CIV102 Project Team 206 Calculations

Contents: This document is scaffolded into two sections Design 0_calculations package and Final Design_calculations package, which present the calculations for the Design 0 and Final design respectively. This calculations package contains the code outputs from the python script (refer to source code) and the hand calculations.

Design 0_Calculations Package:

Design 0_Calculation Package contain the following calculations:

- **Hand Calculations of the Centroidal Axis and Second Moment of Area for Design 0**
- **Hand Calculations for the Failure Mechanism of Design 0**
- **Code Output of the Intermediate Calculations for Design 0 Hand Calculations**
- **Code Output for the Graphical representations of Shear Force Capacities and Bending Moment Capacities**
- **Code Output for FOS for individual failure mechanisms**

Hand Calculations: Calculating the Centroidal Axis and the Second Moment of Area:

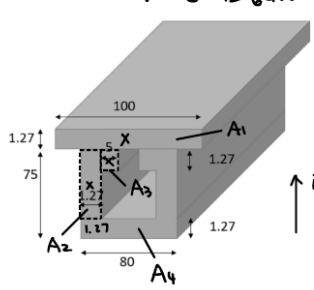
$A_1y_1 = 127(75+\frac{1.27}{2}) = 9605.645$

$2A_2y_2 = 2(5)(1.27)(75-\frac{1.27}{2}) = 944.43549$

$2A_3y_3 = 2(75-1.27)(1.27)(1.27+\frac{75-1.27}{2}) = 7141.70617$

$A_4y_4 = 80(1.27)(\frac{1.27}{2}) = 64.519$

$\sum_{i=1}^{4} A_iy_i = 17756.3$



$\uparrow \bar{y}$

$y_{1b} = 75+\frac{1.27}{2} = 76.635\text{mm}$

$y_{2b} = 38.135\text{ mm}$

$y_{3b} = 75-\frac{1.27}{2} = 74.366\text{ mm}$

$y_{4b} = \frac{1.27}{2} = 0.635\text{ mm}$

$d_1 = 34.205\text{ mm}$

$d_2 = 3.295\text{mm}$

$d_3 = 32.935\text{ mm}$

$d_4 = 40.795\text{ mm}$

Cross Sectional Properties

$A_1 = 127\text{mm}^2$

$A_2 = 2(93.6371) = 187.27\text{mm}^2$

$A_3 = 2(5)(1.27) = 12.7\text{ mm}^2$

$A_4 = 101.6\text{ mm}^2$

$$\bar{y} = \frac{A_1y_{1b} + A_2y_{2b} + A_3y_{3b} + A_4y_{4b}}{A_1 + A_2 + A_3 + A_4}$$

$= 41.43\text{mm}$

$I = 418352\text{ mm}^4$ (python)

$I_{01} = \frac{b_1h_1^3}{12} = \frac{100(1.27)^3}{12} = 17.0699\text{ mm}^4$

$I_{02} = \frac{1.27(2)(75-1.27)^3}{12} = 84836.97\text{mm}^4$

$I_{03} = \frac{5(1.27)^3(2)}{12} = 1.70099\text{mm}^4$

$I_{04} = \frac{80(1.27)^3}{12} = 13.65589\text{mm}^4$

$\sum_{i=1}^{4} I_{0i} = 84869.4\text{mm}^4$

$\sum d_i^2 A_i$

$= 34.205^2(127) + 3.295^2(187.27) + 32.935^2(12.7) + 40.795^2(101.6)$

$= 333482.7566$

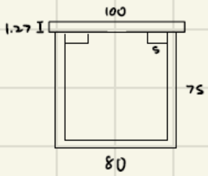
$I = 84869.4 + 333482.7566$

$= 418352.1566\text{ mm}^4$

$= 0.418352 \times 10^{6}\text{ m}^4$

Hand Calculations: Failure Mechanism for Design 0:

Matboard Tension Failure



$V_{max} = 240\,N$

$y_{bot} = 41.43\,mm$

$y_{top} = (75 - 41.43) + 1.27$
$= 34.84\,mm$

$I = 0.418352 \times 10^{-6}\,mm^4$

$M_{max} = 69445.\bar{3}\,Nmm$
$= 69.445\,Nm$

$\sigma_{t,bot} = \frac{69.445\,(41.43 \times 10^{-3})}{0.418352 \times 10^{-6}}$

$= 6.87724\,MPa$

$\boxed{FOS = \frac{\sigma_{tens}}{\sigma_{bot}} = \frac{30}{6.87724} = 4.36}$

Matboard compression Failure

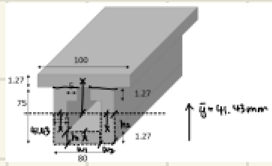
$\sigma_{c,top} = \frac{M_{max}\,y_{top}}{I}$

$= \frac{69.445\,(34.84 \times 10^{-3})}{0.418352 \times 10^{-6}}$

$= 5.78332\,MPa$

$\boxed{FOS = \frac{\sigma_{comp}}{\sigma_{top}} = \frac{6}{5.78332} = 1.03747 \simeq 1.038}$

Matboard shear Failure



$A_1 = 1.27 \cdot 41.43$
$= 52.6161\,mm^2$

$d_1 = \frac{41.43}{2}$
$= 20.715\,mm$

$A_2 = (80 - 2(1.27)) \cdot 1.27$
$= 98.3742\,mm^2$

$d_2 = 41.43 - (\frac{1.27}{2})$
$= 40.795$

$A_3 = 1.27 \cdot 41.43$
$= 52.617\,mm^2$

$d_3 = \frac{41.43}{2}$
$= 20.715\,mm$

$Q = A_1 d_1 + A_2 d_2 + A_3 d_3$
$= (52.6161)(20.715) + (98.3742)(40.795) + (52.617)(20.715)$
$= 6193.0791555\,mm^3$
$\simeq 6193.079\,mm^3$

