Design Report

Team 1

Mark Li

Manan Sawrangpate

Michael Mo

Ruohan Xu

1. Introduction

This design report details the selection of preliminary parameters by altering Design Zero in MATLAB, the selection of deck geometry, the selection of internal supporting materials, the final dimensions of the completed bridge and the whole construction procedure.

2. Preliminary Parameters

We used a for-loop in MATLAB to seek for the best parameters of the cross section. The bridge cross section for design zero is divided into 6 different parts, as shown in Figure 1, and the dimensions for each part are changed in the for-loop.

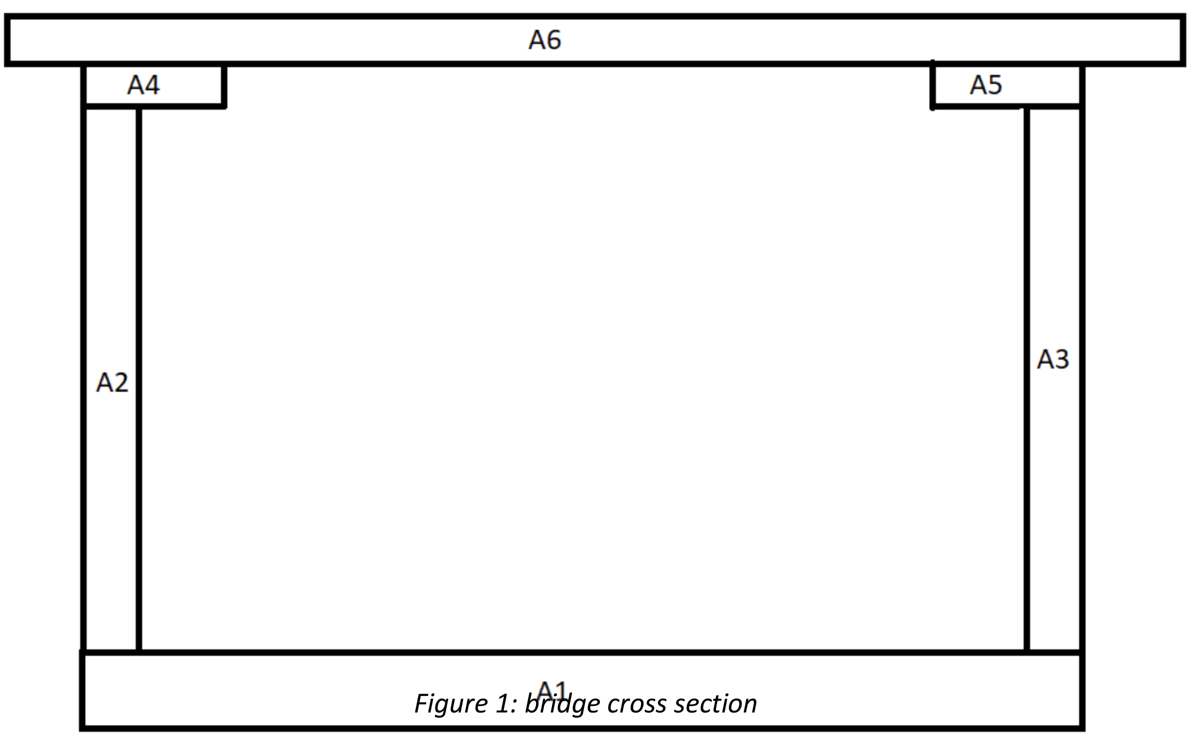


Figure 1: bridge cross section

In total, there are four iteration variables in the for-loop because pair (A2, A3) and pair (A4, A5) changes together. Each variable is looped 5 times for a total of 625 iterations. Below is the list of parameters in the for-loop:

1. The width of A1 is kept constant at 65mm since this is the distance between the center of the wheels, which ensures the force of loads to go directly into the flanges.
2. The height of A4 and A5 is kept constant since we do not need to have multiple glue pieces.
3. The width of A6 is kept constant. As $I = \frac{bh^3}{12}$, increasing the height of A2 and A3 will have much better effect on increasing I than increasing the width of A6.

For each iteration in the for loop:

1. the cross-section area, I, Q_{max}, and Q_{glue} are calculated and stored in a $5 \times 5 \times 5 \times 5$ matrix.
2. Minimum FOS is calculated by $\frac{\sigma_{allowable}}{\max(\sigma_{demand})}$.
3. The volume of material we need is calculated by $\text{cross} - \text{section area} \times \text{length}$. The approximate matboard area needed is $\frac{volume}{thickness}$.
4. The eight FOS are stored in a $5 \times 5 \times 5 \times 5 \times 8$ matrix and the minimum FOS are stored in another $5 \times 5 \times 5 \times 5$ matrix.

