EDUCATING GRADUATE STUDENTS FOR SEISMIC DESIGN VIA HANDS-ON EXPERIMENTAL COURSEWORK

K. M. McMullin

ABSTRACT

Graduate students in structural engineering have mastered basic fundamentals of engineering but are often unable to grasp many of the subtle features discussed in advanced topics such as seismic resistant design. Traditional classroom lecture formats are effective for some students, but as the industry tries to reach a wider range of learning styles, reliance on straight instruction needs to be supplemented by additional means of preparing young engineers. A three-credit graduate level seminar is being used as a means to allow hands-on learning methods to one topic of seismic-resistant design. The topic for the 2017 offering is the behavior of wood shear walls with in-plane discontinuities from the upper level to the lower level. These types of structural discontinuities are defined in current building codes but the methods of interpreting and complying with code requirements vary significantly in industry. The hands-on instruction combines: 1) direct instruction, 2) paper calculation of various aspects of the issue and design of the specimens, 3) physical construction by the students of the specimens and test jigs, 4) analysis of the experimental data, and 5) evaluation of one aspect of the experiments assigned to each student. At the beginning of the term, the students in the class are divided into three groups with each group responsible for the construction and conduct on one test specimen. Experimental research involves a wide variety of smaller tasks and each student in the course is assigned one of these smaller tasks, varying from calibrating instrumentation to developing online means of distributing the data. Assessment of student learning is primarily through two exams and their ability to summarize their work in a written report. Two types of reports are prepared by the students during the course, a summary of the experiment compiled by the students on the team who conducted the experiment, and an individual report discussing the personal task assigned to the student. Lessons learned by the instructor include successful use of online educational system for both delivery of course content and discussion and the use of templates to assist students in preparing reports in a professional manner.

1Professor, Dept. of Civil Engineering, San Jose State University, San Jose, CA 95192-0083(email: kurt.mcmullin@sjsu.edu)
Educating Students about Discontinuous Structural Systems

K. M. McMullin

ABSTRACT

Graduate students in structural engineering have mastered basic fundamentals of engineering but are often unable to grasp many of the subtle features discussed in advanced topics such as seismic resistant design. Traditional classroom lecture formats are effective for some students, but as the industry tries to reach a wider range of learning styles, reliance on straight instruction needs to be supplemented by additional means of preparing young engineers. A three-credit graduate level seminar is being used as a means to allow hands-on learning methods to one topic of seismic-resistant design. The topic for the 2017 offering is the behavior of wood shear walls with in-plane discontinuities from the upper level to the lower level. These types of structural discontinuities are defined in current building codes but the methods of interpreting and complying with code requirements vary significantly in industry. The hands-on instruction combines: 1) direct instruction, 2) paper calculation of various aspects of the issue and design of the specimens, 3) physical construction by the students of the specimens and test jigs, 4) analysis of the experimental data, and 5) evaluation of one aspect of the experiments assigned to each student. At the beginning of the term, the students in the class are divided into three groups with each group responsible for the construction and conduct on one test specimen. Experimental research involves a wide variety of smaller tasks and each student in the course is assigned one of these smaller tasks, varying from calibrating instrumentation to developing online means of distributing the data. Assessment of student learning is primarily through two exams and their ability to summarize their work in a written report. Two types of reports are prepared by the students during the course, a summary of the experiment compiled by the students on the team who conducted the experiment, and an individual report discussing the personal task assigned to the student. Lessons learned by the instructor include successful use of online educational system for both delivery of course content and discussion and the use of templates to assist students in preparing reports in a professional manner.

Introduction

Discontinuous systems are particularly a concern for structural response to earthquake motion. Buildings with discontinuous systems often develop complex load paths for both gravity loads and lateral loads. Engineering students usually work on analyzing structures with simple load paths and rarely are required to track loads through a complex load path. This is due to the limited time most courses have to investigate a single aspect of the building design.

1Professor, Dept. of Civil Engineering, San Jose State University, San Jose, CA 95192-0083 (email: kurt.mcmullin@sjsu.edu)

Small wood structures combine this increased complex load path with other unique characteristic of wood construction. Wood construction can be considered to be rather strong structural elements connected to each other with relatively weak connections. Gravity load in structures is often transferred from one element to another thru bearing, with supplemental connections used primarily to stabilize the elements. Thus, when unexpected loads occur, traditional wood structures often are unable to resist the demands produced. In addition, most university engineering programs provide a single course to wood design with the majority of the time involved with component-level design.

Adding confusion to the industry, current wording of building codes makes it difficult to clarify specific requirements. While code text tends to be very precise, the necessity for code-writers to develop legally binding requirements often overwhelms the ability to produce clear, cohesive guidance leaving wide latitude for engineers to interpret into a wide variety of engineering scenarios.