$V_{max} = 240\,N$

$b = 2 \cdot 1.27\,mm$
$= 2.54\,mm$

$\tau_{xy} = \frac{VQ}{Ib}$
$= \frac{240\,(6193.0791555 \times 10^{-9})}{0.418352 \times 10^{-6}\,(2.54 \times 10^{-3})}$
$= 1.39876 \times 10^{6}\,Pa$
$= 1.39876\,MPa$

$\boxed{FOS = \frac{\tau_{xy\,max}}{\tau_{xy\,cent}} = \frac{4}{1.39876} = 2.85968 \simeq 2.86}$

Glue shear force

$b = (1.27 + 5)(2)$
$= 12.54\,mm$

$Q = Ad$
$= 127(75 - 41.43 + \frac{1.27}{2})$
$= 4344.035\,mm^3$

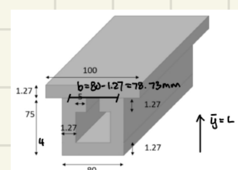
$\tau_{xy} = \frac{VQ}{Ib}$
$= \frac{240\,(4344.035 \times 10^{-9})}{0.418352 \times 10^{-6}\,(12.54 \times 10^{-3})}$
$= 0.1987308\,MPa$

$\boxed{FOS = \frac{\tau_{xy\,glue}}{\tau_{xy\,glue}} = \frac{2}{0.1987308} = 10.06387 \simeq 10.06}$

Thin plate buckling

a) Case 1 : middle flange

$K = 4 \quad b = 78.73\,mm \quad E = 4000\,MPa$
$\mu = 0.2 \quad t = 1.27\,mm$



$\sigma_{crit} = \frac{K\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{b}\right)^2$

$= \frac{4\pi^2\,(4000 \times 10^6)}{12\,(1 - 0.2^2)} \left(\frac{1.27}{78.73}\right)^2$

$= 3.56693\,MPa$

$\sigma_{comp,max} = 5.78332\,MPa$

$\boxed{FOS = \frac{\sigma_{buck}}{\sigma_{top}} = \frac{3.56693}{5.78332} = 0.616762 \simeq 0.617}$

b) case 2 : side flange

$k = 0.425 \quad b = 10 + \frac{1.27}{2} \quad t = 1.27\,mm$

$= 10.635\,mm$

$$\sigma_{crit} = \frac{k\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

$$= \frac{0.425\pi^2(4000\times10^6)}{12(1-0.2^2)}\left(\frac{1.27}{10.635}\right)^2$$

$$= 20.7696\ MPa$$

$$FOS = \frac{\sigma_{buck2}}{\sigma_{top}} = \frac{20.7696}{5.78332} = 3.59129 \approx 3.59$$

c) Web members

$k = 6 \quad b = 75 - 41.43 - \frac{1.27}{2} \quad t = 1.27\,mm$

$= 32.935\,mm$

$$\sigma_{crit} = \frac{k\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

$$= \frac{6\pi^2(4000\times10^6)}{12(1-0.2^2)}\left(\frac{1.27}{32.935}\right)^2$$

$$= 30.5739\ MPa$$

$$FOS = \frac{\sigma_{buck3}}{\sigma_{top}} = \frac{30.5739}{5.78332} = 5.28657 \approx 5.29$$

d) Shear thin plate buckling

$a = 400\,mm = 0.4\,m$

$w = 1.27\,mm \rightarrow \left(\frac{1.27}{2}\right)2$

$h = 75 - 1.27 = 73.73\,mm$

$k = 5$

$$\tau_{crit} = \frac{k\pi^2 E}{12(1-\mu^2)}\left[\left(\frac{w}{h}\right)^2 + \left(\frac{w}{a}\right)^2\right]$$

$$= \frac{5\pi^2(4000\times10^6)}{12(1-0.2^2)}\left[\left(\frac{1.27}{73.73}\right)^2 + \left(\frac{1.27}{400}\right)^2\right]$$

$$= 5.25662\ MPa$$

$$FOS = \frac{\tau_{bulk}}{\tau_{cent}} = \frac{5.25662}{1.39876} = 3.75806 \approx 3.76$$

CODE OUTPUT for Hand Calculations provided in Design 0:

Intermediate Calculation Outputs

(Max Shear Force)

```
x = 200, V = 190.33333333333331
x = 300, V = 148.99999999999994
x = 400, V = 115.66666666666664
x = 600, V = 37.33333333333334
x = 800, V = 116.00000000000006
x = 1000, V = 190.66666666666669
Max V = 240.0, location = 1
```

(Maximum Bending Moment)

```
x = 200, M = 38256.99999999999
x = 300, M = 53066.66666666666
x = 400, M = 61333.333333333336
x = 600, M = 68800.00000000001
x = 800, M = 61333.33333333335
x = 1000, M = 38133.33333333334
Max M = 69445.33333333331, location = 557
```

```
yb = 41.431
I = 418352.209
Q_cent = 6193.079
Q_glue = 4344.035
y_top = 34.839
```

(Cross-sectional Properties)

```
compressive stress capacity: 6
maximum compressive stress: 5.783163955284808
minimum FOS against compression failure: 1.03749436232342

tensile stress capacity: 30
maximum tensile stress: 6.877449421183892
minimum FOS against tension failure: 4.362082243395949

glue shear stress capacity: 2
maximum shear stress at glue location: 0.19873069640570515
minimum FOS against glue shear failure: 10.063870535214328

matboard shear stress capacity: 4
maximum shear stress in matboard: 1.3987563739586804
minimum FOS against matboard shear failure: 2.859683126003872
```

