The University of Sydney

Department of Civil Engineering

CIVL2201 Structural Mechanics

Semester 1, 2003

Time Allowed: 3 hours

Instructions to Candidates

(a) **This paper contains 3 parts: A, B, & C. Part A has 4 questions (Q 1 – Q 4, 40 %), Part B has 3 questions (Q 5 – Q 7, 60 %). Part C has 2 questions (Q 8 - Q 9, 20 %), which are bonus marks).**

(b) All questions may be attempted.

(c) Suitable working, diagrams and explanations are required for each question.

(d) Marks may be deducted for work that is not satisfactorily set out.

(e) **Units are important.**

(f) Programmable and non-programmable calculators may be used.

(g) Read the questions carefully before answering.

(h) **Annotated copies of the "Structural Mechanics Lecture Notes" may be taken into the exam, but no other written material is permitted.** Other sheets of paper may not be inserted into the set of lecture notes.

(i) Students are reminded that satisfactory exam performance is an essential criterion in this course, and a combined mark of 65 % is required in Part A, and a combined mark of 50 % is required in Part B.

Part A – Basic Questions

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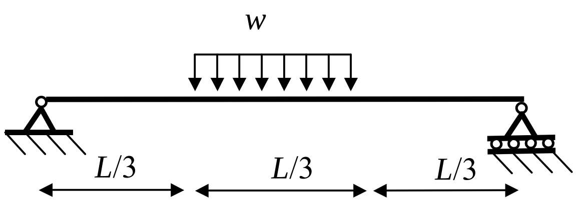
1) The diagram below shows a simply supported beam of total length *L*, with a uniformly distributed load, *w*, which acts on the middle third of the beam only. The beam is made from steel with an elastic modulus E_{steel} = 200000 MPa, and a second moment of area about the axis of bending of $I = 250 \times 10^6$ mm^4. The effects of self-weight are negligible compared to effects of the applied loading, *w*.

   a) **Draw the free body diagram** of the beam clearly showing the support reactions. **Calculate** the value of the support reactions.

   b) **Draw the bending moment diagram (BMD) and shear force diagram (SFD). Clearly indicate the values** of bending moment and shear force at the support, the third-points of the beam, and midspan.

   c) The steel beam is replaced by another steel beam with different cross-section, such that $I_{new} = 500 \times 10^6$ mm^4 (ie the second moment of area about the axis of bending is doubled). The effects of self-weight are still negligible. Without performing any calculations, **how will the BMD (shape and magnitude) and the deflections be affected? Briefly justify the answer.**



Question 1 is worth 10 marks

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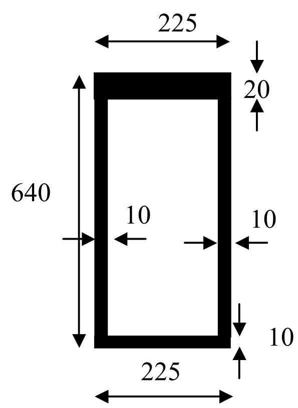
2) Consider the following box section, the dimensions of which are shown in the diagram. The section has a vertical axis of symmetry.

   a) **Calculate the location of the centroid and show this location** on a diagram.

   b) **Calculate the second moment of area** (I_x) of the section about the horizontal centroidal axis.

   c) The thickness of the webs is increased (the webs are the vertical elements), while the flange thickness remain unchanged. **How will the location of the centroid change in both the vertical and horizontal direction?** Calculations are not required. **Briefly justify your answer.**

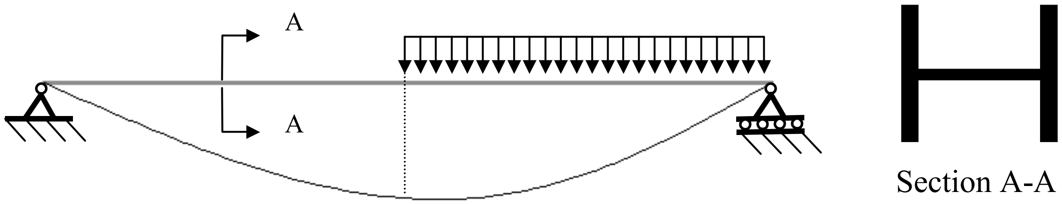


All dimensions are in mm

Question 2 is worth 10 marks

3) In Example 9.2.6 (p 9-11) of the lecture notes, it is shown that the deflection of a simply supported beam with a half UDL is given by $v = \frac{w}{384EI}\left(16\left\langle z-\frac{L}{2}\right\rangle^4 - 8Lz^3 + 7L^3z\right)$.

