

To: Dr. Evans and Ms. Kolesnikov
From: Luke DeVries
Date: October 29, 2024
Re: Individual Beam Design Memo

Introduction

The purpose of the beam project design is to meet all requirements set for the team and do so as effectively as possible. This includes cost-effectiveness, mass limitations, and a final structural endurance test of predetermined loads. For team three, the given design requirements of beam 240104 include the following: x-axis load of 325 lb_f, y-axis load of 200 lb_f, beam weight restriction of 240 g, x-axis deflection maximum of 0.235 in, y-axis deflection maximum of 0.250 in, cost limit of \$10.50, and span length of 21 in. The design required students to create from a limited number of predetermined sizes of basswood in their designs, which also determined their cost. The purpose of the design is to meet all requirements stated to confidently pass the stress test of the corresponding real-world beam.

Beam Information

To begin the design, theory was used to compare different types of beams as well as project their effectiveness under loads. The theories used were formulas for the moment of inertia in both axis of the beam and the deflection of the beam in both directions. These equations are listed as Equation 1 and 2 in Appendix B (page 6). Acknowledging that the real-world can differ slightly from the theoretical was important, since the beam would be tested physically. To account for this, a safety factor will help account for any physical errors or environmental factors that could change the effectiveness of the theoretical design. The decision was made to use a safety factor to increase the chances of a successful test, and the goal was to meet a safety factor between 1.5 and 2. These values were found to be most standard through the account of the SafetyCulture Content Team (2024). This project involves reliable materials and importance of weight in the design, the article lists this scenario under its General Recommendations ranging between 1.5 and 2 (SafetyCulture Content Team 2024).

There are many modes of failure for wooden beams and understanding how they may form was important for the design process. A few of these modes are cracks, bending failure, compression failure, tension failure, and shear failure (Franke et al. 2015). For wood, many factors can cause cracks which weaken the wood itself. This can occur before the beam is even constructed but cracks that form under load create internal stress on the beam (Franke et al. 2015). Bending failure occurs closest to the point of applied force, and it causes wood to go through longitudinal tension that will begin to crack and break near the below the point of the load or near any impurities like knots in the wood (Franke et al. 2015). Compression failure may occur near the supports of the beam or point of the load, it results in the top part of the beam depressing in lower the strength of the wood (Franke et al. 2015). Tension failure results in the splitting of the wood horizontally. Additionally, torsion/rotational forces may cause the wood to split or bend in ways that it cannot support without splitting (Franke et al. 2015). Shear failure happens when the wood slips parallel to the grain, it is like tension failure, but rather than splitting the wood slides along

the failure (Franke et al. 2015). Other failures of wooden beams can be summarized in physical property flaws that weaken the material, resulting in any of the previous modes of failure becoming more likely (Franke et al. 2015).

Beam Designs

The designs were tested and selected through trial and error of many different wood size combinations. The beams found include an I-Beam, H-Beam, and Hollow-Box Beam. Cross-sections for each beam type can be found in Figures 2.1–2.3 in Appendix A (pages 4–5). Equations 1 and 2 were used to create each design and ensure that they would comply with the team specifications seen in Figure 1 of Appendix A (page 4). For each design, the moment of inertia was calculated in both the x and y axes. Next, these values were used in the calculations of deflection for both axes. Once the deflection is calculated, the safety factor can be applied, and the result is compared to the maximum deflection on the specification sheet. If the calculated deflection is less than the specification, the design becomes notable. The cost to build each beam was determined using the 1201 Lumber Yard Price List, and the glue was included in the total as \$0.50 per joint. The cross-sectional area was found using basic geometry and used to calculate the volume. Using the known density of the basswood for the beams, the mass could then be calculated through the density formula listed as Equation (3) of Appendix B (page 6). The complete list of calculations for each beam can be found in Appendix B (pages 6–7). A summary table was completed and can be found as Table 1 in Appendix C (page 8) followed by any additional equations needed to complete the table.

Analysis and Selection

A decision matrix was developed and can be found as Table 2 on Appendix D (page 9). The criteria were chosen based on several decisions revolving around the problem statement of the beam project, and the ratings were determined by comparing how successful each design was to that criterion. After observing these final scores for each beam design, the I-beam was selected to be presented to the team.

Bill of Materials

The bill of materials can be found under Table 3 of Appendix E (page 10). Predetermined basswood board sizes were provided by the 1201 Lumber Yard Price List. Included with it was the corresponding price per board. To find the total cost, the number of pieces needed was multiplied by the cost of the piece and then they were all added up. The same process was used for the number of glue joints and the cost per joint. Finally, the total cost was determined to be \$9.85 for all pieces of basswood and glue joints.

