CIV102 Bridge Project

Description: Last November, we were tasked with designing and creating a bridge that could support a moving train weighing at least 400 N using a fixed amount of matboard and contact cement. If the bridge could withstand the initial 400 N weight, the train would be loaded further, such that the first and last freight cars would weigh more than the central car. The required final length of the bridge was longer than the matboard we were given, so we were also required to connect at least two different pieces of matboard using a splice connection to make the bridge long enough.

Design Process: We initially felt the bridge design challenge would be one of optimization, as we had limited materials, many different possible methods of failure and a plethora of design ideas, from the standard beam design to trusses and even arches. We had an extremely wide scope for our design space, which included essentially every single bridge we had learned of in the course. In the end, after multiple rounds of diverging and exploring a non-beam idea and researching further into the topic, we would inevitably find an aspect that wouldn't work with the constraints and materials - we weren't allowed to use a laser cutter to cut truss frames, and bending the matboard into an arch could cause it to buckle prematurely. After settling on a more standard beam format and performing failure calculations with cross-sections of various designs and dimensions, we found the most common failure modes to be failure of the matboard in compression, potential shear failure of the glue at the splice connection and shear buckling of the entire bridge. In the end, we settled on a pi girder cross-section design with a flange glued near the top of the design. While this design made our bridge very strong against compression failure, it came at the cost of using smaller stiffeners instead of full-size diaphragms, which were less effective at preventing shear buckling. Further, we neglected the importance of strong glue tabs when designing the bridge. Our glue tabs were designed to be 5 mm, but the matboard bending took up most of the glue tab width. Hence, the glue tabs were never flat; there were always gaps between two glued pieces. As a result, while our bridge could theoretically survive loads of up to 1.3 kN, in practice, it could not withstand the initial 400 N train.

Anchoring bias: We were anchored early on by the idea that trusses or arches were the coolest and most fun structural systems, despite material and tool limitations. Even after evidence suggested they wouldn't work, we returned to them multiple times before letting go. Anchoring limited our design space exploration. It slowed convergence on more viable designs, like the beam-based pi-girder.
Gap analysis: Our bridge was theoretically strong (1.3 kN ish capacity), but failed below 400 N. This led us to analyze the reasons behind the performance gap, which included poor glue tab

execution (including unreasonable expectations), construction defects (impossible to realistically eliminate), and an overreliance on perfect assumptions.
PIAA: Perceive: We evaluated our available materials (matboard and glue) and the constraints imposed by the project. Interpret: We interpreted what was feasible: arches would buckle, trusses required tools we didn't have. Act: We chose a beam-based design and refined it via simulations.

Iterative Design: We went through ten major design iterations, adjusting the cross-sectional geometry to identify the optimal configuration. Simulations were our main iteration tool. We favoured it for speed, consistency, and material savings. However, relying exclusively on simulations and not prototyping, as would've been better, didn't help because of inexperience and human error. Rapid physical prototypes for stress points and testing glue tab width would've helped. However, ue to the lack of material available, it was infeasible.

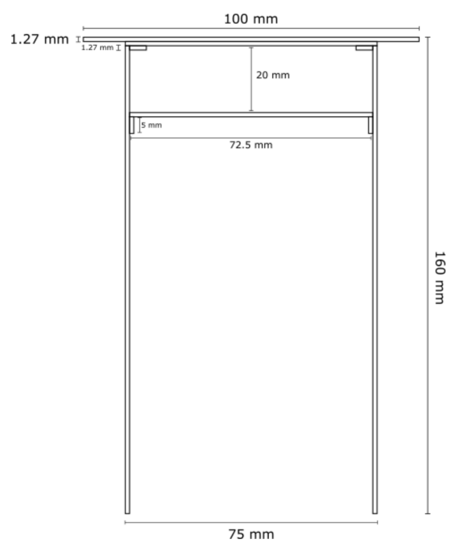

Figure 1: Our final cross section.

Our design iterations focussed on changing the cross-section because it was simple, fast to simulate, and easy to build. In hindsight, we could have simulated variable cross-sections to explore the design space better. Interestingly, the discrepancy between simulation results and our bridge performance suggests we should incorporate physical design iterations too. This means constructing short spans of the bridge with scrap material and comparing our simulated results to the actual bridge performance. Iterating like this would have given us construction experience and *intuition*, so we would have, for example, known to use larger glue tabs in our final design. Unfortunately, the easiest way to gain engineering intuition is through failures. We spent disproportionate time in the development stage, optimizing geometry without revalidating the ability to construct it. By simulating hybrid or variable cross-sections, we could have optimized for different load regions (e.g., thicker sections at splice joints).