Consider the elevation and section shown below. The beam has a span of 4 m, and the applied load w = 20 kN/m. The beam is a 200UB29.8, manufactured by OneSteel. The relevant page of the section properties handbook is given on the back page on this examination sheet. The density of steel is 7850 kg/m^3 and the elastic modulus is E = 200000 MPa.



Section A-A
200UB29.8

(a) **Is the beam being bent about the *x*-axis or *y*-axis?**
(b) **What is the self-weight of the beam per unit length?** Given the magnitude of the applied load, **is it reasonable to ignore the effects of self weight?**
(c) **Determine the deflection of the beam at the first quarter point of the beam** (ie $L/4$), firstly as an algebraic expression in terms of w, I, L, and E, and secondly by substituting the appropriate values for those quantities.
(d) **Is it possible to reduce the deflections while still using the same beam over the same span and supporting the same loads?** If so, how? With the aid of a diagram, explain the answer.

Question 3 is worth 10 marks

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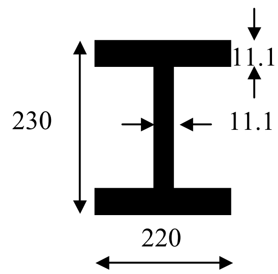
4) Consider the doubly symmetric I-section shown. The second moment of area about the major x (horizontal) centroidal axis is $I_x = 129 \times 10^6$ mm^4, while the second moment of area about the minor y (vertical) centroidal axis is $I_y = 44.6 \times 10^6$ mm^4. The steel has a yield stress of 280 MPa and an elastic modulus of 200 GPa.



All dimensions are in mm

a) **Calculate elastic section modulus for bending about the minor *y*–axis** (Z_y). (I_y is given – so it does not need to be calculated). Given that 1 inch = 25.4 mm, **give the answer in both metric and imperial units**.

b) **Calculate the bending moment** (about the y - axis) that will cause first yield of the section.

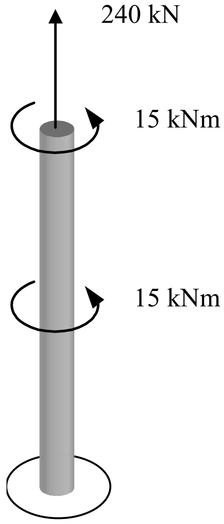
c) **Draw the stress and strain distributions** in the cross-section which correspond to the answer in (b) above.

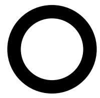
d) With the aid of a diagram(s), **demonstrate the difference in the deformed shape and the stresses and strains induced**, when the beam is bent about the x-axis compared to being bent about the y-axis.

Question 4 is worth 10 marks

Part B – Intermediate Questions

5) A 165.1 × 5.0 CHS manufactured by Palmer Tube Mills is built-in at the base and is experiencing a variety of loads. It experiences 2 applied twisting moments, each of magnitude 15 kNm, and an axial tension of 240 kN. The torques are applied at mid-height and at the end, while the tension is applied at the free end. At the support, there is a point on the outer surface of the CHS which is under consideration.





Cross section at support

The Palmer Tube Mills product catalogue gives the following geometric properties for this section

$A = 2510\ \text{mm}^2$
$I = 8.07 \times 10^6\ \text{mm}^4$
$Z = 97.7 \times 10^3\ \text{mm}^4$
$J = 16.1 \times 10^6\ \text{mm}^4$

(a) **Draw the BMD, TMD and AFD** and determine the internal actions that apply at the cross-section at the support.

(b) At the point under consideration, determine the following:
   i. **Stress due to the torsion**. Is this a normal stress or a shear stress?
   ii. **Stress due to the axial force**. Is this a normal stress or a shear stress?

(c) **Draw a diagram that shows the stresses acting at this point, draw the Mohr's circle, and establish the principal stresses** for this point.

(d) Use both Tresca's and von Mises' yield criteria to **establish if the point has yielded**, given $f_y = 300$ MPa.

(e) **How would the answers to the above change if the point under consideration was on the inside surface** of the CHS? Explain your answer.

