CIV102 Matboard Bridge Design Project

Fall 2024

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1. Project Introduction

In teams of three (3) or four (4), you will apply the concepts taught in CIV102 to design and build a small-scale box girder bridge out of matboard as shown in Figure 1. Your bridge will be subjected to increasing loads until failure. Throughout this project, you will be challenged in your ability to design a bridge that can handle the highest loading possible and to be accurate in your estimation of the final failure load.

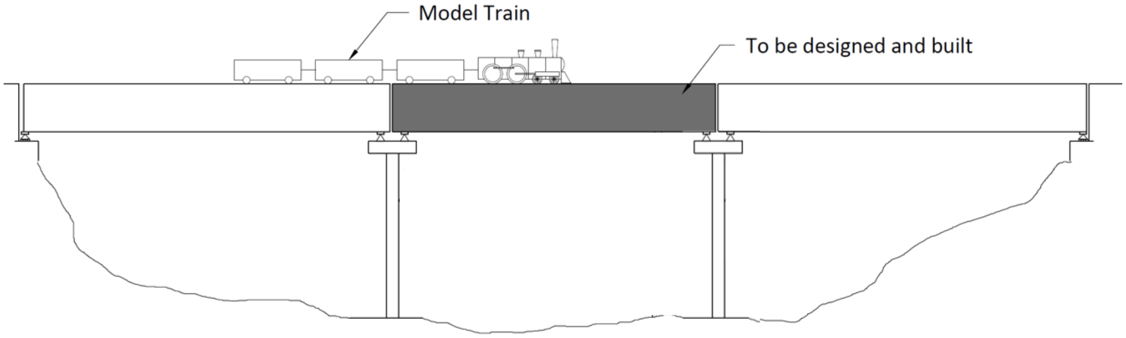


Figure 1. Three span bridge supporting the passage of a 400 N train. Teams must design the middle span.

1.1. Overview

This Matboard Bridge Design Project has **four (4) components.**

1. **<u>Design Report.</u>**
   - The design report describes and documents the decisions your team made during the design and construction processes.

2. **<u>Supporting Calculations.</u>**
   - These are numerical calculations and/or computer code that describe the predicted performance of the bridge when subjected to the specified loading conditions.

3. **<u>Engineering Drawings.</u>**
   - These are drawings showing both how the bridge was built and its final intended geometry.

4. **<u>Bridge Built from Specified Materials.</u>**
   - This is the physical bridge built by your team!

1.2. Primary Objectives

1. Design and build a bridge which can support a 400 N train across a span of 1200 mm.
2. Design and build the strongest bridge possible using the permitted construction materials.
3. Use concepts relating to engineering beam theory and thin plate buckling theory to predict the maximum load the bridge can carry before failure.

1.3. Secondary Objectives

1. Articulate design decisions and document the construction process in a design report.
2. Demonstrate the ability to communicate your design using engineering drawings.
3. Demonstrate project planning and prototyping skills to successfully build the bridge as designed.

2. Project Design Details

2.1. Bridge Dimensions

Figure 2 illustrates the distance to be spanned by your bridge and indicates the maximum permitted dimensions of your bridge.

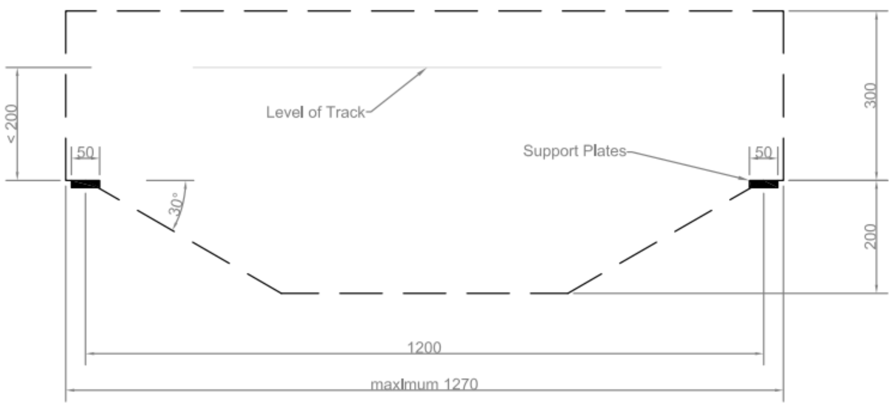


Figure 2. Dimensional constraints of the bridge shown in an elevation view. The dotted line represents the maximum allowable dimensions.

1. In your analysis, you should assume the **distance between the supports is 1200 mm.** The actual supports have a width of 50 mm each, and 1200 mm will span the distance between the middle of these supports (i.e., the centre-to-centre distance).

2. **Your bridge must be at least 1250 mm long.** If your bridge is less than 1250 mm long, it **will not fit** in the testing apparatus, meaning your bridge performance will not be able to be evaluated.

