The University of Sydney

Department of Civil Engineering

CIVL2201 Structural Mechanics

Semester 1, 2004

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) Each question has an "explain"-type component. It is expected that students should answer these parts with a short written explanation (one or two paragraphs) plus a diagram. Performing calculations is not necessarily expected, but using equations might also be useful.

Part A – Fundamental Questions

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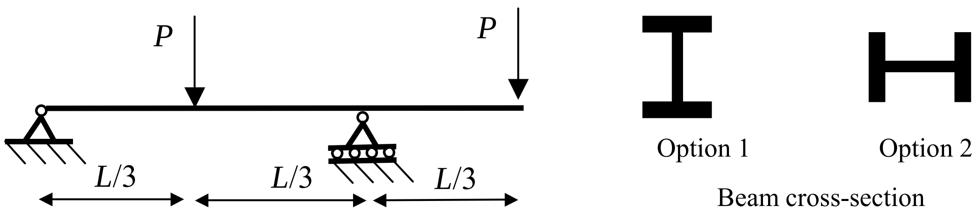
1) 10 Marks

The diagram below shows an overhanging beam of total length L, with two point loads, each of magnitude P, one at mid span and the other at the free end. The effects of self-weight are negligible compared to the effects of the applied loading.

a) **Draw the free body diagram** of the beam clearly showing the support reactions. **Calculate** the values 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 supports, and under the load points.

c) The engineer decides to rotate the beam so that the cross-section at midspan changes from "Option 1" to "Option 2". Without performing any calculations, **how will the BMD change (shape and magnitude)? Briefly justify the answer.**



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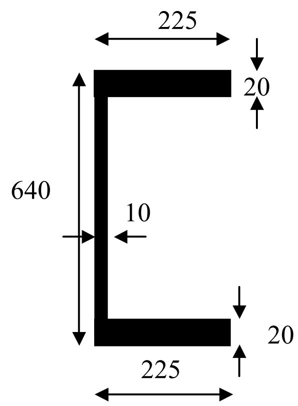
2) 10 Marks

Consider the following channel section, the dimensions of which are shown in the diagram.

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

b) **Calculate the second moment of area** (I_y) of the section about the vertical centroidal axis.

c) The thicknesses of both flanges are increased by the same amount, while the web thickness remains 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

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3) 10 marks

In Example 9.2.3 (p 9-5) of the lecture notes, it is shown that the deflection of a simply supported beam with a UDL is given by $v = \frac{w}{24EI}\left(z^4 - 2Lz^3 + L^3 z\right)$.

Consider a 200UB29.8 steel beam, with a span of 9 m, under its self-weight only. 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. The beam is oriented so that its web is in the vertical plane.

(a) **Draw a diagram that shows the beam layout, the loading, and the support conditions; and also provide a sketch that shows the beam cross section at midspan.**
(b) **Is the beam being bent about the *x*-axis or *y*-axis due to its self weight?**
(c) **What is the self-weight of the beam per unit length?**
(d) **Determine the deflection of the beam at the third quarter point of the beam** (ie 3L/4), firstly as an algebraic expression in terms of w, I, L, and E, and secondly as a numerical value by substituting the appropriate values for those quantities.
(e) The beam is replaced by one with the same dimensions, but made from a new super lightweight alloy, which is half the density of steel, has twice the yield stress of steel, and has the same elastic modulus. **How will the deflection due to its self weight of the new alloy beam compare to the deflection previously exhibited by the original steel beam?**

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4) 10 Marks

Consider a 400 × 400 × 16 square hollow section manufactured by Smorgon Steel Tube Mills. The relevant page of the section properties handbook is given on the back page on this examination sheet. The steel has a yield stress of 450 MPa and an elastic modulus of 200 GPa.

a) The Smorgon Steel table does not give separate values for I_x and I_y. **Explain.**

b) Given that 1 inch = 25.4 mm, **give the value of *I* in imperial units**.

c) **Calculate the bending moment** that will cause first yield of the section.

d) **Draw the stress and strain distributions** in the cross-section due to the bending moment calculated in (c) above. **State whether these are normal or shear stresses and strains.**

e) Considering axial compression only (no bending), **what compression load will cause the section to yield? Calculate the effective length** for Euler buckling that produces the same value of buckling load as for the yield load just calculated.

