Matboard Bridge Design and Construction Report

Introduction & Background

The Matboard Bridge Design and Construction Project requires groups to design, build, and test a bridge using materials given out in class. The following report will outline the process through which Group 410 developed their final bridge design.

Methodology

Bridge Design Procedure

To design and construct a bridge that would support the greatest load possible, the group considered and tested a wide variety of designs before choosing a final design. Design0 was first taken as a reference design, for which hand calculations and MATLAB code were written to perform all the necessary analysis. The analysis consisted of determining the internal forces caused from Load Cases 1 & 2, calculating cross-sectional properties such as $\bar{y}$, I, and Q, then using the material properties to determine the various shear forces and bending moments that would cause a failure in the bridge, and finally, using those calculations to determine the factor of safety for Load Case 1, a failure load for Load Case 2, and the midspan deflection of the bridge.

Once these calculations had been completed for Design0, the code was adapted to fit a broader range of scenarios. Following this change, the cross-sectional and geometric properties of the bridge were changed repeatedly while noting down the various failure loads and factors of safety that resulted from such changes. However, these changes were not arbitrarily chosen; rather, course notes and previous knowledge were heavily referenced in determining potentially effective dimensions for the bridge.

Several additional design considerations were also considered in constructing the bridge, as follows.
The area of the matboard given to groups proved to be a major design constraint in creating the optimal bridge. At each iteration of the group's design, a diagram was constructed to visualize and organize the amount of matboard needed to create the design. Refer to Engineering Drawings, Page 3 for exact Matboard cuts and dimensions used.

Since the dimensions of the matboard do not allow for one smooth piece to be used throughout the length of the board, the flanges and webs had to be cut from pieces and attached together later. Given that the webs carry most of the shear force, and that the flanges carry most of the bending moment in the bridge, these pieces were cut to minimize the shear and bending moment at the cuts.

There are two layers and three pieces that make up the top flange. The two-layer section ranges from x = 0 mm to x = 787 mm ,where the bending moment is positive, and the one-layer section ranges from x = 787 mm to x = 1250 mm, where the bending moment is negative. The top flange was cut into two pieces at x = 344 mm. This is because the absolute value of the shear force is at its minimum between x = 0 mm and x = 550 mm. This cut thus reduces the stress put on to the connection, which was held together by glue on the bottom flange. Cutting the flange at x = 344 mm also allowed for more optimal cutting of the matboard.

For the webs, the cross section changes at x = 788 mm, where the bending moment changes sign and thus equals zero for a short distance. This again reduces the stress experienced at the web connection, which was reinforced by gluing another piece of matboard over the seam.

During calculation, the cross-sections were assumed to be rigid and thus able to resist deformations. However, deformations and the buckling of thin plates is inevitable given the nature of the bridge construction. These deformations will decrease the second moment of area and affect the position of the centroidal axis. Thus, the failure load may decrease as the load increases. This is one reason that the experiment failure load will be less than the theoretical failure load.

Construction Process

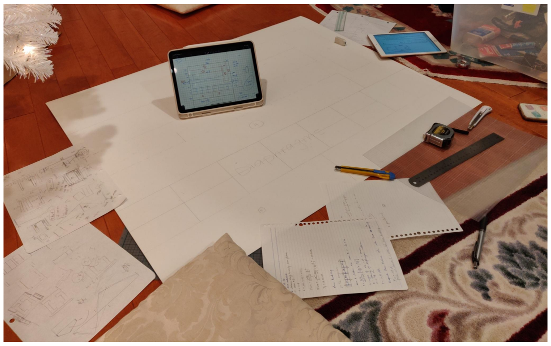


Figure 1. Marking the matboard before cutting.

Figure 2. Applying contact cement to pieces of matboard that have been cut.

Figure 3. Gluing matboard pieces together.

Figure 4. using clamps while glue cures.

Figure 5. Continuing to construct the body of the bridge, applying pressure to ensure proper contact.