3. In addition to the dimensional constraints specified in Figure 2,
   a. The total length of the bridge must be **between 1250 and 1270 mm.**
   b. The level of the bridge deck (also referred to as the track) must be **less than 200 mm** above the level of the supports.
   c. The distance between the track and the level of the supports must be a **multiple of 20 mm.**
      i. Permitted: 120 mm, 140 mm, 160 mm, etc.
      ii. Not permitted: 50 mm, 70 mm, 150 mm, etc.

   d. The bridge deck must be **at least 100 mm wide.**
   e. The bridge deck must be **horizontal** and **permit unhindered passage** of the train. There can be **no steps or grooves** on the top surface for the train wheels to roll over.
   f. There must be a **50 mm long flat portion on both ends** of the bridge to allow your bridge to sit on the support plates.

2.2. Bridge Loading

A train comprised of three (3) cars will be pushed across your bridge. The dimensions of this train (in millimetres) and an illustration of the train movement are shown in Figure 3 and Figure 4.

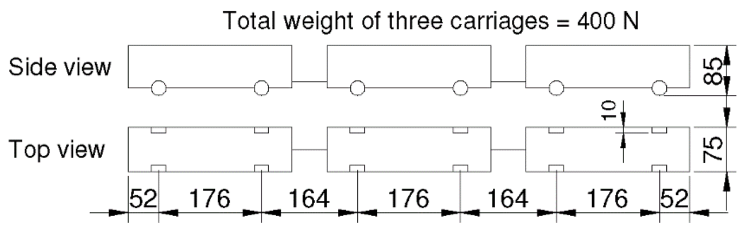


Figure 3. Train dimensions.

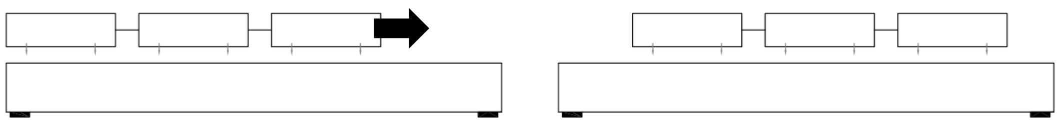


Figure 4. Loading schematic showing the movement of the train.

2.2.1. Load Case 1

Initially, the train will not be loaded with any additional weight. Therefore, the total train weight will be 400 N. This total weight will be evenly divided across the six (6) train axles.

2.2.2. Load Case 2

If your bridge withstands the load applied by the first pass of the train, **congratulations!** Your team will advance towards the next phase of the test. During this phase, the weight carried by the train will progressively increase according to a prescribed, monotonically increasing load protocol.

1. The **first or last car** is designated the **"locomotive"** and the remaining cars are "freight cars".
2. For the first pass across the bridge in Load Case 2, all freight cars will have identical weights.
3. For subsequent passes until eventual failure, the freight car **furthest away** from the locomotive will have a **heavier** weight than the other freight car. The weight of this heavier freight car will be approximately 1.10 times the weight of the lighter freight car for any given subsequent pass.
4. The locomotive weight will be approximately 1.35 times **heavier** than the weight of the heaviest freight car for any given subsequent pass.

For example, in the first pass, if both freight cars weigh 135 N, then the locomotive weight will be 182 N. This train with a total weight of 452 N will act as the **"base case"** train loading for Load Case 2. Please note the locomotive may be at the front or end of the train during each pass but will **never** be in the middle.

2.3. Construction Materials

The following materials will be provided for each team. **Please take care to not lose these!**

1. One (1) rectangular sheet of **matboard.**
   a. Dimensions: 32" × 40" × 0.05" (813 mm × 1016 mm × 1.27 mm).
   b. Approximate mass: 750 grams.

2. Two (2) tubes of **contact cement.**
   a. Approximate volume: 30 mL per tube. Negligible mass when dry.
   b. Full strength will only be attained if the contact cement is properly used and left to cure for **at least** 72 hours (3 days).
   c. All students **MUST** review the linked technical data sheet for contact cement in "Appendix III: Contact Cement Data Sheet" to be informed about its safe use.

The material properties of the matboard and contact cement are shown in Table 1. For each material, you are allowed to use different values if you obtain these through appropriate external material testing.

Table 1. Specified material properties for this bridge design project.

Material	Material Property	Specified Value(s)
Matboard	Specified dimensions	32" × 40" × 0.05" (813 mm × 1016 mm × 1.27 mm)
	Tensile strength, σ_t'	30 MPa
	Compressive strength, σ_c'	6 MPa
	Shear strength, τ_m'	4 MPa
	Young's modulus, E_m	4000 MPa
	Poisson's ratio, ν_m	0.2
Contact Cement	Shear strength, τ_g'	Up to 2 MPa if properly cured**

***Full strength will only be attained if contact cement is properly used and left to cure for at least 72 hours.*

Students are responsible for safely transporting their project materials/completed bridge to and from their practical. **The CIV102 teaching staff are not responsible for storage.**

The use of any other materials or additional materials (such as extra tubes of contact cement) is strictly prohibited and will constitute a violation of academic integrity outlined by the University of Toronto. Prior to testing, your bridge will be weighed. Any excessively or suspiciously large weight will cause your bridge to be inspected and potentially disqualified from testing.

2.4. Calculation Procedure

Your team may consider the following procedure as a guide for calculations required to predict the failure load of the bridge based on the failure mechanisms discussed in CIV102.

