Optimal Design of a Crane Boom Truss

Group Number: 43

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Executive Summary

For this truss design project, the material properties of the basswood used to make the beams and joints were determined through lab calculations and then the truss was designed. The initial truss design was based on the Warren truss and failed due to tear out and buckling with a PV value of 195.585. The idea of the second bridge was to try to maintain the same load while lowering the mass by decreasing the number of beams in the truss. Because the lengths of the beams were needed to be increased the beams began to fail due to buckling, such that the PV value of the second iteration was Figure 6163.608. The third iteration of the truss was based off the first truss iteration since it outperformed the second truss iteration. For this iteration, the triangles in the truss were tilted slightly to reduce the length of the members that fail due to buckling. This resulted in the final and maximum PV value being 199.861.

Lab Results and Data

The goal of the material testing lab was to obtain the material properties of basswood to use in the project. More specifically the density, ultimate yield strength and young's modulus were calculated from the results produced by the lab. All values used can be found in Appendix A.

First the dimensions were taken from two samples to obtain the average volume in cm^3. Next the average values between the two samples were inserted into the equation for density:

$$\rho = \frac{m}{V}$$

$$\rho = \frac{9.5g}{24.688}$$

$$\rho = 0.385\ g/cm^3$$

Next the deflection was obtained from the 3-point bend test for the 2 samples and a force-deflection (P-δ) curve was plotted. Once all the variables were obtained, the equation for the elastic modulus was used with the slope of the graphs representing P/δ. The equation can be found below:

$$E = slope \cdot \frac{l^3}{4bh^3}$$

$$E = \frac{1.163}{10^{-3}} \cdot \frac{(0.2)^3}{4(49.875 \cdot 10^{-3})(1.65 \cdot 10^{-3})^3}$$

$$E = 10.392\ GPa$$

Using a force gauge, the maximum force was found for each sample in the 3-point bend test. From there the ultimate yield stress was calculated with the following equation:

$$\sigma_{ult} = \frac{3Fl}{2bh^2}$$

$$\sigma_{ult} = \frac{3(29.49)(0.2)}{2(49.875 \cdot 10^{-3})(1.65 \cdot 10^{-3})^2}$$

$$\sigma_{ult} = 65.142\ MPa$$

Design Iterations

For the bridge project, the designs selected and optimized were based on the warren truss. The first design was based on the bridge provided in the project problem statement. From there 2 other design iterations were made to attempt to raise the PV values of the bridge. The PVs for the three bridges tested can be seen in Table 1:

Table 1: Shows the mass of each bridge, the maximum mass they can hold and their respective PV.

Bridge #	Mass of Bridge (g)	Mass held by a bridge (g)	PV value
1	14.316	2,800	195.585
2	14.058	2,300	163.608
3	13.009	2,600	199.861

Design 1

As mentioned before the design was selected as a starting point for the project can be seen in Figure 1. The bridge originally failed due to tear out more specifically by the tension force in the bridge located at member 2. To maximize this design, the b value of the members was increased as much as possible given the constraint of the basswood sheet to maximize the weight it could hold as seen in Appendix part B Figure 6. Once this value was obtained the width of the members was reduced as much as possible, until the buckling and tear out stress failed at the same weight to minimize the weight of the bridge. Beam 4 had the highest compression force in the bridge and was the beam failing to due to buckling. Upon maximizing the weight, the bridge could hold 2.8 kg, a final PV of 195.585 was obtained.