Part B – Applied Questions

5) 20 Marks

Consider a closed cylindrical pressure vessel. The vessel has an outer diameter of 0.5 m, length 3 m, and a thickness of 5 mm, and is subjected to an unknown internal pressure. The vessel is made from a linear elastic material with a yield stress of 400 MPa and an elastic modulus of 100000 MPa.

Consider a typical point on the curved surface of the pressure vessel, halfway between the two ends.

(a) **Draw a diagram to show a typical element and the stresses acting on that element.**
(b) **What value of internal pressure will cause the material to yield according to von Mises' yield criterion?**
(c) **What value of internal pressure will cause the material to yield according to Tresca's yield criterion?**
(d) **How would the answers change if the length of the cylinder was doubled to 6 m**, but all other dimensions remained the same? **Explain your answer.**

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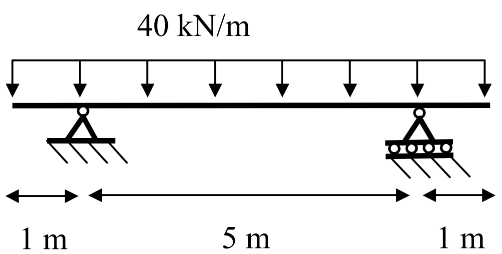
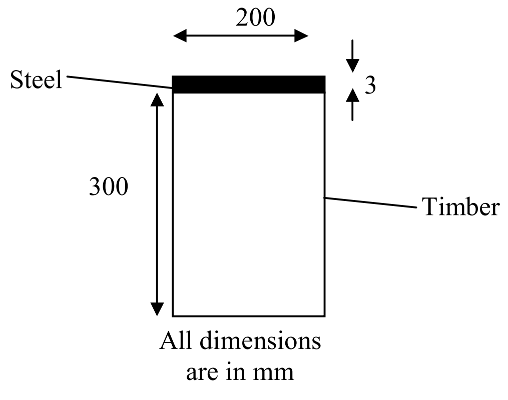
6) 20 Marks

A builder strengthens a 200 mm × 300 mm timber beam by connecting 3 mm steel plate to the top of the beam as shown below. The beam can then be assumed to act compositely. It can be assumed that E_{timber} = 12500 MPa and E_{steel} = 200000 MPa. The beam has a total length of 7 m, with a central span of 5 m and an overhang of 1 m at each end, as shown below. The beam is subjected to a UDL of 40 kN/m.

a) **Draw the bending moment diagram**, and clearly identify the locations and magnitudes of the maximum sagging and hogging bending moments.
b) **Draw the strain distribution** due to bending across the section (values required) at the cross-section over the left hand support (if you have been unable to answer (a) you may assume a hogging moment of 10 kNm).
c) **Draw the stress distribution** due to bending across the section (values required).
d) If the steel plate is thickened to 4 mm and the timber thinned to 299 mm deep (so that the total size remains the same), **how would the location of the neutral axis change? Explain your answer.**





Typical Beam Cross-Section

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7) 20 Marks

A concrete column, length 6 m, with square cross-section 300 mm × 300 mm is symmetrically reinforced with 9 steel reinforcing bars, each of diameter 20 mm. The centre of each corner reinforcing bar is located 60 mm from closest edges of the concrete beam. It can be assumed that $E_{concrete}$ = 40 GPa and E_{steel} = 200000 MPa and that **both materials exhibit linear elastic behaviour**. The column experiences a concentric axial compression force.

The design engineer wants to ensure that the stress in the steel does not exceed $f_{steel,\ max}$ = 350 MPa and that the stress in the concrete does not exceed $f_{conc,\ max}$ = 50 MPa.