1. Calculate **reaction forces, internal forces,** the **shear force diagram (SFD),** and the **bending moment diagram (BMD).**
   a. Denote the SFD as $V(x)$ and the BMD as $M(x)$.
   b. Each of these diagrams will be calculated from a train at one fixed location that is loaded according to Load Case 1 or Load Case 2.

2. Consideration must be made to account for the train being **at every location along the bridge.** This is crucial because the train will move across the bridge and thus the load will also move. As such, you will have multiple SFDs and BMDs.

3. Using these SFDs and BMDs, you will then construct a **shear force envelope (SFE)** and a **bending moment envelope (BME).**
   a. Denote the SFE as $V_{env}(x)$ and the BME as $M_{env}(x)$.
   b. Each respective envelope reflects the maximum values of V and M at every location along the bridge, corresponding to all possible train locations.
   c. Given the nature of this task, it is advantageous to write programming code to accomplish this.

4. Define bridge **geometry (design parameters).**
   a. Define bridge cross-section shape and parameterize dimensions. Some possible parameters include widths (b), height (h), thickness (t), etc.
   b. For variable-depth cross-sections, define changes to cross-sectional dimensions along the length of the bridge.
   c. Choose geometry $\{b(x), h(x), t(x), \dots\}$.

5. Calculate cross-sectional **geometric properties.**
   a. $[\bar{y}(x), Q(x), I(x)] = f(\text{geometry})$.

6. Calculate applied **stresses.**
   a. $[\sigma_{top}(x), \sigma_{bot}(x), \tau_{cent}(x), \tau_{glue}(x)] = f\left(V_{env}(x), M_{env}(x), \bar{y}(x), Q(x), I(x)\right)$

7. Calculate material/thin plate buckling **capacities.**
   a. $\left[\sigma_{tens}(x), \sigma_{comp}(x), \sigma_{buck}(x)\ \tau_{max}(x), \tau_{glue}(x), \tau_{buck}(x)\right] = f(\text{geometry}, \text{material properties})$

8. Compare applied stresses versus capacities to determine **Factors of Safety (FOS)** against each failure mechanism.

$$\text{FOS}_{tension}(x) = \sigma_{tens}(x)/\sigma_{bot}(x)$$

$$\text{FOS}_{compression}(x) = \sigma_{comp}(x)/\sigma_{top}(x)$$

$$\text{FOS}_{flex\_buck\_1,2,3}(x) = \sigma_{buck\_1,2,3}(x)/\sigma_{top}(x)$$

$$\text{FOS}_{shear}(x) = \tau_{max}(x)/\tau_{cent}(x)$$

$$\text{FOS}_{glue}(x) = \tau_{glue}(x)/\tau_{glue}(x)$$

$$\text{FOS}_{shear\_buck}(x) = \tau_{buck}(x)/\tau_{cent}(x)$$

9. Find the **minimum FOS**.
    a. This value represents "how many" trains would fail the current design.
    b. If minimum FOS < 1, the current design will not support the given train.
    c. If minimum FOS > 1, the current design will be able to carry a heavier train. Calculate maximum train weight the current design can hold.

10. For **visualization,** find the shear force capacities $V_{fail}(x)$ and bending moment capacities, $M_{fail}(x)$.

$$M_{fail\_tens}(x) = \text{FOS}_{tension}(x) \cdot M(x)$$

$$M_{fail\_comp}(x) = \text{FOS}_{compression}(x) \cdot M(x)$$

$$M_{fail\_buck\_1,2,3}(x) = \text{FOS}_{flex\_buck\_1,2,3}(x) \cdot M(x)$$

$$V_{fail\_shear}(x) = \text{FOS}_{shear}(x) \cdot V(x)$$

$$V_{fail\_glue}(x) = \text{FOS}_{glue}(x) \cdot V(x)$$

$$V_{fail\_buck}(x) = \text{FOS}_{shear\_buck}(x) \cdot V(x)$$

11. **Repeat from step 4.** Choose new geometry to **increase the minimum FOS** and thus maximum train weight. This new maximum train weight represents your new failure load estimate.

2.5. Design Procedure

To begin the iterative design process, there must be an **initial design** either chosen arbitrarily or based on prior experience. For this project, the initial design (**Design 0**) has been chosen for you. The details of Design 0 are provided in "Appendix II: Design 0 Details".

1. For Design 0, first calculate the **FOS for Load Case 1 by hand.**
2. Find the **two locations** of the 400 N train (loaded according to Load Case 1) that would generate the **largest shear force** and **largest bending moment**.
3. Produce the **SFD** and **BMD** for each of the two locations and determine V_{max} and M_{max}.
4. Use the V_{max} and M_{max} to calculate the **applied stresses.**
5. Calculate the **capacity** of Design 0 for each of the failure mechanisms discussed in CIV102.
6. Use these applied stresses and capacities to **determine the FOS** for each failure mode and the **overall FOS.**

Once these calculations are complete, commence the design of your own bridge by changing the geometric parameters (Step 4 in Section 2.4). For every major design iteration, record the...

1. **Design decisions** you made as a team.
   a. Examples include changes to geometric parameters or how to fold the matboard.

2. **Justification** for each decision made.
   a. This may come from hypothesis, calculations, or experience.