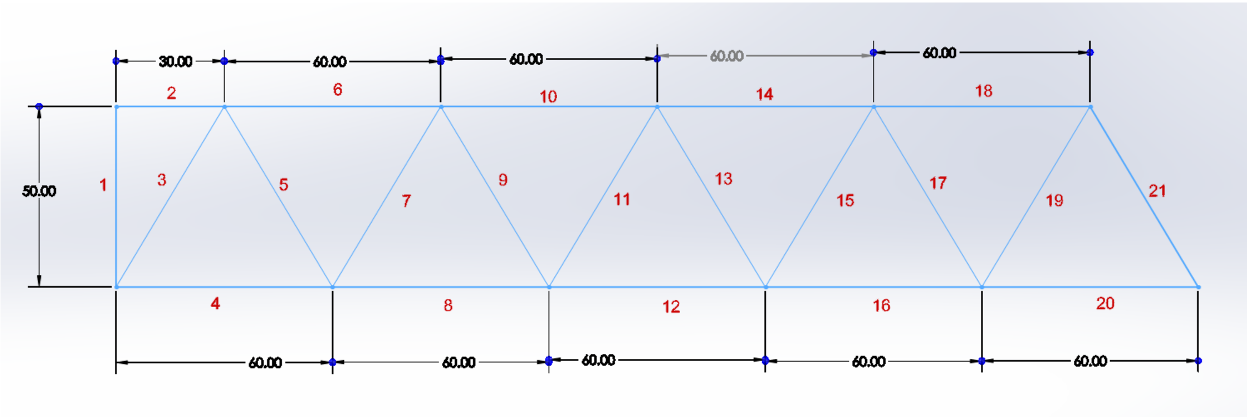

Figure 1: Shows the first design iteration of a warren bridge.

Design 2

The idea for the second bridge was to reduce the mass of the bridge by using fewer diagonal members, which in turn made them longer as seen in Figure 2. This design was optimized like the first one, the main issue with the design was that the longer members made the bridge more susceptible to buckling. In this case, the width was increased as much as the cut-out drawing allowed for, which can be seen in Figure 7Figure 6. Then as before, all values were minimized such that the bridge could hold 2.3kg. Buckling was a large issue with the bridge and the width had to be increased quite a bit compared to the other bridges to be able to hold the weight. This had a significant effect on the mass calculations, essentially contradicting our original hypothesis that removing members would reduce the overall mass. The longer members caused the bridge to fail with less weight, and because the bridge had a similar mass to the first bridge, the second iteration had the lowest PV value of 163.608.

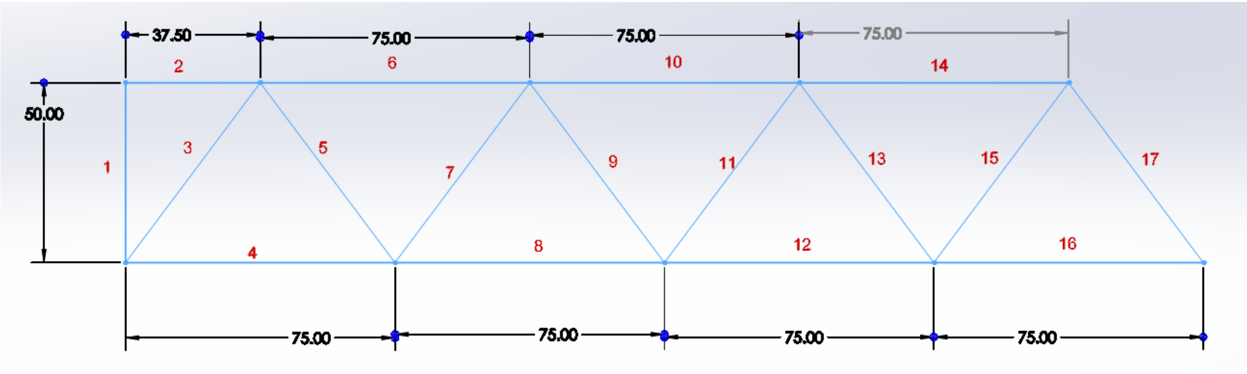

Figure 2: Shows the second iteration of the design with the warren bridge.

Design 3

The third design put a spin on the usual warren design by tilting the inner tringle of the first design to the left as seen in Figure 3. The first design was used as a template as it outperformed the second design by quite a bit. The thought going into this design is to reduce all diagonal members of compression to reduce buckling to get a lower width to get a lower overall area. From the results, it seems that the strategy worked as intended as it sports the highest PV value out of the three designs at 199.861. Like the first design, it failed due to tear out and the b value was larger than the first design as seen in Figure 8. Learning from previous mistakes the width of the members in the truss were able to be lowered drastically making the bridge around 1g lighter than the other two. Despite the fact it did not lift as much as the first bridge the reduction in mass made it the top-performing design out of the 3 iterations.

