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FINAL REPORT

Mechanics of Materials

CVG 2140A

Task #6: Report

Team M04

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Abstract

This report documents the construction process, outcomes and analysis of a wooden truss bridge. By applying principles such as tension, compression, truss analysis, and many others learned throughout the course of CVG2140, it was possible to design an efficient bridge design using balsa wood specifically. The building process includes 5 deliverables ranging from brainstorming and researching to calculating the force (internal and external) and building the truss. Key information was learned throughout the design process such as the distributed load on the truss as well as the internal compressive and tensile forces using methods of section and joints. Once design candidates were narrowed down, the final truss was chosen. Once the design analysis was finished, the truss was then constructed. The bridge was built by creating two separate "2D" trusses and then attaching the connecting braces in between to create the "3D" structure. A lot of obstacles were overcome to meet the deadline of the truss, such as the difficulty of clamping down wood, the amount of wood given, and miscommunication amongst the team. Even with these challenges encountered, the efficiency factor of the bridge constructed was average.

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1. Introduction

In this project, the task was to design a truss with specific requirements and a set amount of balsa wood to withstand as much force as possible. The project aims to simulate a real-world engineering scenario while providing as much hands-on experience as possible. It provides many realistic constraints, such as material availability and proper dimension restrictions.

The primary purpose of this project is to design and build a wooden bridge using only balsa wood and carpenter glue that is capable of supporting a significant load relative to its weight. The project challenges the participating students to optimize the structural integrity, stability, and load-bearing capacity using materials given while using principles taught in the CVG2140 course.

1.1 Scope

This report covers the entire bridge creation process. It documents the process of designing, constructing, and testing the wooden bridge and the following test results and analysis. It covers the key following aspects:

Theoretical Background: An introduction to the principles and theoretical concepts needed for understanding the thought process behind the design process of this bridge. It provides an essential understanding of the behavior of bridge loading. Later sections of this report will refer to terminology and equations found in this section.

Proposed Truss Design: Discuss the truss design methodology employed in the project. It will explain why the specific truss was chosen and provides a basic general outline of the truss in figure 1.

Analysis and Design: Examination of the structural analysis calculations done on the truss. Proves detailed diagrams and calculations of the chosen truss under a theoretical load. Sample calculations also shown.

Construction: Documents the construction process. Includes material preparation, assembly techniques, and any difficulties occurring during the process. Section also includes analysis of results of the truss test. Refers to effectiveness of design, efficiency factor and construction methods employed.

2. Theoretical Background

2.1 Overview

Throughout CVG2140, different theoretical concepts were taught to help aid in the construction of the truss. By understanding the theoretical concepts and applying them to designing the truss, a good foundation and template can be created, which can then be properly executed later on.

The general theoretical concepts taught and used are Equilibrium, Geometric Properties, Axial Deformation, and Columns.

2.2 Equilibrium

Equilibrium occurs when opposing forces acting upon an object are balanced, and the object under examination undergoes no overall change. If a structure is undergoing no change, it is still standing and is in equilibrium. (Philpot & Thomas, 2020, pp. 165-198) To determine equilibrium it is necessary to balance the forces in the x and y direction; the principles of equilibrium involve balancing external forces with internal reaction forces within the structure. Internal reactions may be caused by joints, supports, and members, which must be analyzed to ensure the structure remains stable. (Luebkeman, 1996) The application of this theory involved analyzing the weight of the bridge itself within all of the internal members. Analysis can be conducted with additional load that the bridge may hold. By ensuring the sum of forces and moments is zero at any point, equilibrium and, therefore structural stability can be ensured. Equations necessary to solve for equilibrium:

$$\Sigma Fx = 0$$

$$\Sigma Fy = 0$$

$$\Sigma M = 0$$

2.3 Geometric Properties

The geometric properties of a truss will affect the weight distribution. By changing the shape and angles of the truss, the centroid and center of gravity will change. (Philpot & Thomas, 2020, pp. 671-687) By utilizing such properties optimal shape configuration can be created to get the desired strength, stability, and efficiency. Optimizing a truss design consists of selecting proper geometric configurations that maximize strength-to-weight ratio and minimize stress concentrations. The chosen design maximizes the use of triangles in a specific configuration that attempts to distribute loads as evenly as possible and minimize stress concentrations. It is also necessary that a moment of inertia is also found. Moment of inertia is categorized as an object's resistance to change rotationally and can be used as a measure of mass distribution around a rotational axis. (Britannica, 2024) In Figure 10, the selected design can be seen and it can be observed that the design is symmetrical to hopefully maintain an even distribution. In Table 1 seen below, the stress values under 1 Newton on each member have been recorded. It can be observed that no member has a significantly greater magnitude of force relative to any other member and there are no obvious points of stress concentrations at any joint.

In Lecture 5, the properties of plane areas were given in an equation sheet (Martin-Perez, 2024) See Section 8.2 Link 1.

2.4 Axial Deformation

Axial deformation is the tensile stretching or compression of a structural element along its axis when subjected to axial load. This understanding is necessary as it is crucial that all bridge components withstand these deformations without failure. (Philpot & Thomas, 2020, pp. 72-74) By analyzing the balsa wood and its properties, then correlating the area and volume to tensile stress, allowable stress and deformation can be calculated. In the spreadsheet linked below , all axial strain and key values were calculated. These were important as they would be the theoretical load to which our truss can hold. If these values were satisfactory, no redesign of the truss would be necessary. Refer to the link of the spreadsheet in Section 8.2- Link 2.

$$Axial\ Stress:\ \sigma = \frac{P}{A}$$

$$Axial\ Strain:\ \varepsilon = \frac{\delta}{Lo} = \frac{L - Lo}{Lo}$$

$$Shear\ Strain:\ \gamma = \frac{w}{l} = tan\theta$$

$$Modulus\ of\ Elasticity:\ E = \frac{\sigma}{\varepsilon}$$

$$Elongation:\ \delta = \frac{FL}{EA}$$

2.5 Columns

Columns support loads within a bridge structure. It is necessary that truss designs prevent buckling or crushing and ensure structural stability when under load. (Philpot & Thomas, 2020, pp. 572-578) Members in compression can fail in either buckling or crushing loads, it is necessary to find both as it is important to find which type of failure it will undergo. Buckling is when a member becomes unstable and crushing is when the material itself fails by reaching its ultimate tensile strength. (DartmouthX, 2016) By analyzing each column based on their respective geometry and supports, all loads were found within the same spreadsheet which contains ultimate tensile loads.

