UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATIONS, DECEMBER 2020

CIV102F – Structures and Materials – An Introduction to Engineering Design
Exam Version B

Examiner --- M.P.Collins and A.Kuan

Permissible Aids: Course Notebook, calculator and class notes.

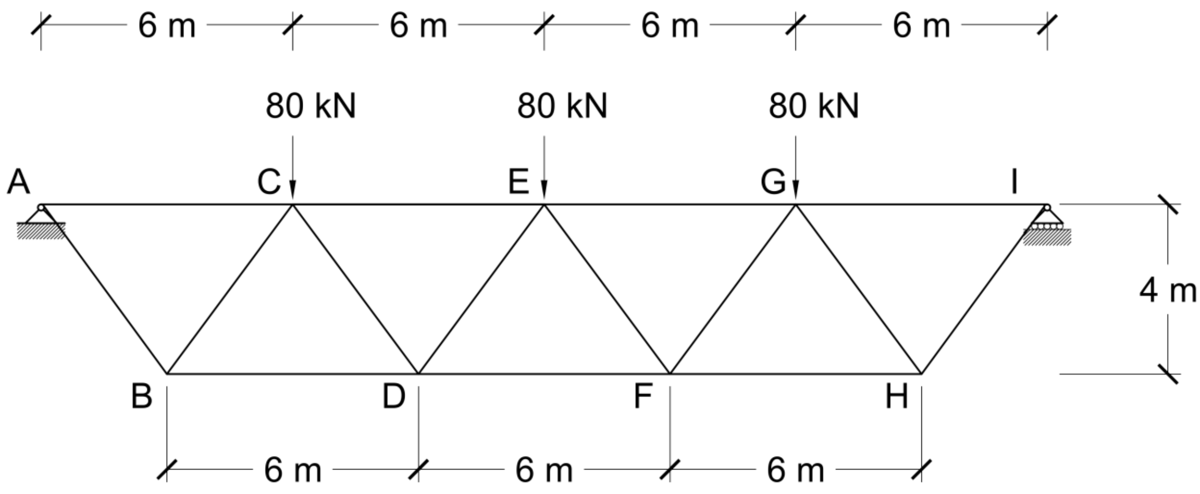
IMPORTANT INSTRUCTIONS

1. You have a total of three hours to complete and submit the final exam. 2.5 hours are allocated for you to complete the questions and 30 minutes are allocated for you to prepare your submission.
2. There are four questions on the exam. Attempt all questions; any questions left blank will receive a grade of zero. Part marks will be awarded for incomplete answers.
3. This exam must be completed independently. All submitted work must be your own.
4. Your full name and student number must be written clearly on the first page of your submission
5. When preparing your solution, please do the following:
    a. Neatly indicate the question number and part on the side
    b. Each page must not contain answers to more than 2 question parts (for example, your answers to Q1a, Q1b, Q1c and Q1d must be distributed over at least two pages)
    c. Draw a box around your final answers
    d. Number your pages on the bottom right-hand corner.
    e. Write clearly and make your writing large enough to be legible

Refer to the "CIV102 Final Exam Instructions" document for more details about submitting your exam.

Question No.	Score	Possible Points
1		30
2		35
3		20
4		24
Total		109

1. The truss shown below supports a pedestrian bridge and is made from steel hollow structural sections with a yield stress of 350 MPa. The truss spans 24 m, and when the bridge is crowded with people, supports the three 80 kN loads as shown.



1(a). Calculate the axial force in each member of the truss due to the 80 kN loads. Produce a neat drawing summarizing the results of your calculations and indicate the calculated forces above the appropriate members. Use the convention +ve for tension and -ve for compression. **(10 marks)**
Intermediate or sample calculations must be provided for full marks.