Question 5 is worth 20 marks

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6) A concrete beam, length 5 m, with square cross-section 300 mm × 300 mm is symmetrically reinforced with 8 steel reinforcing bars, each of diameter 16 mm. The centre of each corner reinforcing bar is located 60 mm from closest edges of the concrete beam. The beam is simply supported and experiences a uniformly distributed load along its entire length. It can be assumed that $E_{concrete}$ = 40 GPa and E_{steel} = 200000 MPa and that **both materials exhibit linear elastic behaviour**. The concrete cracks if the tensile stress in the concrete exceeds 5 MPa. Consider the cross-section of the beam that is experiencing the greatest positive bending moment just as the concrete is about to crack.

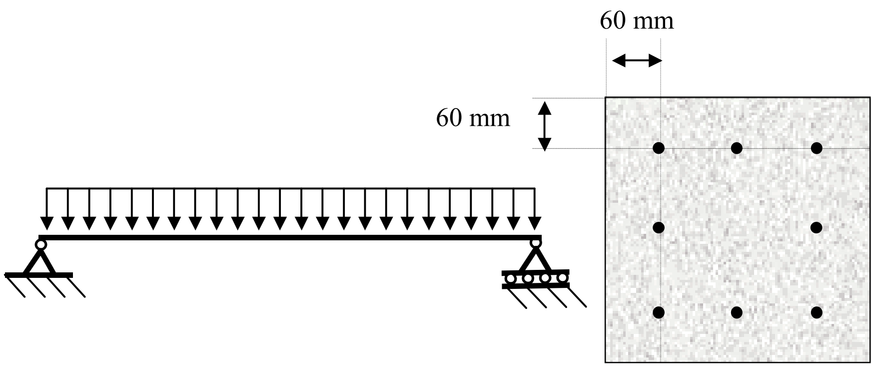
a) Using a diagram, **identify the location** along the length of the beam at which a cross section would experience the greatest values of bending stress. **Is the beam hogging or sagging** at this point?

b) **What is the strain in the concrete when it cracks? Draw the strain distribution** across this critical section (values required). For the steel reinforcement it is sufficient to give the strain at the centre of the reinforcing bar.

c) **Draw the stress distribution** across this critical section (values required). For the steel reinforcement it is sufficient to give the stress at the centre of the reinforcing bar.

d) **What is the bending moment that will cause the concrete to crack? What is the value of uniformly distributed load that will produce this bending moment?**

e) **Explain composite action** with particular reference to the bending behaviour of a reinforced concrete beam such as the one shown below (a diagram would greatly assist the answer).



8 × 16 mm diameter reinforcing bars in 300 × 300 mm concrete section

Question 6 is worth 20 marks

7) A Concrete Filled Double Skinned Tube (CFDST) consists of a hollow section placed inside another larger hollow section, and the space in between filled with concrete. The inside of the inner tube is not filled. Once filled, the CFDST acts compositely. It can be assumed that $E_{concrete}$ = 25 GPa and E_{steel} = 200000 MPa and that **both materials exhibit linear elastic behaviour**.

Consider the CFDST shown below. The outer tube has outer diameter 100 mm and thickness 5 mm, and the inner tube has outer diameter 50 mm and thickness 2.5 mm. The member is used as a column, 4 m in length, and is subjected to an axial compression. The design engineer wants to ensure that the stress in the steel does not exceed $f_{steel,\ max}$ = 350 MPa. High strength concrete is used, so it can be assumed that the stresses in the concrete do not exceed the ultimate strength of the concrete.

a) **What is the strain in the steel** when the steel reaches $f_{steel,\ max}$?

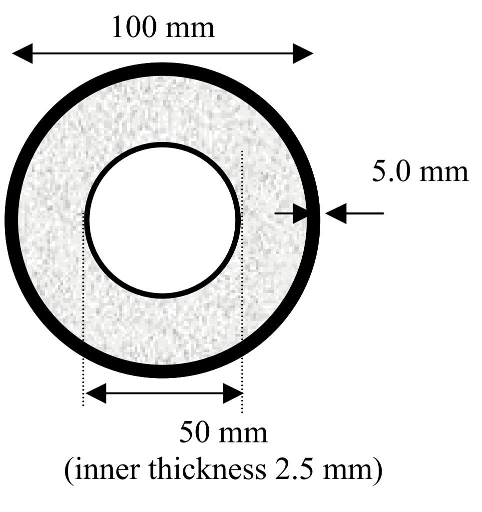
b) **What are the strain and stress in the concrete** when the steel reaches $f_{steel,\ max}$?

c) **What is the maximum axial load** the column can carry while ensuring that the steel stress does not exceed $f_{steel,\ max}$?

