Freshman Level Design – Bridge Building Project

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Abstract

To provide a stimulating introduction on the concepts of Structural Engineering to freshmen students, a hands-on laboratory based course on bridge design and construction was developed. The course provides an overview of strength of materials, structural analysis, computer aided design, and construction over a six week period. Material testing laboratory modules are conducted to provide knowledge on physical strengths of the materials that are used in the project. These material characteristics are then used to support structural analysis methods. Two computer design and analysis modules are used to provide the basics of the engineering design process. Using these tools developed over the first 3 weeks, the students are tasked to design and build a bridge that can support the weight of their professor.

Six class modules are developed and presented in detail. The modules include: 1) Bridge Structures and Components, 2) Strength of Materials, 3) Structural Analysis Basics, 4) Structural Design and Project Management, 5) Computer Design Process, and 6) Detailed Computer Design. The resulting designs and student feedback indicate the course is successful in providing an enjoyable overview of structural engineering.

Introduction

Undergraduate engineering education at Lehigh University is configured to allow freshmen to experience a variety of fields prior to making a decision on which path to pursue for their academic career. All freshmen are accepted to the College of Engineering as undecided with a specified area of interest. To assist with the decision making process the students are required to take an engineering design class in addition to the standard math, science and humanity courses. The class is taught to half of the students, approximately 150, in the Fall semester and the remaining half in the Spring. The class, titled Engineering 5, consists of a series of lectures on engineering issues faced in the working environment and detailed overviews of each discipline of engineering study. This is combined with two design projects which run parallel with the lecture series. The students are given a total of eight design project options, one from each discipline, and asked to pick two of interest. Based on student preferences and availability the class is divided into project groups of 20 to 25 students. These students are then given the opportunity to work on a project within one of the college of engineering departments.

To provide an entertaining overview of the field of structural engineering a bridge design-build project was developed. The goal of the project is to provide enough knowledge so the students can apply their own ideas and personality toward the design and construction. The course is based on the ASCE West Point Design Teaching Curriculum by Ressler[1] designed for high school students. The general outline is condensed and modified to address the advanced knowledge and abilities of freshmen engineering students.

Design Build Project

The project is divided into an education and application phase. The knowledge required for the design and build is provided in six classes over three weeks; a two week build phase follows. The class is ended with presentations of the design concept for each group and load testing of the final designs. This paper provides an overview of the goals and procedures used in the class.

Project Goal

The goal of the project is to design a balsa wood bridge that can support the weight of the professor. With this goal both the student and the professor is tested. The student's knowledge and abilities are tested in the final proof test and the professor's ability to teach is tested in the success rate of the bridges.

A truss bridge configuration is used as a design model for the class. The truss provides simplicity in that only the concepts of compression and tension are needed to develop a good design. In addition a truss can be fabricated with minimal wood-working abilities.

The project is presented as follows: "You are tasked to design a balsa wood truss bridge to support the weight of Professor Naito and any hanging attachments that are needed. The total weight will be provided during the class. The weight will be distributed evenly to two equal loads placed 8 inches apart. The centerline to centerline distance between supports is 28 inches. Do not make your bridge exactly 28 inches long, rather the center of your bearing should be at 28 inches. Simple supports will be used. The supports measure three inches across and one inch wide (bearing). The forces will be applied using 3/4 inch wide plates which are also three inches across."

1. Maximum bridge width is 3.0 inches OUT-TO-OUT Dimension.
2. Maximum TOTAL bridge height (sum of distances above and below supports) is 9.0 inches. Be sure the bridge can be placed on the supports. The supports will be installed on the Fritz Laboratory floor for inspection.
3. Dimensions are overall dimensions; remember your members have thickness.
4. The supports rotate and are designed so that they do not resist horizontal force (therefore an arch <u>without</u> a tension tie is not allowed).
5. The truss must be able to house a 1-1/2" Diameter pipe. Therefore a clear 1-1/2" passage must be provided down the length of the bridge.
6. Only joints may be glued.
7. The winning bridge will be the LIGHTEST to successfully support the weight of Professor Naito and loading attachments for a period of 30 seconds.
8. A maximum deflection of ½ inch is allowed at the loading location. Exceeding this value will result in a damaged Professor and a loss.