1(b). Each of the horizontal chord members are HSS 178x178x4.8, and each of the diagonal web members are HSS 127x127x4.8. Is the truss **safe** under the 80 kN loads? Yes or no? At what value of the loads will the structure be on the boundary between safe and unsafe? **(6 marks)**

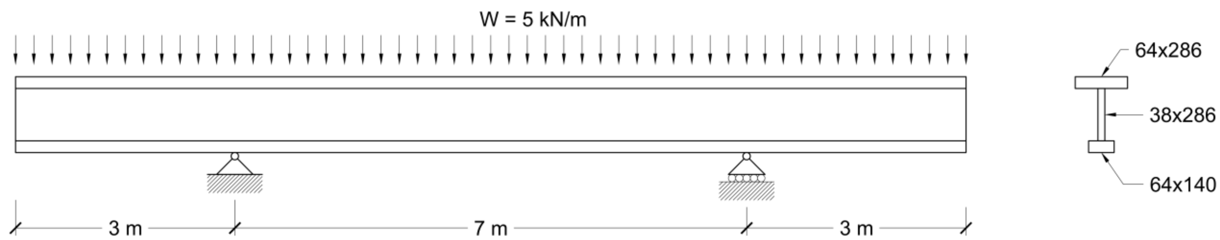
Note: When solving this problem, you do not need to check if the slenderness ratio, L/r exceeds the allowable limit of 200.

1(c). Using the Method of Virtual Work, calculate the vertical deflection of Joint E due to the application of the 80 kN loads. Create, and fill in a table like the one shown below. Note that the table lists the members for only one half of the truss. **(10 marks)**

Member	Member Force, P (kN)	Strain, ε (mm/m)	Length, L (m)	Δl (mm)	Virtual Force, P* (kN)	Work (J)
AC			6			
CE			6			
BD			6			
DF			3			
AB			5			
BC			5			
CD			5			
DE			5			

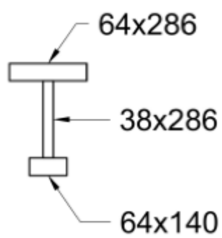
1(d). Calculate the natural frequency of the bridge when it is crowded with people, and comment on the stiffness of the bridge. **(4 marks)**

2. The timber I beam shown below has been fabricated by gluing together three sawn timber sections. The beam is 13 m long, is supported by two supports 7 m apart, and is subjected to a uniformly distributed load, which includes self weight, of 5 kN/m. The modulus of elasticity of the wood is 11,000 MPa. All dimensions are in mm unless indicated otherwise.



2(a). Draw the shear force and bending moment diagrams for the beam. Calculate and show important values. **(5 marks)**

2(b). Determine the location of the centroidal axis and the value of I for the cross-section. **(8 marks)**