After the for loop is finished, all parameters that will cause the cross-section area to exceed material limit are eliminated. Among the leftovers, we selected the parameter set with the highest minimum FOS, which is shown below:

	Width (mm)	Height (mm)
A1	65	1.27
A2 and A3	1.27	75
A4 and A5	6.27	1.27
A6	105	3.81
Material needed (mm^2)	683600	

This set of parameters produces:

- FOS of tension: 4.60
- FOS of compression: 2.38
- FOS of max shear: 2.93
- FOS of shear glue: 7.82
- FOS of plain buckling case I: 19.45

- FOS of plain buckling case II: 19.71
- FOS of plain buckling case III: 39.7
- FOS of shear buckle: 3.60

This means that the bridge will fail in compression first.

3. Deck Geometry

Bending moment increases from minimum at location x = 0 to maximum at location x = 555, which means that the actual FOS of compression is greater than 2.38 at the two ends and decreases to 2.38 at max point. Therefore, we choose a trapezoidal deck for $0 < x < 400$ and $800 < x < 120$ and a larger rectangular deck (See engineering drawing) for $400 < x < 800$ to reduce material and increase minimum FOS.

The FOS at zero are:

- FOS of tension: N/A since bending moment is zero
- FOS of compression: N/A since bending moment is zero
- FOS of max shear: 2.87
- FOS of shear glue: 7.84
- FOS of plain buckling case I: 18.28
- FOS of plain buckling case II: 61.4
- FOS of plain buckling case III: 31.4
- FOS of shear buckle: 3.71

The FOS at 400 are:

- FOS of tension: 5.01
- FOS of compression: 2.61
- FOS of max shear: 5.93
- FOS of shear glue: 15.80
- FOS of plain buckling case I: 21.4
- FOS of plain buckling case II: 21.7
- FOS of plain buckling case III: 47.1
- FOS of shear buckle: 7.67

The maximum FOS are in the middle of the board determined by $\frac{\sigma_{allowable}}{\max(\sigma_{demand})}$:

- FOS of tension: 4.46
- FOS of compression: 2.49
- FOS of max shear: 5.90

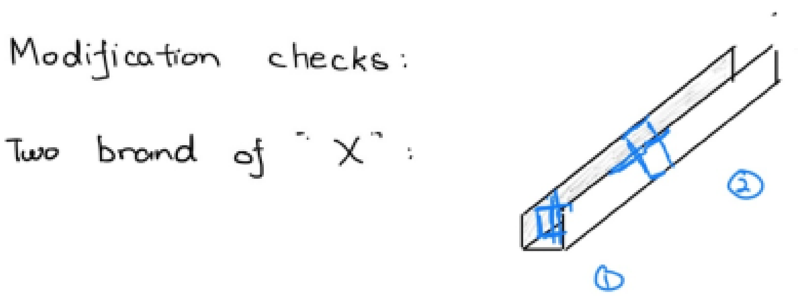
- FOS of shear glue: 15.60
- FOS of plain buckling case I: 20.3
- FOS of plain buckling case II: 13.40
- FOS of plain buckling case III: 50.7
- FOS of shear buckle: 7.63

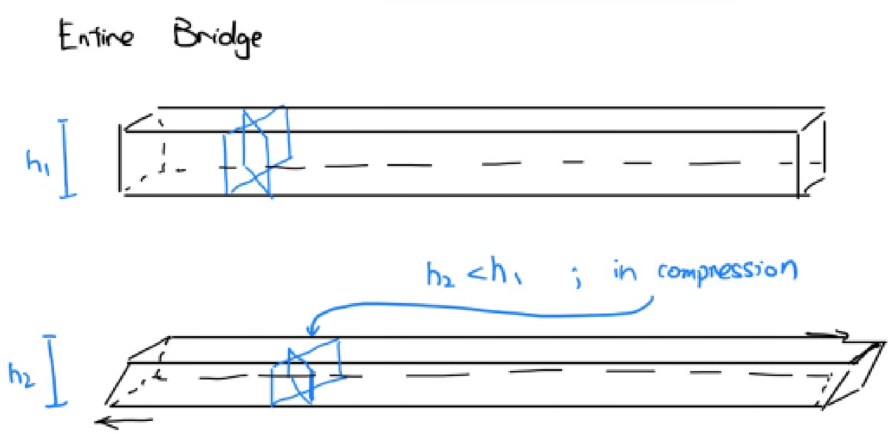
From the above data, we find that the minimum FOS for this new geometry is 2.49 and the material needed to build this bridge reduces to $671000mm^2$.

Therefore, the predicted failure load is $400N \times 2.49 = 996N$.