$$Euler's\ Buckling\ Load\ Equation:\ Pcr = \frac{\pi^2 EI}{(kL)^2}$$

$$Slenderness\ Ratio:\ \lambda = \frac{L}{r}$$

$$Critical\ Stress: \sigma cr = \frac{Pcr}{(L/r)^{2}}$$

3. Proposed Truss Design

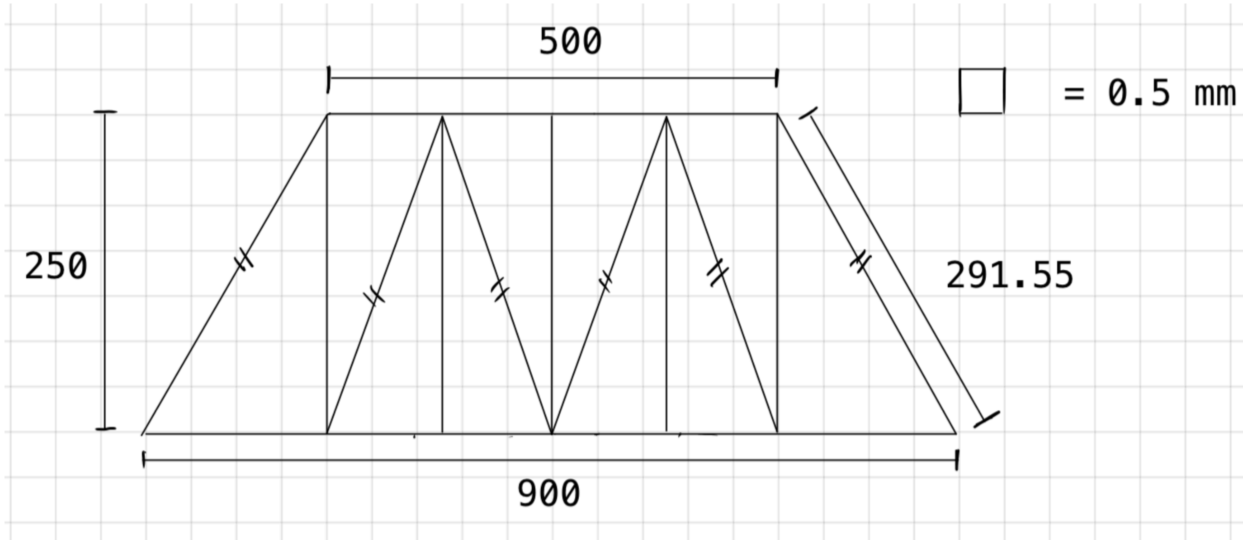


Figure 1: Scaled and Dimensioned Truss Design Drawing

The design of this truss is a mix of a "Warren" and "Pratt" truss. As shown in Figure 1, the bottom length is 900mm, the top length is 500mm, and the height of the truss is 250mm. The diagonals measure 291.55mm. These types of trusses are very efficient under concentrated vertical loads and have a simple design to build, hence why this design was chosen. (Carigliano, 2024) The combination of the Warren truss design includes the diagonal members (in tension) and the Pratts design includes the vertical members which are in compression. This truss is thus more efficient when combining both designs together.

4. Analysis

In analyzing our truss, we made a few assumptions when employing the method of sections analysis method with the software and information to which we were limited. In these calculations, we assumed that the members would be completely straight to allow for simplified calculations of basic static principles. In reality, it may not be possible to have precisely straight pieces. Next, we assumed that the joint on the left corner was a pin joint and that the joint on the right was a roller, neglecting external moments and torques and uniform loading of 1 N, as shown in Figure 2 below. These elements were presumed to reduce the number of unknown reactions and constraints on the truss to make it possible to solve with this method.

4.1 Method of sections

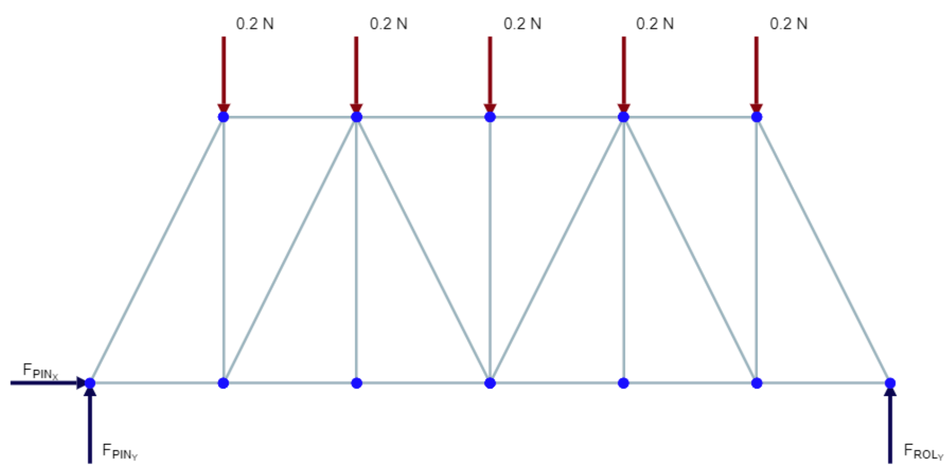


Figure 2: Illustration of 1 N Force Distribution on Truss

$\sum M_{PIN} = 0$

$|0.75-0|F_{Rol_y} = 0.2(0.125-0)+0.2(0.25-0)+0.2(0.375-0)+0.2(0.5-0)+0.2(0.625-0)$

$0.75F_{Rol_y} = 0.2(0.125)+0.2(0.25)+0.2(0.375)+0.2(0.5)+0.2(0.625)$

$0.75F_{Rol_y} = 0.375$

$F_{Rol_y} = 0.375/0.75$

$F_{Rol_y} = 0.5$ N

Calculate the force sum in the X-axis:

$\sum F_X = 0$

$F_{pin_x} = 0$

$F_{pin_x} = 0$ N

Moment sum about the roller support:

$\sum M_{Roller} = 0$

$-|0-0.75|F_{pin_y} = -0.2(0.125-0.75)-0.2(0.25-0.75)-0.2(0.375-0.75)-0.2(0.5-0.75)-0.2$

$(0.625-0.75)$

$-0.75F_{pin_y} = -0.2(0.625)-0.2(0.5)-0.2(0.375)-0.2(0.25)-0.2(0.125)$

$-0.75F_{pin_y} = -0.375$

$F_{pin_y} = -0.375/0.75$

$F_{pin_y} = 0.5$ N

Figure 3 depicts the section cut used for the calculations below**.**

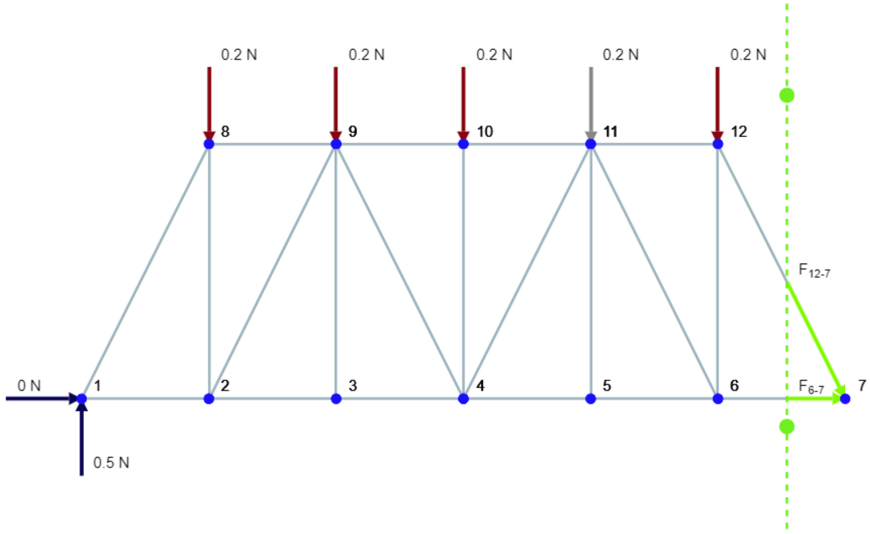


Figure 3: First Section Cut on Truss

Moment sum about Node 1:

$\sum$MN1=0-|0−0.75|F_{12-7} =

sin(63.43∘)0.2|0.125−0|+0.2|0.25−0|+0.2|0.375−0|+0.2|0.5−0|+0.2|0.625−0|+0.5|0−0|

=−0.75F_{12-7}sin(63.43∘)=0.2(0.125)+0.2(0.25)+0.2(0.375)+0.2(0.5)+0.2(0.625)+0.5(0)

=−0.559kN

F_{12-7}= - 0.559N

Moment sum about node 12:

$\sum$MN12 = 0

|0.25−0|F_{6-7}

=−0.2|0.125−0.625|−0.2|0.25−0.625|−0.2|0.375−0.625|−0.2|0.5−0.625|−0.2|0.625−0.625|+0.5|0−0.625|

=−0.25F_{6-7} =-0.2 (0.5)−0.2(0.375)−0.2(0.25)−0.2(0.125)−0.2(0)+0.5(0.625)

F_{6-7}=0.25 N

Figure 4 depicts the section cut used for the calculations below.

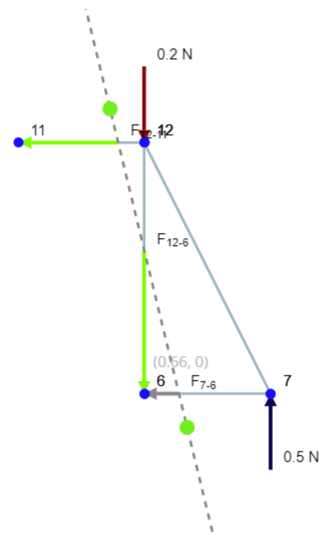


Figure 4: Second Section Cut on Truss

Vertical Force Sum:

$$\sum Fy = 0$$

$$-F_{12-6} - 0.2 + 0.5 = 0$$

$$F_{12-6} = -0.3\ \mathrm{N}$$

Figure 5 depicts the section cut used for the calculations below.

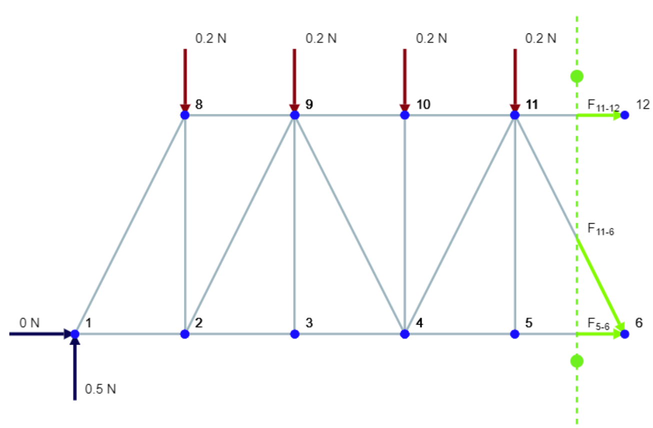


Figure 5: Third Section Cut on Truss

$\sum MN6=0$

$-|0-0.25|\ F_{11-12}$

$=-0.2|0.125-0.625|-0.2|0.25-0.625|-0.2|0.375-0.625|-0.2|0.5-0.625|+0.5|0-0.625|$

$= \ -0.25\ F_{11-12}=-0.2(0.5)-0.2(0.375)-0.2(0.25)-0.2(0.125)+0.5(0.625)$

$F_{11-12}=-0.25$ N

Moment sum about Node 11:

$\sum MN11=0$

$|0.25-0|\ F_{5-6}=-0.2|0.125-0.5|-0.2|0.25-0.5|-0.2|0.375-0.5|-0.2|0.5-0.5|+0.5|0-0.5|$

$0.25\ F_{5-6}= -0.2(0.375)-0.2(0.25)-0.2(0.125)-0.2(0)+0.5(0.5)$

$F_{5-6}=0.4$ N

Vertical Force Sum:

$\sum Fy = 0$

$-\ F_{11-6}\ \sin(63.43^\circ)-0.2-0.2-0.2-0.2+0.5 = 0$

$-\ F_{11-6}\ \sin(63.43^\circ) = 0.3$

$F_{11-6} = -0.3354$ N

Figure 6 depicts the section cut used for the calculations below:

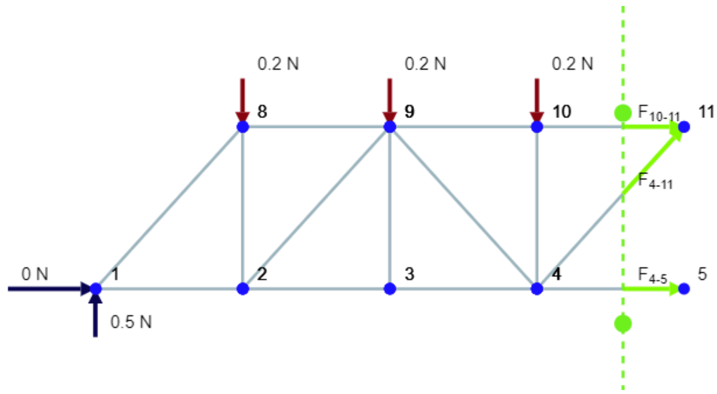


Figure 6: Fourth Section Cut on Truss

Moment of sum about Node 4:

$\sum MN4 = 0$

$-|0-0.25|\, F_{10-11} = -0.2|0.125-0.375| - 0.2|0.25-0.375| - 0.2|0.375-0.375| + 0.5|0-0.375|$

$-0.25\, F_{10-11} = -0.2(0.25) - 0.2(0.125) - 0.2(0) + 0.5(0.375)$

$F_{10-11} = -0.45$ N

Moment sum about Node 11:

$\sum MN11 = 0$

$|0.25-0|\, F_{4-5} = -0.2|0.125-0.5| - 0.2|0.25-0.5| - 0.2|0.375-0.5| + 0.5|0-0.5|$

$0.25 F_{4-5} = -0.2(0.375) - 0.2(0.25) - 0.2(0.125) + 0.5(0.5)$

$F_{4-5} = 0.4$ N

Vertical Force Sum:

$\sum Fy = 0$

$F_{4-11}\sin(63.43\circ) - 0.2 - 0.2 - 0.2 + 0.5 = 0$

$F_{4-11}\sin(63.43\circ) = 0.1$

$F_{4-11} = 0.1118$ N

Figure 7 depicts the section cut used for the calculations below.

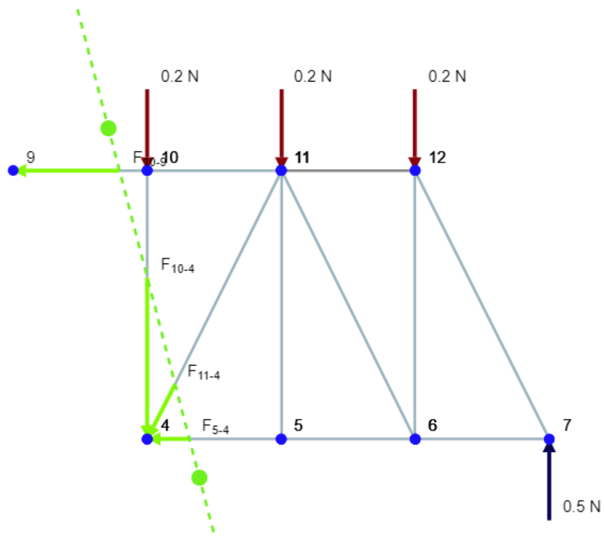


Figure 7: Fifth Section Cut on Truss

Moment sum about Node 4:

$\sum MN4=0$

$|0-0.25|F_{10-9} = -0.2|0.375-0.375|+0.2|0.5-0.375|+0.2|0.625-0.375|-0.5|0.75-0.375|0.25$

$F_{10-9} = -0.2(0)+0.2(0.125)+0.2(0.25)-0.5(0.375)$

$F_{10-9} = -\ 0.45$ N

Vertical Force Sum:

$\sum Fy = 0$

$-F_{10-4} - F_{4-11}\sin(63.43^\circ) - 0.2 - 0.2 - 0.2 + 0.5 = 0$

$F_{10-4} = -0.199993$ N

As the truss is symmetrical about member 10-4, we may equate the following members that mirror the other about member 10-4. (Members are colour-paired according to force equivalence; black represents 0 force members).

Figure 8 is a visual representation of equivalent members forces based on colors, the line of symmetry is the light blue line in the middle.