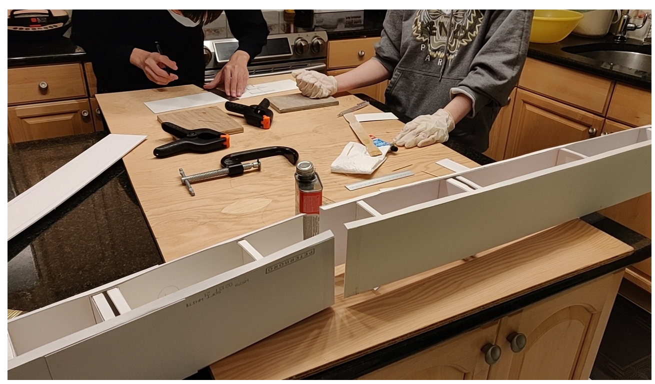


Figure 6. All diaphragms and webs attached together. Continuing to glue remaining pieces.

Figure 7. Bridge completed!

Results & Analysis

Results	Design0	Final Bridge Design
Load Case 1: FOS against failure	FOS = 0.828	FOS = 2.57
Load Case 2: Failure load P	P_{fail} = 193.3 N * 2 = 387 N	$P_{fail\ theory}$ = 702.8 N * 2 = 1406 N $P_{fail\ predicted}$ = 562 N
Expected cause of failure under Load Case 2	Mid flange buckling of top flange at support B.	Web compression buckling at x = 989, 1130, where supporting piece for support B ends.
SFD & BMD plots	See Appendix 1,2	See Appendix 3,4

Predicted Failure Load, P_{fail}

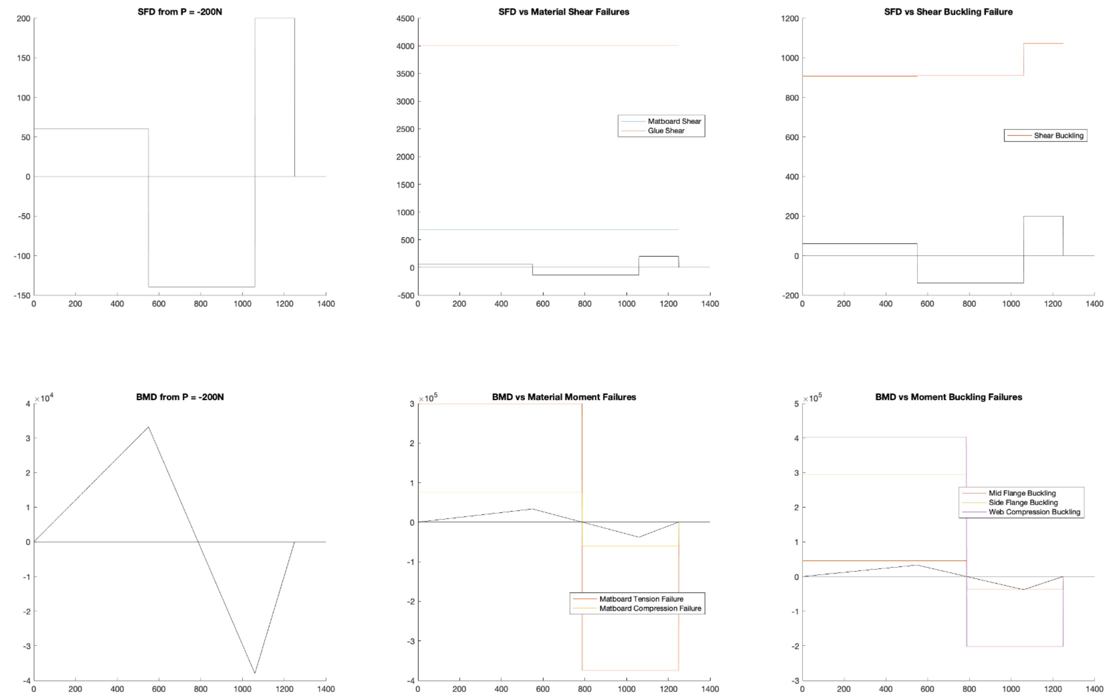
Group 410's final predicted failure load is P_{fail} = 563 N. This is despite the fact that the MATLAB code outputted a failure load of 1406 N, as we believe that this number is an overestimate of our bridge's strength. The primary reason behind this disagreement is the construction quality of the bridge. The code calculates the failure load using ideal conditions, assuming that all joints are rigid, that measurements are perfect and that the strength of the materials is actually as given. However, as noted in the design considerations, the bridge is prone to deformations, which will decrease the strength of the bridge by an amount not accounted for in the program. Additionally, the measurements, joints, and attachments in the final product are not all perfect, and there is a high chance that the glue was not used to its full capacity. With all of these human and construction errors accounted for, we predict that the actual failure load will be ~40% of the theoretical load, which is on par with bridges from previous years.

