ENGINEERING TRIPOS PART IIA

Monday 29 April 2013 2 to 3.30

Module 3D3

STRUCTURAL MATERIALS AND DESIGN

*Answer not more than **three** questions.*

All questions carry the same number of marks.

*The **approximate** percentage of marks allocated to each part of a question is indicated in the right margin.*

Where indicated, "ULS" and "SLS" denote Ultimate Limit State and Serviceability Limit State respectively.

Attachments: 3D3 Structural Materials and Design Data Sheets (12 pages)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book
Graph paper	CUED approved calculator allowed

You may not start to read the questions printed on the subsequent pages of this question paper until instructed that you may do so by the Invigilator

1. A grandstand enclosure is constructed from a series of primary pin-jointed frames as shown in Fig. 1 and spaced at 6 m apart along the grandstand. The primary frames are connected to one another by secondary beams that support metal deck cladding which weighs 0.15 kNm^{-2} and supports a uniformly distributed snow load of 0.75 kNm^{-2}. The frame members are made of grade S355 steel. The structure is subjected to unfactored wind loads in a transverse direction as shown in Fig. 1.

(a) With the aid of sketches where appropriate describe the load path for vertical loads and the load path for horizontal loads in the structure. [15%]

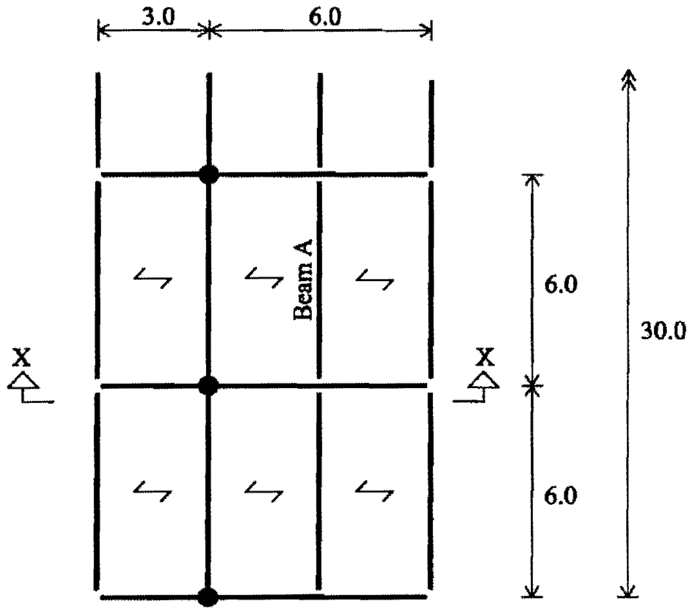
(b) By assuming that the metal cladding provides negligible restraint against lateral torsional buckling of the roof beams, that the SLS deflection limit is span/200 and that the load combination at ULS is: (1.2 × dead load) + (1.2 × snow load) + (1.2 × wind load), select suitable sections for:

(i) the secondary universal beam, labelled A in Fig. 1, that satisfies ULS and SLS requirements. [40%]

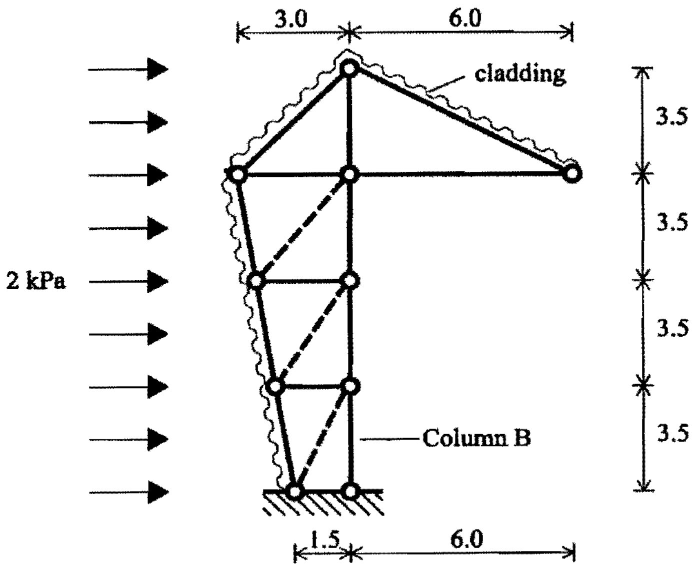
(ii) the universal column, labelled B in Fig. 1, that satisfies ULS requirements. [30%]

State any assumptions you make in your calculations.

