Version MO/3

EGT2
ENGINEERING TRIPOS PART IIA

Monday 25 April 2016 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
Graph 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.

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

1 An 8-storey building, with a plan layout shown in Fig. 1, consists of one-way spanning reinforced concrete slabs supported by reinforced concrete beams and reinforced concrete columns, all having a fire resistance of 2 hours. Each storey has a total height of 4 m and lateral stability is provided by two reinforced concrete lift/stair cores located at the ends of the building. The building is subjected to an unfactored vertical live load of 3 kN m^{-2} on every floor. The load factors for dead and live loads are 1.4 and 1.6 respectively and all concrete elements in the building have a cube strength of 50 MPa and a density of 2400 kg m^{-3}.

(a) By assuming that the concrete elements are lightly stressed and pin-jointed, use the preliminary sizing tables in the Data Sheets to provide initial sizes for the slabs, beams and columns in the building and perform a load path analysis to determine the loads on the typical slab, beam and column. [20%]

(b) By assuming that the connections between all structural elements are pin joints, that all steel reinforcement bars have a yield stress of 460 MPa and that the partial safety factors for concrete and steel are 1.5 and 1.15, respectively, calculate the areas and sketch the cross-sectional layout of:

(i) The longitudinal reinforcement required in the typical concrete slabs. [20%]

(ii) The longitudinal and shear reinforcement required in the internal 8 m concrete beams. [30%]

(iii) The longitudinal reinforcement required in the internal concrete columns at ground floor level. [10%]

(c) An alternative design scheme for the building has non-load bearing lift/stair cores and moment connections between the beams and columns. With the aid of sketches where appropriate, but without performing any further detailed calculations, discuss how the load-paths of this alterative scheme would differ from the original one and how it would affect the reinforcement calculations you performed in part (b). [20%]

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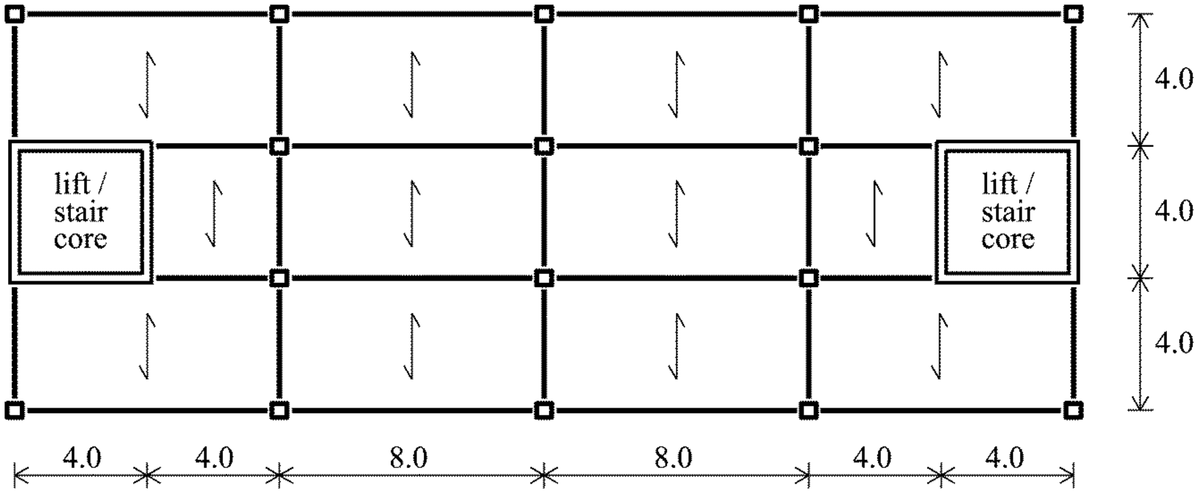


Typical Floor Plan
(all dimensions in metres; ⟷ denotes spanning direction of concrete slab)

Fig. 1

2 Figure 2 shows a joint, made using four pieces of angle, between a primary beam and two secondary beams (in the same plane, one each side of the primary), all in S355 steel. There are sixteen 20 mm diameter bolts in 22 mm holes. The ultimate limit state (ULS) shear capacity of each bolt per shearing plane is 375 MPa on its cross-section, and the ULS bearing capacity in each plate is an average stress of 550 MPa on the nominal bearing area.