3. **Results** to provide evidence for each justification.
   a. This includes important output parameters and the failure load.

At the same time, you will have to balance...

1. **Material constraints,** such as the available matboard area.
2. **Feasibility constraints,** such as construction difficulty.

Design decisions can and should be made **based on constraints** rather than solely the project objective.

2.6. Analysis Methods

Analysis of your own bridge design can be performed using either a **MATLAB** script or a **Python** script. For engineering students, the University of Toronto has an academic license for MATLAB available here, which you may activate in order to install MATLAB onto your local device, such as a laptop. Regardless of the method you choose, please follow these requirements.

1. **MATLAB.**
   a. If this method is chosen, the accuracy of your code must be validated.
   b. Teams must input the following case into their MATLAB script and submit the output as part of their "Design Calculations" submission (more details in Section 3.4).
      - The geometry of Design 0.
      - SFD and BMD corresponding to the scenario where the train is loaded to 400 N according to Load Stage 1.

2. **Python Programming Language.**
   a. If this method is chosen, the accuracy of your code must be validated.
   b. Teams must input the following case into their MATLAB script and submit the output.
      - The geometry of Design 0.
      - SFD and BMD corresponding to the scenario where the train is loaded to 400 N according to Load Stage 1.

3. All results must be presented **neatly** and **concisely.**

4. The output of your script should match the hand calculations for Design 0. Again, these hand calculations for Design 0 must also be submitted.

5. "Appendix I: MATLAB Pseudo-Code" contains example code which can be used as a starting point for developing a MATLAB script.
   a. This method may be helpful for teams interested in building a variable-depth box girder, where different-sized cross-sections exist along the length of the bridge.
   b. This example shows a train loaded to 400 N according to Load Stage 1 (see Section 2.2.1).

2.7. Additional Design Considerations

Despite the wide scope of failure mechanisms covered in CIV102, there are other phenomena not discussed. To ensure the most accurate performance of your design, the following are some design considerations that must be addressed by your teams' engineering judgement.

1. **Splice connections.**
   - The maximum dimension of the provided matboard is shorter than the required span.
   - Therefore, a **splice connection** in the bridge is required at some point.
   - Failure across this location will not be represented in the calculations suggested in Section 2.4.

2. **Rigid cross-sections.**
   - The concepts discussed in CIV102 assume the cross-section **remains rigid** under loading.
   - This assumption may not remain true, which could void the calculations discussed in Section 2.4.

3. **Rigid support sections.**
   - Areas near supports will be subjected to **direct vertical compression.**
   - This is not considered in the calculations described in Section 2.4.

To ensure your bridge's cross section remains rigid and your support zones can withstand the direct vertical compression, it is recommended that **vertical diaphragms** be installed at numerous locations throughout your bridge.

The above considerations (and perhaps others) can be the most difficult to design for due to the lack of evidence and justification for you to make design decisions. However, they are an inevitable part of real-life engineering problems and **neglecting these considerations can cause failure** at lower loads than predicted by your calculations.

2.8. Additional Construction Considerations

Care **MUST** be taken when determining a suitable space for your team to build the bridge.

1. Discipline common rooms or residence common spaces are **not recommended.**
    a. These areas lack the ventilation necessary to keep you and other people safe while applying contact cement.
    b. Moreover, the odour of contact cement may disturb and cause discomfort for others.
    c. These spaces also contain delicate surfaces like tables that can be scratched by sharp knives and couches which can be stained with contact cement.

2. **The common spaces of Myhal are not permitted construction spaces.** Teams that are found to have constructed their bridge in a common space of Myhal may be subject to marking penalties or disqualification.

Some **recommended places** to work are listed below:

1. At a teammate's house, apartment, garage, or backyard, with **permission** from the teammate and/or their parents.
2. **Outside** in a public park or square (such as Front Campus), preferably meeting these criteria:
    a. Clear weather, meaning no precipitation nor wind.
    b. Somewhere with flat surface, such as a table or long bench.
    c. Away from large crowds, children, or animals.

3. At a **community centre:** you could book or rent a multi-purpose room for one or two days.

To supply your own ventilation, you may want to purchase a small, portable electric fan. It is also a good idea to open doors/windows to improve air circulation. Teams may also want to purchase some safety equipment prior to working, such as face masks and flexible work gloves (such as this pair). Other construction tools can be purchased from a suitable store, such as Home Hardware, Canadian Tire, Staples, or Dollarama.

Regardless of the location, you must not damage any space and clean up after each working session. It is strongly recommended that you acquire and use tarps or garbage bags to make the disposal process smoother.

3. Project Deliverable Details

This project is worth **17%** of your final CIV102 grade. Table 2 summarizes the breakdown of marks.

Table 2: Breakdown of marks for this design project.

Category	Deliverable	Marks	Deadline
Writing Components (20%)	Design Report	12%	Nov. 25th (11:59 pm) on Quercus
	Engineering Drawings, Construction Process, and Time Log	8%	Nov. 27th (11:59 pm) on Quercus
Structural Calculations (45%)	Deliverable 1	7%	Nov. 11th (11:59 pm) on Quercus
	Design Calculations	38%	Nov. 25th (11:59 pm) on Quercus
Bridge Performance (35%)	Physical Build	35%	Nov. 26th – Nov. 29th in Tutorial

Your project submission should consist of **4 separate PDF files** as described in the following sections.

