Instructor’s Guide

EARTHQUAKE-RESISTANT BRIDGE COMPETITION

A PROJECT DEVELOPED FOR THE UNIVERSITY CONSORTIUM ON INSTRUCTIONAL SHAKE TABLES

Developed by:
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This project is supported in part by the National Science Foundation Grant Nos. DUE-9950340 and CMS-9733272. Additional support is provided by the College of Engineering at San Jose State University
INSTRUCTOR’S GUIDE

Earthquake Resistant Bridge Design Competition

Goal and Objective

The goal of this project is to use basic engineering concepts to design and build a bridge that can resist the forces induced during an earthquake. The objective is to build a small bridge from balsa wood that can withstand severe ground shaking recorded during actual earthquakes. The winning bridge is selected as the entry that supports the highest mass while being shaken by the most severe earthquake motion.

The project is intended for teams and should take three to five weeks to complete. Teams are usually from three to four members. At San Jose State University a scholarship was awarded to the top three teams. To make for fair competition, any team pursuing the scholarships was allowed to have at most one member who was a senior or junior.

Student Prerequisites

The competition is intended for students in an introductory engineering class. The intent is for a wide variety of backgrounds and for students enrolled in any field of engineering. Previous knowledge of the design of bridges is not expected, however many students will have some background knowledge gained from similar projects in High School. Introductory knowledge of vector addition will assist the students in analyzing the forces in individual members of the truss.

With modification, the competition could also be made appropriate for students in higher levels of civil engineering. By expanding the use of statics, by estimating deflections using classical methods, and/or by including appropriate design strengths for sizing members the complexity of the project could challenge juniors or seniors in civil engineering.

Lecture Materials

Individual instructors may choose various aspects to describe in lecture for preparing the students for the competition. The student handout includes an example truss analysis and a preliminary deflection calculation. These could be expanded and/or illustrated during lecture, particularly the vector analysis of the truss forces. In addition, a brief description of truss configurations shown in the webpages listed in the student handout or in various books can give the students better appreciation of bridge trusses in general.

After having one class complete the project, I found the primary difficulty students had was in meeting the geometric constraints for the abutments and the loading blocks. It became quite apparent that many teams had not paid close attention to the constraints and especially had not considered how these items would fit together in three dimensions.
Instructors are urged to review blueprint reading skills so that students are able to interpret the drawings.

Another potential concern is materials. Students had much confusion about the material to be used. Balsa wood, not basswood, should be used for all members. Basswood has a smooth finish and is approximately double the density of balsa wood. The intent of the competition is that all wood be 1/8-inch balsa. Some students read the 4-mm maximum dimension for the wood and went to local hobby shops to buy 4-mm balsa. They often received 3/16-inch balsa and were disqualified for being over the 4-mm limit. In addition, several store clerks told the students they were buying balsa wood when in reality it was basswood. Considering also the volume of balsa wood required for a class of 300 engineering students, local hobby stores quickly sold out of available stock. For these reasons, it is suggested that the instructor obtain the materials beforehand and distribute it to the student teams.

Once the judges understood the testing process, each bridge required about 30 minutes to complete the testing.

Student learning was assessed based upon the performance of the bridge, the written design report, and the final oral presentation of the project.

**Student Learning Objectives**

Based upon the emphasis of the instructor, some or all of the following learning objectives may be chosen for the project.

At the end of the project, the student will be able to:

1. design a simple engineering prototype that meets specific criteria.
2. analyze a symmetric determinant truss using vector addition.
3. estimate the deflection of a truss.
4. visualize the shaking of a bridge during an earthquake.
5. describe the role of civil engineers in designing bridges to resist earthquake motion.
6. write a detailed engineering report describing a design project.
7. organize and present an oral report of a design project.
8. build and fabricate a small engineering prototype model to a predetermined design.
Items to be fabricated to allow for testing include: Loading Mass Support Block, the Incremental Mass Blocks, and the Abutments.

Figure 1. Loading Mass Support Block

Figure 1 illustrates the Loading Mass Support Block. This assembly is connected by ¼-inch screws through the bottom extenders, and up into the central block. The 2.76-inch long members should protrude beyond the outer face of the trusses and will then clamp to the truss lower chord to hold the mass tightly to the bridge. The assembly shown should be made from machine steel and weigh 2000 grams when complete. Incremental Mass Blocks weighing 500 grams each are slid onto the ends of the 0.39-inch rod to add incremental weight. These blocks have the same 1.38-inch width and 1.97-inch height as the assembly’s main block and are 1.57-inches long. All blocks can be slightly adjusted in dimension with a mill to reach the correct weight.

The abutments can be made from aluminum or steel. They need to fit the dimensions given in the student handout. They are to screw to the top of the table, at holes 16 inches apart.
Testing

In this section, I discuss various suggestions to make the testing run more smoothly.

**Gravity and Transverse Test**

The lab technician fabricated a set of abutments to duplicate the ones for the shaker table. This allowed for installing dial gauges to read the vertical and horizontal deflections as shown in Figure 2. Two dial gauges were used for the vertical deflections to allow for reading each truss. These values were averaged for the deflection. Also, we found that having jigs fabricated for checking geometric criteria removed the debate about whether the correct dimensions had been used. The student in the photo uses the Ring of Shame to verify outside dimensions. A shaft was used to check the interior dimensions and jigs were also fabricated to check maximum truss member cross-section dimensions and maximum height of the top chord above the elevation of the abutments. The purpose of the transverse test is to guarantee a minimal transverse stiffness, so that the ground motion will excite the mass.

