In a survey, a group of practicing engineers and educators recommended that earthquake resistant design, and structural dynamics and vibration related topics should be taught at undergraduate level [9]. Although it is little early, a sophomore level dynamics class is an excellent opportunity to expose students to earthquake engineering related topics. The knowledge gained in this class might help students in other higher level earthquake engineering courses or partial relevant topics that are possibly covered in structural and geotechnical courses. This paper discusses the experience in introducing seismic soil-structure interaction to sophomore level engineering technology students at Southern Polytechnic State University. Learning outcomes and topics covered in a two week time frame are presented. Assessment of learning outcomes was done using an online exam, and two homework assignments.

Keywords: Dynamics, Earthquakes, Structural Dynamics

INTRODUCTION

Graduates of civil engineering or civil engineering technology programs usually find it too difficult or confusing to solve basic structural dynamics problems. This is due to the fact that structural and soil dynamics subjects are not adequately covered in an undergraduate civil engineering curriculum. Some undergraduate programs do not require a soil dynamics or structural dynamics course. The only required course relevant to structural dynamics is probably the sophomore level dynamics course. However, there are also civil engineering and civil engineering technology programs that do not require engineering dynamics course at all.

Wang [8] states that "the most important lesson learned from the past 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". Wang [8] used shake table to help students better understand the structural dynamic behavior in earthquake engineering and emphasized the importance of using models in teaching structural dynamics.

In general, students consider dynamics course as more challenging than a statics course. The nature of dynamics problems is much different than the statics problems. Engineering dynamics brings together basic Newtonian physics and various mathematical concepts which can be very difficult for a typical undergraduate student. A major reason for this difficulty is that dynamics has traditionally been taught without using a physical model [7].

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In a civil engineering curriculum the dynamics course is the first opportunity for the students to be exposed to earthquake engineering subjects. Unfortunately, most current dynamics textbooks [1, 2] are written to be studied by all engineering majors and do not provide practical seismic soil-structure information for civil engineering students. Usually, in a typical engineering dynamics textbook, vibration of a mass attached to a spring is the only subject pertinent to seismic soil-structure field. Furthermore, very little help has been provided for the students to build links from theory to practical seismic soil-structure problems.

In this paper a five-lecture module to introduce seismic soil-structure concepts in an engineering dynamics course is discussed. A cost effective simple physical model to demonstrate structural dynamics is also presented.

COURSE OUTLINE

Dynamics course offered to civil engineering technology students has been revised to include seismic soil-structure topics. It is a 2 credit hour course that meets twice a week. Each class is 50 min long. The learning objectives for the revised portion of the course are;

1. Be able to describe how earthquake waves travel in different subsurface conditions.
2. Explain characteristics of a ground motion and natural vibration of buildings.
3. Apply static force method to find the equivalent forces exerted on a building due to ground shaking.

The contents of the proposed lectures are summarized below.

Lecture 1 — *Basic earthquake terms, how earthquake happens, ring of fire, seismicity of U.S., seismic waves, and characteristics of ground motion*: USGS web site (www.usgs.gov) is an excellent source for basic earthquake knowledge. Fault types, seismic maps of U.S., earthquake induced stress waves, sample ground motions, computer generated fault rupture simulations, recorded earthquake sounds can be found at USGS's web site. During the lecture, ground motions characteristics are limited to duration, predominant frequency, and maximum acceleration.

Lecture 2 — *Natural vibration of buildings, structural response to earthquakes, and resonance state*: Free vibration of stiff and flexible buildings demonstrated using a physical model shown in Figure 1. Resonance state is also illustrated using the same model. The physical model has three threaded rods mounted on a 24 inches by 24 inches plywood panel. The rod C, representing a flexible tall building has the smallest diameter. The rod A, representing a stiff low-rise building has a larger diameter and is shorter than the others. Building weight is modeled by using several washers sandwiched between two nuts. All materials can be found at any hardware store. The rod B is for an average building with a natural vibration period less than rod C but greater than rod A. When the base is shaken by hand (no electric motor is required) in a low frequency mode the flexible building, rod C, shows the largest displacement, and when the base is shaken in high frequency mode stiff building, rod A, displays the maximum deflection.

Lecture 3 — *Dynamic analysis methods and static force method*: The concept of finding static forces that are expected to have a similar impact on the building as the dynamic forces would have is explained. This way, students are able to realize how the dynamic forces are simplified to static forces, and the principles of static equilibrium are used for the calculation of the base shear.

Lecture 4 — *An example problem on finding earthquake induced lateral forces for a 20-story high building using UBC 97*: Base shear and forces at every floor level are calculated in an example using UBC 97. Students realize how location, construction type, the use of the building, and dead weight of the building are taken into consideration in calculating base shear.

Lecture 5 — *Another example problem using IBC 2006*: Students are introduced to the latest version of a widely used building code to make students appreciate the evolution of the seismic building code. It also improved their skills in extracting the correct numbers from the tables and navigating through the provisions, and instructions in a building code.