The setup for testing is schematically shown in Figure 2. The bridge is loaded through a hanging apparatus to ensure that forces are applied in an even manner. To determine a load capacity for bridges not capable of supporting the weight, a load cell is placed in line with the hanger cable. The winning design has the highest ratio of bridge load carrying capacity to weight. The bridges are also judged on aesthetics and the student's presentation preceding the load testing.

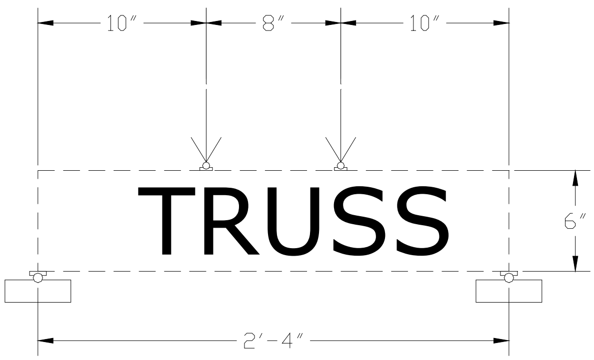


Figure 1: Elevation view of truss evaluation setup

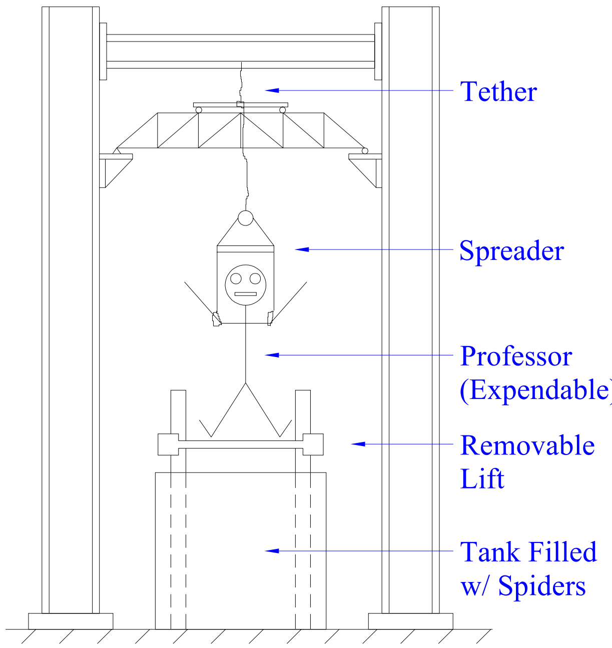


Figure 2: Loading schematic

Class Learning Objectives

The six classes are taught in a three hour format with a mixture of lecture, laboratory and problem working sessions. A moderately heavy load of homework is given to keep pace with the topics covered. The class topics and learning objectives covered are presented in Table 1.


Figure 3: Class 1 sample bridge overview slides

The first class presents the terminology associated with bridge trusses and the general concepts of structural engineering. This is achieved through a visual study of bridge systems and discussion on how bridges support loads (Figure 3). The class terminates with a simple truss fabrication exercise. Since the exercise is conducted on the first day the class gives the student's the opportunity to use their best judgment in fabrication of a truss. A single triangular truss with a 6 inch base is required using the balsa material available. The bridges are weighed and load tested in a later class. This early exercise is provided to give the students a sense of the fabrication process and a better understanding of the materials they are using. Homework consists of choosing two bridges from the internet and identifying their structural system. The

Historic American Buildings Survey/Historic American Engineering Record[2] is a good resource for identifying bridge trusses.