3.1. Deliverable 1

1. Assume the train is centered on the bridge.
2. Suppose the train is loaded according to the "base case" of Load Case 2 (see Section 2.2.2).
3. Submit the shear force diagram $V(x)$ and the bending moment diagram $M(x)$.
4. Calculate and submit the **FOS** against flexural tension failure and flexural compression failure of Design 0 as a **PDF by Nov. 11th at 11:59 PM.**
5. Complete the **team dynamics survey** on Quercus (to be announced).

3.2. Design Report

1. Please submit the design report as a **PDF.**
    a. Name this PDF as "CIV102 Project Team XXX Design Report.pdf". Replace 'XXX' with your team number (to be assigned).
    b. Ideally, the whole report should be generated as your team designs and constructs the bridge.

2. Include an **introduction** section. Within this introduction, please present a description of your bridge and a list of the key design decisions your team made. Write in paragraphs as well.

3. Include a section that discusses your **major design iterations.**
    a. It is expected each team will go through **three (3) to ten (10) major design iterations** before converging upon a final design.
    b. Describe the design parameters you changed and **justify** your reasons (bullet points, small sentences, or small paragraphs).

c. Present the results of those changes using your script(s) or hand calculations. The results of each iteration should be explained using CIV102 knowledge.
d. Decisions can include non-calculation-based considerations.
e. Please **avoid submitting excessive pages of code** output in this design report. You may include snippets or small screenshots of code you wrote to emphasize points.
f. Images can be added to the report, where appropriate. These images should include captions and should not be too blurry.

4. If you used online sources outside of what is available within the scope of CIV102 to research anything, please provide in-text citations using a **consistent citation format.**
   a. Some popular formats include **IEEE** or **APA.**
   b. A **bibliography** will be placed at the end of this design report.
   c. Popular **citation managers,** such as RefWorks or Mendeley, can be used.

5. Submission:
   a. You must submit your design report by **Nov. 25th at 11:59 PM.**
   b. Please write the names of your team members on the first page or title page of this report.
   c. Please remember to write in a **neat** and **professional** manner!

3.3. Engineering Drawings, Construction Section, and Time Log

1. Please submit the engineering drawings and construction section as one **PDF.**
   a. Name this PDF as "CIV102 Project Team XXX Engineering Assembly.pdf".
   b. You must submit this component by **Nov. 27th at 11:59 PM.**
   c. The goal of the drawings is to convey your final bridge design and construction process to others. Think of the drawings that you submit as good drafts of your sketches.

2. The **first portion** of this PDF consists of your **(2D) engineering drawings.**
   a. Please provide the following:
      i. A 2D drawing showing how you plan to cut the matboard.
      ii. Bridge elevation, top, bottom, and cross-section views at important locations.
      iii. Splice, diaphragm, and any other connection details.
      iv. In addition to the 2D drawings, your team has the option of including a 3D rendering or 3D pencil sketch of the entire bridge, if you have time.

   b. Drawings can be done **by hand via pencil (no pen)** or **digitally via software.**
   c. Drawings may be spread across multiple pages. The minimum allowable page size is letter size (8.5" × 11") and the maximum allowable page size is tabloid size (11" × 17").
   d. AutoCAD can be used to make these drawings, if you know how to use it.
   e. Dimensions for drawings shall be in **millimetres (mm)!**
   f. All drawings must be **neatly** drawn and **legible.**
   g. An effort shall be made to make drawings that are **to scale.**
   h. **Labels** may be included in drawings to enhance communication.
   i. **Colours** may be used in drawings, but you do not need to make everything look too beautiful.

3. The **second portion** of this PDF details your team's **construction process.**
   a. Provide **timestamped** photo evidence of work.
   b. Please make sure the photos you take are **not too blurry!**
   c. Add a **caption** for each photo to communicate what is happening.
   d. You **must** include a picture showing all the **precautions** your team took to **keep your building space clean.** This can include tarps, garbage bags, and protective equipment.
   e. You **must** include a picture showing what your building space looked like when you **finished** a construction session. Include photos for all such sessions.
   f. Photos that show your team building your bridge in a common space in Myhal may be subject to mark penalties or disqualification.

4. The **third portion** of this PDF is a **time log.**
    a. Attach a detailed time log for all work on this project.
    b. The tasks and time spent on these tasks should be **clearly recorded** for each team member.
    c. Each team member **must sign** this time log to signify they agree with the reported breakdown of project work.
    d. A **time log template** is available on Quercus (to be posted via an announcement).

3.4. Design Calculations

1. Please submit the design calculations as a **PDF.**
    a. Name this PDF as "CIV102 Project Team XXX Design Calculations.pdf".
    b. You must submit this component by **Nov. 25th at 11:59 PM.**

2. This **first portion** of this PDF includes **hand calculations:**
    a. Hand calculations to determine the **FOS against failure** and **failure mode** for Design 0 under a moving 400 N train loaded according to Load Case 1 (see Section 2.2.1).
    b. Any other hand calculations done to determine the FOS against failure and failure mode of your final design under a train loaded according to the base case of Load Case 2 (see Section 2.2.2).
    c. Presentation of hand calculations can include **non-blurry** photographs of calculations done on physical sheets of paper or electronic ink written using a tablet.
    d. Hand calculations deemed illegible or messy will receive mark deductions.

