CIV102 Bridge Design Report

<u>Iterations:</u>

Design 0:

Our calculations for the design 0 Factors of Safety (FOS) were

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
4.37	1.040	2.86	10.08	0.639	4.07	5.10	3.76

Iteration # 1 - Double Layer Top Flange:

At first, we thought to add a second layer for the top flange in design 0, this is because our FOS for case 1 plate buckling at mid-part of the top flange was very low at about 0.637, thus we thought to increase the thickness. This is beneficial as increasing the thickness increases the stress capacity for this case. This is because in the equation for stress capacity in plate buckling, $\sigma = \frac{4\pi^2 E}{12(1-\mu^2)}(\frac{t}{b})^2$, increasing the doubling t value leads to a much and 4x increase in allowable stress capacity. Therefore we doubled the thickness on the top flange from 1.27mm to 2.54 mm by adding another layer. We will glue this but since the entire area is glue we don't need to worry about shear failure in glue due to the amount of it. Additionally this should also benefit the flexural buckling which was our second lowest FOS. This is because by adding material to the top we increase the value I, and also raise the centroid, therefore decreasing the distance from the top to the centroid. This is beneficial, as in the equation for applied flexural stress $\sigma = \frac{My}{I}$ increasing the value of I and decreasing y results in a lower applied stress, and subsequently a higher FOS.

Previously the allowable stress capacity for case 1 plate buckling was 3.68 Mpa, and after doubling the thickness we get a stress capacity of 14.74 Mpa. This resulted in the FOS increasing from 0.637 to 4.12. For the flexural buckling we increased the FOS from 1.038 to 1.676.

The factors of safety of all 8 checks are:

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
4.74	1.68	2.90	8.35	4.12	26.2	14.29	3.81

Iteration # 2 - Taller Height:

After Iteration #1, our flexural buckling FOS was still the lowest at 1.676 and thus to increase this, we thought to double the height of our web member from 73.7 to 150.46mm. The purpose of this was to increase the I value. In the flexural stress applied stress equation $\sigma = \frac{My}{I}$ increasing the I lowers the applied stress. By increasing the height, we increase I as the equation for I is $\frac{bh^3}{12}$, thus, since the h term is cubed, increasing height makes the I greater by a huge factor. This also benefits our other very low FOS which was shear stress at the centroid for which the equation is $\tau = \frac{VQ}{Ib}$. This is because the increase in I again lowers the applied shear stress in the web. Thus increasing the height should have a great benefit to the FOS for flexural buckling in the top flange and the shear stress in the webs.

Previously the FOS for the buckling was 1.676, and after increasing the height of the web, our FOS increased to 3.77, as expected. Previously the FOS for shear stress was 2.90, and after it increased to 5.56 which is a great result.

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
12.29	3.77	5.56	18.31	9.26	59.0	6.12	1.940

Iteration # 3 - Adding Diaphragms:

After Iteration #2, the weak point of our design was due to shear buckling in the webs. it had a very low FOS compared to other forces at about 1.937. Thus, we introduced 5 more diaphragms for a total of 9 into the design at a spacing of 150 mm each throughout the cross-section, instead of 400mm. The equation for applied stress from shear buckling is $\tau = \frac{4\pi^2 E}{12(1-\mu^2)}\left[(\frac{t}{b})^2 + (\frac{b}{a})^2\right]$, thus increasing the amount of diaphragms reduces the value a and thus reduces the applied stress for shear buckling, and therefore should lead to an increased FOS .

This resulted in increased FOS in shear buckling from 1.937 to 4.16, which now puts all of our FOS's above 3.

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
12.29	3.77	5.56	18.31	9.26	59.0	6.12	4.16

Iteration # 4 Narrow bottom Flange:

Due to material constraints, making it taller is very expensive, and thus we decided to reduce the width, from 80 to 66.27, for the bottom flange. This is because, it is more beneficial to have the design be taller, than for it to be wider as the h term in the equation for I $\frac{bh^3}{12}$ is cubed, thus decreasing width, and increasing height of the cross section increases, the second moment of area, leading to lower applied flexural stress values and shear stresses. Additionally, this width specifically was chosen, so that the webs are directly below the center of the wheels of the train. Thus, the points load of the wheels are not only supported by the top flange and are fully supported by the web as well.

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
11.31	3.68	5.48	17.91	13.37	20.3	6.46	4.10

Final Design:

Due to the dimensions of the board even though we have enough area, the cutting of the board does not allow us to get all the pieces we need to construct it. Subsequently, some modifications and splices had to be put into place to make the dimensions of the pieces work. Firstly the main portion of the bridge is one piece including the bottom, webs, and glue tabs. This portion was split into 75% and 25% of the total length of 1250mm as we want to put it where the forces are minimized. However the lowest bending moment occurs at the end, but the highest shear forces occur at the end as well, on the other hand, the max bending moment is near the middle, and the lowest shear force is near the middle too. Thus we split the difference and put the splice in the middle of both maxima of the forces as we think it's the optimal place to put it.

Additionally, we spliced the first layer of the top flange such that one spans the max length of the board we're given at 1016mm and then the other piece covers the rest of the 234mm to get to a 1250mm span. And the second layer of the top flange is split into 2 equal parts. This was done as we wanted to misalign the splices, and because the splices in the top flange don't matter as much since their entire surface is glued to each other making it almost solid. Making this assumption, we could fit the other pieces we wanted into our cut design.

Moreover, for the cut design, we wanted 9 diaphragms for our original design but this couldn't fit, so we decided to split one of the diaphragms into 4 pieces to make it work. We will place this suboptimal diaphragm in the middle, as that is where shear forces are the lowest.

Finally, for the cut design to work we had to decrease the height of the webs from 150.46mm to 135mm this was because we needed to increase the size of the glue tabs a bit due to practicality reasons. With 5mm glue tabs, even though they are strong enough, they will be hard to fold properly, thus we decided to increase their width even at the cost of height, thus decreasing the I value. We also needed more area for adding glue tabs to our diaphragms as their edges are not wide enough to be securely glued to the sides and top.

With all the changes this hurts FOS a bit but it should result in a better construction, and thus will benefit the design. Since our FOSs are already above 3 we had the liberty of bringing them down to make the construction and cut design to work.

Flexural Tension	Flexural Buckling	Max Shear Stress	Glue Shear	Plate Buckling Case 1 (k=4)	Plate Buckling Case 2 (k=0.425)	Plate Buckling Case 3 (k=6)	Shear Buckling (k = 5)
9.70	3.30	4.96	23.3	12.0	18.1	7.64	3.29

Thus overall even our final design has a minimum FOS of 3.29 resulting in a failure load of 1316N theoretically.