CIV102 Bridge Project Design Report

Team 701: Karan Chawla, Xiyue Jiao, Chris Peng, David Shoeib

Teaching Assistant: Rouhollah

November 23rd, 2025

Introduction

This report is a documentation of the iterative design process, engineering rationale, and major decisions that Team 701 undertook throughout the development of the Bridge Design Project. The objective of this report is to clearly communicate how our team approached designing and optimizing a structurally efficient bridge within the constraints of this project.

To accomplish this, we will outline the key design considerations our team used to guide our final design decisions, including a detailed account of all major design iterations (the diverging process). Throughout the iterative process, we evaluated changes in geometry, matboard allocation, and the structural behaviour of the bridge using CIV102 concepts. This includes: tensile and compressive forces, shear forces, buckling, and cross-sectional analysis. Each modification was assessed on the basis of structural performance and material limitations.

The following figure is a wide-body shot of our bridge.

Figure 1. Wide body shot of Team 701's bridge.

To describe the features of the final design, below will consist of a walkthrough summary of our team's key design decisions. The quantitative and engineering-based justifications will be presented underneath the **Major Iterations** section.

Key Design Decisions

- We identified which regions of the bridge would be controlled by shear forces and which regions would be controlled by the bending moment. Based on this, we divided the bridge into equal thirds, with the two outer thirds being shear-dominant and the middle third where bending is dominant.
- Therefore, the matboard used to reduce bending was reduced in the outer thirds, and the combined width of our glue tabs is approximately *27.4mm*.
- The thickness of the top flange was doubled by adding an extra layer of matboard, going from *1.57mm* to *2.54mm* to improve bending capacity and Case 1 plate buckling.
- The middle third section had a glue tab that spanned *80mm*, the entire distance between the two webs. In other words, the two webs and glue tab are connected in one piece of matboard.
- The web height of our final design is *120mm*, enhancing most if not all aspects of the structure's stiffness.
- The entire bottom flange was removed after determining it contributed relatively little to structural performance, allowing reallocation of materials into other areas.
- The final design included diaphragms with a maximum spacing of *100mm*, and the diaphragms got closer together near the two supports. These diaphragms had their own dedicated glue tabs.

Major Iterations

Our team's "Design 0" used the Bridge Design Project's Design 0 [1] as its reference. Design 0 (depicted in Figure 2 on the page below) was our inspiration for the cross section and each bridge property's associated values.

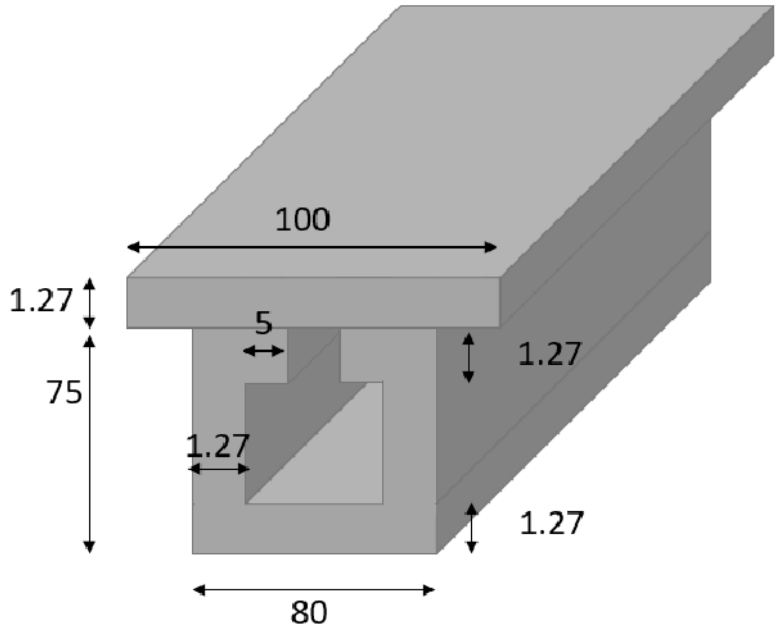

Figure 2. Design 0 cross section and measurements (in mm.)

An important feature of this design was the fact that the top flanges extended beyond the webs, and that there was generally more material towards the top making the centroidal axis, which was calculated to be roughly *41.43mm*, closer to the top section. After computing all the stresses this cross section experiences for the initial load case (of *400N*), we found that this design **fails** due to Case 1 plate buckling. Case 1 buckling occurs in the restrained section of the top flange. This design is also very prone to compressive failure.