The above five-lecture module is loaded with great amount of new information and should be delivered at a level that students can absorb. Therefore, instructor must be very well prepared for each lecture. Tables and handouts should be used as needed to expedite students' learning experience. Physical model was found to be an effective tool to explain important seismic soil-structure interaction fundamentals such as free vibration and resonance.

ASSESSMENT

One quiz, one homework assignment, and a student survey were used for assessment. The quiz was given online using Vista, formerly WebCT, online course delivery system. The quiz was mainly on earthquake ground motion and structural response, and the quiz average was above 90 in both Fall 2008 and Spring 2009 semesters. End of semester student learning outcome surveys were given. In one of the survey questions students were asked if they agree, not sure or don't agree about how well they understood ground vibration characteristics and structural response to seismic shaking, and static force analysis. 71% and 75% agreed in semesters Fall 2008 and Spring 2009, respectively. Students repeatedly expressed that they enjoyed the subject and found it very exciting especially the way how the static forces were used to solve a structural dynamics problem.

Homework problems were comprised of a hypothetical building at a given location. The students were asked to find the base shear and story forces using the building codes UBC97 and IBC2006. The homework averages were also found to be above 90. Homework problems are shown in Appendices A and B.

CONCLUSIONS

The proposed five-lecture revision to a sophomore level engineering dynamics course for the purpose of delivering seismic soil-structure interaction related topics has been successfully applied. Survey results indicated that the civil engineering technology students benefited from the earthquake engineering related topics. The use of the cost-effective simple physical model significantly helped the students understand soil-structure interaction under ground shaking.

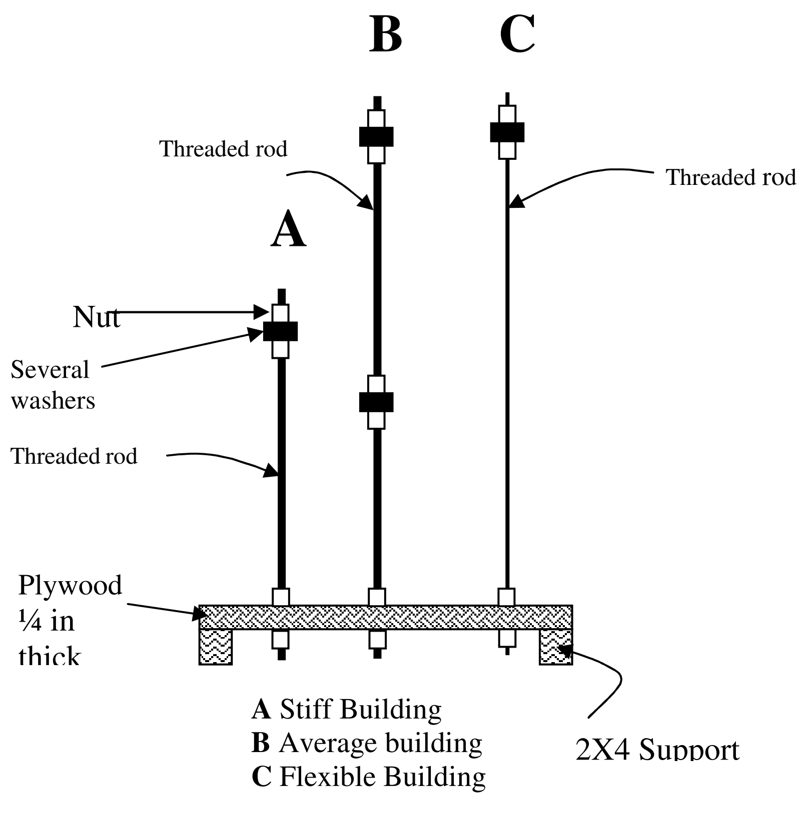

Figure 1. Physical model used to demonstrate the dynamic behavior of structures during earthquakes.

REFERENCES

[1] Bedford, A., Fowler, W., 2008, *Engineering Mechanics: Dynamics*, 5/E, Prentice Hall, NJ

[2] Hibbeler, R., 2007, *Engineering Mechanics: Dynamics*, 11/E, Prentice Hall, NJ

[3] Maguire, J.R., 2002, *Dynamics: An introduction for civil and structural engineers, Institution of Civil Engineers (Great Britain)*, Thomas Telford Publications.

[4] Matamoros, A., Roddis, K., 2007, *AISC Web Enhanced Teaching of Structural Steel Design*.

[5] Uniform Building Code, UBC, 1997.

[6] International Building Code, IBC, 2006.

[7] Jolley, W., Rencis J., Hagglund, R., and Cobb, E., 2003, "A Fun and Challenging Engineering Dynamics Project Using a Lego Construction Set", *Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition.*

[8] Wang, Y., 2002, "Illustration of Shake Table Experiments in Structural Engineering Curriculum", Proceedings of the 2002 American Society for Engineering Education Annual Conference & Exposition.

