

Balsa Wood Truss Bridge Design Group Project Project Definition, Details & Deliverables – Due Date TBD

Each ES 101 student group will design a truss bridge that will be made of balsa wood and wood glue. To aid in the exploration for possible truss design alternatives, we will model and analyze the trusses using an online software program called ForceEffect. Each student will start with one individual design that they model and analyze. Based on the information collected from the individual computer truss analysis results, and also from hand calculations and preliminary member sizing of tension and compression members, each group will select the “best” truss design to move forward with. This truss will be modeled in ForceEffect to determine the member forces and based on that information the group will select the member cross-section size for each truss member. Each group will then build their “best” truss design using the balsa wood and wood glue provided by the instructor. The truss bridge will be tested to failure and the cost of the truss and the truss load capacity efficiency will be determined.

Design Objective:

Build a truss bridge with minimal cost that can carry the required loads. To achieve this you will design a truss layout and select member section sizes that minimize the volume of material used. You will need to decide on the # of members, # of joints, direction of the diagonals, etc. to design the truss. Individual group Members and the group will model and analyze their bridge designs using the online program ForceEffect. As you search for your possible truss design alternative, change the truss geometry to see what happens to the forces in the members. If you can reduce the forces that the truss members will need to carry, you should be on the path to finding an efficient design. You will probably need to go through multiple iterations of your design, in which each one has a different geometry that is investigated. Keep in mind that you want to keep your bridge as light as possible but also that you need to consider the maximum allowable stress limits for tension members and the critical buckling load limits for compression members.

Design Criteria

Minimize the Cost of the Truss Bridge - Keep the cost of the truss bridge as low as possible in order to maximize the efficiency of the bridge in carrying the required loading.

Maximize the Design Efficiency – The design efficiency can be calculated as

$$\text{Efficiency} = \text{Total Load Supported (lbs)} / \text{Truss Model Self-Weight (lbs)}$$

(Note: that the Total Load Supported in calculating the Efficiency is capped at the required load level of 30 lbs.)

Maximize Aesthetics – Truss Bridge should be aesthetically pleasing.

Design Constraints

Type of Material Constraints:

Trusses will be constructed using 1/4” x 1/4” and/or 3/16” x 3/16” cross-sections of balsa wood.

Gusset plates will provide the joint connections and will be cut out of Manila file folders

Wood glue will be supplied by the instructor.

Six paper clips will be formed into the gusset plate connection at three of the bottom chord joints to provide locations to attach the test loads.

No coating of the truss bridge members with glue or paint is allowed

Material Property, Strength and Buckling Constraints:

Balsa Wood Density: 0.0027 lb/in³

Balsa Wood Maximum Tensile Allowable Stress (w/ Factor of Safety of 1.5): $\sigma_{\text{allow}} = 540 \text{ lb/in}^2$ or 540 psi

Balsa Wood Modulus of Elasticity: $E = 78,000 \text{ psi}$ - Use E and the member cross-sectional area to calculate Pcr for different possible member lengths, L.

Ex. with the 1/4” x 1/4” cross-section

For L = 3” Pcr = 27.8 lbs

For L = 4” Pcr = 15.7 lbs

For L = 6” Pcr = 6.7 lbs

For L = 8” Pcr = 3.9 lbs

etc.

Geometric Constraints:

Span - The truss bridge must span a gap of 18 inches between two level platforms that will be used to provide the end supports. Since the span is 18 inches, the truss bridge will need to be somewhat longer in order to rest on the platforms.

Supports – The truss bridge supports will only be able to rest on the platforms. No glue or attachments can be made between the truss bridge and the support platforms. The supports are modeled as a pin support and a roller support.

We will keep this problem in 2-D by sandwiching your truss between two sheets of Plexiglas in a test frame, like an ant farm, when we physically test your truss bridge model.

Overall Height of Truss - There are no limits on the height or the distances above or below the test platform locations (as long as it will allow enough room for the test bucket of sand under the bridge).

Required Loads – Three fixed loads will be applied to the middle three joints of the truss bridge. The magnitude of these loads are 6 lbs, 18 lb, and 6 lbs as shown in Figure 1 and Figure 6, which is discussed in further detail later. A loading plate will be connected to the three load connection points and a bucket of sand will be hung from the loading plate. The total required load that your truss bridge is required to carry will be 30 lbs.