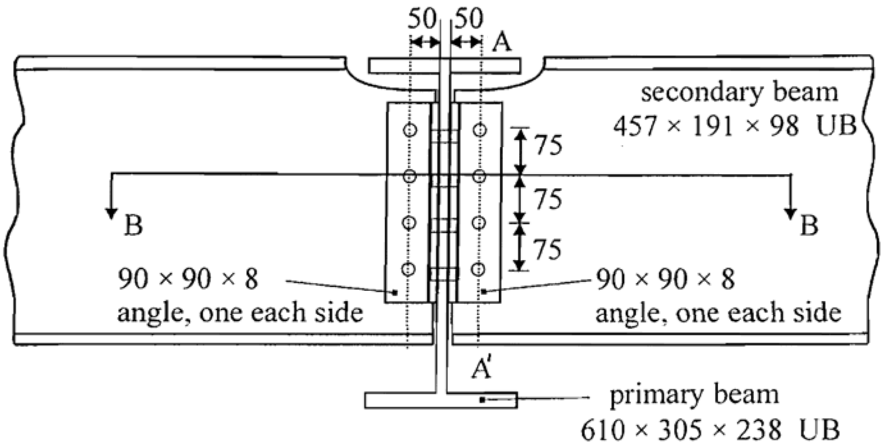
(a) An engineer checks a load path through the joint in which each secondary beam applies to the primary beam only a single downward force. This force is assumed to act along the vertical line of bolts through the secondary web (e.g. A-A'). Determine the maximum (ULS) value of this force. [15%]

(b) Supposing that this maximum force is applied simultaneously by both secondary beams, what are the design forces on the bolts through the primary web? If the ULS tensile capacity of a bolt is 500 MPa on its nominal area, and the sum of the ratios of applied shear and tensile forces to the respective bolt capacities must not exceed unity, is the connection to the primary web adequate? What other checks on the load path through this joint should be carried out? [35%]

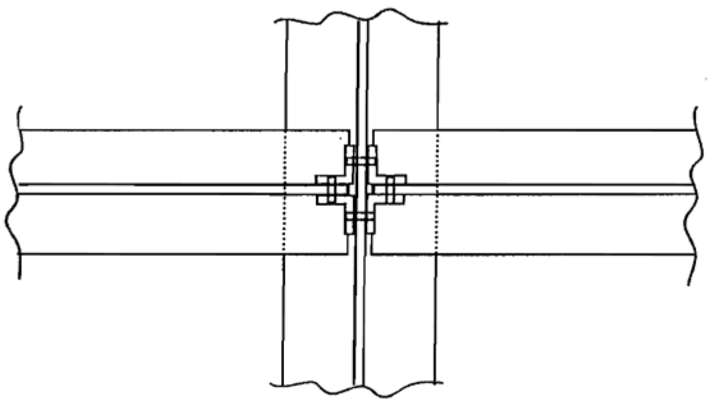
(c) In a particular case, the required ULS vertical reaction is only 350 kN on each secondary beam. An engineer points out that it might then be advantageous to consider another load path taking a hogging moment, applied externally to the secondary beam, through the joint to restrain it against rotation.

(i) Considering one vertical line of bolts through a secondary web, estimate the maximum value of this hogging moment at A-A'. [35%]