3. This **second portion** of this PDF includes **evidence of programming:**
    a. Code output for **all intermediate calculations** (such as centroidal axis location, moment of area, etc.) performed in the hand calculations of Design 0 under a moving 400 N train loaded according to Load Case 1.
    b. A graphical presentation of all **shear force capacities** (i.e., an SFE) of Design 0 for Load Case 1 and for your final design under Load Case 2.
    c. A graphical presentation of all **bending moment capacities** (i.e., a BME) of Design 0 for Load Case 1 and for your final design under Load Case 2.
    d. Code output of all **FOS values** along the bridge for Load Case 1 and for your final design under Load Case 2.
    e. Include the **entire script,** showing comments, formatting, and user-defined functions you made. Also indicate the packages you installed as well, such as "NumPy".
    f. Code deemed illegible or messy will receive mark deductions.

3.5. Bridge Performance

1. Marks will be allotted for:
   a. Construction **quality.**
   b. Bridge **performance** (the value of the test failure load... a rough measure of **strength**).
   c. **Accuracy in estimation** of test total failure weight.
   d. The **ratio between performance and bridge weight (strength-to-weight ratio).** This means a strong, heavy bridge is not necessarily as good as a less strong but lighter bridge.

2. Prior to testing, your bridge **must be clearly marked** with the following:
   - Your **team number!**
   - Your **team member names!**
   - Your **team's name,** if you have one!
   - Your **bridge's name** (can be creative)!
   - Your **teaching assistant's name!**
   - The **predicted total failure weight,** in newtons (N)!

3.6. Use of Artificial Intelligence (AI)

Humans have made great advancements in the field of artificial intelligence (AI), and it is inevitable that we will become increasingly accustomed to the use of AI throughout our lifetime, inside or outside of academia. For this bridge design project, **AI can only be used at the professor's discretion. If you use AI as an unauthorized aid for this project, this will constitute a violation of academic integrity outlined by the University of Toronto.**

1. Please read the scenario described in this University of Toronto Academic Integrity page concerning the use of AI tools on marked assessments.
2. While one of the primary objectives of this project is to build the strongest bridge possible from the given materials, we are not asking students to obsessively optimize every facet of the process. We intend for students to **appreciate the structural analysis and design processes** and not solely focus on getting big numbers at the end.
3. If your team is struggling with writing code, **please talk to a teaching assistant (a human) first.** You **cannot use AI to write code** for your team and blindly copy this into your submissions.
4. If your team is encountering difficulty with brainstorming design ideas, please talk to a teaching assistant, ask around for suggestions, or **take a nice walk outside with friends** and **look at an actual built bridge** for some inspiration.