Improvements Made Between Design0 and Final Design (:eyes:)

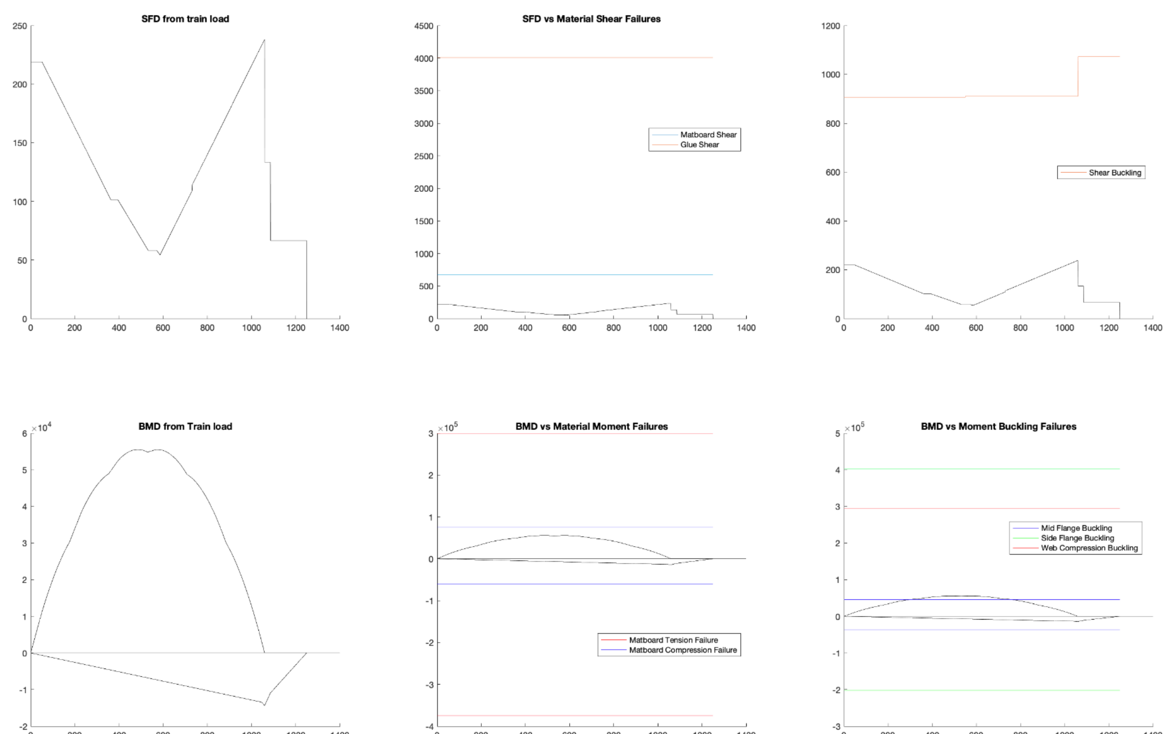
Improvement	Justification
Increase the overall height of the bridge (elongating webs and adding a top flap on right side)	The second moment of area (I) is cubically related to the height of the bridge. A higher second moment of area reduces the stress due to bending moments experienced by the bridge, guaranteeing a larger failure load and failure moment: $\sigma = My/I$.
Change the cross section where moment changes sign to maximize tensile stress, $\sigma_c = My_{top}/I$, while reducing compressive stress, $\sigma_c = My_{bot}/I$.	The moment diagram indicates that the bending moment switches from (+) to (-) as distance increases. Due to the difference between the tensile and compressive strength of matboard, the cross section at positive moments was shaped to have a greater y_{top}, whereas the region with a negative moment were shaped to have a larger y_{bot}.
Add supporting pieces to support B to increase the failing buckling stress, $\sigma_{crit} = k\pi^2Et^2/b^2 12(1-\mu^2)$.	Support B is the location with the weakest tolerance to thin plate buckling. Therefore, rectangular supporting pieces were added to reinforce the web at support B, providing a greater thickness t, which results in a greater σ_{crit}.
Add flaps above the bridge deck to the right cross section.	Flaps increase the height of the bridge, providing a larger second moment of area. This reduces $\sigma_c = My_{bot}/I$.
Increase the number of diaphragms, especially in high shear regions such as at the far right side	The failure load for shear buckling can be increased by adding more diaphragms, which reduces the diaphragm spacing a and thus τ_{crit}. $\tau_{crit} = 5\pi^2E/12(1-\mu^2) * ((t/h)^2 + (t/a)^2)$