[9] Bhatti, M. A., Nixon, W., "Structural Analysis abd Design in Tomorrow's Civil Engineering Curriculum" Poster Session, *Proceedings of the 2000 American Society for Engineering Education Annual Conference & Exposition.*

[10] Dyke, S. J., Nepota, B., Caicedo, J. M., Johnson, S. M., Oware, E. A., "Earthquake Engineering Education: A modern Approach", *Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.*

[11] http://www.asce.org/pdf/seismicdesign.pdf

[12] International Code Council, "*2006 IBC: Structural Seismic Design Manual – Code Application Examples*.", 2006, Structural Engineers Association of California (SEAOC)

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APPENDIX A

Homework Problem #1 [4].

CET2215 ENGINEERING MECHANICS – DYNAMICS
FALL 2008

NAME:____

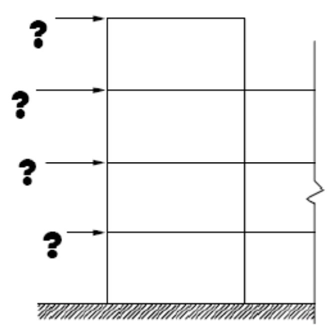
HOMEWORK

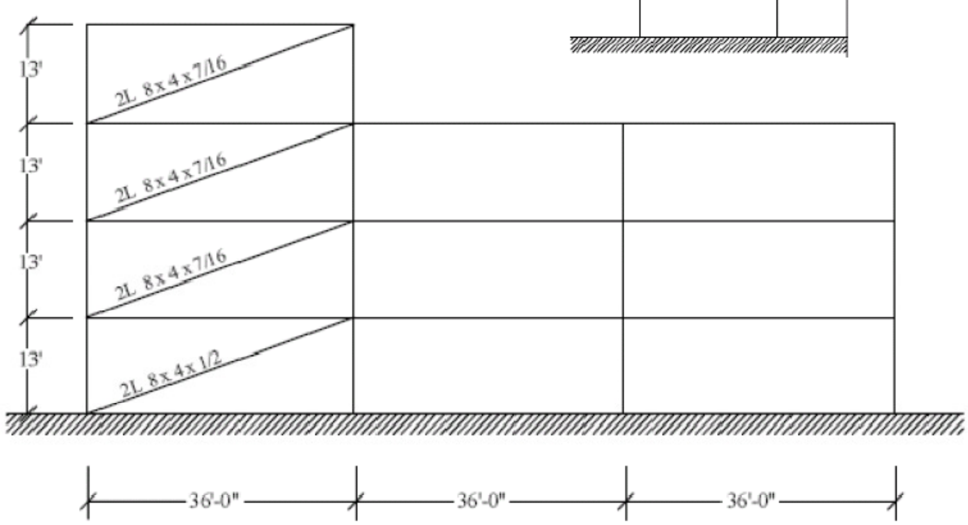
Seismic Analysis of Buildings

Find lateral earthquake forces for the given building per UBC 97.

Building: Office building
Location: Lawrence, Kansas
Construction Type: Frame to be structural steel, concentrically braced, simple connections
Site: Suburban, Relatively Smooth Topography
Soil Type: Stiff Soil, S_D
Seismic Source Type: C, Faults that are not capable of producing large magnitude earthquakes and that have a relatively low rate of seismic activity. There are no active faults within 15 km.

Level	Weight (Kips)
4	45.3
3	451.1
2	864.5
1	864.5





APPENDIX B
Homework Problem #2 [12].

SOUTHERN POLYTECHNIC STATE UNIVERSITY

CET2215 ENGINEERING MECHANICS – DYNAMICS
Fall 2008

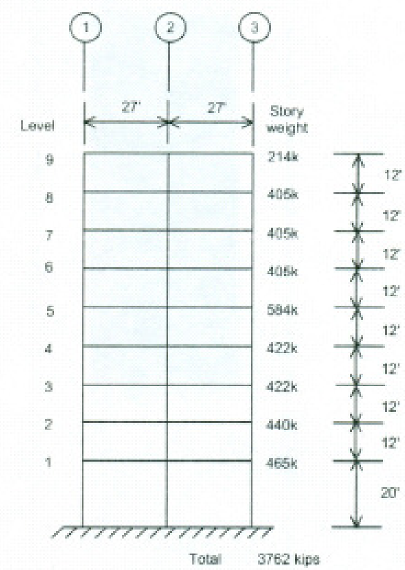
NAME:____

HOMEWORK
Seismic Analysis of Buildings

Find the vertical distribution of lateral earthquake forces for the given moment-resisting buildin[g] per IBC2006.

The following information is given.

W = 3762 kips
C_s = 0.062
R = 8.0
Ω_o = 3.0
I = 1.0
T = 1.06 sec



To solve this example, follow these steps.

1. **Determine V**

2. **Find F_x at each level**

3. **Find the distribution exponent k**

4. **Determine vertical force distribution**