(ii) What are now the ULS design forces on the bolts in the primary web? [15%]



side view
(all dimensions in mm)



section B-B

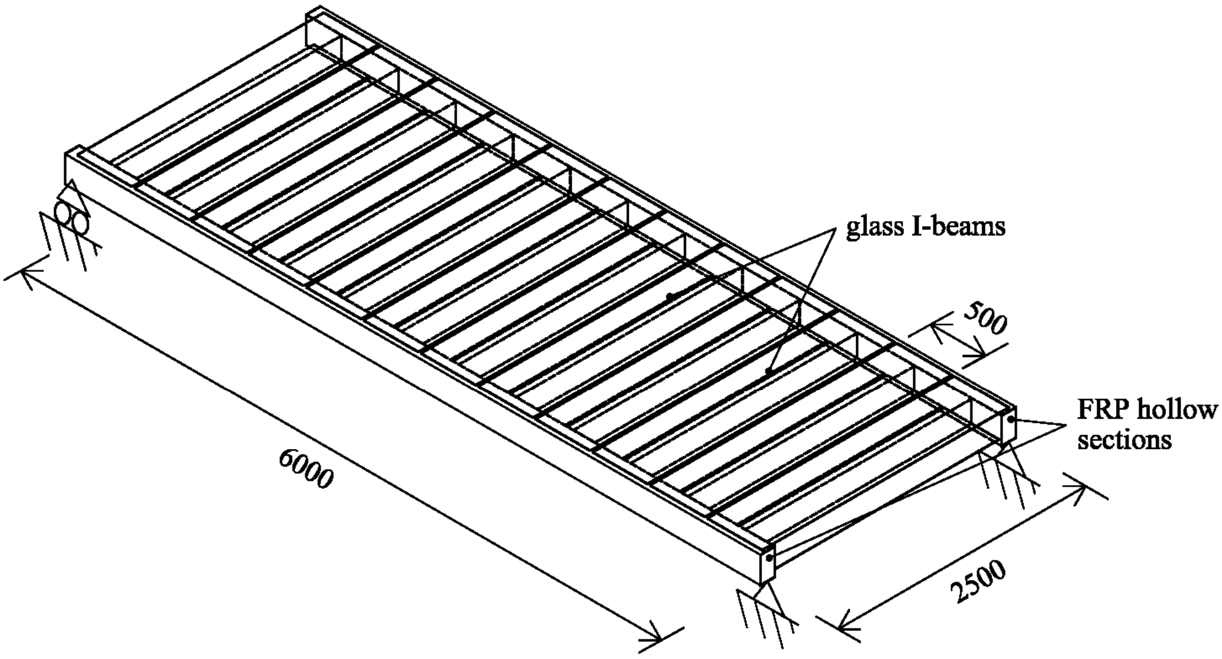
Fig. 2

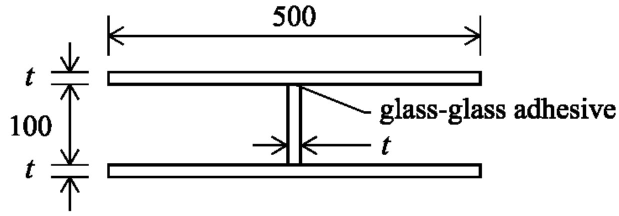
3 Figure 3 shows a glazed floor consisting of secondary 2.5 m long glass I-beams simply supported by 6 m long primary pultruded fibre reinforced hollow sections that are in turn simply supported at their ends. The bridge is subjected to a short-term live load of 4 kN m^{-2} and the load factors for dead and live loads are 1.4 and 1.6, respectively.

(a) By assuming that the glass flanges and the glass web in a typical I-beam are of equal thickness t and that full composite action is achieved between the glass flanges and the glass web, identify the flange locations at mid-span of the glass I-beam where maximum tensile stresses would occur. Calculate the tensile stresses at these locations in terms of thickness t and determine the thickness and type of glass required. In your answers you may assume that the glass has a density of 2500 kg m^{-3} and a Poisson's ratio of 0.22. You should also assume that f_{rk} = 90 MPa, f_{gk} = 45 MPa, γ_{mA} = 1.8, γ_{mV} = 1.2, k_A = 1 and that k_{mod} is 1.0 and 0.3 for short and long term loads, respectively. [50%]

(b) The pultruded hollow sections are 100 mm wide and 150 mm deep and consist of E-glass fibre (E_f = 76 GPa) with a polyester resin matrix (E_m = 3 GPa). The fibre volume fraction is 60% and the resulting composite material has σ_{LT} = 520 MPa and σ_{LC} = 410 MPa. By assuming that the pultruded hollow sections have a uniform wall thickness, calculate the thickness required to resist the maximum bending moment at mid-span and calculate the maximum deflection at mid-span induced by the superimposed loads. [30%]