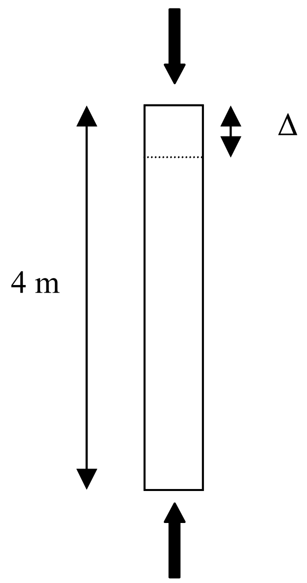
d) **What is the axial shortening (Δ)** of the column due to this compressive load calculated in c)?

e) Both steel tubes are replaced by aluminium tubes with the same dimensions, however the aluminium has an elastic modulus $E_{aluminium}$ = 70 GPa. The concrete is not changed. Assuming that the same load as calculated in (c) above is applied, **would the following increase or decrease (compared to the original case)?** Calculations are not required, but some justification of the answers is required.

- Total axial shortening
- Concrete strain
- Concrete stress
- Aluminium strain (compared to the original steel strain)
- Aluminium stress (compared to the original steel stress)



Typical column cross-section



Question7 is worth 20 marks

Part C – Advanced Questions

The questions in this section are designed for students who seek to obtain a mark of Distinction or higher. They are not necessarily mathematically difficult, but require more thinking, visualisation, and application than the other questions. The majority of marks will be awarded to completed questions, and only minor marks will be awarded to partially answered questions – ie it is better to complete one question fully, than half complete 2 questions.

The marks awarded in this section are bonus marks.

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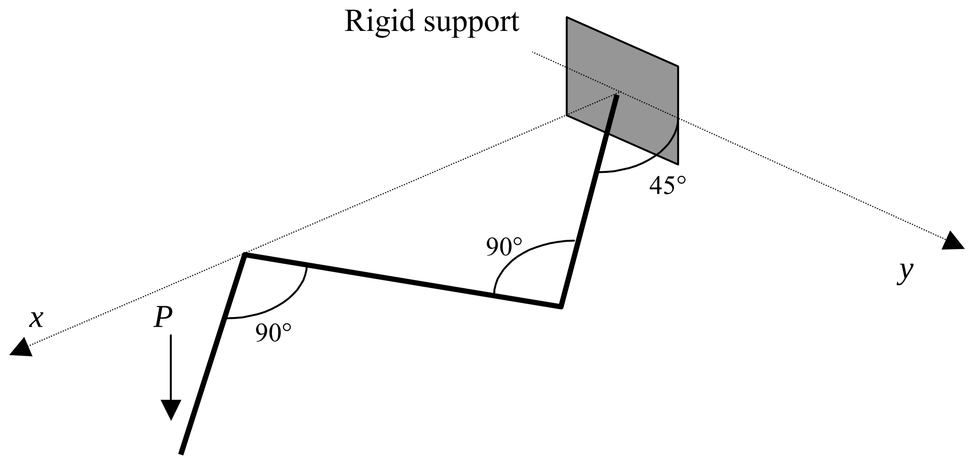
8) A beam is made up of three components, each of length *L*. The structure lies in the horizontal *x*-*y* plane shown and each segment is perpendicular to the adjacent segment. There is a vertical load *P* at the free end of the structure. The support is completely fixed, preventing deflection in every direction, and rotation about any axis. The segment nearest the support meets the support at an angle of 45° in the horizontal plane. **Draw the bending moment, shear force and twisting moment diagrams for the structure.**



Question 8 is worth 10 marks

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9) Consider a circular hollow section with outer diameter 200 mm and thickness 4 mm. It is made from steel with linear elastic – perfectly plastic material properties and a yield stress of 350 MPa. **Calculate the shape factor and plastic moment of the cross section.**

Question 9 is worth 10 marks

This is the end of the examination paper, but there is an additional data page on page 8.