In order to set up the iterative process, the team set up code in order to streamline calculations. This code incorporated functions to plot the shear force and bending moment envelope, as well as calculate the factors of safety for each case of stress, with eight total factors of safety to find. These being: tensile, compressive, matboard shear, glue shear, plate buckling (three cases), and shear buckling. Equations were used to calculate all these factors of safety, as well as setting up variables to define the cross section, which is depicted in Figure 3 on the page below.

```
# -------Defining Cross Section--------

#                           top_flange
#               ***************************************
#               ***************************************
#                      ************************
#                      **                    **
#                      **                    **
#                      **                    **
#               web    **                    **
#                      **                    **
#                      **                    **
#                      **                    **
#                      **                    **
#                      **                    **
#
top_flange = 100
top_flange_thickness = 2.54
web = 120
web_thickness = 1.27
glue = 80-2.54
glue_thickness = 1.27

# Renamed bottom flange into this to reflect what is being measured
web_separation = 80
```

Figure 3. Code used to define variables of the cross-section.

The code in Figure 3 made it very easy to make multiple iterations, as all that was needed to do was to change the variable names and the code would automatically output each factor of safety, which could be compared against the previous iteration.

After creating the code, our team pursued the following iterative process (with five major iterations). For each iteration, we specified certain bridge properties (cross-sectional and non cross-sectional), which, when changed, would impact the bridge's structural integrity. Below is a legend that will help explain the iteration tables.

Legend For Iteration Tables

Red Text : Values from the previous iteration that were changed. For iteration one, the red values indicate values from Design 0 that were changed.

Green Text : Change or addition to the previous value.

Iteration One

Bridge Property	Value (mm)
Top Flange Width	100
Top Flange Thickness	1.27 -> 2.54
Web Height	80 -> 78.73
Web Thickness	1.27
Glue Tab Width	10 (combined) -> 80 (combined)
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	400

The first iteration described three major changes. The biggest change was to double the thickness of the top flange, essentially adding another layer. The rationale behind this was to increase the resistance against Case 1 plate buckling, which was the failure mechanism of Design 0. Additionally, while not specified in the table above, the bottom of the bridge was removed. The extra material gained from removing the bottom flange was able to be used in extending the glue tab across the entire distance between the two webs, essentially creating a third top layer. This change greatly increased the factor of safety of glue shear. However, to reflect the change made by making the glue tab span the web distance, the height of the webs had to be reduced by the thickness of the glue tab.

The results of this initial iteration found that the bridge no longer failed due to Case 1 plate buckling; in fact, none of the eight factors of safety fell below the value of one. This means that, in theory, this bridge would hold up against Load Case 1 (400N). However, given that this was only the first iteration, we believed there was more optimizing that could be done.

The three lowest factors of safety after Iteration 1 were: compression, tension, and shear buckling (in order). What this team noticed was that the compressive and tensile stresses were proportional to the height of the centroidal axis, and inversely proportional to the cross section's second moment of area (I). When calculating against compression, we calculated the distance from the centroidal axis to the top of the cross section (because that section is the section in compression). Therefore, to reduce the amount of stress experienced (and thus increasing the factor of safety), the team figured to decrease the distance between the centroidal axis and the top of the cross section and increase the second moment of area. A photo of the factors of safety after Iteration 1 is depicted below.

```
FOS_tension 2.120233188288005
FOS_compression 1.671594071933979
FOS_shear_mat 2.317170638882668
FOS_shear_glue 55.846394320922414
FOS_buck_1 3.9749690477083988
FOS_buck_2 26.178405636317486
FOS_buck_3 55.59345030457149
FOS_buck_4 2.6829286062376463
```

Figure 4. Iteration 1 factors of safety.

Iteration Two

Bridge Property	**Value (mm)**
Top Flange Width	100
Top Flange Thickness	2.54
Web Height	78.73 -> 100
Web Thickness	1.27
Glue Tab Width	80 -> 77.46
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	400 -> 100

In the second iteration, our primary goal was to improve performance against compression. To achieve this, the web height was increased from *78.73mm* to *100mm*. This adjustment helped reduce both compressive and tensile stresses at the points where the bending moment is maximized. Additionally, we slightly reduced the glue tab width from *80mm* to *77.46mm* to maintain material feasibility while still preserving continuity between the webs.