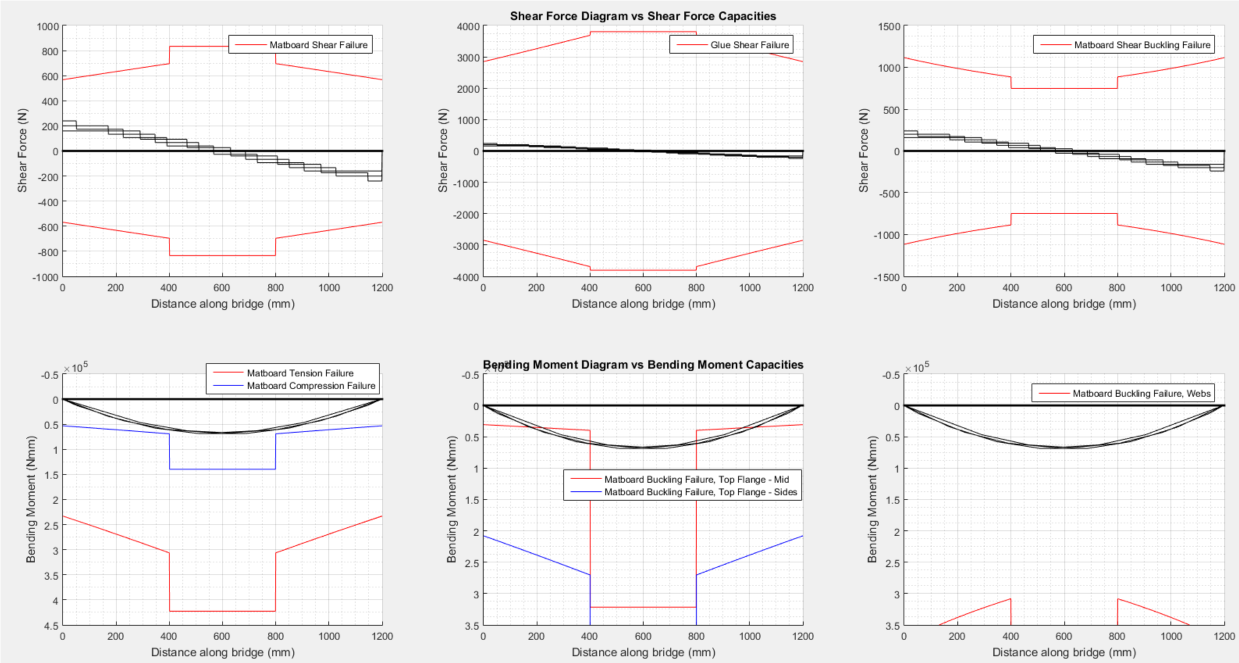
4. Appendix I: MATLAB Pseudo-Code

The following MATLAB code is meant as a guide only. It was written by a (famous) previous head TA of CIV102, Raymond. You are not required to follow any of its given methods or format. As a reminder, you may also use Python to write code if that is your team's preference.

```
clear; close all;
%% 0. Initialize Parameters
L = 1200;                                       % Length of bridge
n = 1200;                                       % Discretize into 1 mm seg.
P = 400;                                        % Total weight of train [N]
x = linspace(0, L, n+1);                        % x-axis

%% 1. SFD, BMD under train loading
x_train = [52 228 392 568 732 908];             % Train Load Locations
P_train = [1  1   1   1   1   1] * P/6;

n_train = 3;                                    % num of train locations
SFDi = zeros(n_train, n+1);                     % 1 SFD for each train loc.
BMDi = zeros(n_train, n+1);                     % 1 BMD for each train loc.

% Solve for SFD and BMD with the train at different locations
for i = 1:n_train
    % start location of train

    % sum of moments at A eqn
    % sum of Fy eqn

    % construct applied loads
    % w(x)

    % SFD = num. integral(w)
    % BMD = num. integral(SFD)
end

SFD = max(abs(SFDi));                           % SFD envelope
BMD = max(BMDi);                                % BMD envelope

%% 2. Define Bridge Parameters
%       = xc,   bft,  tft,
param   = [0,   100, 1.27,...
           400, 100, 1.27,...
           800, 100, 1.27,...
           L,   100, 1.27, ...]
%x_c     Location, x, of cross-section change
%bft     Top Flange Width
%tft     Top Flange Thickness


% Extracting user input assuming linear relationship
bft     = interp1(param(:,1), param(:,2), x);
tft     = interp1(param(:,1), param(:,3), x);
```

```
%% 3. Calculate Sectional Properties
% ybar. location of centroidal axis from the bottom
ybar =

ybot =
ytop =

% I
I =


% Q at centroidal axes
Qcent =


% Q at glue location
Qglue =

%% 4. Calculate Applied Stress
S_top  =
S_bot  =
T_cent =
T_glue =

%% 5. Material and Thin Plate Buckling Capacities
E  = 4000;
mu = 0.2;
S_tens  =
S_comp  =
T_max   =
T_gmax  =
S_buck1 =
S_buck2 =
S_buck3 =
T_buck  =

%% 6. FOS
FOS_tens    =
FOS_comp    =
FOS_shear   =
FOS_glue    =
FOS_buck1   =
FOS_buck2   =
FOS_buck3   =
FOS_buckV   =

%% 7. Min FOS and the failure load Pfail
minFOS      =
Pf          =

%% 8. Vfail and Mfail
Mf_tens  =
Mf_comp  =
Vf_shear =
Vf_glue  =
Mf_buck1 =
Mf_buck2 =
Mf_buck3 =
Vf_buckV =

%% 9. Output plots of Vfail and Mfail
subplot(2,3,1)
hold on; grid on; grid minor;
plot(x, Vf_shear, 'r')
plot(x, -Vf_shear.* SFD, 'r')
plot(x, SFDi, 'k');
plot([0, L], [0, 0], 'k', 'LineWidth', 2)
legend('Matboard Shear Failure')
xlabel('Distance along bridge (mm)')
ylabel('Shear Force (N)')
```

Sample output:

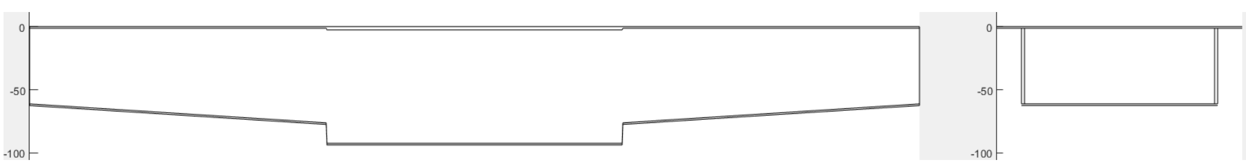


In the above analysis, the proposed bridge is:

- Far from failing due to glue failure (FOS = 11.87).
- Far from failing due to buckling in the webs (5.03).
- Far from failing due to tension (5.00).
- Far from failing due to shear buckling (4.49).
- Far from failing due to buckling in the side flanges (4.42).
- Close to failing due to shear (2.37).
- Very close to failing due to compression (1.127).
- **Going to fail due to buckling in the middle flange (FOS = 0.649).**