4. Internal supporting materials

Other than failures caused by stress or buckling mentioned above, the deformation in bridge's cross section deformation was took in consideration. This deformation can be caused by multiples reasons, including shear stress or simply the potential uneven load acting on the bridge. "X" sections were made and placed in the bridge to prevent such deformation. Because the amount of material is limited, "X" is not placed along the bridge. Instead, it was placed at equal distance along the bridge.





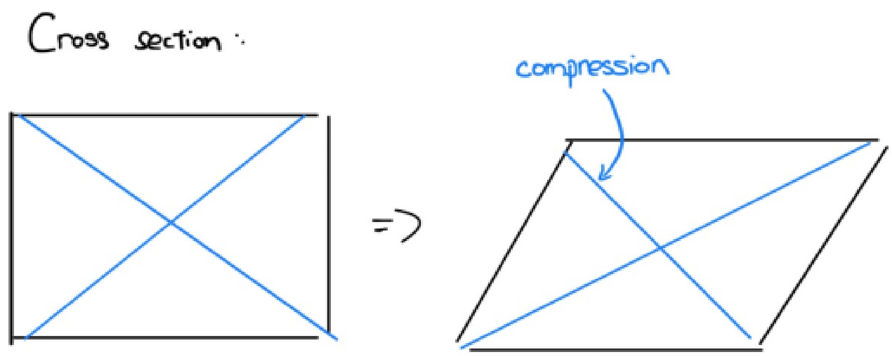


Figure 2

As shown in the figure above, the minimum stress required to deform the cross section of the bridge is 6 MPa, because one of the boards must fail under compression.

The placing of “X” into the bridge has also side effects which are positive: at the two edges of the bridge two vertical “X” were placed so that the bridge would not fail due to the high normal force on the edge; at the connection parts between beams two horizontal “X” placed, and they acted “wraps” at the edges to enhance the bridge so that the bridge is less likely to fail because of glue.

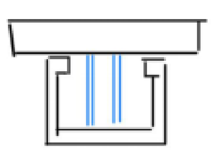
Although this design prevents potential deformation of the bridge, it also changes part of the cross sections where these designs are. To ensure the adding of “X” does not decrease FOS because of compression stress, the height of neutral axis and the value of I was calculated.

1. vertical : Top view:

side view :

$|\bar{y}_{new} - \bar{y}_{old}| / \bar{y}_{old} < 10\%$

$I_{new} / I_{old} > 10\%$



generally, the cross section with vertical x is the same as having 2 more vertical pieces as shown below

$y_{new} = a \cdot y_{old}$ = distance from top to $\bar{y}$; $a < 7\%$

$I_{new} = b \cdot I_{old}$ $b > 10\%$

$$\frac{\sigma_{new}}{\sigma_{old}} = \frac{M y_{new} / I_{new}}{M y_{old} / I_{old}} = \frac{y_{new}}{y_{old}} \times \frac{I_{old}}{I_{new}}$$

$$= \frac{a \cdot y_{old}}{y_{old}} \times \frac{I_{old}}{b \cdot I_{old}} = \frac{a}{b} < 1$$

$\sigma_{new} < \sigma_{old}$

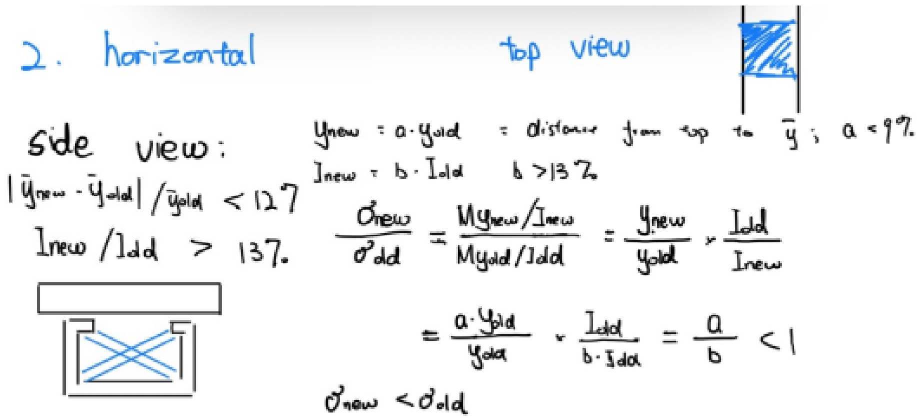


Figure 3. Calculation of neutral axis, I and some extended calculations for stress

According to calculation, it decreases the compression stress at the top deck of the bridge. Thus, it does not contradict with the FOS calculated above due to compression stress. Meanwhile, although the bottom of bridge receives higher tension stress by over 5% and less than 15%, because the tension stress is much lower than 30 MPa, it does not affect the overall FOS.

