Version ME/2

EGT2
ENGINEERING TRIPOS PART IIA

Wednesday 30 April 2014   9.30 to 11

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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D3 Structural Materials and Design datasheets (8 pages).
Engineering Data Book

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

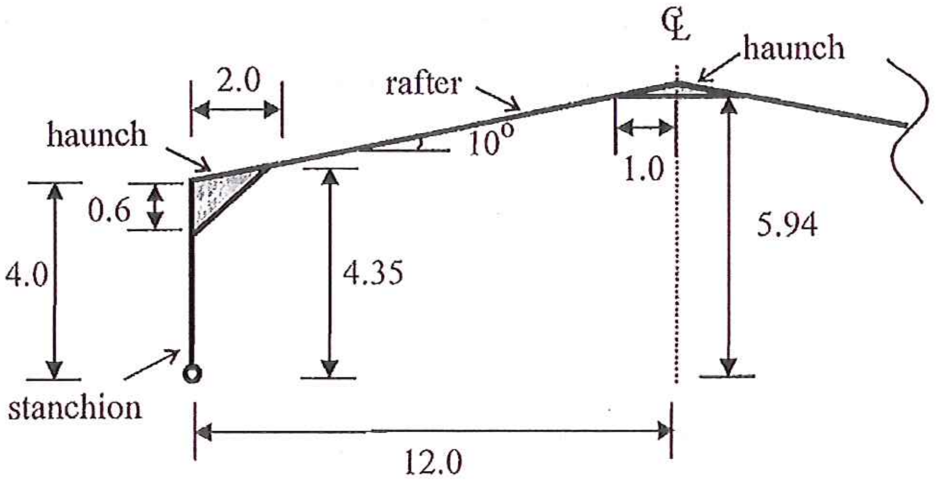
1 (a) A 5m high column may be regarded as a vertical cantilever fixed at its base but otherwise unrestrained. At the ultimate limit state it is to carry an axial compressive force of 1300 kN, applied at the top of the column. Select an efficient Universal Column section in the 305 by 305 group in S355 with material safety factor $\gamma_m = 1.05$ (using curve b on the relevant chart). [20%]

(b) Figure 1(a) shows schematically in elevation the main features of a symmetrical single-bay pinned-foot pitched-roof portal frame in S275 steel, with strengthening haunches at the corners. Ultimate Limit State (ULS) design is governed by vertical loading – a total (including an allowance for self-weight and appropriate factors on live and dead load) of 10 kN per horizontal metre, uniformly applied to the rafters across the 24 m span.

(i) By considering a symmetric mechanism of deformation, outline briefly, without doing any calculations, how you would find an equilibrium system with equal magnitudes of bending moment in the rafter at the four ends of the haunches. [10%]

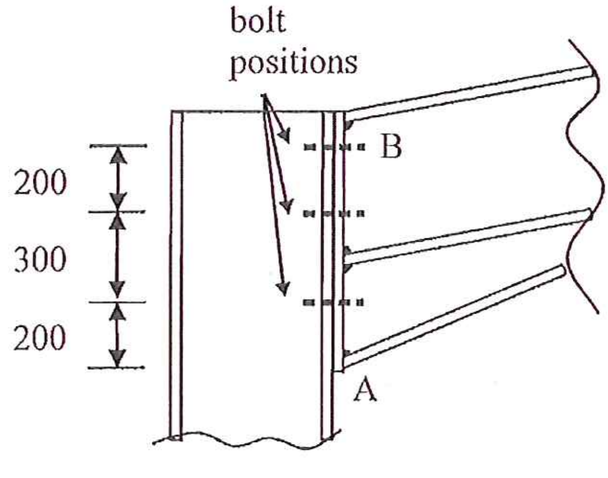
(ii) Assuming that the horizontal reaction at the frame feet is an inward force of 90 kN, sketch the bending moment diagram for the frame, giving values at salient points. Suggest an initial choice of a section for the stanchion. What further considerations would be required to refine the design? [40%]

(iii) Figure 1(b) shows some features of the bolted joint between the stanchion and a hunched end of the rafter, with its welded-on end plate. Without carrying out any further calculations, briefly discuss what stiffeners and lateral restraints would be needed in this zone and in the rest of the frame? Make a rough estimate of the forces to be transmitted by the bolts at position B. [30%]



all dimensions in m

Fig. 1 (a)



all dimensions in mm

Fig. 1 (b)