Table 1: Class learning objectives

Class 1: Bridge Structures and Components • Define a truss. • Identify the major components of a truss bridge. • Identify truss bridges types. • Apply structural engineering concepts of force, load, reaction, equilibrium, tension, compression, and strength. • Explain how a truss bridge works—how each individual component contributes to the ability of the entire structure to carry a load. • Explain how construction quality affects the performance of a structure.	Class 2: Strength of Materials • Calculate the cross-sectional area of a structural member. • Describe the yielding, rupture, and buckling failure modes. • Explain the factors that affect the tensile strength and the compressive strength of a structural member. • (LAB)Determine the tensile strength and the compressive strength of structural members through experimentation.
Class 3: Structural Analysis Basics • Calculate the components of a force vector. • Add two force vectors together. • Explain the following structural engineering concepts: free body diagram, equilibrium, structural model, symmetry, static determinacy, stability, and factor of safety. • Use the Method of Joints to calculate the internal force in every member in a truss. • Determine the strength of every member in a truss. • Evaluate a truss, to determine if it can carry a given load safely.	Class 4: Structural Design – Project Management • Describe the engineering design process • Design truss members • Calculate the forces acting on a joint • Identify the stages of an engineering project • Determine the necessary stages of a bridge design project
Class 5: Bridge Computer Design • Describe the problem solving process • Explain how the engineering design process is applied to the design of a highway bridge • Explain how engineers use computers to enhance the engineering design process • Design a truss bridge, using the West Point Bridge Designer software	Class 6: Bridge Computer Design – Visual Analysis • Explain how the factor of safety is used in design. • Explain how scientific principles, mathematic tools, engineering concepts, experimental data, and practical considerations contribute to the engineering design process.

The second class provides an overview of strength of materials. The concepts of compression and tension force and failure modes are discussed. Buckling failure modes are described with physical models and proof tested on the trusses built in the preceding class. Each student is required to calculate the failure capacities and predict the mode of failure. Observations on the failure are taken and discussed. This laboratory provides a better understanding of the materials that they will be working with, an actual measure of the strength, and a few lessons on fabrication. The trusses are tested in a tabletop loading setup in the Undergraduate structures Laboratory at Lehigh University. The load is applied using a hand actuated press with a load cell inline (Figure 4 note – photo illustrates loading system with full bridge).

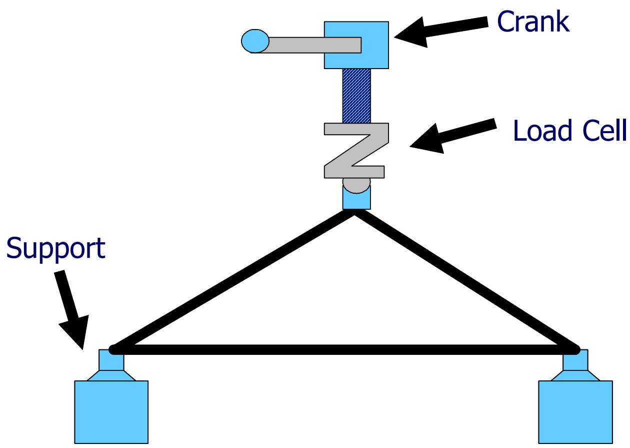


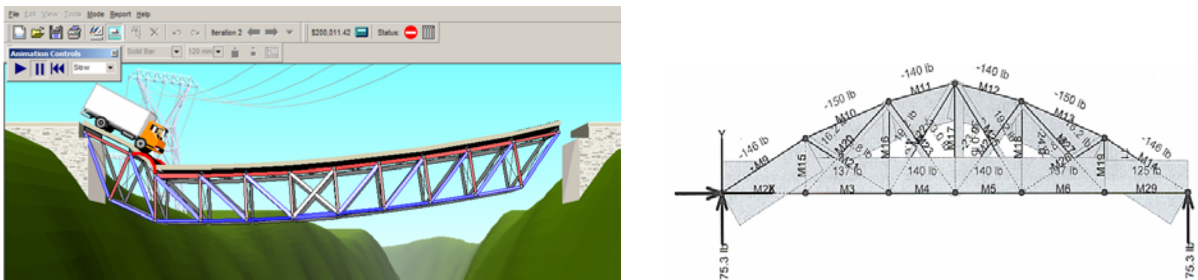
Figure 4: Loading setup

Class three covers the concept of method of joints. The goal of the class is to teach the students the basic ideas of force transfer in trusses so they can use it for their final designs. The class covers force equilibrium and uses the previously designed trusses as a basis for the class. As homework the students are tasked to determine the forces in all members of their truss at the failure load.

Class four covers the concept of design. The internal forces previously evaluated are compared to the design strengths of the members. The buckling load is computed and the tensile capacity is measured. The truss is then re-designed to support a new fictitious load. In addition, the design construction process is described in detail.