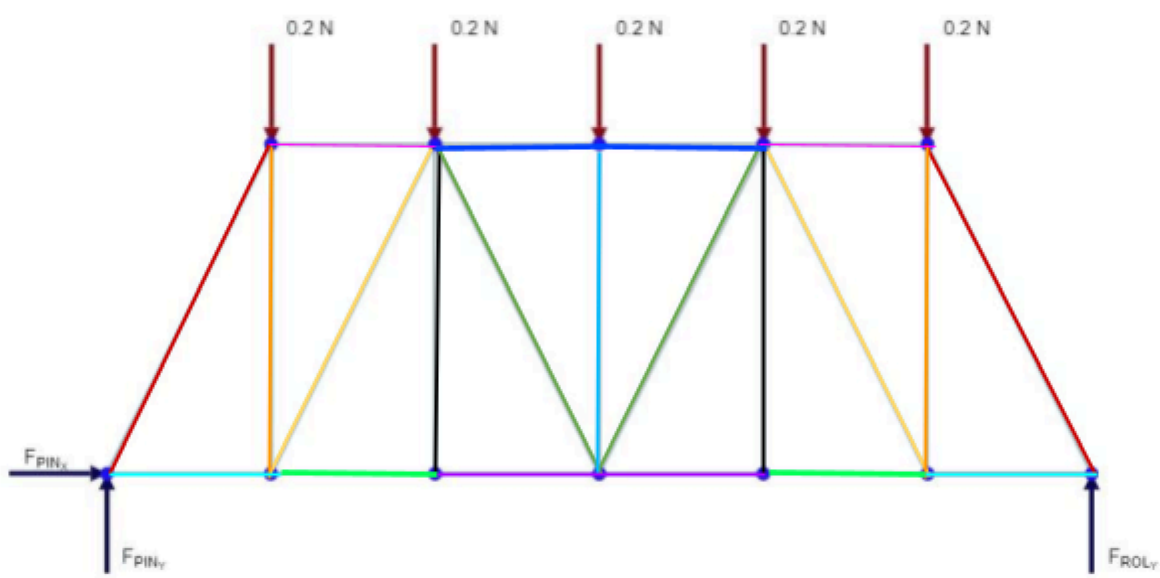


Figure 8: Depiction of Equivalent force members, coded by color

In Table 1, a summary of all the forces calculated in each member from the method of sections is summarized and identified by their corresponding numbers and letters from Figures 9, 10, and 3. It is also outlined whether they are in compression or tension.

Table 1: Summary of Internal Forces of each Member and Tension/Compression Specification

Member		Force (N)	Tension (T) or Compression (C)
12-7 & 1-8	**AH**	-0.559	C
6-7 & 1-2	**AB**	0.25	T
12-6 & 8-2	**HB**	-0.3	C
11-12 & 8-9	**HI**	-0.25	C
5-6 & 2-3	**BC**	0.4	T
11-6 & 2-9	**BI**	-0.3354	C
11-5 & 9-3	**CI**	0	N/A
10-11 & 9-10	**IJ**	-0.45	C
4-5 & 3-4	**CD**	0.4	T
4-11 & 9-4	**DI**	0.1118	T
10-4	**DJ**	-0.2	C

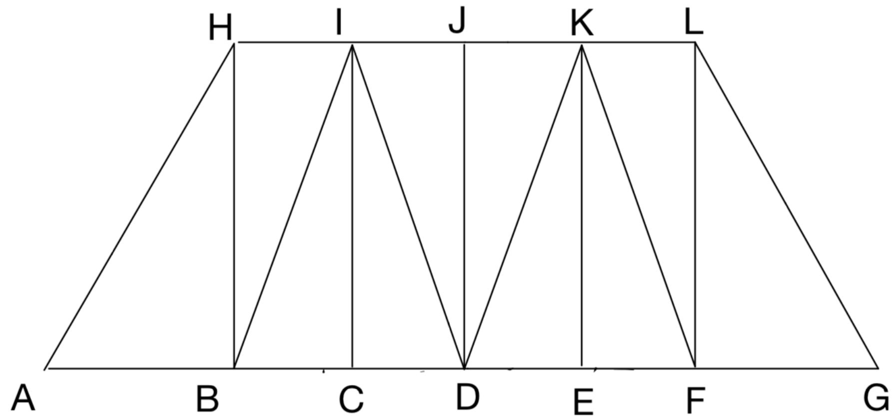


Figure 9: Visual Identification of Each Member

5. Design

In designing the truss members, various factors were taken into account to maximize the overall performance and capacity of the truss. Firstly, it was crucial to outline which members were in compression and tension, as it is known that balsa wood is far stronger in tension than compression. This is due to the fact that it has a sufficient cross sectional area to ensure ensuing normal stress is below the material's tensile strength, balsa wood having a tensile strength of 23.5 Mpa, and even the smallest piece of wood is a 3.2x3.2 square, the stick would not break until the internal force reached 240.64N, so no matter which piece of wood was chosen it would fail due to the material's strength and not the chosen member dimension. Therefore, an emphasis was placed on refining the members in compression. Compression members may fail due to a lack of strength (crushing) or buckling. A short member in compression fails when its axial stress exceeds the materials' compressive strength. A long, straight, slender member will abruptly buckle sideways and break. Hence, buckling will occur prior to normal stress reaching the strength of the material for a long and slender member. For that reason, the capacity of the compression members was decided based on the minimum load to first cause either of those failures. Ergo, the dimensions of our compression members were designated based on which would provide the ultimate optimization amidst their buckling or crushing failure, given the limited sizes and quantities of wood we had.

Further, the pieces of wood that could bear the most weight were allocated to the members that carried the largest load ratio. Next, larger cross-sections of wood generally offer greater strength until a certain threshold, beyond which excessive weight compromises member strength. As such, a compromise was found between maximizing the strength of a member and the weight that the wood piece required to accomplish that requires. In order to employ these optimization techniques, a spreadsheet was constructed, testing a variety of combinations of cross sections of wood with different members. The combination that resulted in the highest $P_{Efficiency}$ was selected; its properties are illustrated below in Table 2.

Table 2: Truss Design Summary

Member	Internal Axial Force (N)	Length (mm)	Cross Section (mm)	Capacity (N)	Factor Of Safety	Total Volume (mm^4)/ Weight SW (N)	Capacity Load to Weight Ratio or $P_{Efficiency}$
AB	0.25 (T)	900	3.2 x 25.4	7640.32	6.10981	0.02631	1852
HB	0.3 (C)	250	9.5 x 9.5	1250.5	1	0.04869	
HI	0.25 (C)	600	3.2 x 25.4	4779.26	3.82188	0.02631	
AH	0.559 (C)	291.55	9.5 x 9.5	2373.3	1.89788	0.05679	
IC	0	250	4.7 x 4.7	N/A		0.005525	
ID	0.118 (T)	291.55	4.7 x 4.7	4643.25	3.71311	0.01390	
BI	0.25 (C)	291.55	9.5 x 9.5	5306.7	4.24366	0.05679	
BC	0.4 (T)	150	3.2 x 25.4	4775.2	3.81863	0.02631	
CD	0.4 (T)	150	3.2 x 25.4	4775.2	3.81863	0.02631	
IJ	0.45 (C)	150	3.2 x 25.4	2655.15	2.12327	0.02631	
DJ	0.2 (C)	250	9.5 x 9.5	6633.375	5.30458	0.04870	

5.1 Methodology/ Procedure

The design of the proposed truss was based on a careful analysis of each of the members to be used in the truss. The variables calculated in order to determine the most efficient design of the truss included the internal axial force, length of each piece of wood, cross sections, capacity, the total volume of balsa wood required for each member, and the load-to-weight ratio or $P_{Efficiency}$. The most efficient design was chosen and constructed after analyzing several combinations of cross sections and determining which one provides the highest load-weight ratio or $P_{Efficiency}$.

