ENGINEERING TRIPOS PART IIA

Wednesday 7 May 2003 9 to 10.30

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.*

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

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1 (a) Outline briefly Ashby's method of selecting material and section shape, when designing simple beams for specified bending strength so as to minimise mass per unit length. What standard of comparison for cross-sections is being used? Mention any limitations of the method. [30%]

(b) (i) Determine the shape-efficiency factor ϕ_e for stiffness in elastic bending for a $914 \times 419 \times 388$ UB structural steel section bent about its major axis. [10%]

(ii) For a complicated bridge it will be fair to use the total mass of structural material, including stiffeners, gusset plates etc., in determining the equivalent solid section for comparison. A simply-supported truss bridge of uniform depth is reported to incorporate 850 tonnes of structural steel for a span of 146 m, and to have been designed so that the midspan deflection under the structure's own weight is less than 1/300 of the span. By considering an equivalent beam, estimate the shape-efficiency factor ϕ_e for this bridge. Comment on your result. [25%]

(c) Explain briefly why the ratio of span L to depth d plays an important role in the design of beams in different materials. Derive a formula for the limiting span/depth ratio for a fixed-ended beam, in linear-elastic/perfectly-plastic material, which is to carry a uniformly-distributed total load $\gamma_f W$ without collapse, using the material strength σ_f to the full, but is not to deflect more than L/F under load cW. Could the formula usefully be modified for a brittle material? [35%]

Note: The central deflection of a fixed-ended elastic beam under uniform load is one fifth of that for a simply supported beam.

2 It is proposed to weld up from S355 steel plate a uniform I-section girder of overall depth 1.1 m, to span 26 m simply supported. The two flanges would be 500 mm wide and 35 mm thick, and the web would be 1030 mm deep and 10 mm thick. The partial safety factor γ_m on material strength is to be 1.1.

(a) Assuming fully plastic behaviour, show that a uniformly distributed total load of approximately 2,100 kN at ULS (including any specified load factors) would exhaust the bending resistance at midspan. [20%]

(b) Discuss what calculations would be required for regions near the supports, where there is to be a bearing below the bottom flange, to demonstrate that this loading could indeed be carried at ULS, and suggest what stiffener(s) if any would be needed. What further checks might be needed at midspan, and what main force(s) would be considered in designing the welds between the main plates? [30%]

(c) Consider the top flange of the beam as a column under axial compression only, pin-ended at points where the flange has lateral supports. Hence, using the Steel Datasheet, estimate the maximum spacing of lateral supports needed for the compression flange near midspan, if the full yield stress is to be attainable at midspan. [30%]

(d) An engineer suggests that rather than have lateral supports to prevent buckling, it would be better to build a rectangular box of the same overall dimensions and flange thickness, but with two web plates each 5 mm thick. Such a box would have increased I_{yy}, negligible warping factor C_w, and a basic torsion constant J increased to approximately 245,000 cm^4. Discuss whether this alternative would be practical and advantageous. [20%]

3 (a) Discuss how the lower bound theorem of plasticity theory may be exploited in the design of structures for the ultimate limit state. What assumptions and/or material properties underlie this theorem? Briefly discuss any required limitations or restrictions on its exploitation when designing in (i) steel, (ii) reinforced concrete and (iii) timber. [30%]

(b) Fig. 1 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 its corners. Assume that ULS design is governed by vertical loading – a total (including appropriate load factors on live and dead components, and an allowance for self-weight of the frame) of 9.5 kN per unit horizontal distance, applied uniformly everywhere across the span.

(i) Explain briefly why it is not necessary to consider elastic behaviour in selecting the bending moment diagram for use in design at ULS. Use a mechanism method, taking appropriate dimensions from the right side of Fig. 1, to select a diagram with equal magnitudes of bending moment in the sloping rafter next to the inner and outer haunches. Hence suggest a suitable UB cross-section for the (uniform) rafter. Suggest a suitable cross-section for the stanchion, and briefly discuss what other checks would be needed to confirm these two suggestions.[50%]

(ii) Sketch the main features of the bolted joint between the stanchion and the haunched end of the rafter. Discuss briefly what stiffeners and lateral restraints would be needed in this zone, and the main considerations involved in designing this joint. [20%]