Two computer design lectures are used at the end of the class to allow the students to produce designs which are more complex then their hand calculation abilities allow (Figure 5). The first computer design class uses West Point Bride Designer[3] as a basis. The program is used annually for a national high school level competition in which students attempt to build the most cost effective bridge. The program, while simplistic for college level students, provides a superb example of the design process. The program allows the students to virtually construct a truss of their choosing, check capacities, and resize members to prevent undesirable failure modes. An in-class competition assignment is given at the end of the software familiarization. The goal is to design a bridge of a given span with a total cost less than a targeted value. The most cost effective design receives a bonus. The students are asked to sketch three designs for advanced analysis on the final day of class.

With the fundamentals of bridge design provided in classes one through five, the final class exposes the students to advanced analysis tools. Visual Analysis[4] is used for the class however any structural analysis program will suffice. The students are taught how to enter members and loads and how to determine the resulting internal forces generated in the members. Moving from West Point Bridge Designer (WPBD) to advanced structural analysis software often creates confusion on the part of the students. WPBD is configured to automatically calculate the forces in the members and compare them with the design load. In the advanced analysis tool used this feature is not provided. To assist with this process a spreadsheet formulation is developed and used in class. The students are divided into groups of three to four students. Each student then must design his or her bridge to a specified design load. The lightest design in each team is chosen for fabrication. If the students complete their design early they can commence fabrication.



a) Simplified design (WPBD[3]) b) Detailed analysis (VA[4])

Figure 5: Computer design

The fabrication process is conducted in the laboratory using knives and saws. The students are assisted by a class teaching assistant and by the faculty. Construction can be a thought provoking and enjoyable experience for the students (Figure 6). The final project is judged on a combination of presentation (Figure 7a), construction aesthetics (Figure 7b), and measured load carrying performance (Figure 7c).

Figure 6: Construction

Design Project Discussion

As a whole the student projects were well constructed and designed. In most cases, however the students over estimated the capacities of their bridges. This was attributed to the variability in the balsa wood materials. To ensure that the final bridge designs are capable of withstanding the design loads a conservative factor of safety should be developed for the material used. In addition, a load cell should be used during the hanging load test in the case of premature failure. This allows the students to have an idea of their design performance in the case of a brittle failure. The students demonstrated a good understanding of their design through presentations and the discussion in their final reports. In many cases they were able to describe the force distribution in their designs and in some cases accurately predict the ultimate failure mode.

a) Aesthetics

b) Presentation

c) Load testing

Figure 7: Bridge judging

There was significant positive feedback on the class as a whole. A survey of one group of students participating in the course resulted in 4.5 out of 5 on questions regarding the quality, effectiveness, and overall level of learning in the project. Students commented that they enjoyed the competition and real world applications.

The negative feedback included the short schedule for the construction phase of the project and, for some, the high amount of homework. The course could be significantly enhanced with additional time available however based on past performance the class schedule is feasible with the time allotted. With regards to the homework levels, freshmen engineering students are not used to a heavy load of assignments. Given the responsibility however they inevitably are able to get the job done.

One of the truly enjoyable facets of the project is the ability to go through all aspects of structural engineering. This includes preliminary design, detailed design, procurement, construction, evaluation and forensic investigations into failure. No other course in the structures program allows for this path to be fully traversed. To enhance the structural engineering path a companion course could be developed as part of a senior level capstone project. This course could use the design and analysis skills developed over the student's academic career to design and build a structure. This could range from a pedestrian bridge to tensegrity domes. The possibilities are open to student's imagination and determination.

References

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Dr. Naito is an assistant professor of structural engineering in the department of Civil and Environmental Engineering at Lehigh University and an associated faculty of the ATLSS Research Center. He received a B.S. degree from the University of Hawaii Manoa and a M.S. and Ph.D. from University of California Berkeley. He is responsible for teaching courses in structural analysis, construction management, and prestressed concrete design. His research interests focus on the design and enhancement of large scale structural systems subject to extreme load effects from explosions and earthquakes. Current projects include: NSF/PCI Project: Development of a Design Methodology for Precast Diaphragms and PITA Project: Evaluation of Self Consolidating Concrete for Use in Precast/Prestressed Bridge Beams. Professor Naito is a licensed engineer in the state of California.