The ASCE7-10 code [1] specifically multiplies the Overstrength Factor times the output from the analysis of the structure for the code defined base shear. It should be pointed out that this output does not include the loads identified by the code to be caused by vertical acceleration. Thus the only vertical effects which are related to Q are the upward and downward forces produced by the overturning moments from lateral loads.

CE269 – Fall 2017

San Jose State University uses a place holder course, CE269, to be a seminar for various topics in structural engineering. The course is a three-credit semester long opportunity for faculty to introduce topics that are not closely aligned with the traditional topics of structural engineering education. Past offerings have included courses on masonry design, bridge engineering and experimental testing.

In Fall 2017 a new version of CE269 is being delivered where students participate in a course-wide research investigation involving full-scale experimentation. The topic for the course is in-plane discontinuity of wood shear walls. The centerpiece of the course is the completion of three full-scale, two-story specimens using a cyclic static loading protocol.

The first step in delivering the course is writing detailed learning objectives aligned with Bloom’s Taxonomy [2]. A total of 28 learning objectives were defined; some were much more critical than others. Table 1 lists some of the most important learning objectives to the overall course content.

The second step was in organizing class room instruction to address the learning objectives. Lecture notes were developed which were specifically to explain terminology and discuss the underlying theory. Lectures did not include examples as students were expected to work homework problems while reviewing the online examples to be able to fully incorporate the material. The lectures were developed on PowerPoint and were delivered to the class during the
first three class periods of the semester.

There were two curricular areas of particular importance to the instructor. One content area was in analyzing complicated load paths through a shear wall system. Particularly in wood design, these systems often have elements assembled in a way that creates a highly indeterminant system but practicing engineers usually break this down into a series of determinant components. However with no clear definition of how this is done, it is challenging for engineering students to be able to make appropriate simplifying assumptions. Thus the instructor defined the following assumptions that all the students should use:

1. All columns are assumed to be pinned at the top and bottom of each story.
2. All shear walls are assumed to have a post/column at each end of the shear wall.
3. All beams are assumed to be simply supported between posts and/or columns.
4. Shear walls are the only lateral resistance from one floor to a lower floor.
5. Shear walls are not expected to resist vertical load but they do transfer vertical shear to the end post of the shear wall.

The second area of concern was being able to clearly distinguish the various components contained in a discontinuous system and understand which components require the Overstrength Factor according to the building code. Four groups were defined:

1. Group A are the components of the upper system which is discontinuous,
2. Group B are the components of the lower supporting system which resist the vertical effects of the horizontal loads on the upper system,
3. Group C are the components of the lower supporting system which resist the horizontal effects of the horizontal loads on the upper system,
4. Group D are the components that connect the elements of Group A to components which are part of either Group B or Group C.

The ASCE Code [1] explicitly requires that only elements of Group B are required to be designed for the Overstrength Factor.

The third step was to provide meaningful resource materials for the students. One challenge is that to conduct meaningful engineering research, the topic under discussion needs to contain content that is beyond the traditional scope of engineering textbooks. Thus the instructor prepared detailed examples and lecture notes for each of the learning objectives and provided them to the students via the universities online educational platform. San Jose State University uses the CANVAS educational platform from instructure [3]. A total of twelve PowerPoint examples were developed in the first few weeks of the course to illustrate several scenarios for calculating the various results needed to solve typical questions.

To allow students to apply the content prior to the exams, homework assignments were given to small teams of four students who were randomly assigned to work together. The purpose of team assignments was the expectation from the instructor that each student in the team was likely to bring a different perspective to the assignment. San Jose State recruits a wide variety of graduate students into the civil engineering program and students often take structural engineering courses when their specialty is a different branch of civil engineering. Thus students may have worked in engineering offices, at construction sites, be straight out of the universities
undergrad program, or be from backgrounds in a variety of areas of construction. This diversity is multiplied when considering a large international student population, many of which come from countries where timber construction is rare. Thus, the mixing of students into teams allowed sharing of backgrounds and engineering expertise in a nontargeting environment. When teams found they were overwhelmed and had little understanding of the assigned problem, the ability to approach the instructor as a group rather than an individual allowed them to more easily admit their shortcoming.

Table 1. Learning objectives and assessment data from the first midterm.