(c) The three inclined tension members below the roof deck (shown dashed in Fig.1) are undesirable as they impede sight lines and access. By considering the entire 30 m long grandstand, devise an alternative scheme and load path for the structure. Use sketches where appropriate. [15%]



Roof Plan
(all dimensions in metres; cladding spans in dircetion shown)



Section XX
(all dimensions in metres; dashed members removed in part (c))

Fig. 1

2 The 2-pinned single bay portal frame shown in Fig. 2(a) is made from S275 steel. The portal frame is subjected to factored vertical loads (excluding self-weight) of 9 kNm^{-1} uniformly distributed over the entire span and the partial safety factor for steel, γ_m, is 1.05.

(a) By assuming the rafters to be horizontal and fixed ended show that a UB 457 x 152 x 67 is a suitable first estimate and calculate the revised vertical load including self-weight. [10%]

(b) By considering a collapse mechanism with two plastic hinges in the rafter as indicated in Fig. 2(b) show that the rotations of the rigid parts between the plastic hinges are $\theta_1 = d\delta_2/ec$ and $\theta_2 = \delta_2/c$ and the plastic moment at the hinges for a uniformly distributed load w is:

$$M_p = \frac{wc^2}{4}\left[\frac{1+(2f/c)}{1+(d/2e)}\right]$$

State any assumptions you make in your calculations. [30%]

(c) Use answers to parts (a) and (b) above to determine the horizontal reactions at the pinned column bases and sketch the bending moment diagram and the axial forces for the entire frame. Verify whether the UB section estimated in part (a) is adequate. [40%]

(d) Sketch the main features of the bolted joint between the rafter and the column. By making reference to the load path and possible forms of instability, discuss briefly the considerations involved in designing this joint. [20%]

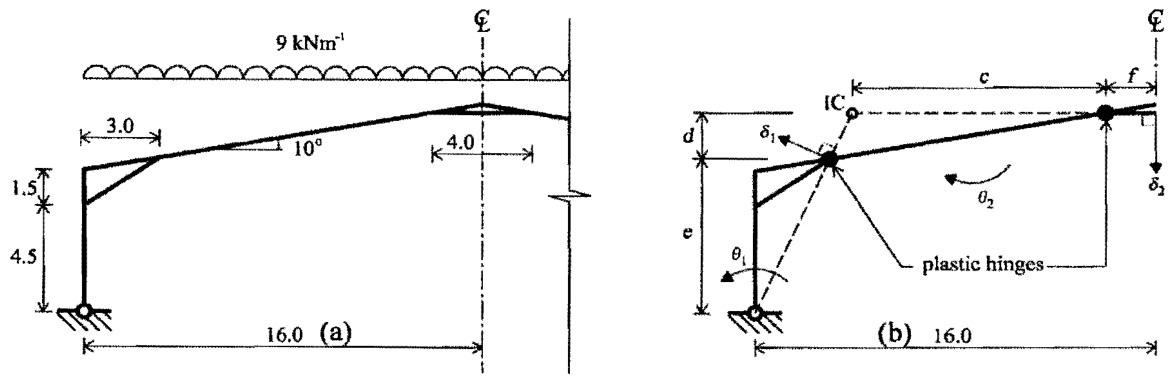


Fig 2

Final version

3 A 6m long glass and steel T-beam is supported as shown in Fig. 3. The beam is subjected to a factored uniform live load of 15 kNm^{-2} and has a negligible self-weight.