Figure 1. Sketch showing the geometric constraints

Construction Constraints*Connections of Members Meeting at Joints:*

Connections at all joints are to be made using *gusset plates*, as sketched in Figure 2 and Figure 3. You are not permitted to overlap bars at joints; bars are glued to gusset plates, front and back. In addition, no bars can run through in one piece a joint. See Figure 4 for examples of a legal joint connection and an illegal joint connection. Ideally, you want the bars meeting at a joint to be concentric and in close contact, and you want to have sufficient area for glue contact to each bar. The gusset plate used will be cut out of Manila folders. The gusset plates can be of any shape or size. However, there is a cost for the gusset plate material in $\$/\text{in}^2$ of material used.

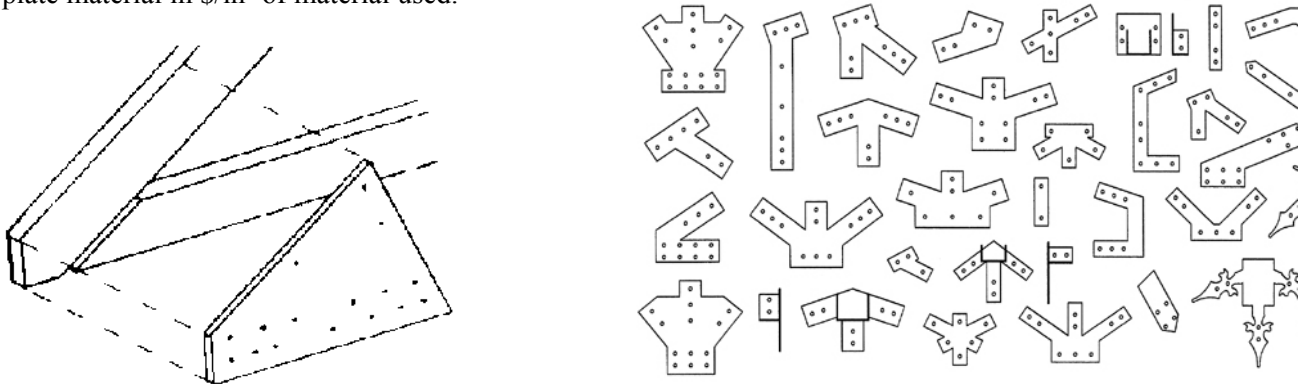


Figure 2. Example of a gusset plate at a truss joint (Note: gusset plates are usually used on each side of the joint, not just on one side as implied by this picture.) Each joint will have two identical gusset plates.

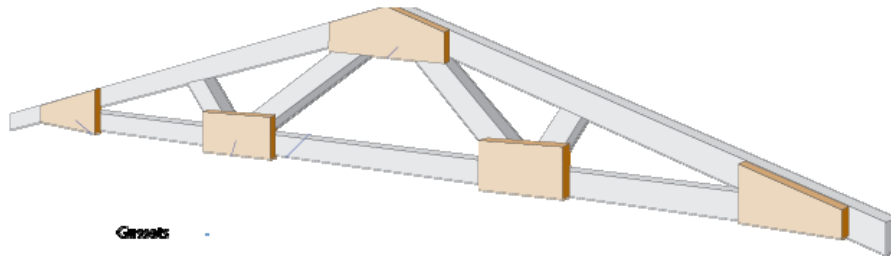


Figure 3. Gusset plates at each joint in the truss

Figure 4. Example of a Legal Joint Connection and an Illegal Joint Connection

Built-up Double-Bar Truss Members:

You have the additional choice of building individual truss members from one or two bars in parallel, but you cannot glue bars together along their whole length to create the double bar cross-section. If you want to use two bars to make a truss member, these must be placed within the uniform thickness of truss as shown in Figure 5. You can either just have the two bars in parallel (which works fine for tension members) or you can glue gusset plate material along the length of the double bar cross-section as shown in Figure 5. However, this gusset material will be included in the cost calculations so ‘gusseting’ the entire length of a double bar may not be very cost-effective.

Figure 5. Examples of Legal Double Bar Truss Members and Illegal Double Bar Truss Members

All joints must be of equal overall thickness for the test frame to maintain your truss in 2-D. Even if you use double bar members, all of your joints will be of uniform in thickness, consisting of the single bar thickness and two gusset thicknesses. If you use the 3/16” cross-section material, you can add gusset plate shims to fill out the thickness of the joints if you prefer or just use glue to help maintain the uniform thickness as best as possible.