I have neither given nor received any unauthorized help on this assignment, nor witnessed any violation of the UNC Charlotte Code of Student Academic Integrity.

Luke DeVries 10/29/2024

References

- Franke, Steffen, Bettina Franke, and Annette M. Harte. 2015. "Failure modes and reinforcement techniques for timber beams – State of the art." *Construction and Building Materials* 97: 2–13. <https://doi.org/10.1016/j.conbuildmat.2015.06.021>.
- SafetyCulture Content Team. 2024. "Factor of Safety: Ratio for Safety in Design and Use." *SafetyCulture*, April 8. <https://safetyculture.com/topics/factor-of-safety/>.

Appendix A. Specifications sheet and computer-generated beam cross-sections.

XLIX Engineering Design Firm 9201 University City Blvd Charlotte, NC 28223		Structural Beam Design Requirements	Team 3
Beam Number	240104		
X-Axis Load	325 lb _f		
Y-Axis Load	200 lb _f		
Beam Weight Restriction	240 g		
X-Axis Deflection:	max. = 0.235 in		
Y-Axis Deflection:	max. = 0.250 in		
Cost Limit	\$10.50		
Span Length	21 inches		

Figure 1. Specifications sheet.

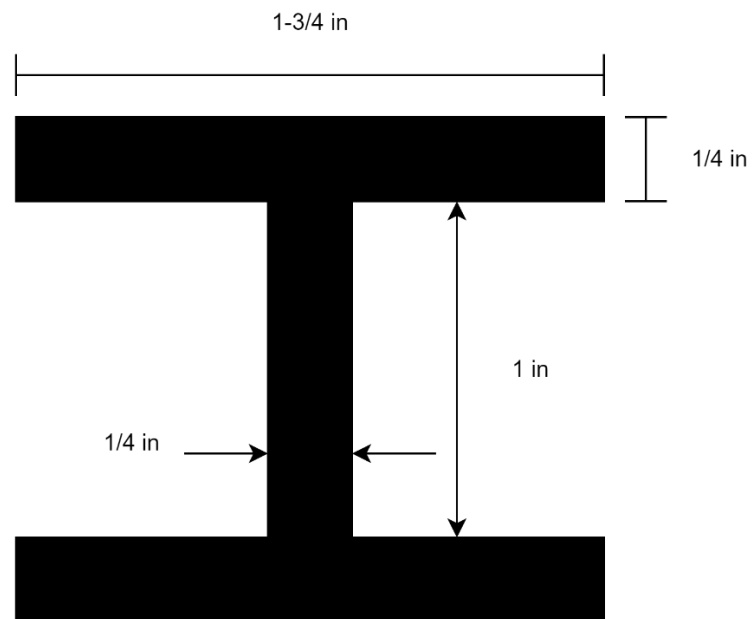


Figure 2.1. I-Beam cross-section.

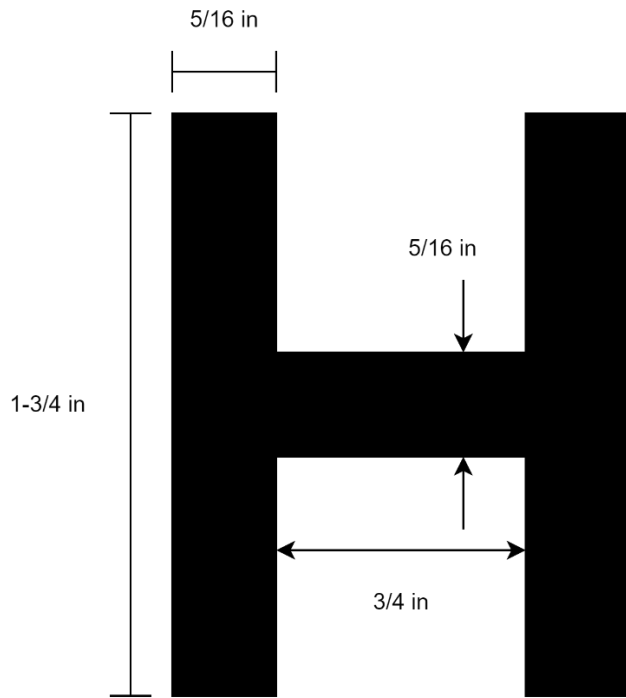


Figure 2.2. H-Beam cross-section.