Finally, the maximum diaphragm spacing was significantly reduced from *400mm* to *100mm*. This change was introduced to improve the rigidity of the cross-section and reduce shear buckling. This is because the **critical** shear buckling stress increases as the distance between diaphragms decreases. This stress wants to be maximized, therefore, decreasing the distance between diaphragms (in other words, adding more diaphragms) would remedy this concern. The maximum distance was used in order to be safe, although some diaphragms in our design had a spacing of less than that.

This iteration improved several key factors of safety, bringing up the three main concerns from Iteration 1: compressive, tensile and shear buckling. Thus, we were provided with a more stable baseline for subsequent refinements.

```
FOS_tension 3.2966614222385866
FOS_compression 2.3700795426207457
FOS_shear_mat 2.9568498867516206
FOS_shear_glue 65.008412353083
FOS_buck_1 5.635933376830277
FOS_buck_2 37.117207280640685
FOS_buck_3 33.492598194678436
FOS_buck_4 4.085864735910485
```

Figure 4. Iteration 2 factors of safety.

Iteration Three

Bridge Property	Value (mm)
Top Flange Width	100 -> 120
Top Flange Thickness	2.54
Web Height	100
Web Thickness	1.27
Glue Tab Width	77.46
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	100

In Iteration 3, we explored increasing the top flange width from *100mm* to *120mm*. The remaining properties, including web geometry, glue tab width, and diaphragm spacing were kept constant to isolate the effects of the increased flange width. The intent of this change was to examine how increasing the contribution to the second moment of area impacted the structural performance of the bridge. This iteration demonstrated some positives and negatives.

The positives were that it did increase the factors of safety for stresses that depend on the second moment of area, like compressive, tensile, and shear. However, increasing the width of the top flange significantly reduced the resistance against Case 2 buckling (which comes from the unrestrained edges), since those edges were longer, and the distance between webs remained the same. The factor of safety against Case 2 buckling decreased by almost a factor of four.

This iteration prompted our team to evaluate whether the added width would compare against increasing the height of the webs, and given the results of iteration three, it did not seem as such.

```
FOS_tension 3.350650487981848
FOS_compression 2.6668444127740383
FOS_shear_mat 2.9420081691426914
FOS_shear_glue 60.956927868697555
FOS_buck_1 6.3416257414494845
FOS_buck_2 10.441191431986459
FOS_buck_3 45.23341803751116
FOS_buck_4 4.0653560009657825
```

Figure 4. Iteration 3 factors of safety.

Iteration Four

Bridge Property	**Value (mm)**
Top Flange Width	120 -> 100
Top Flange Thickness	2.54
Web Height	100 -> 120
Web Thickness	1.27
Glue Tab Width	77.46
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	100

Building on the insights from the previous iteration, Iteration 4 focused on shifting material away from the flange and into the webs. The top flange width was reduced back to *100mm*, while the web height was increased from *100mm* to *120mm*. This decision was based on the observation that increasing web height had a more significant impact on overall bending performance than maintaining a wider flange. The taller web also improved shear buckling resistance. By redistributing material into the vertical direction, this iteration provided a more efficient use of matboard and increased several factors of safety simultaneously.

Though many factors of safety did increase, the team began to see trade-offs. Due to the drastic increase in web height, Case 3 plate buckling becomes more prominent, as it does depend on the web's height. This decreased the factor of safety against Case 3 plate buckling from Iteration 3. However, given the increase in every other factor of safety, we stuck with keeping the web height as *120mm*. This step brought the design closer to its final form by emphasizing vertical stiffness rather than horizontal width.

```
FOS_tension 4.614198084977195
FOS_compression 2.9378333811410746
FOS_shear_mat 3.560467817190301
FOS_shear_glue 80.58121275317544
FOS_buck_1 6.986024270742631
FOS_buck_2 46.00865439445199
FOS_buck_3 22.690639245695714
FOS_buck_4 4.1683013724325955
```

Figure 4. Iteration 4 factors of safety.

Iteration Five

Bridge Property	Value (mm)
Top Flange Width	100 -> 104
Top Flange Thickness	2.54
Web Height	120
Web Thickness	1.27
Glue Tab Width	77.46
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	100

Iteration 5 refined the cross-section by making smaller, targeted adjustments. The top flange width was increased slightly from *100mm* to *104mm* to make better use of the remaining available matboard and to experiment with the constraints of the project. Since the web heights were constrained to multiples of 20, the top flange width allowed for more freedom, so it was changed slightly. All other structural properties (web height, diaphragm spacing, and glue tab geometry) remained constant. This iteration primarily served as a testing step, ensuring that the design took advantage of available material without introducing unnecessary complexity or compromising earlier improvements. The gradual convergence of changes indicated that the design was nearing its optimal configuration.