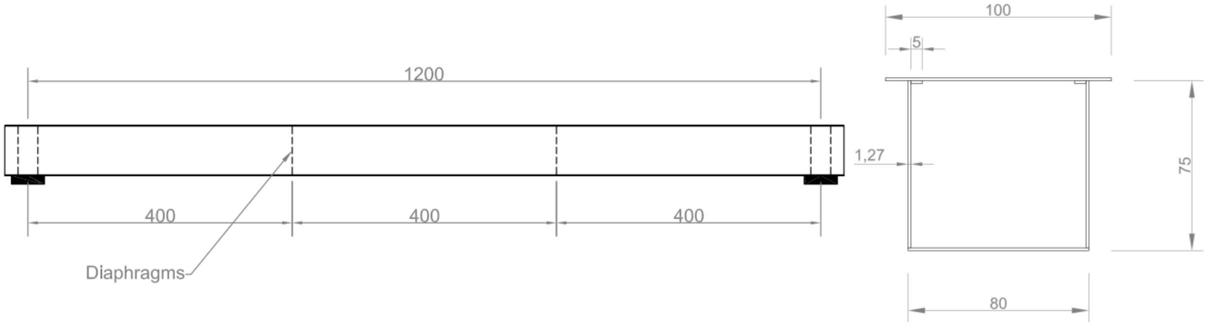
Thus, the maximum train this bridge can support weighs 260 N.

The bridge had the following geometry. This output is not required.

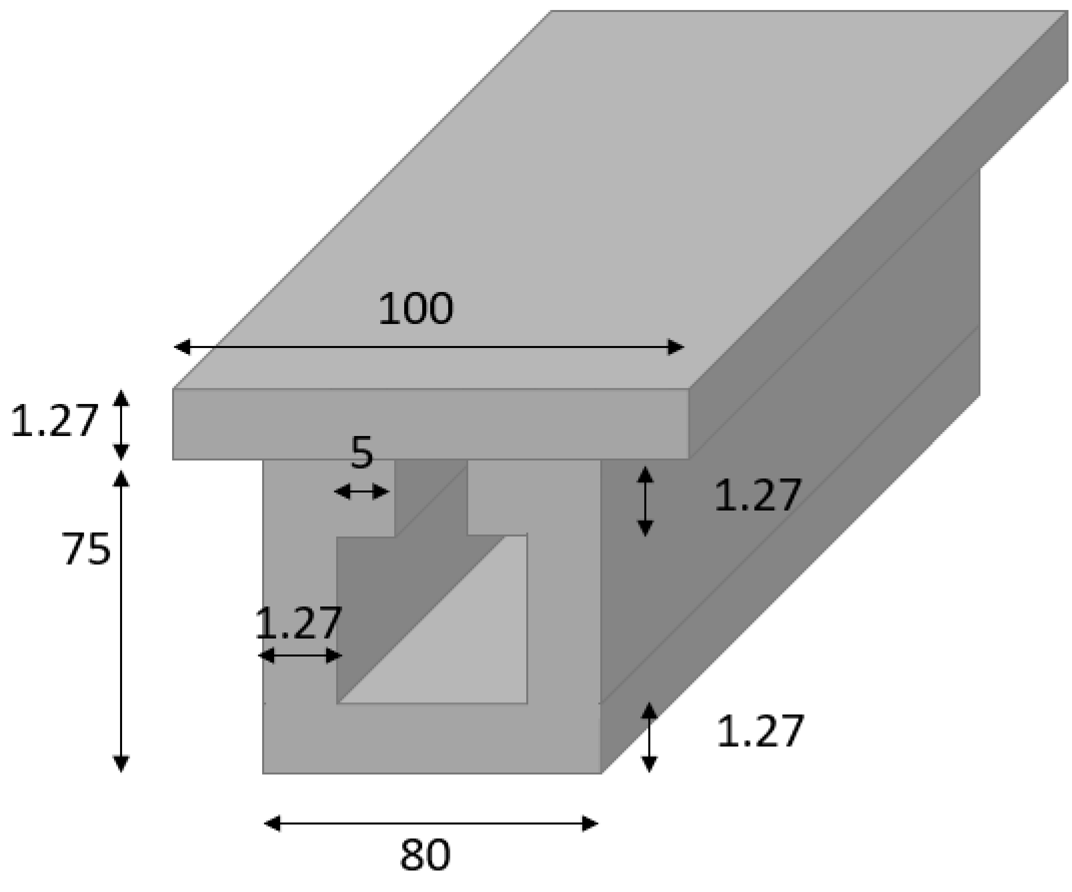


5. Appendix II: Design 0 Details

Elevation view and cross-section view of Design 0 (same cross-section view along the entire span):



Cross-sectional shape and dimensions of Design 0:



This is a **not-to-scale sketch.** The 5 mm wide piece is a surface for which glue on be applied to attach the bottom "U" piece to the top. There are other ways to glue your bridge together—this is only showing one example.

6. Appendix III: Contact Cement Data Sheets

An older version of the technical data sheet for contact cement is available [here.]

A recent version of the safety data sheet for contact cement is available [here.]

Please note that the ***contact cement is volatile*** and prolonged exposure to its smell is ***not*** healthy. ***Take breaks while working.***

Make sure you work in a ***well-ventilated*** environment.

Contact cement is difficult to clean, so please do not get it everywhere.