(Factor Of Safety)

```
mid-flange buckling capacity: 3.566926726812471
maximum shear stress in the mid-flange: 1.3987563739586804
minimum FOS against mid flange buckling: 0.6167777283147782

side-flange buckling capacity: 20.76962432028886
maximum shear stress in the mid-flange: 1.3987563739586804
minimum FOS against side flange buckling: 3.5913946899791815

web buckling capacity: 30.575915958270766
maximum shear stress in the mid-flange: 1.3987563739586804
minimum FOS against web buckling: 5.287056738263436

shear buckling capacity: 5.256619850378164
maximum shear stress: 1.3987563739586804
minimum FOS against shear buckling: 3.7580667714858587
```

CODE OUTPUT for 8 Minimum FOS

```
minimum FOS against compression failure: 1.037
minimum FOS against tension failure: 4.362
minimum FOS against glue shear failure: 10.064
minimum FOS against matboard shear failure: 2.860
minimum FOS against mid flange buckling: 0.617
minimum FOS against side flange buckling: 3.591
minimum FOS against web buckling: 5.287
minimum FOS against shear buckling: 3.758
```

CODE OUTPUT - Graphical Representation(s) for Design 0 from the Python Script:

Figure 0.1: Shear Force Envelope

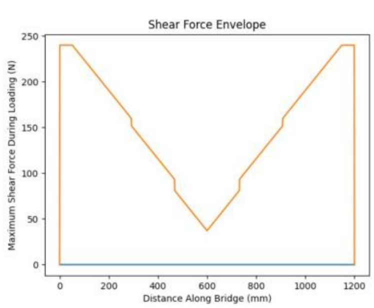


Figure 0.2 Bending Moment Envelope

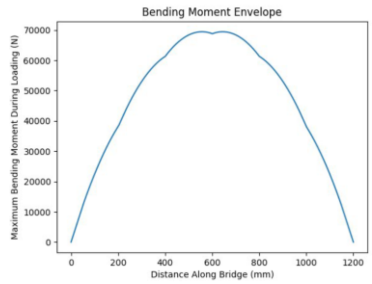


Figure 0.3: Tensile Stress vs Capacity

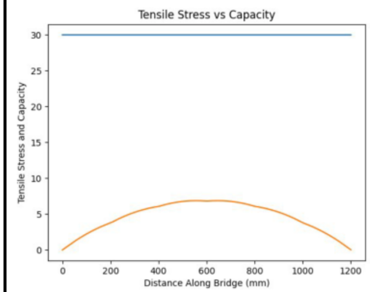


Figure 0.4: Compressive Stress vs Capacity

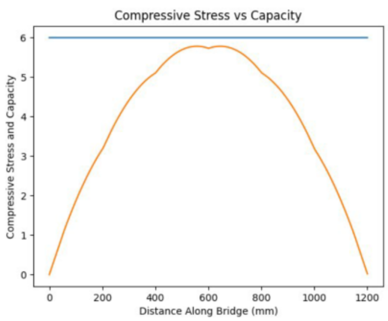


Figure 0.A.5: Matboard Shear Demand vs Capacity

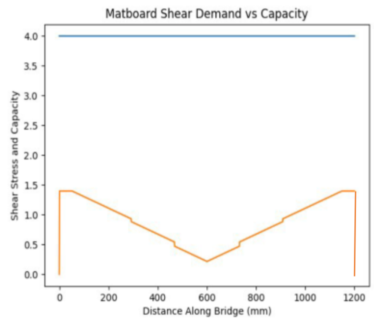


Figure 0.6: Glue Shear Demand vs Capacity

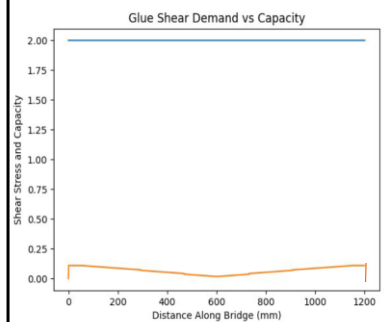


Figure 0.7: Mid-Flange Buckling vs Capacity

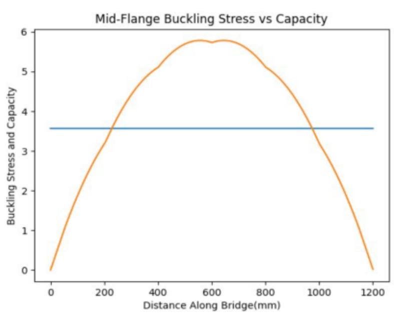


Figure 0.8: Side-Flange Buckling Stress vs Capacity

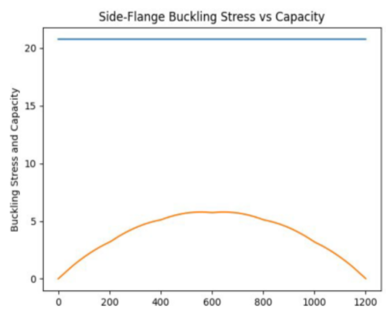


Figure 0.9: Web Buckling Stress vs Capacity

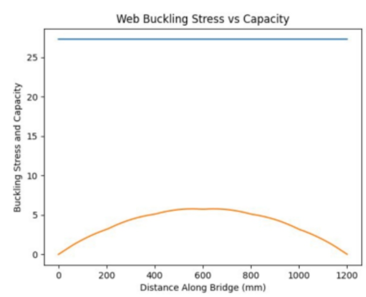
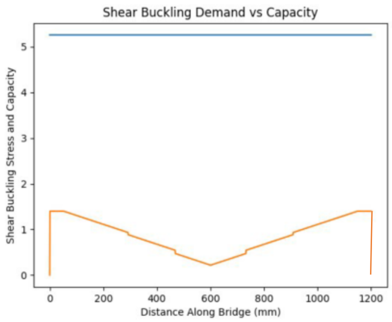