However, the slight increase in the top flange thickness did not really impact the performance of the bridge, and we figured that the extra matboard could be allocated towards ‘extras’ in case we needed it.

Final Design

Our team initially converged to Iteration 5 being our final design. However, after comparing the total available matboard area with the material consumption of the fifth iteration, we ran into issues. Though the total area of the matboard Iteration 5 used was below the area of the matboard we were given, the **shape** of the pieces proved to be a major constraint, as we were not able to fit all of our pieces onto one piece of the matboard. Thus, some changes had to be made in order to converge into one final design.

The top flange width was finalized at *100mm* to stay at a round even number (which would help given the dimensions of the matboard). The web height remained at *120mm*, as this dimension consistently produced strong improvements in stiffness, shear performance, and buckling resistance. The glue tab width was optimized by using a wide *77.46mm* tab in the middle third, where bending demands are highest, and a much smaller *30mm* combined tab (meaning *15mm* on each end) in the outer thirds to reflect the fact that shear was dominant and moment was not much of a worry. This one change allowed us to fit all of our required cuts onto the piece of matboard we were given.

Diaphragm spacing was fixed at a maximum of 100 mm, with additional diaphragms near the supports to counteract shear distortion. These changes are reflected in the final table below.

Bridge Property	Value (mm)
Top Flange Width	104 -> 100
Top Flange Thickness	2.54
Web Height	120
Web Thickness	1.27
Glue Tab Width*	77.46* & 30*
Glue Tab Thickness	1.27
Max. Distance between Diaphragms	100

***The glue tab width is 77.46mm for the middle third (416.6mm) of the design, and 30mm (combined) for the outer thirds of the bridge.

Given that the factors of safety from Iterations 4 and 5 suggested that our bridge would be able to support up to 3x the weight of Load Case 1, the team opted to take a look at Load Case 2 (452N) to see how the bridge fared against it.

Factors of Safety for the Final Design (Using Load Case 2)

Force	FOS*	Force	FOS*
Tension	4.07/4.10	Case 1 Plate Buckling	5.91/6.21
Compression	2.49/2.61	Case 2 Plate Buckling	38.9/40.9
Shear (Matboard)	3.02/3.01	Case 3 Plate Buckling	17.9/20.2
Shear (Glue)	25.1/68.2	Shear Buckling	3.54/3.53

*Red text indicates the outer thirds, green text indicates the middle third.

On the page below, this table is re-generated, choosing the minimum values of the factors of safety, and this will be the final Factor of Safety table for our bridge.

Force	FOS	Force	FOS
Tension	4.07	Case 1 Plate Buckling	5.91
Compression	2.49	Case 2 Plate Buckling	38.9
Shear (Matboard)	3.01	Case 3 Plate Buckling	17.9
Shear (Glue)	25.1	Shear Buckling	3.53

Across all five major iterations and the subsequent refinement into our final design, our team consistently followed a quantitative approach, justifying each step with knowledge we had from CIV102, to improve the structural performance of our bridge while staying within the material and construction constraints of the project. Each iteration targeted specific weaknesses identified in the previous design, whether in compression, tension, shear behaviour, or plate buckling, and translated these observations into purposeful geometric adjustments.

The overall progression of our work showed that early iterations made broad, high-impact changes such as doubling the top flange thickness, removing the bottom flange, increasing web height, and expanding the central glue tab. These decisions addressed the fundamental failure modes present in Design 0 and established a strong foundation for further optimization. Mid-stage iterations focused on balancing bending stiffness with buckling resistance as we experimented with reallocating material between the top flange and the webs. Later iterations introduced only small adjustments, which signaled that the design was converging toward an efficient configuration.

The final design represents the culmination of these incremental improvements. By combining a *120mm* web height, strategically varied glue tab widths, and closely spaced diaphragms, the final cross-section efficiently resists bending, shear, and all three forms of plate buckling. Importantly, the design also satisfies practical constraints, fitting within the available matboard geometry.

Overall, the iterative process allowed our team to make decisions at every stage, steadily increasing the minimum factor of safety and strengthening the bridge against both Load Case 1 and Load Case 2 conditions. The final product reflects not only an optimized structural design and an understanding of geometry, material behaviour, and failure mechanisms taught in CIV102.

References

[1] E. Bentz. “CIV102 Matboard Bridge Design Project.” Downloaded from Quercus, 2025.