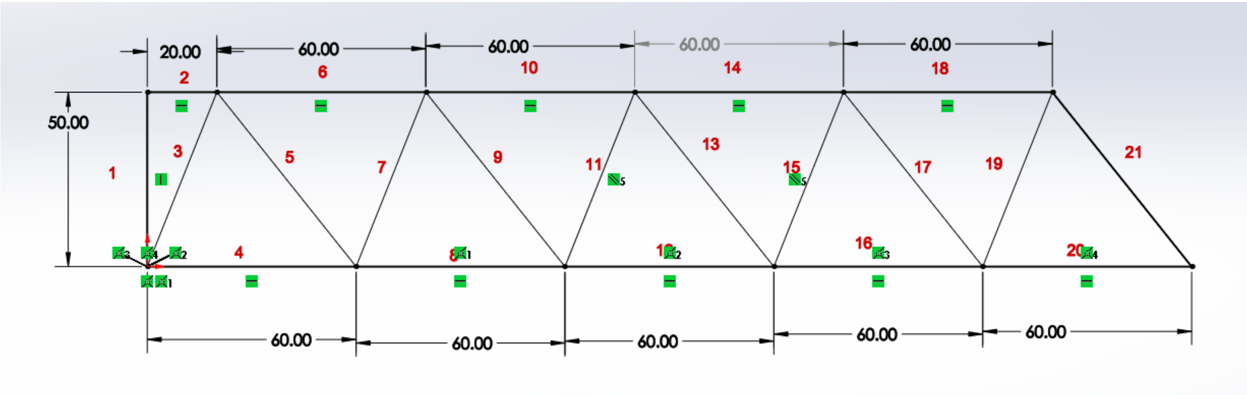

Figure 3: Shows the third iteration of the design putting a unique twist to the usual warren bridge.

Findings and performance

Overall, from the three bridges, it seems that the width of a member had a large impact on the bridge's overall PVs. The third design with the shortened diagonal compression members was able to have the lowest mass while being able to hold a respectable 2.6 kg. Next, the first design, which able to hold the largest mass had and approximately an extra 1.3 grams of mass with a slightly smaller PV compare to the third iteration. Lastly, the third bridge weighed too much from the required support of the larger diagonals to prevent buckling and being able to lift the least amount of mass. While comparing the designs it seems that the relation between the width and length of the members had a large role in increasing the PVs for the bridges demonstrated through the 3 iterations above.

Reflections and Recommendations

It would have been interesting to try different support designs and shape outlines to reduce the average stress in the members. On top of this, it would have been interesting to make the outer design a triangle instead of a quadrilateral and observe oh the forces would react. Triangles are typically used in this type of support system and can be seen in construction, and it looks as though it would use fewer material. Changing the shape of the design as well as the diagonal support members could've been used to reduce forces on susceptible members are perhaps lower the weight of the truss.

Another way that we could have improved on the designs would be to write an optimization function. For simplicity one change to the width or b values would be the same across all other members. Writing a program to optimize the dimensions of each beam to make the stress just below the maximum would decrease the weight of the bridges increasing the PV value.

Another thing to consider is the manufacturing of the bridge. The worst bridge would be the easiest to manufacture with the least number of members. The best bridge would be the hardest although it shares the number of pieces with the first one it has more pieces of different lengths making it more difficult to machine and assemble.

For this project, I would recommend the 3rd design as it has the highest PV value. The answer would be different once factors in real life are considered. The first design can hold more weight than the others and would be easier to manufacture. Even though it uses more materials I argue that the materials would be relatively cheap when compared to the ease of manufacturing and assembly of the first design. Therefore, in a real-life scenario, I would recommend the first design which can carry a respectable load while being easy to manufacture and assemble.

Conclusions

Overall based on this project, it was determined that the final truss design was the best choice as it had the highest PV value of 199.861. This was because this truss iteration was best at reducing buckling failure by minimizing the length of beams which tend to be in compression.

Appendix A – Lab Data

Table 2: Includes the dimensions, mass and volume of sample size one and 2.

