Yosemite Bridge

Design Competition – Scoring, Constraints and Final Report Guidelines

The objective of this competition is to demonstrate through hands-on experience your skill in designing, analyzing, building, and testing a simple truss structure. It is intended to establish your expertise in the following areas:

- designing with a team,
- integrating the process of design-analysis-build-interpret,
- observing the behavior of structures under load through failure,
- understanding the importance of fabrication techniques, load, and deflection measurements,
- understanding structural design principles for slender members in tension and compression,
- presenting your design process, analytic findings, and testing results in a written format.

Competition and Scoring –

This design competition will be held over the space of two weeks from the time your team receives the build materials to the competition testing. During this time, you will be expected to submit at least two bridge designs on paper for pre-review, construct a prototype bridge for testing, test the bridge in competition with other teams and submit a report of your findings to the Review Committee.

The Review Committee will award up to 100 points to each team, with the possibility of earning an additional 10 bonus points. Points will be awarded for the the following:

Activity	**Points Awarded**	**Timing**
Pre-Review Bridge Designs	5 points	Due one week prior to Testing Day
Pre-Review Draft Final Report	5 points	On Testing Day
Bridge Performance (99 N – 145 N)	60 points	Testing Day
Project Report	30 points	Due two days post Testing Day
Total	**100 points**	
Bonus – Weight (Top 25% of lightest designs)	*5 points*	Awarded on Testing Day
Bonus – Design (Non-standard Howe or Pratt)	*5 points*	Awarded on Testing Day

Materials and Fabrication Details –

Teams can use any tools for fabrication. Exacto™ knives are not provided, but are typically useful when working with balsa wood. Each team will receive the following items for construction:

- Seven (7) 3-foot lengths of balsa wood (3.175 mm x 3.175 mm)
- A bottle of standard wood glue *
- A sheet of foam core *
- A sheet of wax paper
- A sheet of sand paper
- A half-sheet of card stock for roadbed gussets + gusset specification sheet
- Straight pins *
- Two metal right angle braces *

* - Materials returned after class

Technical Details and Design Constraints -

Requirement	Specifications
Competition Description	Build and test a functional prototype of the bridge that will span the Tuolumne River at the Glen Aulin High Sierra Camp
Bridge Dimensions	
Structure	Truss
Span	minimum 24 cm, maximum 25 cm
Height - Maximum (outer dimension)	10 cm, from deck to highest truss point
Height – Minimum (inner dimension)	3.5 cm, for test road bed insertion
Width - Maximum (outer dimension)	4.5 cm
Width – Minimum (inner dimension)	3.5 cm, for test road bed insertion
Weight – Maximum 20g	Top 25% contestant lightest bridge (+5 Bonus Points)
Design Approach - Bonus	Non-standard Howe or Pratt truss design (+5 Bonus Points)
Test Rig Specifications	
Test Road Bed dimensions *(includes hooks)*	3.0 cm x 3.0 cm x 21.0 cm (*width x height x length*)
Hook locations (*from end of road bed*)	Four hooks - 6.7 cm, 9.2 cm, 11.8 cm, 14.3 cm
Target Loads	
Target Load applied to Road Bed	66 N
Minimum Factor of Safety	1.5 (= 99 N)
Maximum Factor of Safety	2.2 (= 145 N)
Maximum Internal Compressive Load – Buckling[1]	$F_{buckling} = \pi^2 EI/(kL)^2$
Maximum Internal Compressive Load – Crushing[2]	$F_{crushing} = A * \sigma_{compression}$
Maximum Internal Tensile Load *(axial)*	735 N
Construction Materials	
Truss Material	Balsa wood
Balsa wood cross-section dimensions	3.175 mm x 3.175 mm
Gussets	7.5 mm x 4.0 mm maximum area and only allowed on the joints of the lower plane of the bridge road bed
Adhesion	Standard wood glue, no epoxy
Maximum Cost (team expenditure)	$10.00

Notes:

1. **Force (Buckling):** $k=1$(pin connected at both ends); L is the length of the member; $I=bh^3/12$ (area moment of inertia for rectangular cross section), where b is the width of the section and h is the height of the section. Young's modulus for the balsa wood in tension was measured as $E_{tension} = 3.5$ GPa and in compression it was measured as $E_{compression} = 1.2$ GPa. Previous testing also shows that truss members over 6 cm in length are subject to buckling failure and under 6 cm are subject to compressive failure.