<table>
<thead>
<tr>
<th>Learning Objective</th>
<th>Students Achieving Expectation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade</td>
<td>A Level Work</td>
</tr>
<tr>
<td>Determine the force-displacement graph for a system of nonlinear springs.</td>
<td>50</td>
</tr>
<tr>
<td>Calculate the energy dissipated from a bi-linear hysteresis cycle.</td>
<td>19</td>
</tr>
<tr>
<td>Calculate the force on a shear wall anchorage using statics.</td>
<td>38</td>
</tr>
<tr>
<td>Apply appropriate code designated adjustments to the design load for a component of a discontinuous system.</td>
<td>50</td>
</tr>
<tr>
<td>Sort components of a discontinuous system into their associated Design Group.</td>
<td>58</td>
</tr>
</tbody>
</table>

Several course periods were used by small groups to complete various steps of preparing and conducting the experiments. The class period for the course was one night a week from 6:00 to 8:45 each week. The first three class periods were used by the instructor to provide the background material for the experiments, particularly the load path through a discontinuous wall system and the behavior of nonlinear hysteretic spring systems. Another class period later in the term was used to introduce students to the methods of collecting and processing experimental test data. Most of the evening periods were used by the instructor to work with a small group of students to build and assemble the experimental specimens. The students in the class were divided randomly into three groups, with each group responsible for building and conducting one experiment. These groups of students performed much of the work of nailing the wood framing together, nailing the sheathing to the framing and installing the holdowns, straps and clips to connect the wood components. These tasks can be completed manually, without use of power tools. Due to the large number of students working on the specimen and the variety of carpentry skills the instructor completed the work that required power tools, such as cutting with the circular saw and nailing with the nail gun.

Students also completed several hands-on tasks through their assignment of an Independent Study task. A list of likely tasks was distributed by the instructor and students were allowed to
pick one or two choices as the task of their assignment. Tasks varied from working in the steel shop to prepare steel test jigs to developing an online presence for the testing. Most of these tasks were not related to learning objectives of the course but were critical for the successful completion of the experimental study. Students were asked to file progress reports every three weeks, even if no work had been completed in the period. To assist the students, the instructor formed a template for their progress report. This template and the associated file naming format was an assistance to the instructor in quickly evaluating the work progress during the semester. Alas, as the semester and the experimental testing progressed, the ability of the instructor, technician and students to align their schedules resulted in many tasks being completed without the student’s involvement. Hence the work assigned to students remained in flux for much of the semester. Students who had not been involved in the Independent Study were assigned additional work on processing data as the experiments evolved.

Closed-book exams were used for the majority of assessment of student learning. One midterm and one final exam were conducted. Most of the material for the two exams was similar, with the final exam also including questions about the processing of experimental data. Table 1 includes a summary of student performance on the learning objectives during the midterm exam. Students performed best on questions related to building code requirements, both about when the Overstrength Factor is to be applied and in determining when various code requirements such as the redundancy value and the 25% increase in collector forces is relevant. Students performed poorer in those questions which required lengthy calculation, such as determining the load path through a complicated structure and the hysteretic energy dissipation of a bilinear spring. This was disappointing; the midterm was administered during a three-hour class period so that time would not be critical. The problems were very similar to the examples and homework assignment problems but of course, the closed book format required students to ‘know’ the material in sufficient detail to be able to apply it to a slightly modified situation. Surprisingly, the average of all student scores on the learning objectives was essentially the same.

Lessons Learned

The instructor has the following suggestions for others to consider while implementing a similar hands-on course delivery:

1. Safety is job 1. Student safety is critical, particularly when working in close proximity in an engineering lab. The first lecture of the course was related to safety and students were constantly reminded that the work should never move forward if a student is concerned about an unsafe situation. Students were restricted to working with hand tools except for the Independent Study work when they were closely supervised by the laboratory technician. However, the high level of safety monitoring was unable to prevent cuts and scratches while working with the installation of the cold-formed metal hardware.

2. Students struggle with nonlinear behavior of systems. This has been an issue the instructor has seen in many courses over the past decades. Undergraduate education is so focused on linear analysis and linear behavior that students and many practicing engineers struggle with plastic mechanics. For this course, the nonlinear behavior was restricted to axially-loaded springs. Multiple spring systems were only analyzed for
monotonic loading; hysteretic cycles were only used on bilinear components. Still, students struggled with how the system would respond to a displacement-controlled loading.

3. Matching an experimental program calendar with an academic calendar is a struggle. Several weeks were required to resolve an instrumentation issue. While a few week delay is common in experimental research, the loss of time was critical when matching to an academic calendar. As a result, the experiments needed to be completed under a compressed timeline preventing them from being completed during class periods. This prevented a number of students from witnessing the experiments.

4. Student templates were critical in obtaining work in a professional manner. While instructors expect students to be able to organize and present their work in a suitable manner, it seems that expectation is unrealistic, particularly in light of the wide variety of backgrounds that students bring to the graduate program. In a research environment, that expectation is probably more unrealistic since writing progress reports, saving files in an organized manner, graphing data in a usable form are not skills students have been consistently required to do. In fact, one motivation for the instructor to develop the course was to prepare future thesis students to a suitable means of summarizing their work on independent study work.

References