5. Construction Procedure

Step 1: Deck

The entire deck consists of nine matboard pieces glued together by cement. The three layers of matboard pieces in each section were first glued together, with a drying time of 15 minutes every time glue was being applied. Then, the three separate sections were glued together along the short and thin edges. Two small matboard pieces were glued underneath each splice connection to provide support. (See engineering drawing)

Figure 4: group member gluing deck pieces

Step 2: U-Shape Cross Section Portion

Each of the three $230\text{mm} \times 420\text{mm}$ matboard pieces were folded along the 230mm edge at 6.27mm, 82.54mm, 147.54mm, and 223.81mm point to create the U-shaped portion of the cross section (See engineering drawing). The three sections were glued along the thin edges, with a drying time of 15 minutes every time glue was being applied. One small matboard piece was glued to each side of a splice connection and the bottom of the connection on the outside to provide support.

Step 3: Internal X Supports

Internal X support pieces are created by interlocking two pieces of matboard together at a thin cut in the middle of the pieces. One horizontal X support was glued to each split connection, touching the glue piece and the bottom of the cross section. Two vertical X supports were glued to each of the two end sections and one vertical X support was glued to the middle section, touching the bottom of the cross section and reaches the height of the glue piece.

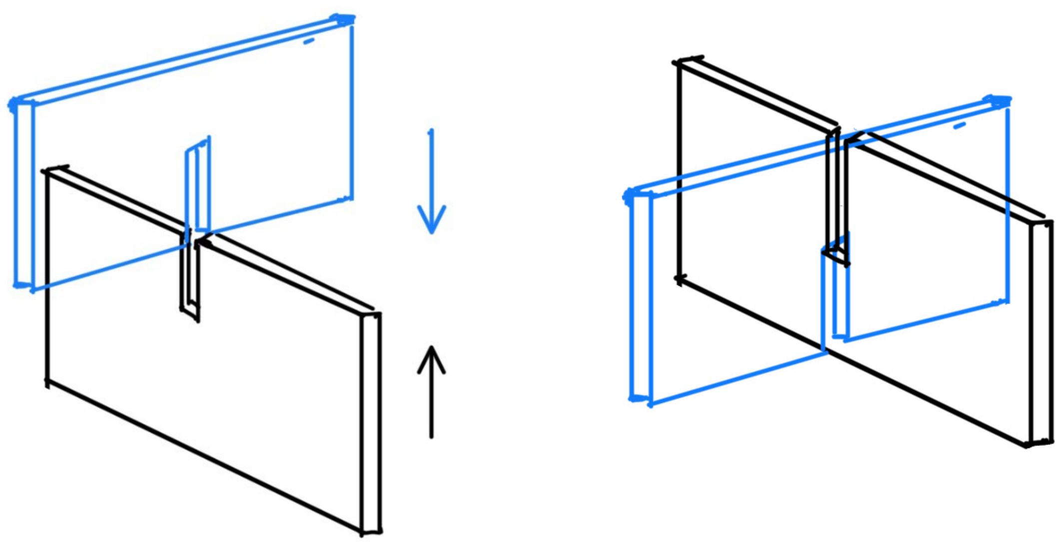


Figure 5: X Support Assembly

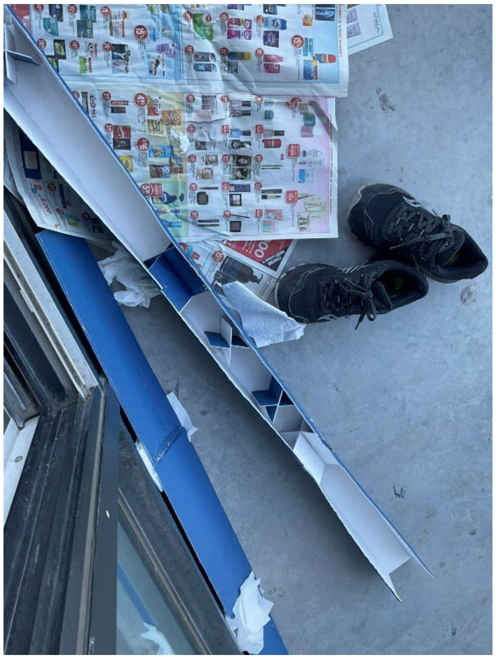


Figure 6: Internal X Supports in the bridge

Step 4: Combining U-shape Portion and Deck

Cement was first applied to the glue piece on the U-shape portion and the top of the vertical X supports. Then, cement was applied to the sides of the deck where the glue piece would be attached. Lastly, the U-shaped portion was put onto the deck and pressed down for 30 minutes in the upside down direction. Extra cement was applied to the connection between the U-shaped portion and the deck. At the end of the 30 minutes, the bridge was left in the upside down position; heavy loads were placed on top of the bridge to hold the pieces down as the glue dry for the next 72 hours.

Figure 6: Loads weighing down on the bridge as glue dries