2. **Force (Compression):** A is the area of the cross section; the compressive ultimate strength $\sigma_{compression}$ we tested averaged 35 MPa for balsa wood along the grain. However, there were some weaker elements that were only 8-10 MPa in strength (not included in the above average). Suggest designing to a compressive strength of 70 N.

Getting Started – Design and Analysis

- Agree as a team on the target design load for the bridge which must be within 99 N (1.5 safety factor) and 145 N (2.2 safety factor).
- Agree as a team on your Design Approach – will you design a standard Howe or Pratt truss bridge or will you design something noticeably different? If you choose different, you must be prepared to explain the novelty of your changes from the standard designs.
- Sketch out at least two and ideally more rough designs (a homework requirement) for your bridge. Agree as a team which designs are of most interest.
- Consider inputting your designs into a truss software program for preliminary analysis. Useful, free software tools are available, such as the Johns Hopkins Bridge Designer (http://pages.jh.edu/~virtlab/bridge/truss.htm) or MASTAN2 (http://www.mastan2.com/)
- Truss bridges are two-sided and each side carries one-half the target maximum load.
- The target maximum load will be carried by cross members along the road bed on the bottom of the bridge. Count the number of cross members and exclude the cross members on the ends of the bridge that will not carry any of the load force from the 21.0 cm test road bed.
- The load force for each side is divided by the number of cross members and results in the force applied to each individual cross member. This is the starting point for failure analysis.
- Analyze the forces on each member of the bridge side using either Method of Joints or Method of Sections. Forces can be adjusted to the target failure force by adding or removing members and/or lengthening or shortening members. Remember to show your work for credit.
- HINT: for this material (balsa wood) in this dimension (3.175 mm x 3.175 mm), members over 6 cm in length are subject to buckling (use the buckling formula) and under 6 cm in length are subject to crushing (use the compression formula).

Getting Started – Construction

- Spend some time upfront deciding on construction roles and duties. It takes a team to build a bridge, so spread out the work equitably.
- Plan your time. It takes at least 12 hours for the glue to dry solid for sanding. Start with the bridge testing time and work backwards as you define the construction schedule.
- Create a 2D to scale drawing of your bridge side. This can be done in SolidWorks, Autodesk Inventor, PowerPoint or by hand on graph paper. It helps to put both sides on the bridge on one page so you can work on each side simultaneously.
- Place drawing on foam board and cover with wax paper. Tape the papers to the foam board and secure.
- Mark and cut individual members. It is helpful to cut the individual member a little larger than needed then sand them to the proper length and shape.
- Glue members by spreading a thin film of glue on each member end, working the glue into the fibers of the balsa wood for strength.
- Secure members in place with pins into the foam board. NOTE: do not pin through the members as that significantly alters the strength profile.
- Construct joints by either butting right angle members or beveling to accommodate angles. The line of action of each member in a joint must move through a single point in the joint.
- After completing each side, let dry until firm enough to handle. Remove from foam board and lightly sand away excess glue at joints.
- Cut the cross members to length. Remember, the inner dimension of the bridge must be at least 3.5 cm to accommodate the test road bed. Make the cross members longer to be safe.
- Using a metal right angle, tape one bridge side in a vertical position. Glue one end of the cross members to the vertical side. Using a second metal right angle, glue the second side to the other end of the cross members. Start with the cross members on the road bed, attach upper cross members afterwards.
- Once the glue is dry enough to handle the bridge, lightly sand all joints.
- Attach gussets to the bottom side of the road bed plane at each joint where a cross member attaches to a side. Gussets are cut from the card stock provided (4.0 mm x 7.0 mm)
- With a fine point pen, label each member consistent with your Analysis Plan. Lightly color members red that are in compression, blue that are in tension and green if it is a zero force member.
- Let all glue joints dry for at least 12 hours. Carefully bring your bridge to the testing location.

Report Guidelines for Draft and Final Project Report

Overview

The following provides suggestions on content and an example of proper formatting and style for the draft and final reports for the Yosemite Bridge Project Report. Remember that an essential part of being an engineer is being able to communicate your design strategies, analytical techniques and supporting calculations to your fellow engineers and team members, as well as clients, customers, and your employer.