Sample	Length (l) [mm]	Span (l) [mm]	Width (b) [mm]	Thickness (h) [mm]	Mass (m) [g]	Volume (V) [cm^3]
1	300	200	49.85	1.63	9	24.37665
2	300		49.9	1.67	10	24.9999

Table 3: Displays the resultant deflection of each sample from the applied mass.

Mass [g]	Deflection (Displacement) [mm] (0.001 inch = 0.0254 mm)			
	Sample 1		Sample 2	
	Increasing load	Decreasing Load	Increasing Load	Decreasing Load
0	0	1	0	2
50	17	18	21	22
70	24	25	28	29
90	31	31	35	35
110	37	38	41	43
130	44	44	48	49
150	50	51	54	55
170	57	57	61	61
190	63	63	67	67
210	70	70	73	73
230	76		80	

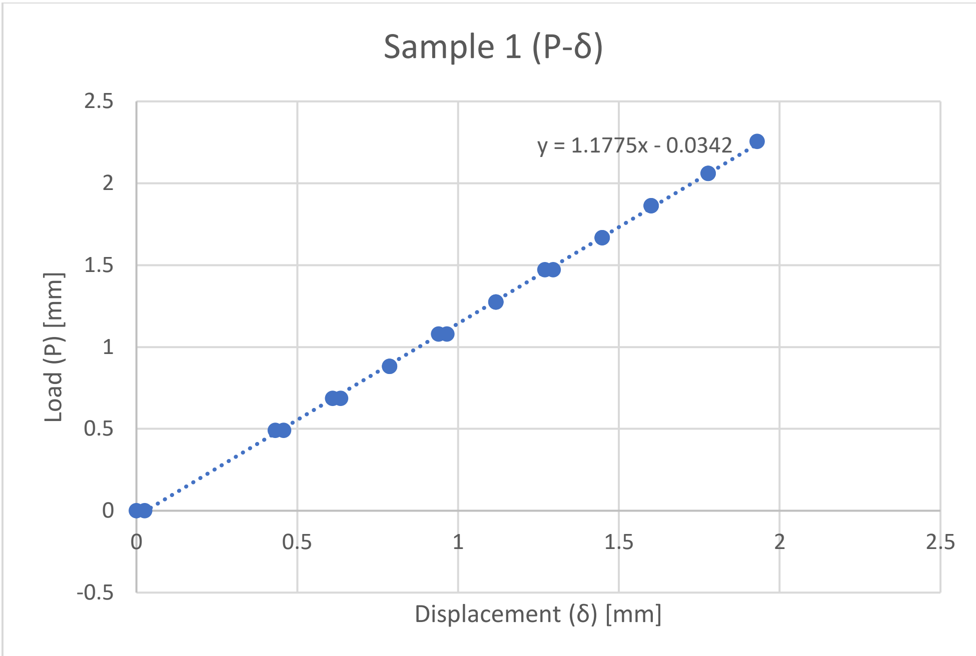

Figure 4: Displays the P-δ graph for sample 1.