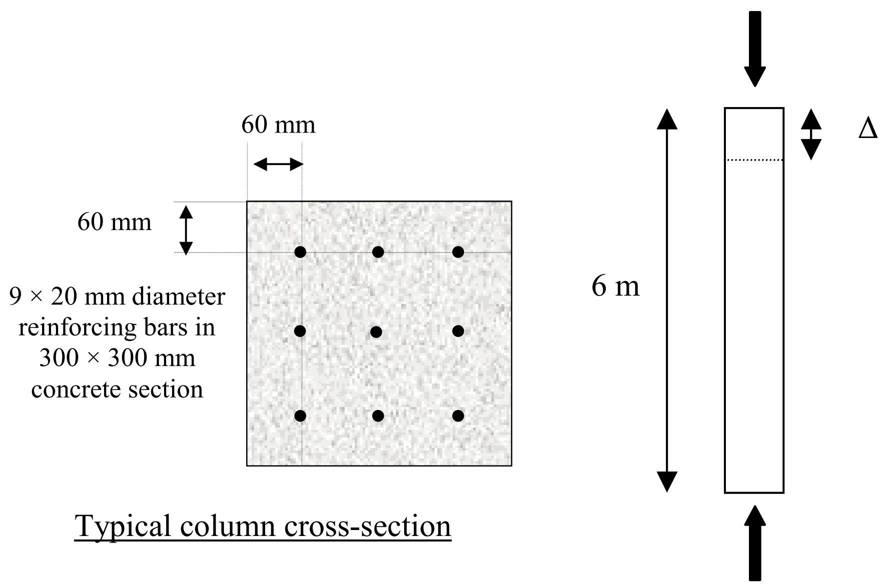
a) As the load increases from zero, **which material, steel or concrete, reaches its maximum permitted stress first? At what value of axial compression force does this occur?**

b) **For the value of load calculated in part (a) above, give the following:**

- Steel strain
- Steel stress
- Concrete strain
- Concrete stress
- Total axial shortening

c) The 20 mm diameter steel bars are replaced with 16 mm diameter bars. The concrete is not changed (it is reasonable to ignore the slight increase in concrete area). Assuming that the same load as calculated in (a) above is applied, **would the following increase or decrease (compared to the original case)? Explain your answers.**

- Steel strain
- Steel stress
- Concrete strain
- Concrete stress
- Total axial shortening



Typical column cross-section

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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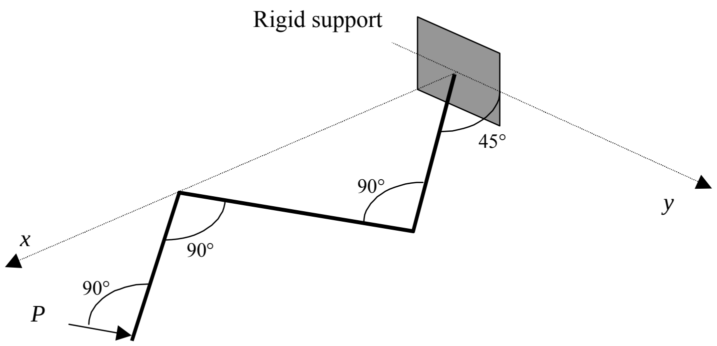
8) 10 Marks

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 load P applied at a right angle at the free end of the structure in the x-y plane as shown. 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.**



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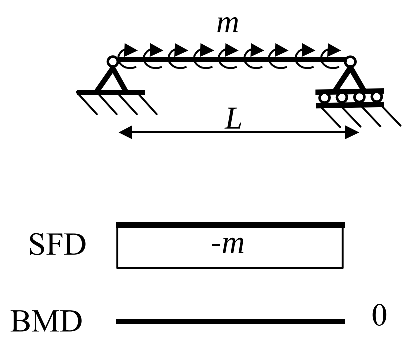
9) 10 Marks

Consider the beam shown. The shear force diagram and bending moment diagram are also shown.

m is a uniformly distributed moment (eg 10 kNm/m)



a) **Draw the free body diagram of the beam and determine the reactions.**

b) By making an arbitrary cut at any cross-section in the beam, and releasing the internal actions, **verify that the SFD and BMD given are correct.**

c) The moment and shear force do not satisfy the theory developed in Section 3.5 of the lecture notes: that $V = dM/dz$. **How can this be accounted for? If possible, derive an alternate differential equation that will explain this behaviour.**

[*Hint*: consider any assumptions made in the Lecture Notes – are they applicable in this case?].

This is the end of the examination paper, but there are 2 additional data sheets on pages 7 & 8.