2 (a) For a simply-supported rectangular timber beam of width b and depth h and span L under uniformly distributed load, find the limit on the ratio b/h if lateral torsional buckling is to occur before the deflection limit of $L/200$ is reached. Note that for a rectangular beam with $G = E/16$ subjected to uniform moment, the elastic critical moment M_{crit} is given by:

$$M_{crit} = \frac{\pi E b^3 h}{24 l_{cr}}$$

Assume that $l_{cr} = L$, and that only flexural deflections need to be considered. For a beam under this loading, the equivalent uniform moment for buckling calculations may be taken as 0.88 times the maximum bending moment in the beam. [30%]

(b) A series of C24 75 × 220 mm timber floor beams at 600 mm centres with negligible restraint to the top flange are to carry a factored long-term uniform load of 3.5 kNm^{-2} over the entire floor area. Ignore self-weight of the beams, and take $\gamma_m = 1.3$, $k_h = 1.0$ and $k_{ls} = 1.0$. The beam service class is 2 and $E_{0,05}$ should be used.

(i) Calculate the maximum simply-supported span which meets the requirements on bending strength. [50%]

(ii) Explain the quantities γ_m, k_h, k_{ls} and $E_{0,05}$ mentioned above, and any other factors you have introduced into your calculations. Discuss whether the span calculated in part (i) is likely to satisfy a deflection limit of span/200 at the serviceability limit state. Assume that the load factor used in part (i) was 2. [20%]

3 A designer of a building with four storeys is considering three possible variations for the form of construction. In all cases the external walls will be of masonry and the internal floors and structural elements will be of concrete. The building must carry its own weight, superimposed loads on the floors and the roof, and must resist wind pressures and suctions. The three options are:

Option (1): The external walls are load-bearing and carry the weight of the walls above, and also supports the floors.

Option (2): The building has an internal load-carrying frame while the external walls are a façade that fits tightly against the floors above and below.

Option (3): The building has an internal load-carrying frame with the external walls acting as a façade. A movement joint is provided below each floor that allows relative vertical motion between the wall and the floor but prevents horizontal movement.

In each case, consider the load paths involved and if possible derive equations that you would use to assess the capacity of the wall to resist axial loads (if present) and lateral wind loads. Compare the merits and disadvantages of the three options. [100%]

(TURN OVER

4 (a) A simply supported glass fibre reinforced polymer (GFRP) plate has a span of 70 mm and a width of 20 mm. The lay-up is specified to be balanced and symmetric consisting of layers of 0.125 mm GFRP plies. The constituent material properties of the E-glass/epoxy are consistent with those used on pages 7 and 8 of the 3D3 Structural Materials and Design Datasheet. The plate is to be produced with most of the plies laid at either 0° or 90° angles. The x-direction is at angle 0°.

(i) A Young's modulus E_x of 29 GPa is required and 33% of plies are to be oriented in the ±45° directions. Find the percentages of plies required in the different directions in order to meet this specification. [15%]

(ii) Find G_{xy}, ν_{xy} and E_y for the plate found in part (i). [10%]

(iii) A uniform line load of total force 145 N is applied across the width of the plate at mid-span. Find the minimum laminate thickness required so that the failure strain limits of e_T = 0.3% and e_C = 0.7% are not exceeded. Suggest an appropriate lay-up. Assume that the possibility of a failure in shear can be disregarded. [35%]

(b) Derive an expression for the elastic shear deflection at mid-span of a rectangular simply supported beam with a point load V at mid-span. The beam is of width b, height h, span l and made of a material with shear modulus G. Would you expect shear deflections in advanced composite structures to be significant? Give reasons. [40%]

END OF PAPER

List of Numerical Answers – 3D3 – 2013/14

1 (a) – 305 X 305 X 118 UC

2 (a) – b/h $\leq$ 0.164

(b) – About 5.2m

4 (i) 33% for $\pm$ 45°, 50% for 0° and 17% for 90°

(ii) G_{xy} = 7400 MPa, ν_{xy} = 0.25, E_y = 17000 MPa

(iii) t_{min} = 2.96mm (x-direction) and t_{min} = 1.93mm (y-direction). Therefore a minimum thickness of 3mm (equivalent to 24 layers) is required. Layers should be symmetric and balanced (12 plies at 0°, 4 plies at 90° and 8 plies at $\pm$45°