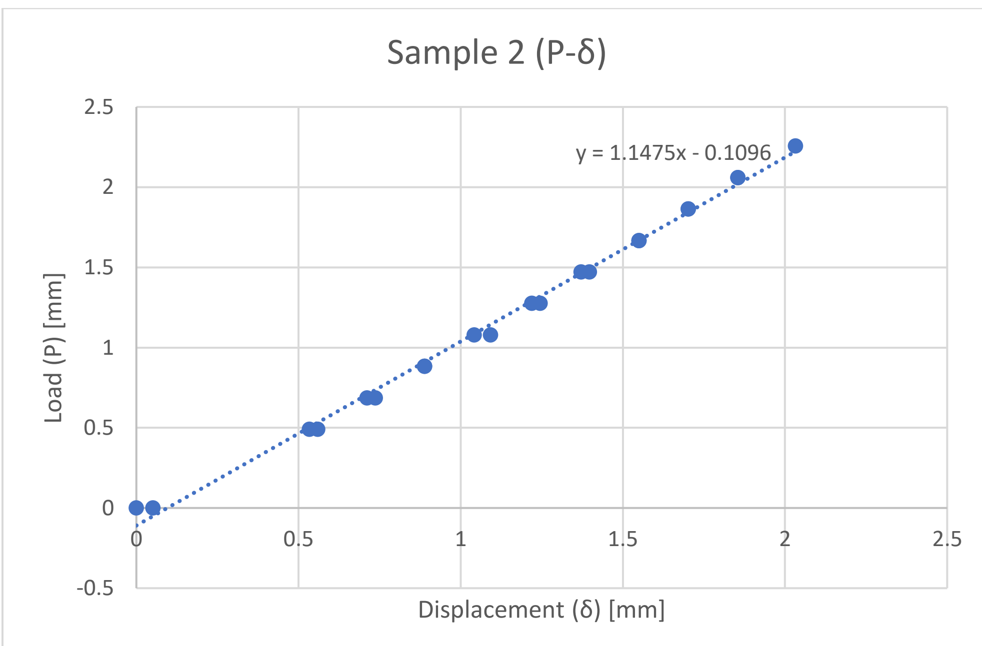

Figure 5: Displays the P-δ graph for sample 2.

Table 4: Shows the max force that the two samples were able to withstand.

Sample	Max Force [N]
1	28.71

2	30.27

Appendix B – Bridge Cutting Design

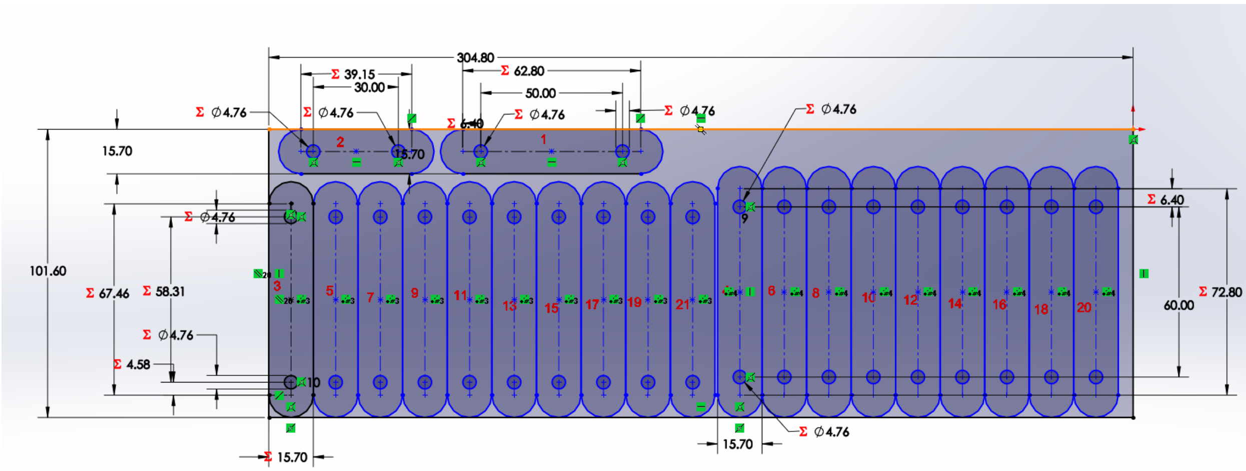

Figure 6: Cut-out patterns for bridge 1.