Figure 0.10: Shear Buckling Demand vs Capacity



Legend for Figure 0.3 to 0.10 inclusive:

~~O~~ Capacity
~~O~~ Demand

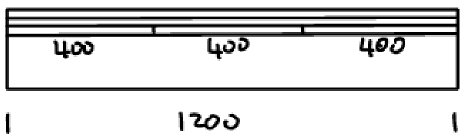
Final Design _Calculations Package:

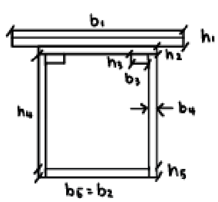
Final Design_Calculation Package contain the following calculations:

- **Hand Calculations of the Centroidal Axis and Second Moment of Area for Final Design**
- **Hand Calculations for the Failure Mechanism of the Final Design**
- **Code Output for the Graphical representations of Shear Force Capacities and Bending Moment Capacities for the Final Design**
- **Code Output for FOS for individual failure mechanisms for the Final Design**

Final Design Hand Calculations for Failure Mechanism:

Final Design Hand Calculations





$b_1 = 100mm$
$h_1 = 2.54mm$
$b_2 = 75mm$
$h_2 = 1.27mm$
$b_3 = 10mm$
$h_3 = 1.27mm$
$b_4 = 1.27mm$
$h_4 = 80mm$
$b_5 = 75 - 2(1.27) = 72.46mm$
$h_5 = 1.27mm$

$y_1 = 80 + 1.27(2) = 82.54mm$

$y_2 = 80 + \frac{1.27}{2} = 80.635mm$

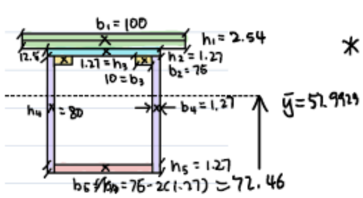
$y_3 = 80 - \frac{1.27}{2} = 79.365mm$

$y_4 = \frac{80}{2} = 40mm$

$y_5 = \frac{1.27}{2} = 0.635mm$

Area :

Zone A: 400-800mm



*glue tabs and web members counted as 1 piece

$y_{1b} = 80 + 2(1.27) = 82.54$ $A_1 = b_1h_1 = 100(2.54) = 254$

$y_{2b} = 80 + \frac{1.27}{2} = 80.635$ $A_2 = b_2h_2 = 75(1.27) = 95.25$

$y_{3b} = 80 - \frac{1.27}{2} = 79.365$ $A_3 = 2b_3h_3 = 2(10)(1.27) = 25.4$

$y_{4b} = \frac{80}{2} = 40$ $A_4 = 2b_4h_4 = 2(1.27)(80) = 203.2$

$y_{5b} = \frac{1.27}{2} = 0.635$ $A_5 = b_5h_5 = (75 - 2(1.27))(1.27) = 92.0242$

$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3 + A_4y_4}{A_1 + A_2 + A_3 + A_4}$$

$$= \frac{82.54(254) + 80.635(95.25) + 79.365(25.4) + 40(203.2) + 0.635(92.02)}{254 + 95.25 + 25.4 + 203.2 + 92.0242}$$

$$= \frac{38847.95012}{669.8742}$$

$$= 57.9929 mm$$

$d_1 = y_1 - \bar{y} = 82.54 - 57.9929 = 24.5471$ mm
$d_2 = y_2 - \bar{y} = 80.635 - 57.9929 = 22.6421$ mm
$d_3 = y_3 - \bar{y} = 79.365 - 57.9929 = 21.3721$ mm
$d_4 = \bar{y} - y_4 = 57.9929 - 40 = 17.9929$ mm
$d_5 = \bar{y} - y_5 = 57.9929 - 0.635 = 57.3579$ mm

$I_{o1} + A_1 d_1^2$

$$= \frac{100(2.54)^3}{12} + 254(24.5471)^2$$

$= 153186.8289$ mm^4

$I_{o2} + A_2 d_2^2$

$$= \frac{75(1.27)^3}{12} + 95.25(22.6421)^2$$

$= 48844.11435$ mm^4

$I_{o3} + A_3 d_3^2$

$$= \frac{20(1.27)^3}{12} + 25.4(21.3721)^2$$

$= 11605.2871$ mm^4

$I_{o4} + A_4 d_4^2$

$$= \frac{2.54(80)^3}{12} + 203.2(17.9929)^2$$

$= 174158.2507$ mm^4

$I_{os} + A_s d_s^2$

$$= \frac{72.46(1.27)^3}{12} + 92.0242(57.3579)^2$$

$= 302765.4248 \text{ mm}^4$

$$I = \sum_{i=1}^{n} I_{oi} + A_i d_i^2$$

$I = 690559.86 \text{ mm}^4$

$M_{max} = 69.445\overline{3} \text{ Nm}$

$V_{max} = 118 \text{ N}$

Capacities (both A and B)

1. Compression: 6 MPa
2. Tension: 30 MPa
3. Matboard shear: 4 MPa
4. Glue shear: 2 MPa
5. Mid flange thin plate buckling:

zone A: $t = 3(1.27) = 3.81\text{mm}, b = 73.73\text{mm}$

$$\sigma_{crit} = \frac{4\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$

$$= \frac{4\pi^2(4000\times10^6)}{12(1-0.2^2)}\left(\frac{3(1.27)}{75-1.27}\right)^2$$

$= 36.6040 \text{ MPa}$

zone B: $t = 2.54\text{mm}, b = 73.73\text{mm}$

$$\sigma_{crit} = \frac{4\pi^2 E}{12(1-\mu^2)}\left(\frac{t}{b}\right)^2$$
$$= 16.268 \text{ MPa}$$