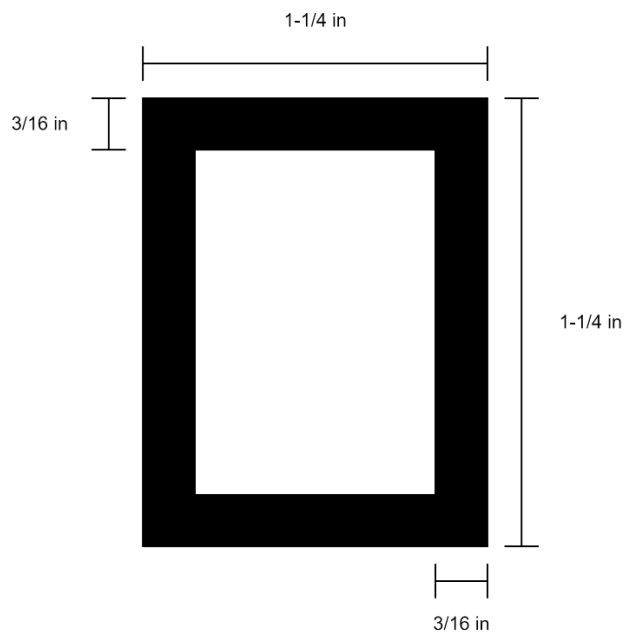


Figure 2.3. Hollow-Box Beam cross section.

Appendix B. Calculations for all designs.

Specifications:

$P_x = 325 \text{ lb}_f$	$\Delta x \leq 0.235 \text{ in}$	Span (L) = 21 in	$E = 1.46 \times 10^6 \text{ psi}$
$P_y = 200 \text{ lb}_f$	$\Delta y \leq 0.250 \text{ in}$	Beam length (l) =	$\rho = 28 \text{ lb}_m/\text{ft}^3$
Weight $\leq 240 \text{ g}$	Cost $\leq \$10.50$	24 in	

Equation 1: $I = \frac{bh^3}{12}$

Equation 2: $\Delta = \frac{PL^3}{48EI}$

Equation 3: $\rho = \frac{m}{v}$

I-Beam

Flange width (in) = 1-3/4 in

Flange thickness (in) = 1/4 in

Web width (in) = 1 in

Web thickness (in) = 1/4 in

Safety Factor = 2

$$I_x = \frac{(1.75)(1.5)^3}{12} - \frac{(1.75 - 0.25)(1)^3}{12} = 0.367 \text{ in}^4$$

$$I_y = 2 * \frac{(0.25)(1.75)^3}{12} + \frac{(1)(0.25)^3}{12} = 0.222 \text{ in}^4$$

$$\Delta x = \frac{325(21)^3}{48(1.46 \times 10^6)(0.367)} = 0.117 \text{ in} \times 2 = 0.234 \text{ in} < 0.235 \text{ in}$$

$$\Delta y = \frac{200(21)^3}{48(1.46 \times 10^6)(0.222)} = 0.119 \text{ in} \times 2 = 0.238 \text{ in} < 0.250 \text{ in}$$

$$\text{Area} = (1.75)(1 + 2(0.25)) - (1.75 - 0.25)(1) = 1.125 \text{ in}^2$$

$$\text{Volume} = 1.125 \text{ in}^2 \times 24 \text{ in} = 27 \text{ in}^3$$

$$\text{mass} = 27 \times 28 \times \left(\frac{1}{12}\right)^3 \times \frac{1}{2.2} \times 1000 = 198.86 \text{ g} < 240 \text{ g}$$

$$\text{Cost} = 2 \times \$3.43 + \$1.99 + 2 \times \$0.50 = \$9.85 < \$10.50$$

H-Beam

Flange width (in) = 1-3/4 in

Flange thickness (in) = 5/16 in

Web width (in) = 3/4 in

Web thickness (in) = 5/16 in

Safety Factor = 1.5

$$I_x = 2 * \frac{(0.3125)(1.75)^3}{12} + \frac{(0.75)(0.3125)^3}{12} = 0.281 \text{ in}^4$$

$$I_y = \frac{(1.75)(1.375)^3}{12} - \frac{(1.75 - 0.3125)(0.75)^3}{12} = 0.329 \text{ in}^4$$

$$\Delta x = \frac{325(21)^3}{48(1.46 \times 10^6)(0.281)} = 0.153 \text{ in} \times 1.5 = 0.229 \text{ in} < 0.250 \text{ in}$$

$$\Delta y = \frac{200(21)^3}{48(1.46 \times 10^6)(0.329)} = 0.080 \text{ in} \times 1.5 = 0.120 \text{ in} < 0.235 \text{ in}$$

$$Area = (1.75)(0.75 + 2(0.3125)) - (1.75 - 0.3125)(0.75) = 1.328 \text{ in}^2$$

$$Volume = 1.328 \text{ in}^2 \times 24 \text{ in} = 31.872 \text{ in}^3$$

$$mass = 31.872 \times 28 \times \left(\frac{1}{12}\right)^3 \times \frac{1}{2.2} \times 1000 = 234.747 \text{ g} < 240 \text{ g}$$