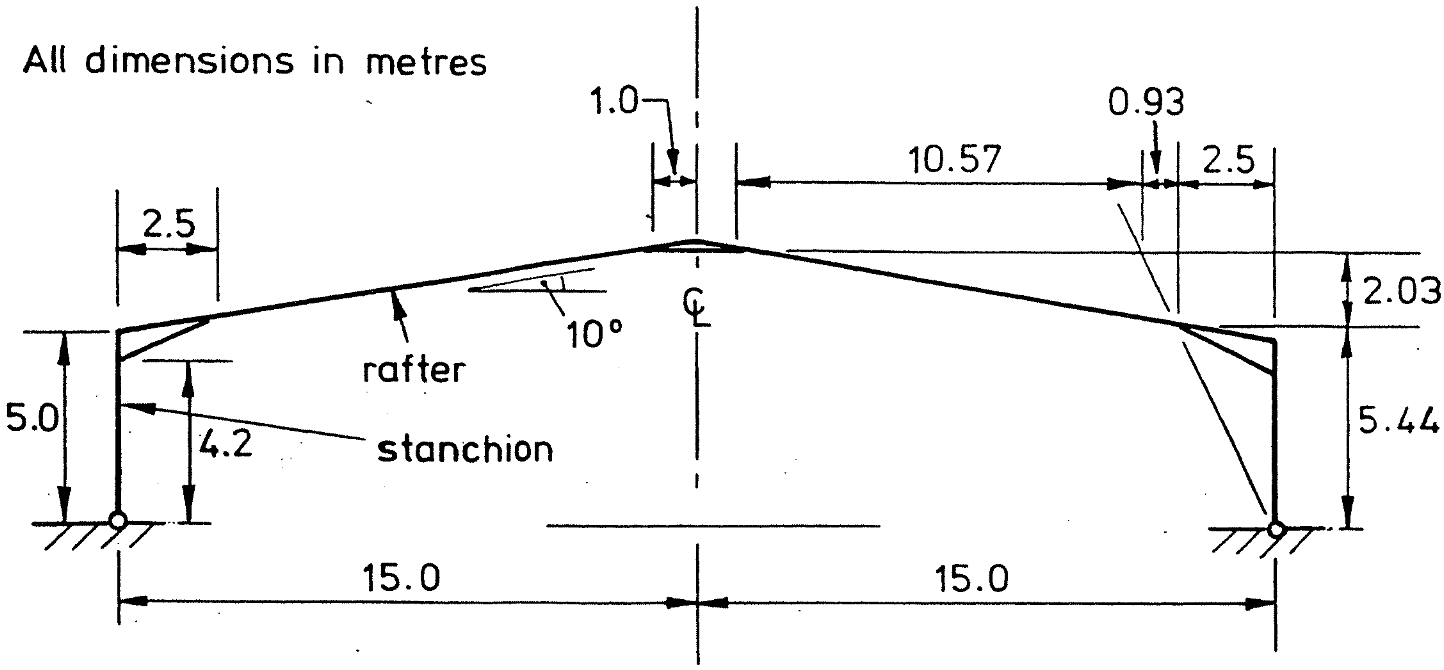

Fig. 1

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

(b) The cross-section of a rectangular concrete beam is shown in Fig. 2. The concrete cube strength is 30 MPa and both the top and bottom steel have yield strength 450 MPa. The maximum tensile strength of the concrete is 3 MPa and the relevant modulus of elasticity of the concrete $E_c = 26\,\text{GPa}$. The concrete cover to the reinforcement surface is 40 mm.

(i) Find the applied sagging moment which 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 reaches $\varepsilon_c = 0.0005$. 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%]

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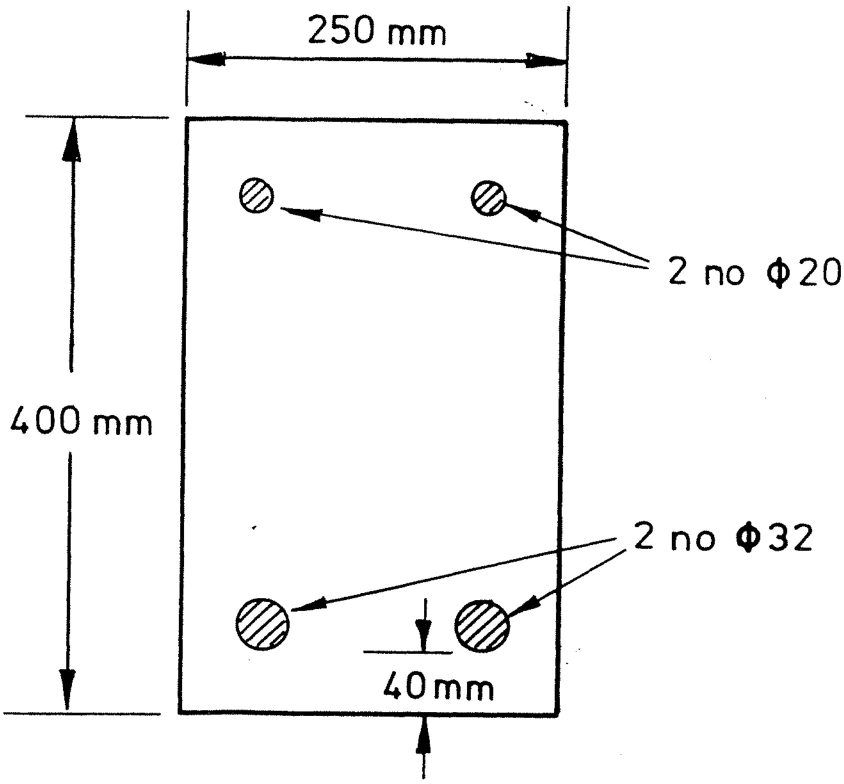

Fig. 2

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5 (a) For a simply-supported rectangular timber beam of width b 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 $G \sim E/16$ subjected to uniform moment, the elastic critical moment $M_{\text{crit}} = \pi E b^3 h / 24 \ell_{cr}$. Assume that $\ell_{cr} = L$, that there is no precamber, and that only flexural deflections need 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 kN/m^2 over the entire floor area. Ignore the 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 approximately 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, and discuss whether the span calculated in (i) is likely to satisfy a deflection limit of span/200 at the serviceability limit state. [20%]

END OF PAPER

No answers have been received from the Examiner for this Module