6. Side flange thin plate buckling

$t = 2(1.27) = 2.54$ mm

$b = (100-75) \div 2 + 1.27 = 13.77$ mm

$$\sigma_{crit} = \frac{0.425\pi^2 E}{12(1-\mu^2)}\left(\frac{2.54}{13.77}\right)^2$$
$$= 49.556 \text{ MPa}$$

7. Web buckling

$t = 1.27$ mm, $b_A = 80 + \frac{1.27}{2} - 57.9929 = 22.64$ mm

$b_B = 80 + \frac{1.27}{2} - 55.49 = 25.145$ mm

$$\sigma_{crit_A} = \frac{6\pi^2 E}{12(1-0.2^2)}\left(\frac{1.27}{22.6421}\right)^2 \qquad \sigma_{crit_B}$$
$$= 64.689 \text{ MPa} \qquad = 52.451 \text{ MPa}$$

8. Shear buckling

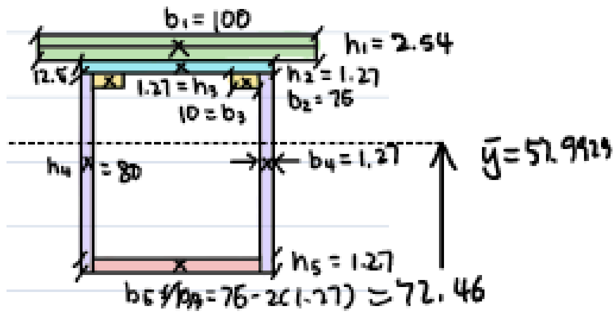
$a_1 = 205$ mm, $a_2 = 250$ mm, $a_3 = 360$ mm

$$\sigma_{crit_1} = \frac{5\pi^2 E}{12(1-0.2^2)}\left[\left(\frac{1.27}{80.27}\right)^2 + \left(\frac{1.27}{205}\right)^2\right]$$
$$= 5.116281 \text{ MPa}$$

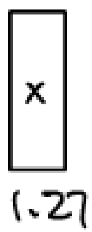
$$\sigma_{crit_2} = 4.900844 \text{ MPa}$$

$$\sigma_{crit_3} = 4.671903 \text{ MPa}$$

Q_{cent}



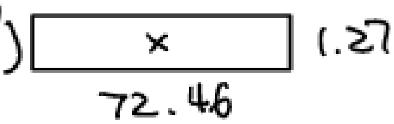
$Q_{cent} = 2A_1d_1 + A_2d_2$



$57.9929 = \bar{y}$

$2A_1d_1$
$= \frac{2(1.27)(57.9929)^2}{2}$
$= 4271.234\ mm^3$

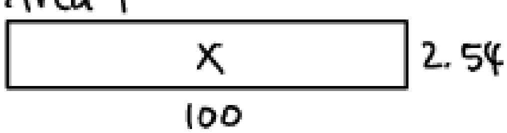
A_2d_2
$= 72.46(1.27)(57.9929 - \frac{1.27}{2})$
$= 5278.31486\ mm^3$



$Q_{cent} = 9549.54895\ mm^3$

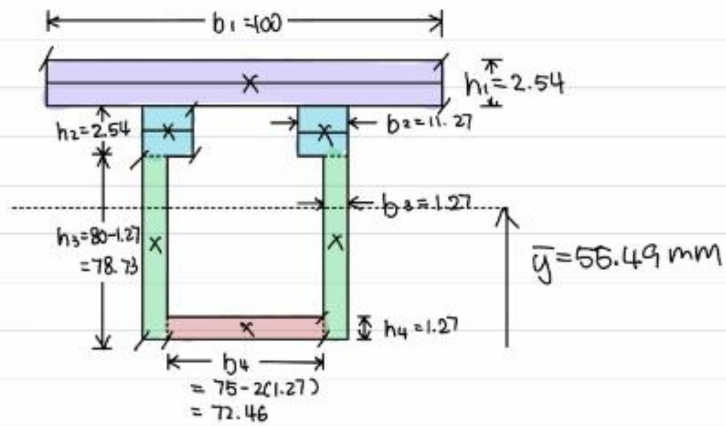
Q_{glue}

Area 1



$A_1d_1 = 100(2.54)(83.81 - 1.27 - 57.9929)$
$= 6234.9634\ mm^3$

Zone B: 0-400, 800 - 1200



$A_1 = b_1 h_1$

$= 100(2.54)$

$A_1 = 254 \text{ mm}^2$

$y_1 = 80 + 2(1.27)$

$y_1 = 82.54 \text{ mm}$

$A_2 = 2 b_2 h_2$

$= 2(11.27)(2.54)$

$A_2 = 57.2516 \text{ mm}^2$

$y_2 = 80 \text{ mm}$

$A_3 = 2 b_3 h_3$

$= 2(1.27)(78.73)$

$A_3 = 199.9742 \text{ mm}^2$

$y_3 = \frac{78.73}{2}$

$y_3 = 39.365 \text{ mm}$

$A_4 = b_4 h_4$

$= 72.46(1.27)$

$A_4 = 92.0242 \text{ mm}^2$

$y_4 = \frac{1.27}{2}$

$y_4 = 0.635 \text{ mm}$

$$\bar{y} = \frac{A_1 y_1 + A_2 y_2 + A_3 y_3 + A_4 y_4}{A_1 + A_2 + A_3 + A_4}$$