(c) By referring to your answers to the previous parts of the question, comment on whether you deem the design of this structure to be acceptable and suggest further design checks you would perform and modifications you would make. [20%]





Section through typical glass I-beam

(all dimensions in mm)

Fig. 3

4 A pitched roof consists of a series of tied-rafter frames at 2 m centres. Each tied-rafter frame consists of two pin-jointed C24 timber rafters and an S355 steel rod that ties the rafters to one another as shown in Fig. 4(a). The roof carries the following vertical design loads: a long term dead load of 2.5 kN m^{-1} and an additional short term maintenance load of 0.6 kN m^{-1}. The load factor for ultimate limit state (ULS) 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 rafters, showing salient values and calculate the axial force in the steel rod. [40%]

(b) By assuming that the C24 timber rafters are 150 mm wide and that the rafters are restrained laterally, determine the minimum depth h of a timber rafter required to satisfy shear strength requirements and bending strength requirements and determine the diameter of the S355 steel rod. In your answers you may assume that $k_h = k_{ls} = 1.0$, and the material safety factors for timber and steel are 1.3 and 1.15 respectively. [30%]

(c) The steel rod has steel plates at both ends that are connected to the timber rafter by means of a single S355 steel bolt that bears directly on the timber rafter, as shown in Fig. 4(b). By assuming that the material safety factor for the steel bolt is 1.15, determine the diameter of the bolt. [30%]

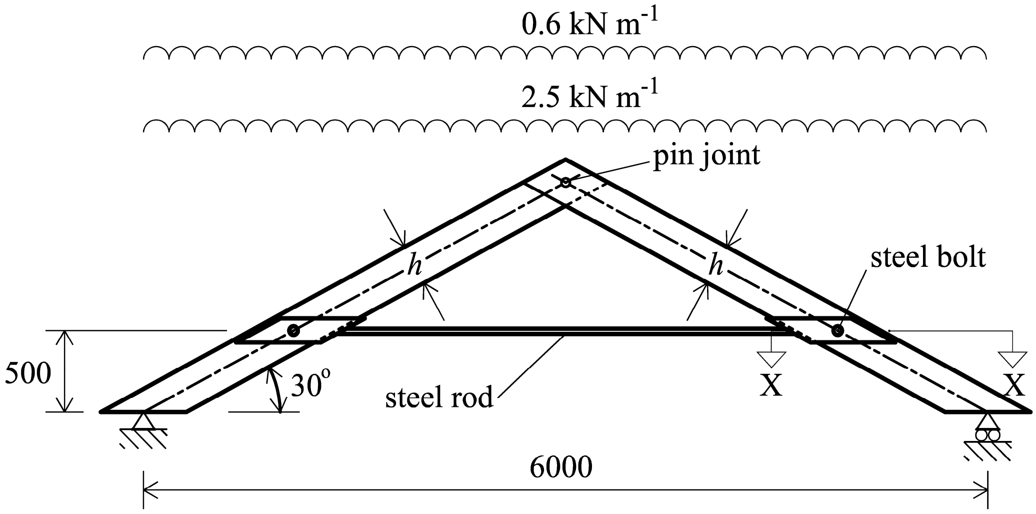
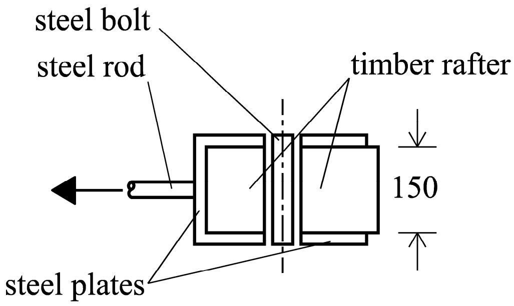


Fig. 4(a)



Section XX

Fig. 4(b)

(all dimensions in mm)

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