The internal axial force was determined by analyzing if the member would be in tension or compression based on the free body diagrams and the application of the load, which was spanned across the top five joints of the truss. A method of sections and a method of joints was used to calculate these values, as seen in section 4 of the report. The members with negative values as calculated results were determined to be in compression, and those with positive values were in tension. The members in tension fail due to crushing since the member is not strong enough to withstand the load applied. Members in compression either fail due to crushing or buckling. Buckling is when the members deform, and the truss will begin to lose its shape; crushing is when they break. The internal axial force can also be called the ratio of load that the member can withstand. The lengths of each member were selected based on the proposed truss design and materials available. The cross sections were selected based on the ones that provided the highest load-weight ratio or $P_{Efficiency}$ value. The capacity of a member is the maximum amount of force Newtons can withstand. It can be calculated based on the minimum magnitude of the internal axial force the member can withstand, comparing the values of buckling or crushing if in compression and only using the crushing magnitude in tension. It is then divided by the internal axial force of that member. The total volume of balsa wood required was determined based on the summation of the individual members' weights, combining the values to encompass the members of the two combined trusses. The factor of safety is a ratio that shows the member's strength compared to the stress that would be applied to it. Since it is expressed as a ratio, the result is the number of times that a member could support the limiting capacity. It has been calculated by dividing the capacity of the member being analyzed by the limiting capacity of the truss; in our course, the limiting member is HB with a capacity of 1250.5 Newtons (N).

The theoretical load-to-weight ratio of the proposed truss was 1852 Newtons (N). This value was calculated using the member with the lowest capacity, as it would be the truss's limiting factor, and it was divided by the overall weight of the truss, also known as the volume of balsa wood.

5.2 Equations

Capacity:

$$P_{Max} = \frac{N_{Max}}{Internal\ Axial\ Force}$$

Total Volume of Balsa Wood:

$$SW_{Sum} \sum_{IC}^{HI} SW * 2 - SW_{JD}$$

Note that JD is subtracted as it is only included one time in the final bridge.

Factor of Safety:

$$Factor\ of\ Safety\ =\ \frac{P_{Max}\ of\ Analyzed\ Member}{P_{Max}\ of\ Limiting\ Member}\ =\ \frac{P_{Max}\ of\ Analyzed\ Member}{P_{Max}\ HB}$$

Load to Weight Ratio/ $P_{Efficiency}$:

$$P_{Efficiency}\ =\ \frac{P_{Max}}{SW}$$

6. Construction Process

6.1 Methodology & Procedure

6.1.1 Preparation

Materials:

- ➔ For the construction of the truss, the following balsa wood sticks are supplied, each with a length of 914 mm, and with five sticks per size:
  - ◆ 5 sticks measuring 9.5 mm x 9.5 mm x 914 mm
  - ◆ 5 sticks measuring 4.7 mm x 2.7 mm x 914 mm
  - ◆ 5 sticks measuring 3.2 mm x 3.2 mm x 914 mm
  - ◆ 5 sticks measuring 3.2 mm x 25.4 mm x 914 mm
- ➔ This allocation results in a total length of 4,570 mm for each type of material, necessitating careful planning and utilization to meet the project requirements.

Equipment Used:

- ➔ Measuring Tape
- ➔ Wood Glue
- ➔ Exacto Knife
- ➔ Hand Saw
- ➔ Clamps
- ➔ Sandpaper
- ➔ Pencil
- ➔ Ruler

6.1.2 Cutting Dimensions and Required Parts

The provided materials will be cut into specific lengths as detailed in Table 3. This table also outlines the quantity of each part needed for assembly, ensuring clarity and efficiency in the preparation phase.

Table 3: Member Properties

Member Type	Member ID	Section (mm x mm)	Length (mm)	Quantity
Bottom Chord	A	3.2 x 25.4	900	2
Strong Vertical	B	9.5 x 9.5	250	6
Top Chord	C	3.2 x 25.4	600	2
Strong Diagonal	D	9.5 x 9.5	291.55	8
Weak Vertical	E	4.7 x 4.7	250	4
Weak Diagonal	F	4.7 x 4.7	291.55	4
Small Diagonal	G	4.7 x 4.7	150	4
Gusset Plates	H	3.2 x 25.4	25	20
Flat Brace	I	3.2 x 25.4	150	6
Large Brace	J	9.5 x 9.5	150	4
Top Straight Brace	K	4.7 x 4.7	150	3
Top Diagonal Brace	L	4.7 x 4.7	195	4
Bottom Short Diagonal Brace	M	4.7 x 4.7	180	2
Bottom Long Diagonal Brace	N	4.7 x 4.7	205	2

6.1.3 Truss Assembly

Following the guidelines illustrated in *Figure 10*, we proceed with the construction of the truss. Each member involved in the assembly is identified according to the specifications detailed in *Table 3*, as referenced in the previous section.