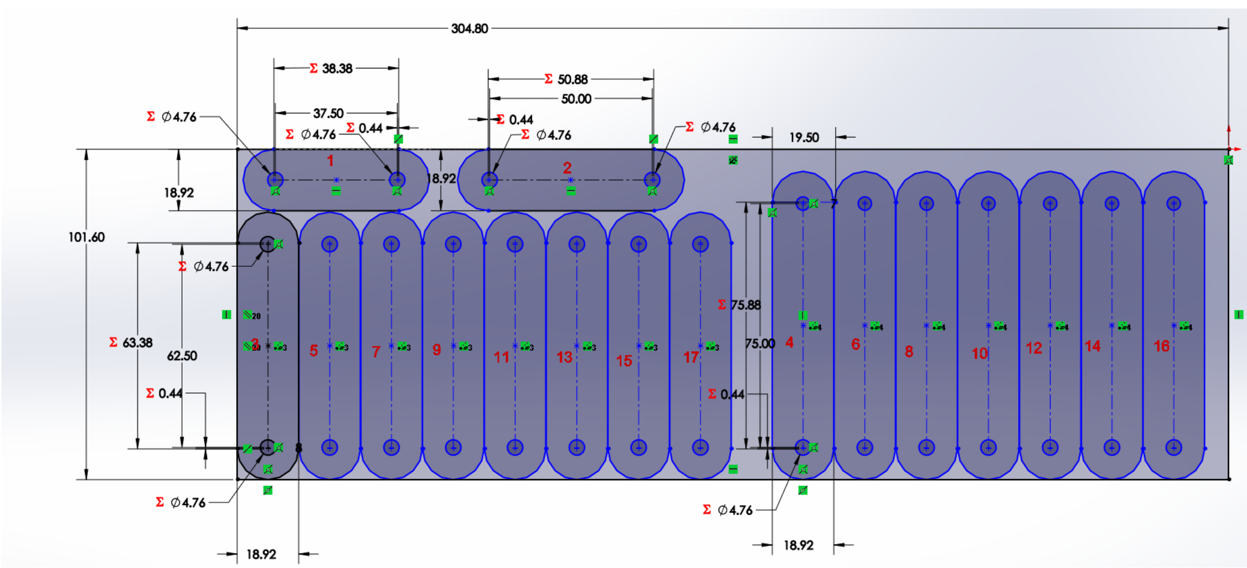

Figure 7: Cut-out patterns for bridge 2.

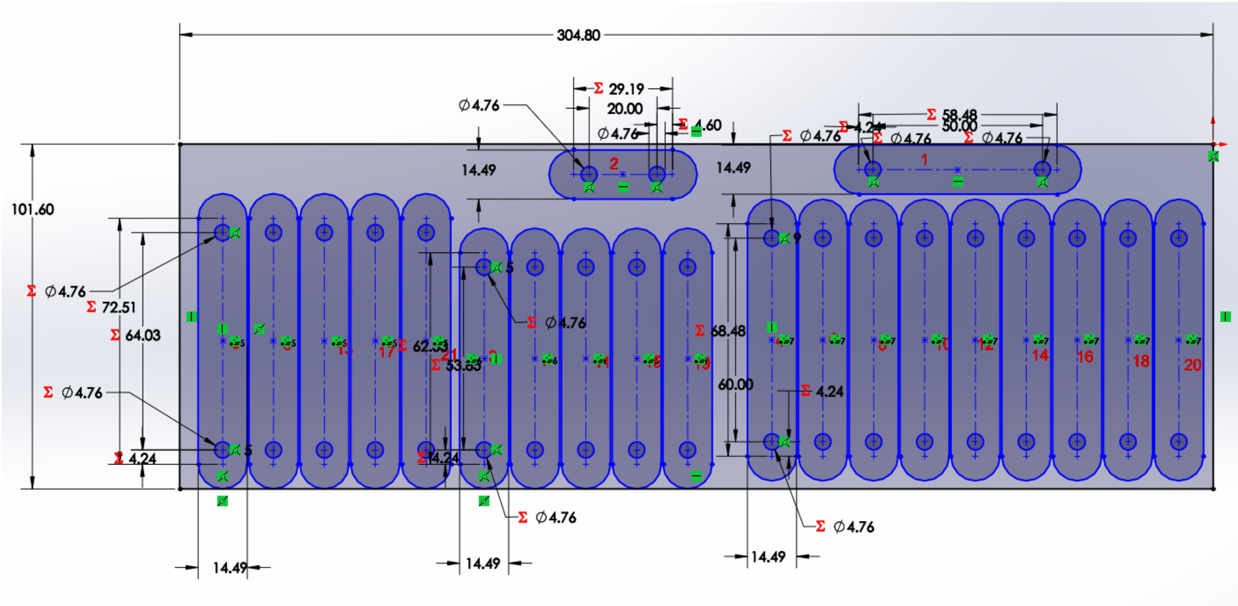

Figure 8: Cut-out patterns for bridge 3.