The Two Joints at the End Support Locations:

Your structure will rest upon the test platform at its two support points. The joints at those two locations should anticipate that condition. You are allowed to build out the support joint ends to either side by placing two, 1” long pieces of balsa wood parallel to the truss members and on each side of the joint as shown in Figure 5. The support joints can be built-out since they will not be sandwiched between the Plexiglas panels during the test.

Figure 5. Build-out of Support Joints of Truss.

Bottom Chord Load Support Configuration:

In order to have load attachment points along the bottom chord of the truss to connect the required loads to six paper clips will be glued into the gusset plate configuration at three bottom chord joint locations. For any truss configuration, the middle three truss joints will be specified regardless of how far apart these three joints maybe geometry-wise. See Figure 6 to see examples of the load connection locations.

Figure 6. Example of two possible load support locations for different truss geometries

The use of three load support locations and the embedment of the paper clips will allow the load apparatus to be self-adjusting, and allow an easy way to apply the load in the test frame setup.

Cost Constraints:

Each material has a cost per unit area or per unit volume. In order to calculate the total cost of your group's truss design you will need to tally the volume of balsa wood used to construct the truss. This can be calculated by multiplying the cross-sectional area of each member by its member length.

The total volume of balsa wood material required by your truss design therefore can be calculated:

$$Volume = \sum_{i=1}^{\#members} A_i L_i \quad \text{where } A_i = \text{cross-sectional area of } i^{\text{th}} \text{ member (in}^2\text{)} \ \& \ L_i = \text{length of } i^{\text{th}} \text{ member (in.)}$$

You will also need to tally the total area of gusset plates that you use in the design. This can be calculated by measuring the dimensions of the gusset plates and summing up the total area in in². In cases where the shape of the gusset plate is not conveniently a square, rectangle, triangle, circle, etc. and the area is easy to calculate, you will need to approximate the area of material used (overestimation is preferred in this case if necessary).

The material costs are:

Balsa Wood - \$0.13 per in³

Gusset Plates – \$0.08 per in²

Glue – no cost

Paper Clips – no cost

Physical Testing of the Truss Bridge Balsa Wood Models

We will have one scheduled test day arranged outside of class time in order to test all twelve group designs. In addition to pen and paper, you should bring a camera to help you collect data pertaining to the progression of structural failure under the increasing load levels applied. In addition, you will need to observe the performance of other group's truss design in order to help your group summarize what you observed on the test date in the final group project report.

Each truss will be placed in the test frame and the load plate will be connected to the three load support points. Sand will be slowly added to the bucket in 1 lb increments supported by the load plate, until either the required total load of 30 lbs is reached or until the truss bridge fails under the load applied. The total load supported includes the self-weight of the truss bridge model, the loading block, the bucket, and the sand.

Group Project Deliverables and Group Report Requirements

Individual Truss Design and Analysis Sections – Your group will have three or four of these in the report

Sketch of truss geometry, with dimensions and load locations

A hand-drawn sketch of your truss design alternative geometry that includes dimensions of members and angles of members

Printout of ForceEffect Analysis Model with annotations marked

Provide a screen capture printout of your final truss layout as analyzed by the ForceEffect program. The summary of the analysis results provided should include writing all the member forces on the printout and indicating which of the members are in tension and which are in compression. Also identify all necessary truss dimensions and the preliminary member cross-section areas selected to meet allowable stress and critical buckling load limits. Calculate the total volume of balsa wood material in your truss and report this calculated total volume in the lower right hand corner of the printout page. Much of this information can be added most easily by hand to the printout from ForceEffect.

Hand calculation of support reaction forces

FBDs and hand-calculated joint equilibrium checks for 3 joints

In addition to a hand calculation of the support reaction forces for your truss, present three checks of the ForceEffect analysis results provided by running by hand calculation for three selected joints of your truss the force equilibrium to show that the sum of the forces in the x and y directions are zero at each of the three selected joints

Table summarizing truss member forces, T or C, Length, and cross-sectional area selected to meet allowable stress or critical buckling load limits

In addition to the truss member forces and whether T or C, present in the table the cross-section size that will be used for each member of your truss based on the maximum allowable stress of balsa wood for tension members and the critical buckling load for compression members.

Summary of Truss Design

Based on the cross-section selected for each truss member, determine the critical members in the truss – the one or ones that will be most likely to reach their stress limits or buckling loads first when the truss is loaded. Note the locations of these members. From your investigation and preliminary calculations, how and where do you expect your bridge to fail?

Discuss in a couple of sentences what the advantages and disadvantages of your truss design may be.