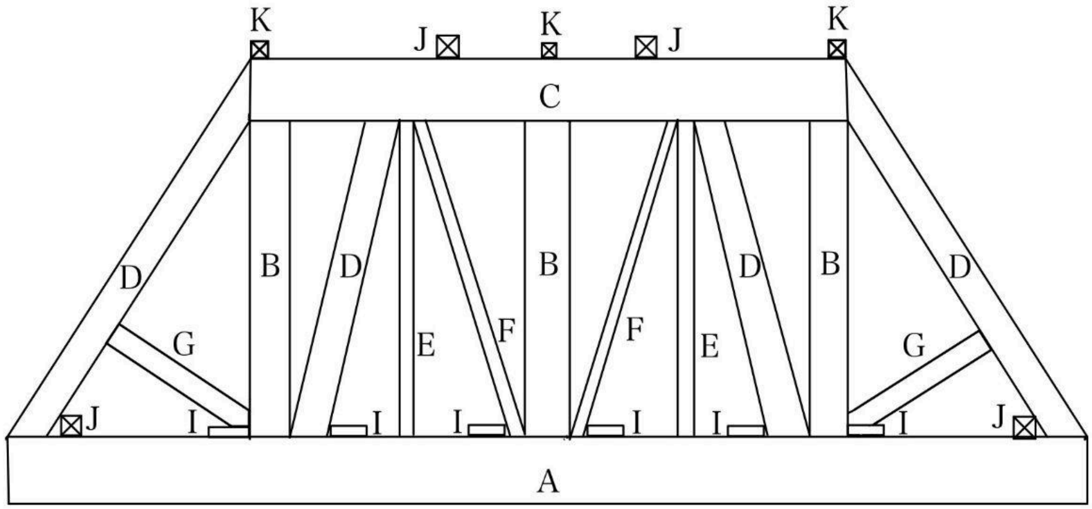


Figure 10: As-Built Truss Configuration

➔ **Step 1: Attaching Strong Vertical Members (B)**

◆ Apply wood glue to attach each strong vertical member (B) to the Bottom Chord, placing a gusset at each connection. Secure the joint with a clamp to apply even pressure while the glue dries for 30 minutes.

➔ **Step 2: Attaching Weak Vertical Members (E)**

◆ Attach weak vertical members (E) to the Bottom Chord using wood glue. Unlike the strong members, do not use gussets here. Clamp each joint to maintain pressure as the glue sets, waiting 30 minutes.

➔ **Step 3: Joining the Top Chord (C)**

◆ Attach the Top Chord (C) ensuring its top aligns perfectly with the tops of the vertical members. Clamp the connection to hold everything in place for 30 minutes until the glue dries.

- **Step 4: Adding Outer Diagonal Members**
  - Attach each outer diagonal member (D) so its top aligns with the Top Chord (C). Use wood glue and a gusset plate (H) to secure the connections between members B, C, and D. Clamp as needed.
- **Step 5: Installing Remaining Diagonal Members**
  - Attach the rest of diagonal members (D) ensuring their bottoms are flush with the Bottom Chord and tops flush with the Top Chord (C). Use clamps to hold each in place while the glue dries.
- **Step 6: Attaching Weak Diagonal Members**
  - Install weak diagonal members (F) throughout the truss structure. Strengthen joints, specifically at connections C, D, E, F, and B, F by adding gusset plates with wood glue.
- **Step 7: Building the Second Truss**
  - Repeat Steps 1 to 6 to construct the second truss, ensuring it mirrors the first in all dimensions and attachments.
- **Step 8: Positioning the Trusses**
  - Stand both trusses upright, 150 mm apart. Use stability aids to keep them upright and perpendicular to the workspace.
- **Step 9: Attaching Flat Braces**
  - Start from the outer edges, attaching flat braces (I) between the trusses. Keep a 250 mm gap between each brace, using wood glue and a large clamp to apply pressure towards the trusses. Ensure braces are perpendicular to members A, B, H on both trusses, gradually working inward, aligning with members A, H, and D.

- **Step 10: Installing Large Braces**
  - Attach large braces (J) at the bottom corners, ensuring they're perpendicular to members A, H and in contact with D. Use wood glue to secure.
- **Step 11: Adding Bottom Short Diagonal Braces**
  - Secure each short diagonal brace (M) between the trusses. One end should connect with a truss's gusset plate and the other with the opposing truss's gusset plate and member I, using wood glue.
- **Step 12: Installing Bottom Long Diagonal Braces**
  - Place long diagonal braces (N) between sections B and D, mirroring the orientation of the short diagonal braces (M). Use wood glue for attachment.
- **Step 13: Attaching Top Straight Braces**
  - Install top straight braces (K) at the top corners, ensuring they are flush with member C on both trusses. Clamp down to maintain pressure as the glue dries.
- **Step 14: Installing Top J Braces**
  - Measure 125 mm away from the center on both sides of the top structure. Attach the top J braces at these marks, ensuring they are parallel to each other and perpendicular to the truss. Use wood glue for a secure bond.
- **Step 15: Attaching the Center Top Member**
  - Place the center top member (K) across the top of the trusses. Ensure it is flush with the ends of the Top Chord (C) on both sides for a seamless fit. Secure with wood glue and check alignment.

➔ **Step 16: Attaching Top Diagonal Members**

- Refer to the below image, *figure 11,* to correctly position the top diagonal members (L). Ensure each member follows the intended direction and angle as shown. Attach these members using wood glue, double-checking their alignment with the photo to guarantee accuracy.