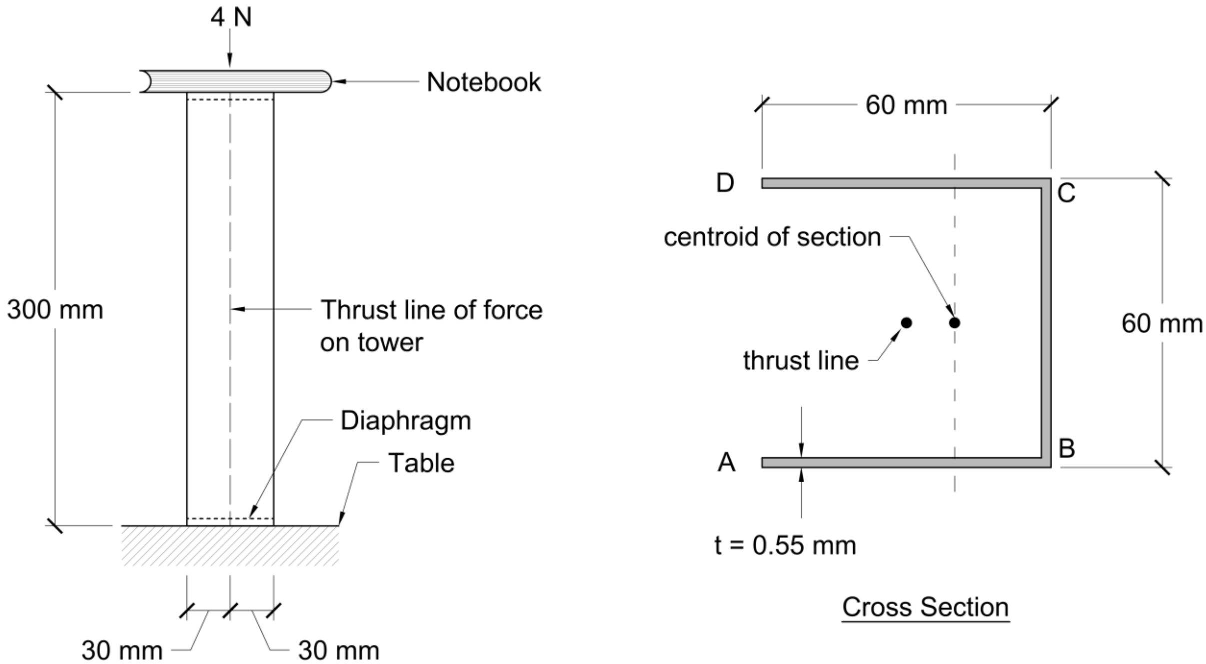


2(c). Determine the maximum flexural compressive stress and the maximum flexural tensile stress that occur in the beam. Using words or a drawing, indicate where these maximum stresses occur on the beam. **(8 marks)**

2(d). Determine the maximum shear stress that occurs in the glue. Does this maximum shear stress occur on the upper glued surface or the bottom glued surface? **(7 marks)**

2(e). Determine the magnitude of the vertical displacement of the beam at midspan. Also calculate the slope of the beam at the location of the supports. **(7 marks)**

3. For a classroom demonstration, a professor constructs a small tower using thin cardboard. The tower is 300 mm high and has a U-shaped section consisting of 3 sides each 60 mm wide. The cardboard is 0.55 mm thick, has a compressive strength of 6 MPa, a modulus of elasticity of 4000 MPa and a Poisson's ratio of 0.2. Square diaphragms are placed at the top and bottom of the tower to help maintain the shape of the section. A standard CIV102 notebook (used in previous years) weighing 4 newtons is placed on top of the of the tower, with the centre of gravity of the notebook located 30 mm from each side of the tower as shown in the figure.



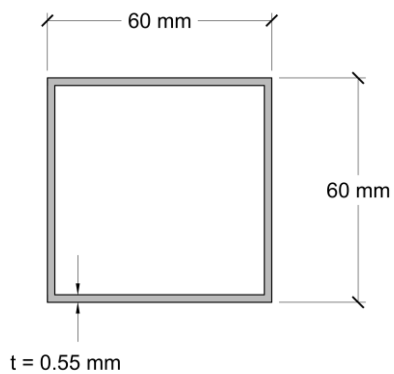
3(a). Determine the location of the centroidal axis of the section and values of A and I. **(5 marks)**

3(b). What will be the compressive stress at the free edges A and D caused by the weight of the one notebook? What will be the compressive stress at B and C caused by the weight of the notebook? **(5 marks)**

3(c). How many notebooks can the tower support before it collapses? **(4 marks)**
Hint: When selecting which plate buckling equation to use, your decision should prioritize the displacement boundary conditions (i.e., consideration of restraints). Also, explicitly consider the cardboard thickness when calculating your value of "b" in the equations.

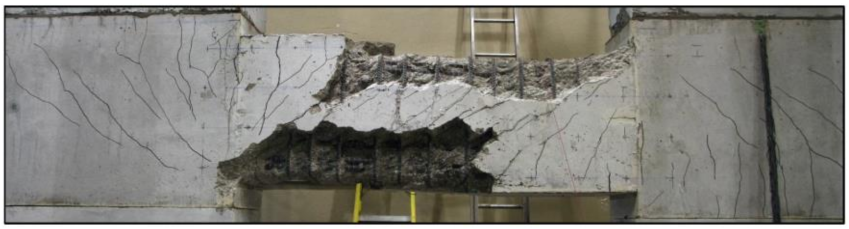
3(d). A second cardboard tower was built, which has the same height as the original U-shaped tower, but now has a fully closed cross section, which is shown below. If it is loaded in the same manner as the previous tower, how many notebooks can this new tower carry before it collapses? What mode of failure governs its strength? (**6 marks)**

Hint: Use the equations on page 93 of the course notes to determine A and I.



Revised Cross Section

4. The reinforced concrete beam shown in the photo below was tested by Andrew Fischer in 2015 as part of his MASc research project. The longitudinal reinforcement was provided by 24-30M bars which each had a yield strength of 563 MPa, while the transverse reinforcement was provided using 2-leg 15M stirrups (with a yield strength of 422 MPa) spaced at 60 mm apart. To fit the stirrups into the beam, their horizontal position within the cross section was staggered, resulting in the configuration shown in the figure below. The concrete compressive strength, f_c', was equal to 66.5 MPa and the modulus of elasticity, E_c, was equal to 38,600 MPa. The beam was tested so that it was subjected to constant shear over its length and had bending moments linearly varying along its length.