$$Cost = 2 \times \$3.54 + \$2.09 + 2 \times \$0.50 = \$10.17 < \$10.50$$

Hollow-Box Beam

Box beam width (outside dimensions, inches) = 1-1/4 in

Box beam height (outside dimensions, inches) = 1-5/8 in

Wall thickness (top/bottom) for box beams (in) = 3/16 in

Wall thickness (sides) for box beams (in) = 3/16 in

$$I_x = \frac{(1.25)(1.625)^3}{12} - \frac{(1.25 - 2(0.1875))(1.25)^3}{12} = 0.305 \text{ in}^4$$

$$I_y = \frac{(1.625)(1.25)^3}{12} - \frac{(1.625 - 2(0.1875))(1.25 - 2(0.1875))^3}{12} = 0.195 \text{ in}^4$$

$$\Delta x = \frac{325(21)^3}{48(1.46 \times 10^6)(0.305)} = 0.141 \text{ in} \times 1.5 = 0.2115 \text{ in} < 0.250 \text{ in}$$

$$\Delta y = \frac{200(21)^3}{48(1.46 \times 10^6)(0.195)} = 0.136 \text{ in} \times 1.5 = 0.204 \text{ in} < 0.235 \text{ in}$$

$$Area = (1.25)(1.625) - (1.25 - 2(0.1875))(1.25) = 0.938 \text{ in}^2$$

$$Volume = 0.938 \text{ in}^2 \times 24 \text{ in} = 22.5 \text{ in}^3$$

$$mass = 22.5 \times 28 \times \left(\frac{1}{12}\right)^3 \times \frac{1}{2.2} \times 1000 = 165.720 \text{ g} < 240 \text{ g}$$

$$Cost = 4 \times \$1.87 + 2 \times \$0.50 = \$9.48 < \$10.50$$

Appendix C. Summary Table.

Table 1. Summary table for beam designs.

Beam Configuration on Primary Axis (e.g. H-Beam, Hollow Box, or I-Beam)	Calculated Mass		Calculated Volume		Total Cost of Wood and Glue Joints	X-Axis Calculations		Y-Axis Calculations	
	lbm	g	ft ³	in ³	\$	I (in ⁴)	Δ (in)	I (in ⁴)	Δ (in)
I-Beam	0.4375	198.86	0.0156	27	9.85	0.367	0.234	0.222	0.238
H-Beam	0.5165	234.75	0.0184	31.872	10.17	0.281	0.229	0.329	0.12
Hollow Box	0.3646	165.72	0.013	22.5	9.48	0.305	0.2115	0.195	0.204

Note: The I-Beam deflection values were found with the safety factor of 2, while the H-Beam and Hollow-Box Beam deflection values were found with the safety factor of 1.5.

Appendix D. Decision matrix.

Table 2. Decision matrix.

Criteria	Weight (1/3)	I-Beam		H-Beam		Hollow-Box Beam	
		Rating (1/5)	Weighted Score	Rating (1/5)	Weighted Score	Rating (1/5)	Weighted Score
Cost (\$)	3	4	12	2	6	4	12
Mass (g)	1	3	3	1	1	5	5
Deflection Safety Factor used	3	5	15	2	6	2	6
Difference from max dX	2	1	2	2	4	2	4
Difference from max dY	2	2	4	4	8	3	6
Total Score			36		25		33

The criteria were mainly determined by the problem statement of the project. This involved meeting certain design specifications including the cost, mass, and deflection values. It was determined that with two different safety values, the safety value itself should be a weighed criterion. The criteria were rated from 1 to 3 since it gives a clear cut between not very important, beneficial, and very important. To rate the beams, the designs were compared against each other and then ranked on a scale of 5. For the first criterion, the less a beam design required in cost to be made, the higher its score. For mass, the lowest mass yielded the highest score and the largest was given a 1. For the safety factor applied to deflection, the I-Beam which used a safety factor of 2 was given a rating of 5 while the H-Beam and Hollow-Box Beam only used a safety factor of 1.5 which gave them a rating of only 2. For the differences of deflection in both axes, the larger the distance from the specified limit, the higher the rating. With all of these bounds, the decision matrix shows a total score for each beam, and the I-Beam appears to grant the most favorable outcome.

Appendix E. Bill of materials.

Table 3. Bill of materials for designed I-Beam

	Number of Pieces needed	Price Per Piece	Total Cost Per Piece
1/4 in x 1-3/4 in	2	\$3.43	\$6.86
1/4 in x 1 in	1	\$1.99	\$1.99
Glue Joints	2	\$0.50	\$1.00
Total Cost			\$9.85