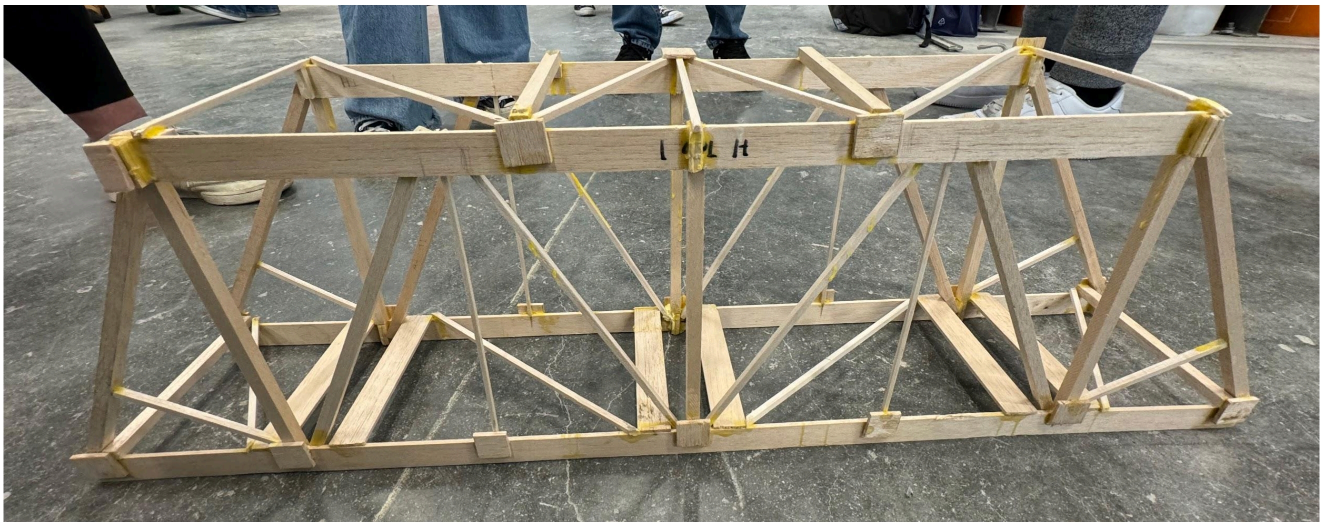


Figure 11: Side view of the completed bridge with visuals of diagonal braces.

6.2 Challenges Encountered

In the following section 3 of the challenges encountered will be discussed.

6.2.1 Difficulty Applying Clamps

Challenges were faced when applying glue in certain areas due to the absence of suitable attachment points for clamps, making it hard to maintain constant force. A solution was devised to use alternative methods for applying pressure. In instances such as attaching top braces, heavy objects like metal pieces were utilized to exert sufficient force on the braces, ensuring a secure bond.

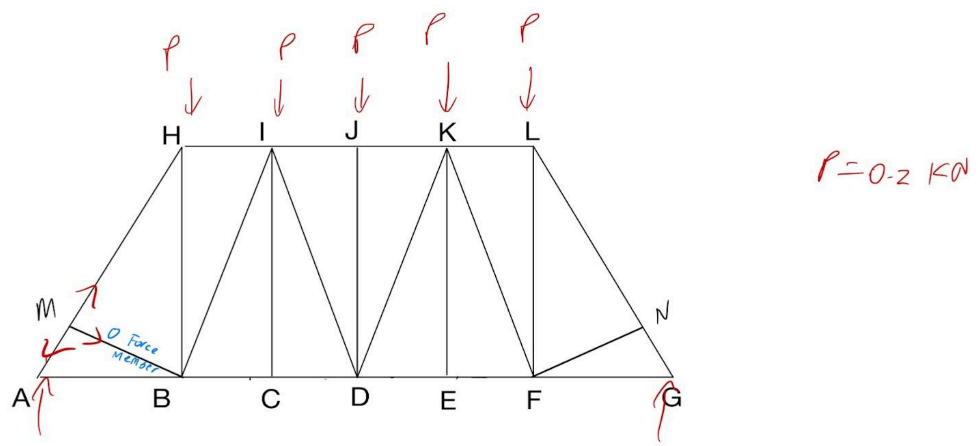
6.2.2 Wood Quantity Constraints

The provided quantity of wood imposed limitations, especially when selecting the ideal dimensions for various truss parts. Initially, it seemed optimal to use 9.5 x 9.5 mm wood for the top chord. However, after detailed calculations, it was apparent there was insufficient 9.5 x 9.5 mm material for constructing both top chords. Subsequent analysis determined that 3.2 x 25.4 mm wood was the most suitable alternative, balancing material availability with structural needs.

6.2.3 Miscommunication Issues

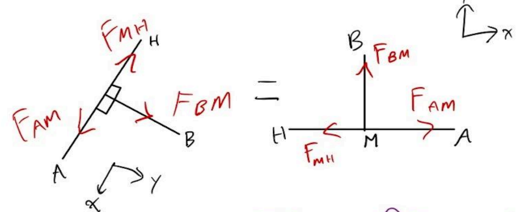
Miscommunication during the bridge construction led to unintended modifications, such as the addition of small wooden knobs to the top and bottom chords. These modifications interfered with the flush attachment of vertical members to points A and C. Furthermore, the introduction of gussets in certain areas reduced the surface area available for gluing, compromising the structural integrity and sturdiness of the truss. These issues underscore the importance of thorough communication within the team, ensuring that any changes to the design are discussed and agreed upon before implementation.

6.3 Re-Analyzing the Built Truss to Ensure Consistency



The Analysis will be identical to the previous analysis. The only Difference will be new member m.

Joint M



$\Sigma F_x = F_{MH} - F_{AM} = 0$

$F_{MH} = F_{AM}$

$\Sigma F_y = F_{BM} = 0$

O Force Member

From Previous Analysis:

$F_{11-6} = F_{AH}$

$F_{AH} = 0.3354N$

Since $F_{BM} = 0\ N$

$F_{AH} = F_{MH} = F_{AM}$

$0.3354N = F_{MH} = F_{AM}$

Figure 12: Calculations used to re-analyze the truss.

7. Conclusion

In conclusion, the mix of the Pratt and Warren design truss built by the team had a load-to-weight ratio of 292.5, which, compared to the other teams, is average. The weight of the bridge was 187.5 g, and it withstood 538 N. In theory, the efficiency factor of the bridge should have been 1852 N. This number is based on the lowest capacity in Newtons that a member can bear before failing. The member HB, with 1250.5N capacity, was used to calculate the load-to-weight ratio since it was the lowest value. The margin of error of the theoretical and practical is due mainly to the length of the bridge, thus affecting the load distribution which was supposed to be distributed on the 250x250mm plate and extend to the end of the truss. In real life, since the bridge was too long, the load applied was turned into shear stress and applied before the truss's end. The zero-force member was the first one to fail during the experiment thus it affected the structural integrity of the truss. In brief, the final design calculations did not correlate with the values collected during the testing since the theoretical one had better efficiency.

8. References

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9. Appendix

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