![Figure 2. Geometry and Deflection Check](image)
Earthquake Test

Students were asked to install the bridge on the table and to add weights so that they took responsibility in case something was damaged during the process. A sheet of plywood was placed beneath the bridge to protect the table’s top surface as shown in Figure 3. The student is tightening screws that will clamp the bridge chords to the top of the abutment. If these chords are loose and able to slide, the experiment will not work appropriately.

Figure 3. Mounting on the Shaker Table
Figure 4 shows a bridge installed with the mass-mounting block. Incremental Mass Blocks are slid onto the horizontal rods from each end of the bridge. A horizontal metal pin installed near the bottom of the additional masses keeps them from rotating on the rod during the ground shaking.

Figure 4. Mass Support System on Bridge
Failure of a bridge was defined as any part of the bridge or mass assembly touching the plywood below or any of the mass touching any portion of the bridge.

Figure 5. Failure of a Bridge
At the request of one of the instructors, a finer gradation of applied mass was used (rather than the 1000 grams originally intended). Figure 6 shows a student adding washers to the end of the rod to make smaller increments in the increase in mass. Future instructors are encouraged to consider any gradation that they desire. Gradations of 1000 grams will likely lead to ties.
Some bridges were disqualified for not following the design criteria. Because several scholarships were at stake, we were particularly concerned about making the competition fair. Some violations were gray areas as shown in Figure 7. The first was disqualified because the connections are reinforced with additional gussets of balsa. The second did not provide a bottom chord at the level of the abutments.

Figure 7. Disqualified Bridge Designs

Whenever possible, disqualified bridges were tested but not considered in the competition. Students were very curious to see how their bridges performed even when not considered for the final competition.
Assessment of Project

The project was used in Spring 2001 by the Introduction to Engineering class of approximately 300 students and five instructors. Overall the project appeared to be enjoyed by most of the students and at the end a survey was conducted (the survey form is appended to this document). As developer of the project, I would appreciate any feedback that can be made from those who use the project in the future. If possible, I would like the survey form to be completed by your students and mailed to:

Kurt McMullin  
Department of Civil and Environmental Engineering  
San Jose State University  
Department of Civil and Environmental Engineering  
One Washington Square  
San Jose, CA 95192-0083

As I receive completed surveys from various schools I will update the totals shown below. To process the data, I divided the student populations into two pools: everyone (154 replies) and freshmen (84 replies). Hence the second population is a large subset of the first. In the tables, the first number is for the number of responses divided by the population for the first group (all students) and the second number is the same ratio for the freshmen.

Assessment of First Offering of Project

Knowledge about Civil Engineering

<table>
<thead>
<tr>
<th>Prior Knowledge</th>
<th>Unchanged</th>
<th>Increased</th>
<th>Significantly Increased</th>
<th>No Opinion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Little</td>
<td>0.026 / 0.048</td>
<td>0.169 / 0.155</td>
<td>0.000 / 0.000</td>
<td>0.026 / 0.024</td>
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<tr>
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<td>0.006 / 0.000</td>
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<tr>
<td>Very Large</td>
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<td>0.013 / 0.000</td>
<td>0.000 / 0.000</td>
<td>0.000 / 0.000</td>
</tr>
<tr>
<td>No Opinion</td>
<td>0.000 / 0.000</td>
<td>0.013 / 0.024</td>
<td>0.000 / 0.000</td>
<td>0.013 / 0.012</td>
</tr>
</tbody>
</table>

Conclusions:
- The most common response, at 40% for both groups, was that students came in with little prior knowledge and were able to increase that knowledge.
- Almost four-fifths felt they had increased or significantly increased their knowledge.
- Three-quarters of the freshman felt they had very little or little prior knowledge of civil engineering. This remained the same for the total population of students.
### Knowledge about Bridges and Earthquakes

<table>
<thead>
<tr>
<th>Prior Knowledge</th>
<th>Unchanged</th>
<th>Increased</th>
<th>Significantly Increased</th>
<th>No Opinion</th>
</tr>
</thead>
<tbody>
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<td><strong>0.175 / 0.205</strong></td>
<td>0.013 / 0.024</td>
<td>0.006 / 0.000</td>
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<tr>
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<td><strong>0.312 / 0.253</strong></td>
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<td>0.000 / 0.000</td>
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<td>0.006 / 0.012</td>
<td>0.006 / 0.012</td>
<td>0.013 / 0.012</td>
</tr>
</tbody>
</table>

**Conclusions:**
- The most common response was that students came in with little prior knowledge and were able to increase that knowledge.
- Over three-fifths of the students felt they had increased their knowledge and almost four-fifths marked that they had increased or significantly increased their knowledge.
- Three-fifths of the freshman felt they had very little or little prior knowledge of bridges and their behavior during earthquakes. This increased to two-thirds for the total population of students.
APPENDIX: PROJECT ASSESSMENT

Semester _______ University ___________________ Instructor ______________

This project was interesting and challenging.
Strongly Agree Agree Disagree Strongly Disagree No Opinion

If given the chance, I would like to work with the same team members in a future course.
Strongly Agree Agree Disagree Strongly Disagree No Opinion

I would like to increase my knowledge about bridges and earthquakes.
Strongly Agree Agree Disagree Strongly Disagree No Opinion

My current academic status is:
Freshman Sophomore Junior Senior Other

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Before doing this project, my knowledge of Civil Engineering was:
Very little Little Significant Very Large No Opinion

After doing this project, my knowledge of Civil Engineering was:
Unchanged Increased Significantly increased No Opinion

Before doing this project, my knowledge of the way bridges behave during earthquake was:
Very little Little Significant Very Large No Opinion

After doing this project, my knowledge of the way bridges behave during earthquake was:
Unchanged Increased Significantly increased No Opinion

Any comments?