(a) Plot the bending and shear force diagrams and show salient values. [10%]

(b) By assuming that the beam behaves compositely, the design shear strength of the adhesive is 5 MPa, and the Young's modulus of glass is 70 GPa:

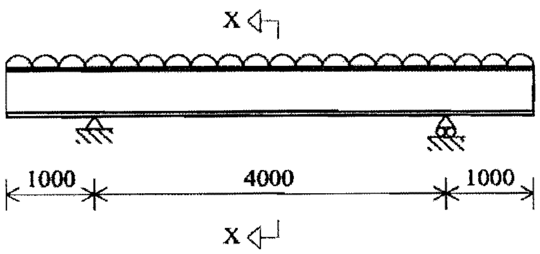
(i) Determine the centroid and the 2nd moment of area of the T-beam and sketch the stress profile at mid-span and at the support showing salient values. [30%]

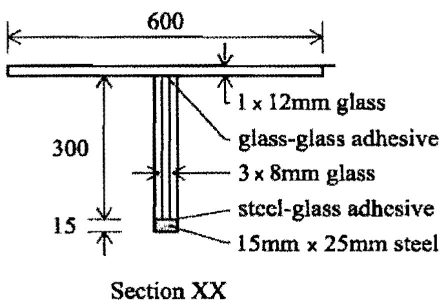
(ii) By considering the maximum principal stresses at mid-span and at the support select a suitable grade of steel and the type of glass for the components of the T-beam. (Take σ_{adm} = 50 MPa for fully toughened glass and σ_{adm} = 7 MPa for annealed glass). [30%]

(iii) Calculate the width of adhesive required for both the glass-glass and steel-glass interfaces. [10%]

(iv) Calculate the SLS deflection of the beam at both mid-span and at the free end and comment on this result. [10%]

(c) Describe two further design considerations or measures you would recommend for ensuring a stable and robust beam. [10%]





(All dimensions in mm)
Fig 3

4. (a) Sketch a typical moment-curvature diagram for an under-reinforced concrete beam loaded until failure in bending, noting salient values and regions of behaviour. [20%]

(b) The cross-section of a rectangular concrete beam is shown in Fig. 4. The concrete cube strength is 30 MPa and both the top and bottom steel have yield strength 460 MPa. The maximum tensile strength of the concrete is 3 MPa and the relevant modulus of elasticity of the concrete E_c = 26 GPa. The concrete cover to the reinforcement surface is 40 mm.

(i) Find the applied sagging moment that will result in first cracking, neglecting the effect of the steel in this region of behaviour. [10%]

(ii) The applied loading is increased until the compressive strain at the top surface of the concrete reached $\varepsilon_c = 0.0005$. Find the associated applied moment and the curvature, assuming linear-elastic behaviour with no tension in the concrete. [30%]

Explain briefly why design codes limit the widths of cracks at the serviceability limit state. [10%]

(iii) Taking material safety factors of 1.5 and 1.1 for concrete and steel respectively, find the ultimate moment capacity of the section assuming both the top and bottom steel have yielded. Check whether this assumption is valid, but do not carry out any further calculations even if it is found not to be true. The ultimate concrete strain can be taken to be $\varepsilon_{cu} = 0.0035$ and the steel yield strain $\varepsilon_y = 0.002$. [30%]

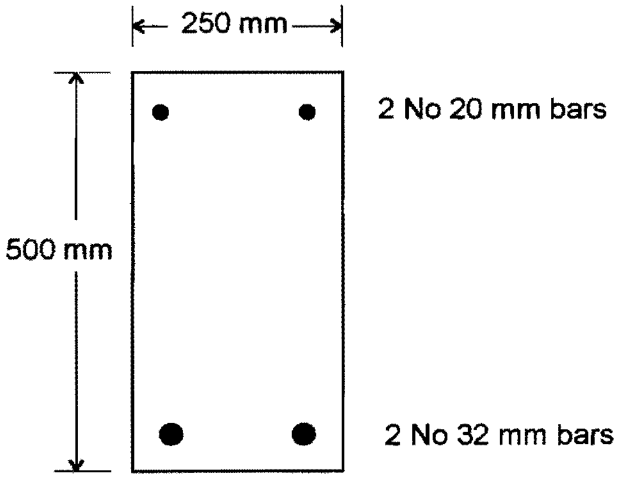


Fig. 4

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3D3 2013. Numerical answers

1 (b) (i) UB 203×102×23

(ii) UC203×203×46

2 (a) 9.93 kN/m

(c) 111.4 kN; 159 kN

3 (b) (i) 226 mm, 199.6×10^{6} mm^{4}

(iii) 12.3 mm, 4.4 mm

(iv) 0.94 mm, -0.62 mm

4 (b) (i) 31.25 kNm

(ii) 109.2 kNm; 4.89×10^{-6} mm^{-1}

(iii) 271.3 kNm