Content Guidelines for the Report

We have provided a template for your Yosemite Bridge Project Report in Microsoft Word, titled *"Yosemite Bridge Team [your team number] Final Report Template.docx"*. Save a working copy of this, replace *[your team number]* with your team number and delete "*Template*". This template is formatted with all the required sections and tables. It also contains a Table of Contents that will automatically update the page number as you add content.

The report will not be complete without the member force table in Section B.2. Make sure that each member is labeled and listed and the member that is designed to fail at the design load is highlighted and described in the caption for the member force table.

Formatting Guidelines for Figures and Tables

All photos, sketches and graphics that you include in the report must be given a figure number and captioned with a concise description. Figure captions should appear below the figure. A figure should be placed in the body of the report near where it is referenced and all figures should be referenced in the text prior to their appearance in the text. For example, Figure 1, or if you prefer Fig.1, shows the chance that your report score will go up as a function of how long you spend reading this document. If your figure is a plot, make sure that is has appropriate axes labels and clearly defined units.

Showing Equations

Equations that explain your process should be shown with the equations and a reference number to the right. Use the reference number to connect the reader with the equation in your description. For longer and more involved calculations, it is best to put them in the Appendix at the end of the document.

$$\sum \vec{F} = \vec{0} \qquad \text{Equation (1)}$$

Make sure that you reference the material in the Appendix at the appropriate place in the body of the text. The Appendix always starts on a new page. If you have more than one Appendix, you can label them as Appendix A, Appendix B and so on. The equations, figures and tables that are in the Appendix should be numbered so that they can be referenced in the body of the document.

Report Sections - Described

The project report will be comprised of five sections. Each section is described below:

Section A: Bridge Design Description (4 pages maximum)

A.1- Designs Considered During Brainstorming

- *What design approaches were considered when the team was first approaching the problem? What criteria became a priority? How was a final approach selected? Photos, drawings and sketches will help convey this information. All figures/photos/sketches should be numbered (e.g., Figure 1, Figure 2) and captioned. Figures should be referred to in the text before the figure appears.*

A.2- Detailed Description of Final Design

- *Description of the final design should make reference to the "Design Specification Table" and the "Bridge Diagram."*

A.3- Design Specification Table

- *The completed table should show number of joints, number of members, and confirmation that it meets the stated dimensional, cost, and weight criteria. Template is shown below:*

Table X: Design Specifications – Requirements and As Built

	Design Requirement	**Your Prototype Bridge (as built)**
Number of joints	Not specified	XX
Number of members	Not specified	XX
Span	minimum 24 cm, maximum 25 cm	XX cm
Height - Maximum (outer dimension)	10 cm, from deck to highest truss point	XX cm
Height – Minimum (inner dimension)	3.5 cm, for test road bed insertion	XX cm
Width - Maximum (outer dimension)	4.5 cm	XX cm
Width – Minimum (inner dimension)	3.5 cm, for test road bed insertion	XX cm
Weight – Maximum 20g	Top 25% contestant lightest bridge (+5 Bonus Points)	XX g
Design approach	Non-standard Howe or Pratt truss design (+5 Bonus Points)	? Describe
Design Target Load Range	Between 99 N – 145 N	XX N
Exact Failure Load	Test failure load	XX N

- *Pay attention to the Design Requirements, because this will be the first step in judging your bridge. Your finished bridge must* ***be at least 24 cm long*** *or it will not fit on the test apparatus. Also, and this is important, the* ***<u>inner dimension</u> of your bridge must be at least 3.5 cm wide and 3.5 cm tall*** *to fit the test road bed. You may consider making the inner dimensions at least .5 cm more than the minimum to provide some construction flexibility.*

A.4 - Bridge Diagram (label max tension and compression members)

- *Include a to-scale drawing that shows all the members and indicates the force being carried by each member at the bridge "design load." Individual members should be uniquely labeled. Identify the member(s) that should fail at target design (maximum tension and maximum compression). Also make it clear what you are defining as the "target design load," as part of the caption for this figure.*

Section B: Analysis and Construction of Bridge (4 pages maximum)

B.1 - Description of Analysis Process

- *Description of how the analysis was done—method of joints? method of sections? Did you use a software package (if so, what package)? What assumptions were made in the analysis? Include supporting calculations in an appendix that is referenced in the text. Include a reference to the "Member Force Table."*

B.2 - Member Force Table (with Factor of Safety)

- *This table should list each member and the force in it. Make sure that the reader can see where each member is in your design (referenced back to the bridge diagram), what safety factor the bridge was designed for/to, and which members are in compression and which are in tension.*

Table X: Member force table of member loads for applied load of 99 N (SF 1.5). Shaded row indicates member predicted to fail at applied load.

