EGT2
ENGINEERING TRIPOS PART IIA

Wednesday 1 May 2019 2 to 3.40

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

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 A rectangular single-storey building is constructed from five nominally identical pin-jointed frames of span 9 m as shown in Fig. 1 and spaced 6 m apart along the building. The frames are connected to one another by eaves steel beams at the vertices of the frame. The building is clad with a metal deck that weighs 0.2 kNm^{-2} that is simply supported between the primary frames and in turn supports a uniformly distributed snow load of 0.75 kNm^{-2}. The building is subjected to the wind pressures shown in Fig. 1. All steel members are of grade S355 and the partial material factor γ_m for steel is 1.1.

(a) Devise a suitable bracing scheme in the roof and walls of the building to ensure lateral stability without encroaching on its internal floor space. With the aid of sketches where appropriate, describe the vertical and horizontal load paths for the whole structure. [25%]

(b) Assuming fully plastic behaviour and a load combination at ULS of: (1.2 × dead load) + (1.2 × live load) + (1.2 × wind load), determine:

(i) The lightest channel sections required for the eaves beam and for the bracing elements in the roof and walls. [40%]

(ii) The lightest UB section required for a primary steel beam in a typical frame. In your calculations you should assume that the primary steel beams are restrained against lateral torsional buckling and that the SLS deflection limit is span/100. [25%]

(c) In real-world conditions the wind direction will vary from that shown in Fig. 1. Without performing further detailed calculations, describe with the aid of sketches how the structural scheme you proposed in part (a) could be adapted to cater for different wind directions. [10%]

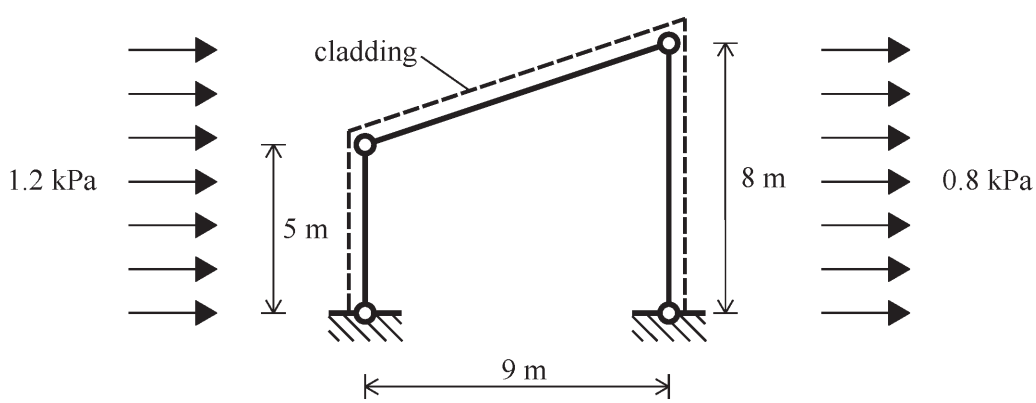


Fig. 1

2 (a) Figure 2 shows a bolted joint connecting a secondary beam to a primary beam in a steel structure. The primary and secondary beams are UB 533×210×122 and UB 457×191×67, respectively, both of S275 steel. They are connected using equal angle cleats of 150×150×10, also of S275 steel. There are four bolts through the web of the primary beam and three bolts through the web of the secondary beam as shown. All bolts are M20 Grade 4.6. At the ULS, the joint is to transmit a shear force of 200 kN from the secondary beam into the primary beam. Assuming that no bolt transmits any tensile force, determine for bolt C only:

(i) the shear force per shear plane; [10%]

(ii) the web bearing stress; [10%]

(iii) the cleat bearing stress. [10%]

(iv) Assuming that, at ULS, an M20 bolt can carry 39.4 kN and the webs and cleats can sustain a bearing stress of 1.5 times the yield stress, determine the maximum shear force that the joint can transmit, based on the considerations for bolt C alone. All material partial safety factors may be taken as unity. [10%]

(b) Determine the design compressive axial force that may be sustained by a 4 m column of UC 356×368×202 in S275 steel. The column ends are restrained against sway. For flexure about the minor axis, the end supports are pinned-pinned and for flexure about the major axis, the end supports are fixed-fixed. Material partial safety factors may be taken as unity. [30%]

(c) Determine the design value of the uniform major-axis bending moment that may be sustained by a 6 m beam of UB 305×165×54 section in S275 steel. The beam ends are simply supported with respect to major and minor axis flexure. The ends are also restrained against torsional rotation and are free to warp. Material partial safety factors may be taken as unity. [30%]

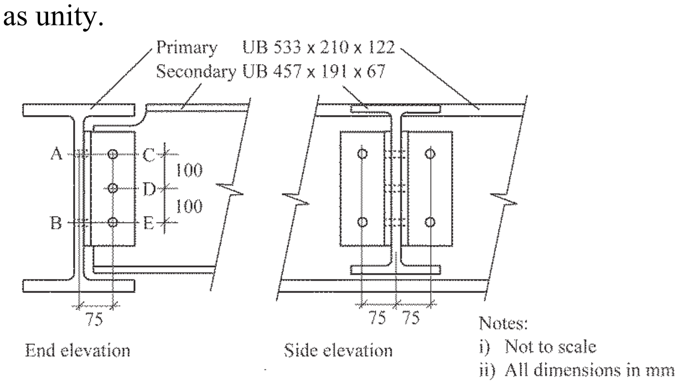


Fig. 2

3 An 8 m long reinforced concrete beam is supported at A and B as shown in Fig. 3. The beam is 300 mm wide by 600 mm deep and carries a characteristic live load of 40 kNm^{-1}.