Group Truss Design and Analysis Sections – Your group will have one of these in the report

Discussion of Process and Criteria Used in “Best” Truss Selection

Briefly discuss why your group selected this bridge design as the “best” design. Discuss in a couple of sentences what the advantages and disadvantages of the selected “best” truss design may be.

Sketch of truss geometry, with dimensions and load locations

A hand-drawn sketch of the truss design alternative that your group selected as the “best” bridge design your bridge design alternative geometry. The sketch should include dimensions of members and angles of members.

Printout of ForceEffect Analysis Model with annotations marked

Provide a screen capture printout of your group’s “Best” truss layout as analyzed by the ForceEffect program. The summary of the analysis results provided should include writing all the member forces on the printout and indicating which of the members are in tension and which are in compression. Also identify all necessary truss dimensions and the preliminary member cross-section areas selected to meet allowable stress and critical buckling load limits. Calculate the total volume of balsa wood material in this truss and report this calculated total volume in the lower right hand corner of the printout page. Much of this information can be added most easily by hand to the printout from ForceEffect.

Hand calculation of support reaction forces***FBDs and hand-calculated joint equilibrium checks for 3 joints***

In addition to a hand calculation of the support reaction forces for your truss, present three checks of the ForceEffect analysis results provided by running by hand calculation for three selected joints of your truss the force equilibrium to show that the sum of the forces in the x and y directions are zero at each of the three selected joints. If one of the individual design was selected “as-is” by the group, run the three checks on different joints in this part of the report.

Table summarizing truss member forces, T or C, Length, and cross-sectional area selected to meet allowable stress or critical buckling load limits

In addition to the truss member forces and whether T or C, present in the table the cross-section size that will be used for each member of your truss based on the maximum allowable stress of balsa wood for tension members and the critical buckling load for compression members.

Calculation of Cost of Truss & Calculation of Efficiency of Truss

Provide calculations that tally the volume of balsa wood used and the area of gusset plate material used. Provide a calculation of the total cost of your group’s “best” truss design. Using the maximum load carried on test day, provide a calculation of the efficiency of your group’s “best” truss design.

Summary of “Best” Truss Design

Based on the cross-section selected for each truss member, determine the critical members in the truss – the one or ones that will be most likely to reach their stress limits or buckling loads first when the truss is loaded. Note the locations of these members. From your investigation and preliminary calculations, how and where do you expect your bridge to fail?

Discuss in a couple of sentences how your group’s bridge performed on test day. Did the failure occur in the critical members you identified or were other members involved in the failure behavior?

Discuss the changes that you would you make to your “best” truss design based on the behavior you saw occurring on test day or to further minimize the overall volume of material used or improve the aesthetics.

Discussion of Class Truss Design Forms and Test Day Performance

Discuss what you learned about truss form and truss failure behavior by watching the performance of the other eleven truss designs built by the other groups in this class. This discussion should include both designs that performed well and designs that struggled (if any!).

Grading Sheet for Each Individual Truss Analysis in Final Report

Sketch of truss geometry, with dimensions and load locations	3 points _____
Printout of ForceEffect Analysis Model with annotations marked	5 points _____
Hand calculation of support reaction forces	1 point _____
FBDs and hand-calculated joint equilibrium checks for 3 joints	8 points _____
Table summarizing truss member forces, T or C, Length, and cross-sectional area selected to meet allowable stress or critical buckling load limits	5 points _____
Summary of Truss Design	3 points _____

TOTAL 25 points _____

Grading Sheet for Group Final Truss Analysis in Final Report

Discussion of Process and Criteria Used in "Best" Truss Selection	5 points _____
Sketch of truss geometry, with dimensions and load locations	5 points _____
Printout of ForceEffect Analysis Model with annotations marked	10 points _____
Hand calculation of support reaction forces	3 points _____
FBDs and hand-calculated joint equilibrium checks for 3 joints	12 points _____
Table summarizing truss member forces, T or C, Length, and cross-sectional area selected to meet allowable stress or critical buckling load limits	15 points _____
Calculation of Cost of Truss	5 point _____
Calculation of Efficiency of Truss	5 points _____
Summary of "Best" Truss Design	5 points _____
Discussion of Class Truss Design Forms and Test Day Performance	5 points _____
Overall report organization and clarity of presentation	5 points _____

TOTAL 75 points _____

Comment on Group Final Report Grades

The level of group coordination and effort can significantly impact your report grade. All members of your group are collectively responsible for the completeness, accuracy, and consistency of your report. Simply dividing up the effort amongst the group members, and then waiting for the pieces to arrive (often at the very last minute), is not recommended.