$\bar{y} = 55.49 \text{ mm}$

$d_1 = 82.54 - 55.49 = 27.05 \text{ mm}$

$d_2 = 80 - 55.49 = 24.51 \text{ mm}$

$d_3 = 55.49 - 39.365 = 16.127 \text{ mm}$

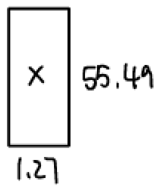
$d_4 = 55.49 - 0.635 = 54.857 \text{ mm}$

$$I = \sum_{i=1}^{n} I_{oi} + A_i d_i^2$$

$$= \frac{b_1 h_1^3}{12} + A_1 d_1^2 + \frac{b_2 h_2^3}{12} + A_2 d_2^2 + \frac{b_3 h_3^3}{12} + A_3 d_3^2 + \frac{b_4 h_4^3}{12} + A_4 d_4^2$$

$$= 652622.797 \text{ mm}^4$$

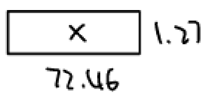
Q_{cent}



$A_1 d_1$

$= 2(1.27)(55.49)\left(\frac{55.49}{2}\right)$

$= 3910.8269 \text{ mm}^3$



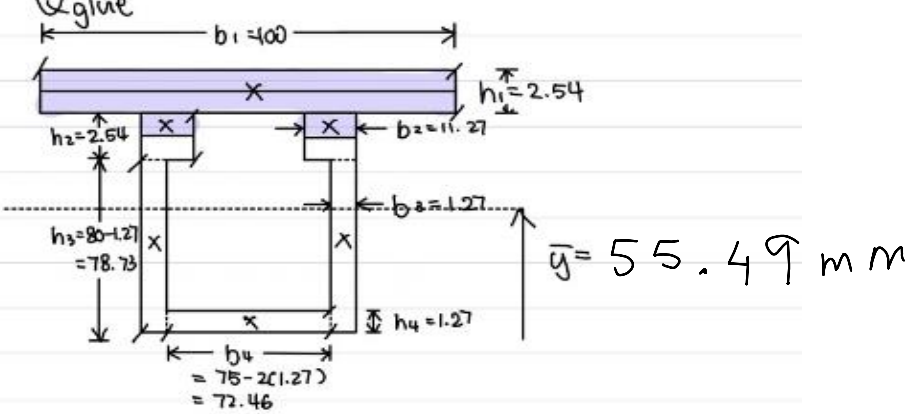
$A_2 d_2$

$= 72.46(1.27)\left(55.49 - \frac{1.27}{2}\right)$

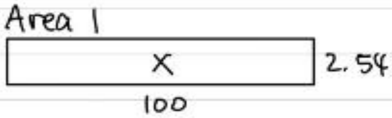
$= 5048.1956 \text{ mm}^3$

$Q_{cent} = 8959.0227 \text{ mm}^3$

Q_{glue}

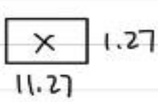


Area 1



$A_1 d_1 = 100(2.54)(83.81 - 1.27 - 55.49)$

$= 6870.7 \text{ mm}^3$



$2A_2d_2$

$= 2(11.27)(1.27)(80 + \frac{1.27}{2} - 55.49)$

$= 719.7957\ mm^3$

$Q_{glue} = 7590.496\ mm^3$

Demand

1. compression

- zone A:

$M_{max} = 69.445\ Nm$

$y_{top} = 25.8171\ mm$

$I = 690559.86\ mm^4$

$\sigma_{comp} = \frac{M y_{top}}{I}$

$= 2.59625\ MPa$

$FOS = \frac{6}{2.596}$

$= 2.31$

- zone B:

$M\ , = 61.284\ Nm$

$y_{top} = 28.32\ mm$

$I = 652622.797\ mm^4$

$\sigma_{comp} = \frac{M y_{top}}{I}$

$= 2.659351\ MPa$

$FOS = \frac{6}{2.659}$

$= 2.26$

2. tension

zone A:

$\bar{y} = 57.9929\ mm$

$\sigma_{tens} = \frac{M\bar{y}}{I}$

$= 5.832799\ MPa$

$FOS = \frac{30}{5.8328}$

$= 5.14$

zone B:

$\bar{y} = 55.49\ mm$

$\sigma_{tens} = \frac{M\bar{y}}{I}$

$= 5.210742\ MPa$

$FOS = \frac{30}{5.2107}$

$= 5.76$

3. Matboard shear failure

zone A:

$V_{max} = 116 N$

$Q_{cent} = 9549.55 mm^3$

$I = 0.69055986 mm^4$

$b = 2.54 mm$

$\tau_{xy} = \frac{VQ}{Ib}$

$= 0.631547 MPa$

zone B:

$V_{max} = 240 N$

$Q_{cent} = 8959.0 mm^3$

$I = 0.652628 mm^4$

$b = 2.54 mm$

$\tau_{xy} = \frac{VQ}{Ib}$

$= 1.297093 MPa$

Min FOS:

$FOS = \frac{4}{1.297}$

$= 3.08$

4. Glue shear failure

zone A

$Q_{glue} = 6883.111 m^3$

$b = 2(11.27) = 22.54 mm$

$\tau_{xy} = \frac{VQ}{Ib}$

$= 0.051296 MPa$

zone B

$Q_{glue} = 7590.497 mm^3$

$b = 22.54 mm$

$\tau_{xy} = \frac{VQ}{Ib}$

$= 0.12384 MPa$

Min FOS:

$FOS_{min} = \frac{2}{0.12384}$

$= 16.15$

5. Mid flange buckling

zone A:

$\sigma_{capacity} = 36.6040 MPa$

$\sigma_{demand} = 2.59625 MPa$

(from check #1)

zone B:

$\sigma_{capacity} = 16.268 MPa$

$\sigma_{demand} = 2.6593 MPa$

(from check #1)

Min FOS:

$FOS_{min} = \frac{16.268}{2.6593}$

$= 6.12$

6. Side flange buckling

$\sigma_{capacity} = 49.556\ MPa$

zone A:

$\sigma_{demand} = 2.59625\ MPa$

zone B:

$\sigma_{demand} = 2.6593\ MPa$

$$FOS_{min} = \frac{49.556}{2.6593}$$

$$= 18.63$$

7. Web buckling

Zone A:

$\sigma_{capacity} = 64.689\ MPa$

Zone B:

$\sigma_{capacity} = 52.45\ MPa$

$$FOS_{min} = \frac{52.45}{2.6593}$$

$$= 19.7$$

8. Shear buckling

zone A:

$\tau_{xy\,capacity,min} = 4.67\ MPa$

$\tau_{xy\,demand} = 0.6315\ MPa$

Zone B:

$\tau_{xy\,capacity,min} = 4.9\ MPa$

$\tau_{xy\,demand} = 1.297\ MPa$

$$FOS_{min} = \frac{4.9}{1.297}$$

$$= 3.78$$

min FOS = 2.26

∴ governing failure is compression in zone B

$P_{crit} = 2.26(400)$

$P_{crit} = 904\ N$

Conclusion: Predicted Failure Load is 904 N caused by buckling due to compression observed in Zone B according calculations.