(a) Sketch the bending moment and shear force diagrams for the concrete beam and identify the salient values and their locations. [30%]

(b) Design and sketch a layout for the longitudinal and shear reinforcement at support B. In your calculations you should assume a concrete cube strength of 50 MPa, minimum cover of 40 mm, the steel reinforcement has a yield stress of 460 MPa and the diameter of longitudinal bars and stirrups are 25 mm and 12 mm, respectively. The partial safety factors for concrete and steel are 1.5 and 1.15 respectively, and the load factors for dead and live loads are 1.4 and 1.6 respectively. [40%]

(c) After completing your design you are asked to advise on whether the beam could be tapered by reducing the beam height linearly from 600 mm at B to h_A at A and h_C at C, as shown in Fig. 3. By assuming that the bending moments and shear forces along the beam are unchanged from those in part (a), and by assuming that the maximum percentage of longitudinal and shear reinforcement determined in part (b) is not exceeded at any cross-section of the beam, determine the minimum depths for h_A and h_C. [30%]

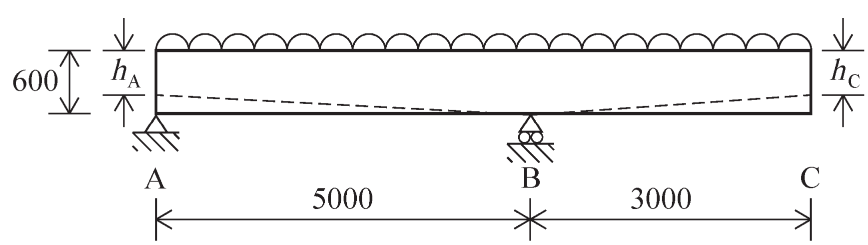


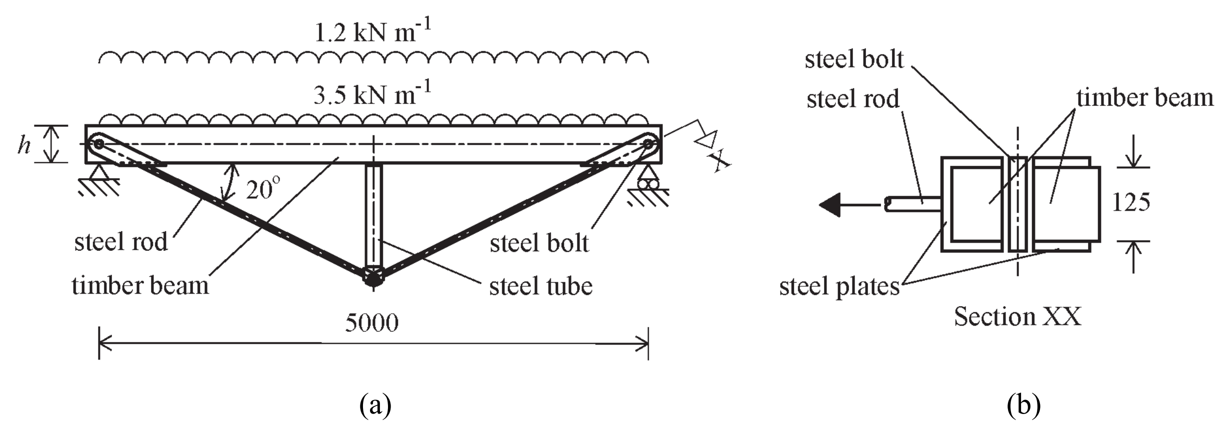
Fig. 3

4 The structure in Fig. 4 consists of a horizontal timber beam that is propped at mid span by a steel strut and tie system. The steel strut is a square hollow section and the steel tie is a solid rod, both are made of grade S355 steel. The timber beam is made of grade C16 timber. The beam carries the following vertical design loads: a long term dead load of 3.5 kNm^{-1} and an additional short term load of 1.2 kNm^{-1}. The load factor for ultimate limit state is 1.5 and the timber exposure corresponds to service class 1.

(a) By considering both the short and long term load cases, plot the bending moments, shear forces and axial forces in the timber beam, showing salient values and calculate the axial forces in the steel strut and ties. [40%]

(b) The timber beam is 125 mm wide and is restrained laterally. Determine the minimum depth h of a timber beam required to satisfy shear strength requirements and bending strength requirements. In your answers you may assume that $k_h = k_{ls} = 1.0$, and the material safety factor for timber is 1.3. [30%]

(c) The steel rods are connected to the timber beam by means of steel plates and a single S355 steel bolt that bears directly on the timber rafter, as shown in Fig. 4(b). By assuming that the material safety factors for the steel bolt and the timber beam are 1.15 and 1.3 respectively, determine the diameter of the bolt. [30%]



(all dimensions in mm)

Fig. 4

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