EGT2
ENGINEERING TRIPOS PART IIA

Tuesday 25 April 2017 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.*

*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 A ten storey, 35 m tall, building consists of a pin-jointed S355 steel frame with a braced internal core for lateral stability. The floor layout, shown in Fig. 1, consists of one-way spanning simply-supported concrete slabs that have an unfactored self-weight of 3.6 kN m^{-2} and an unfactored superimposed live load of 2.5 kN m^{-2}. The total horizontal wind pressure on the building is 2 kPa, acting uniformly over the height of the building.

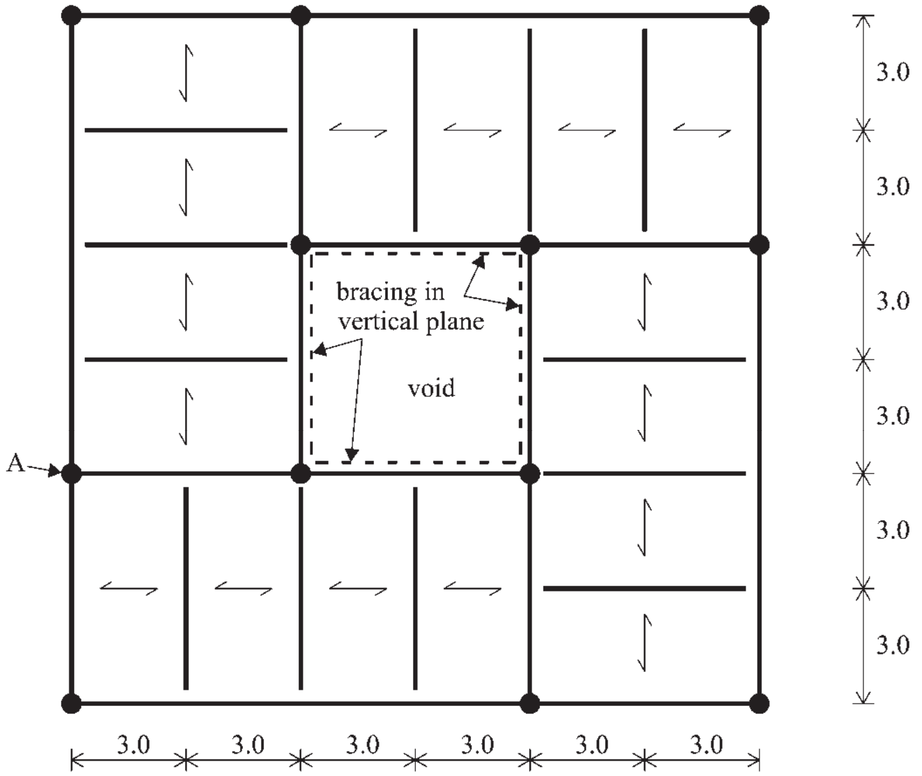
(a) With the aid of sketches, where appropriate, describe the load path for vertical loads and the load path for horizontal loads in the structure. [20%]

(b) Sketch two alternative floor framing layouts that could be used as efficient alternatives to that shown in Fig. 1. [10%]

(c) By assuming that the concrete floor slabs provide full restraint against lateral torsional buckling to the steel beams, that the SLS deflection limit is span/200 and that the load combination at ULS is: (1.4 × dead load) + (1.6 × live load), determine the shallowest UB section required for the heaviest loaded 6 m long floor beams in Fig. 1. [30%]

(d) By considering the layout shown in Fig. 1 and assuming a load combination at ULS of: (1.2 × dead load) + (1.2 × live load) + (1.2 × wind load), select the smallest possible UC section for the four internal, centrally located columns around the void, at ground floor level. [30%]

(e) The client wishes to create an 18 m clear span along one edge of the building at ground floor level by removing the perimeter column (labelled A) at this level. Without doing any detailed calculations, sketch one viable option for achieving this. [10%]



Typical Floor Framing Layout
(all dimensions in metres; ⟵⟶ denotes spanning direction of concrete slab)

Fig. 1

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. Each of 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, find the uniformly distributed total load (including any specified load factors) that would exhaust the bending resistance of the section 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. 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%]

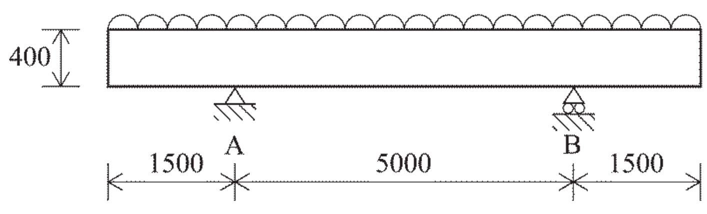
3 (a) With the aid of suitable free-body diagrams, describe how the bending moment capacity of a reinforced concrete beam is governed by the concrete and longitudinal steel elements within it. [20%]

(b) The 200 mm wide by 400 mm deep by 8 m long reinforced concrete beam shown in Fig. 2 is supported by 1.5 m long, 3 m high masonry blockwork walls at A and B. The beam carries a uniformly distributed working live load of 20 kNm^{-1} and its self-weight. The concrete cube strength is 40 MPa. The longitudinal reinforcement bars have a diameter of 25 mm and shear reinforcement bars have a diameter of 12 mm. All bars have a yield stress of 460 MPa and a minimum cover of 40 mm. 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.

(i) Sketch the bending moment and shear force diagrams for the concrete beam and identify the salient values and their locations. [20%]

(ii) Design a layout for the longitudinal and shear reinforcement at the critical cross-sections. By considering the variations in bending moment and shear force along the beam, but without performing further detailed calculations, sketch an optimised longitudinal reinforcement layout. [50%]

(iii) Identify the two likely failure modes for the blockwork walls and determine the minimum wall thickness required to support the reinforced concrete beam. In your calculations you should assume the compressive strength of the masonry is 8 MPa and the partial safety factor for the masonry wall is 3.5. [10%]



(all dimensions in mm)

Fig. 2

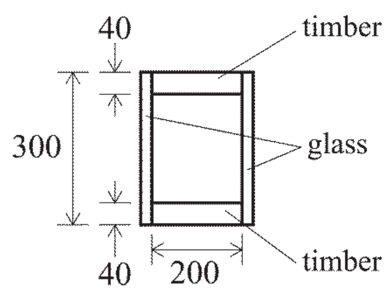
4 (a) By considering both shear and flexural deformations, show that the mid-span deflection of a simply supported beam of depth h, width b and length L subjected to a uniformly distributed load of total magnitude W is given by:

$$v_{tot} = \frac{5WL^3}{32Ebh^3}\left(1 + \frac{6Eh^2}{5GL^2}\right)$$ [40%]

(b) A 4000 mm long by 200 mm wide C24 timber beam carries a characteristic uniformly distributed load of 30 kN.

(i) Determine the minimum depth h of the timber beam required to satisfy an instantaneous deflection limit of span/200 at mid-span, shear strength requirements and bending strength requirements. In your calculations you should assume that the beam is laterally restrained, that $k_{mod} = k_h = k_{ls} = 1.0$, $\gamma_m = 1.3$ and that the load factor for ULS is 1.5. [30%]

(ii) An alternative composite beam has a rectangular hollow cross-section made of C24 timber and glass as shown in Fig. 3. The designer considers whether to use annealed or fully toughened glass. Determine the thicknesses required for the two types of glass to satisfy an instantaneous deflection limit of span/200 at mid-span, and bending strength requirements. You should also assume that E_{glass} = 74 GPa, 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 for short term loads. State clearly any further assumptions you make in your calculations. [30%]



(all dimensions in mm)

Fig. 3

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