Appendix

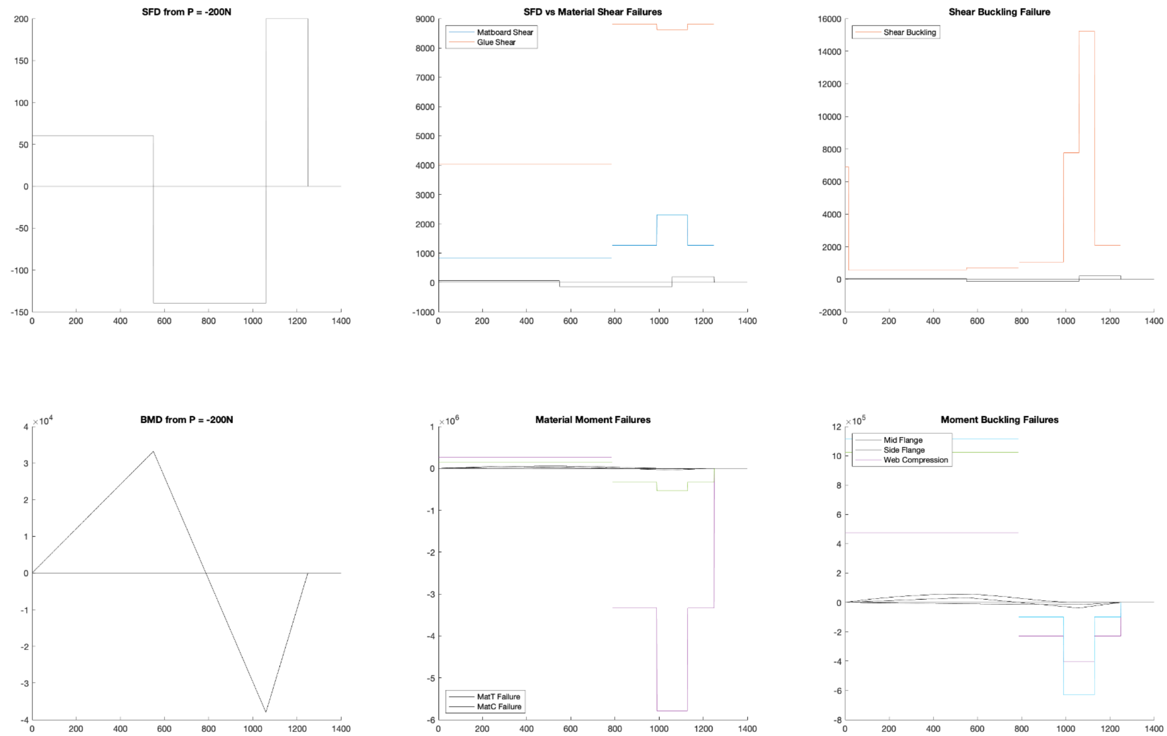
I. SFD/BMD against different failure loads; Design0



2.SFD/BMD against train load, Design0



3.SFD/BMD against different failure loads, final bridge design



4.SFD/BMD against train load, final bridge design