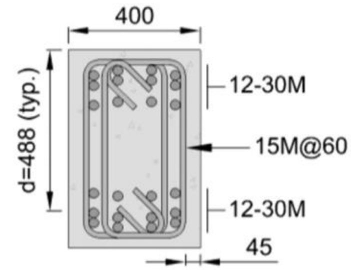
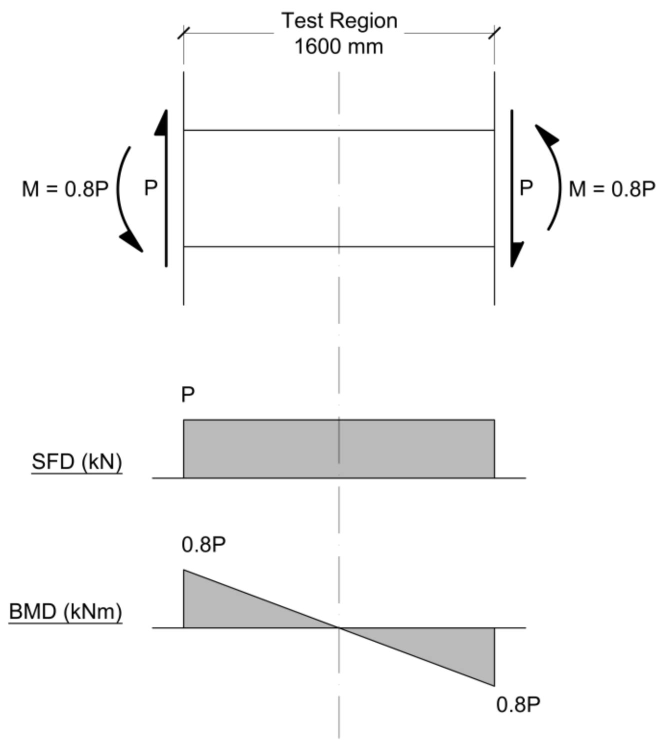


Photo of tested specimen (left) and cross section details (right). **Refer to the text when determining A_v.** All dimensions are in mm unless otherwise indicated.



Elevation view showing applied loads (top), shear force diagram (middle), bending moment diagram (bottom)

4(a). Calculate the highest value of the bending moment, and corresponding value of P, which can be **safely** resisted by the beam so that the tensile stress in the longitudinal reinforcement does not exceed $0.6 \times f_y = 338$ MPa and the compressive stress in the concrete does not exceed $0.5 \times f_c' = 33.3$ MPa. Neglect the longitudinal steel in compression when performing your calculations. **(8 marks)**

4(b). Calculate the highest shear force, and corresponding value of P, which can be **safely** resisted by the beam. When performing your calculations, use the value of jd which was computed in question 4(a). **(6 marks)**

4(c). The simplified procedures for the moment and shear design of reinforced concrete incorporate safety factors by reducing the concrete contributions by a factor of 0.50 (corresponding to a factor of safety of 2.0) and by reducing the steel contributions by a factor of 0.60 (corresponding to a factor of safety of 1.67).

Using your calculations from questions 4(a) and 4(b) and the above information on the factors of safety to predict the value of P which caused failure of the beam. Did the beam fail in flexure or shear? **(6 marks)**

Note: Assume that a flexural failure is caused by yielding of the tension reinforcement and not crushing of the concrete.

4(d). The American Concrete Institute (ACI) code uses the following equation to determine the shear strength of reinforced concrete members:

$$V_{ACI} = V_{c,ACI} + V_{s,ACI} \leq V_{max,ACI}$$

$$V_{ACI} = 0.166\sqrt{f_c'}b_w d + \frac{A_v f_y d}{s} \leq 0.83\sqrt{f_c'}b_w d$$

Calculate the predicted strength of the member if the ACI code was instead used to predict its shear strength. Comment on the relative accuracy of the CIV102 (Canadian) procedures and the ACI (American) procedures if the specimen failed at a value of P = 1830 kN. **(4 marks)**