Member	Load	Tension-Compression	Member Length	Failure Mode	Load Capacity
AB	100 N	Tension	3.5 cm	Yield	735.0 N
AC	-40 N	Compression	10.0 cm	Buckling	30.0 N
BC	350 N	Tension	4.0 cm	Yield	735.0 N
BD	500 N	Tension	4.0 cm	Yield	735.0 N
CD	-60 N	Compression	5.0 cm	Crushing	69.5 N
DE	…	…	…	…	…
EF	…	…	…	…	…

B.3 - Description of Construction Process

- *Describe the manufacturing process---including photos, sketches and any key assembly strategies*

Section C: Testing Results & Failure Analysis (1-2 pages)

C.1 – Testing Process and Failure Load

- *Describe the testing process and the failure load results of your bridge. You will be given a "Testing Results" sheet on Testing Day which should be included as an Appendix of this report.*

C.2 – Method of Failure

- *Describe how did your bridge failed. If your bridge did not meet the safety factor requirement include a discussion and analysis of why it did not. Did it fail at the expected joint/member, in the expected manner? What other factors might have been involved in the failure that may have effected your results? Construction issues? Be as complete as possible in discussing the probable causes of failure.*

C.3 – Suggestions for Improvement

- *Do you have any suggestions for improvement? How would you improve your design? Construction? Are there any suggestions for improvement in the instructions or testing process?*

Section D: Summary of Project Processes (1-2 pages maximum)

D.1 - Description of Work Process and Schedule

- *As a team, when and how did you "do" the project? How much time did you spend on brainstorming ideas? When did you start to do analysis? When and how did you decide on a "final approach"? In this discussion, the reader should get a sense of your "team's story" in creating a design solution.*

D.2 - Description of Individual Contributions

- *How was the work divided up? Who took a lead on what parts? How was it decided who would work on what part?*

D.3 - Reflections on Process and Results

- *Now that the project is done, what would the team follow the same process and design? What would it do differently? What are the biggest "takeaways" for everyone?*

Section E: Business Model Canvass (1 page)

- *This is the final page of your report. To be considered complete there must be something written in the five designated boxes. Some of the subject material will be known and easy to complete, while others may take some thought and imagination.*

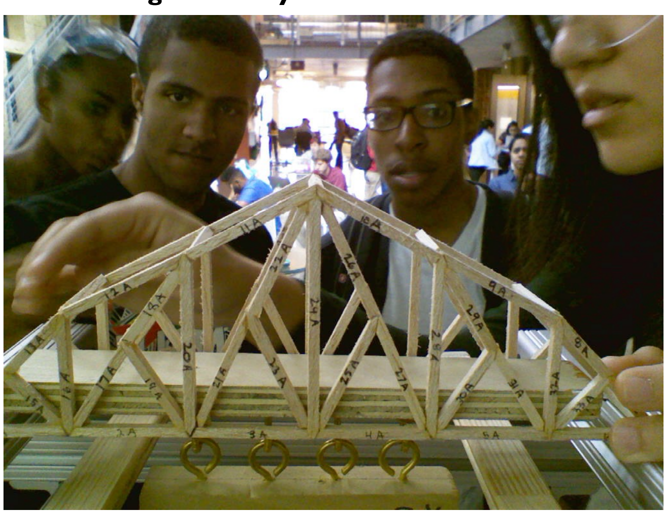
References:

- *List any reference material used in report. This includes software, background information, even websites like Wikipedia. References should be shown using the APA Style (www.apastyle.org)*

Appendices:

- **Supporting Calculations**
  These are the equations and calculations, which create the load report. If software was used, be sure to include some hand-calculations to confirm the software solution.
- **Testing Day Results Sheet**
  Include the one-page summary of your results from Testing Day.

Visualizing Test Day



This is a picture of a prototype bridge on the Vernier Structures & Materials Tester (VSMT) ready for testing.

This is a 24 cm non-standard bridge design with each member labeled. The 21 cm test road bed is placed inside the bridge with hooks extending below the road bed surface. The force gauge is connected to these hooks and when the test run begins, force is applied (and measured) until structural failure.

The bridge prototype is removed for in-depth failure analysis, required for completion of the Bridge Project Report.

NOTE: safety glasses <u>are required</u>.