Code Output for the 8 Minimum FOS in Final Design across Zone A and B

Zone A FOS

```
minimum FOS against compression failure: 2.311011590535187
minimum FOS against tension failure: 5.144043861603292
minimum FOS against glue shear failure: 38.98903408157252
minimum FOS against matboard shear failure: 6.333651899405308
minimum FOS against mid flange buckling: 14.098717409130842
minimum FOS against side flange buckling: 19.087392918252025
minimum FOS against web buckling: 24.916300794908594
minimum FOS against shear buckling: 7.397553131559167
```

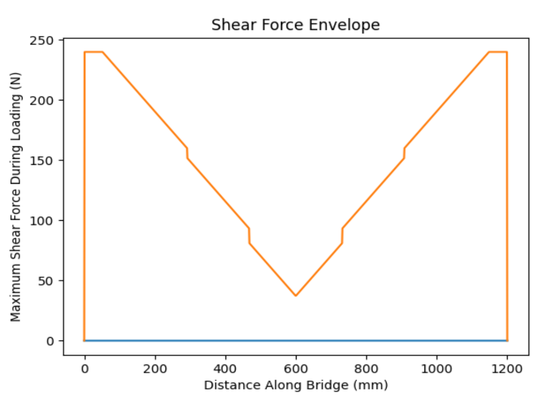
Zone B FOS

```
minimum FOS against compression failure: 2.2563694325073067
minimum FOS against tension failure: 5.7571337130824976
minimum FOS against glue shear failure: 16.149708700110235
minimum FOS against matboard shear failure: 3.0837848442928477
minimum FOS against mid flange buckling: 6.117939410854254
minimum FOS against side flange buckling: 18.63608564465335
minimum FOS against web buckling: 19.728760810404186
minimum FOS against shear buckling: 3.7782871909208633
```

Minimum FOS: 1.99

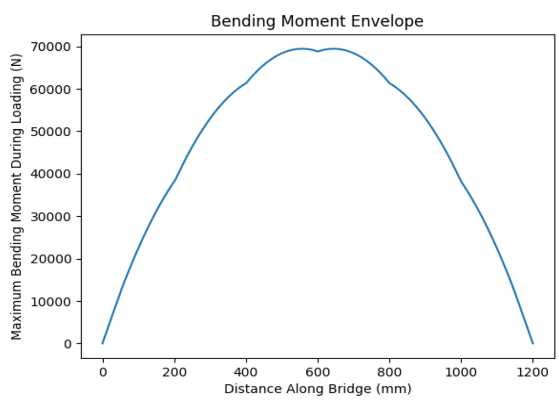
Final Design Code Outputs (Graphical Representations):

Figure 0.1: Shear Force Diagram




```
x = 200, V = 190.33333333333331
x = 300, V = 148.99999999999994
x = 400, V = 115.66666666666664
x = 600, V = 37.33333333333334
x = 800, V = 116.00000000000006
x = 1000, V = 190.66666666666669
Max V = 240.0, location = 1
```

Figure 0.2 Bending Moment Envelope




```
x = 200, M = 38256.9999999999
x = 300, M = 53066.6666666666
x = 400, M = 61333.333333333336
x = 600, M = 68800.00000000001
x = 800, M = 61333.33333333335
x = 1000, M = 38133.33333333334
Max M = 69445.33333333331, location = 557
```

Zone A: Mid Span Cross-section

Legend for Figure 1.3 to 1.10 inclusive:

–O– Capacity
–O– Demand

Cross section View of Zone A:

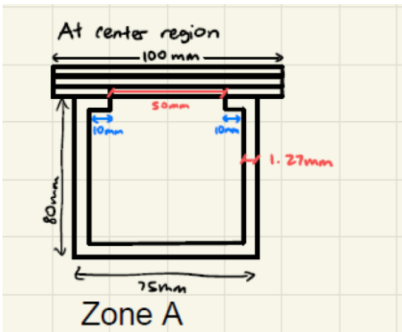


Figure 1.A.3: Compressive Stress vs Capacity

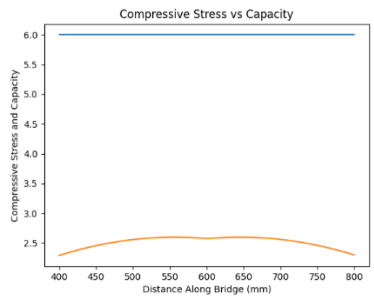


Figure 1.A.4: Tensile Stress vs Capacity

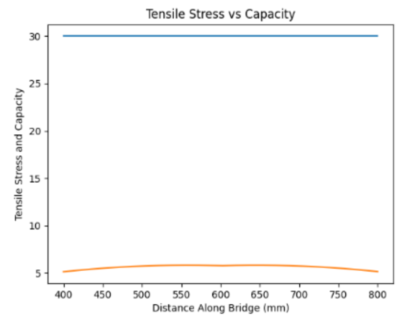


Figure 1.A.5: Matboard Shear Demand vs Capacity

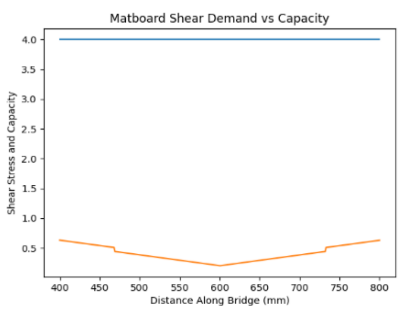


Figure 1.A.6: Glue Shear Demand vs Capacity

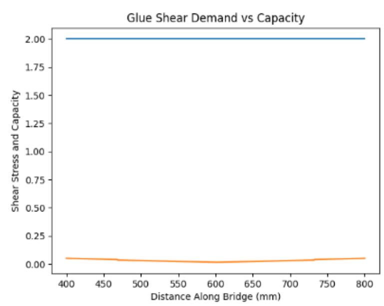


Figure 1.A.7: Mid Flange Buckling Stress vs Capacity

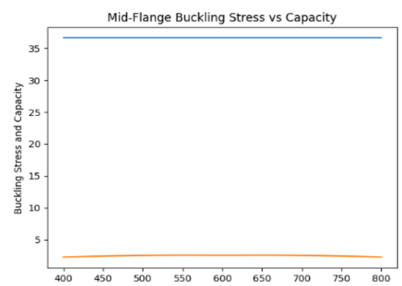


Figure 1.A.8: Side-Flange Buckling Stress vs Capacity

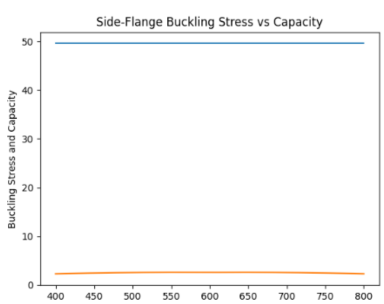


Figure 1.A.9: Web Buckling Stress vs Capacity

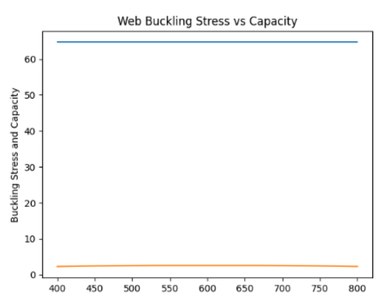
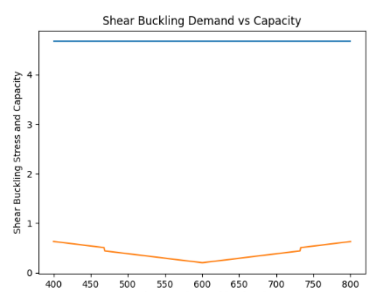


Figure 1.A.10: Shear Buckling Demand vs Capacity



Zone B: Sides of the Bridge

Legend for Figure 1.11 to 1.18 inclusive:

Capacity
Demand

Cross section View of Zone B:	**Figure 1.B.11:** Compressive Stress vs Capacity	**Figure 1.B.12:** Tensile Stress vs Capacity

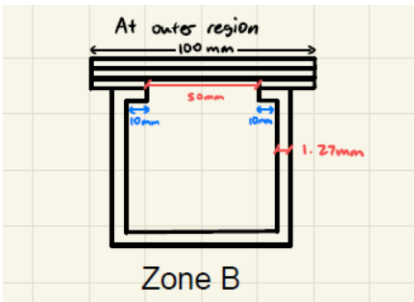
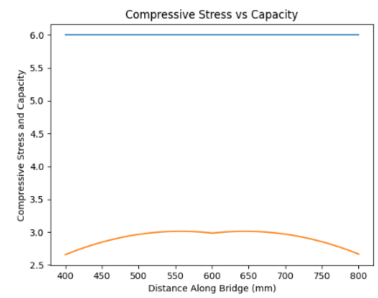
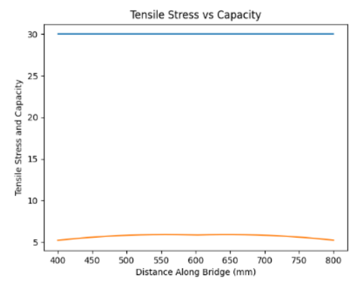

		

Figure 1.B.13: Matboard Shear Demand vs Capacity	**Figure 1.B.14:** Glue Shear Demand vs Capacity	**Figure 1.A.15:** Mid-Flange Buckling Stress vs Capacity

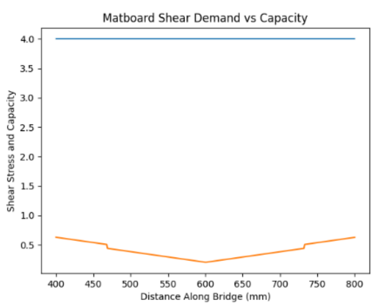
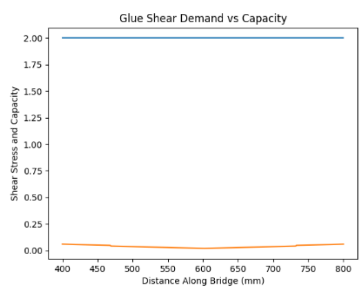
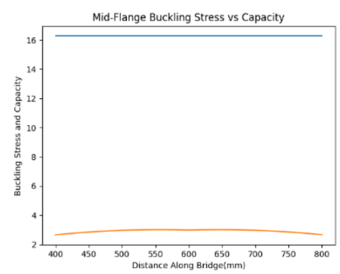

		

Figure .A.15: Side-Flange Buckling Stress vs Capacity	**Figure 0.B.17:** Web Buckling Stress vs Capacity	**Figure 0.B.18:** Shear Buckling Demand vs Capacity