Version MO/4

EGT2
ENGINEERING TRIPOS PART IIA

Monday 27 April 2015 9.30 to 11.00

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.*

Where indicated, "ULS" and "SLS" denote Ultimate Limit State and Serviceability Limit State respectively.

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
Engineering Data Book
CUED approved calculator allowed
Attachments: 3D3 Structural Materials and Design Data Sheets (12 pages)

10 minutes reading time is allowed for this paper.

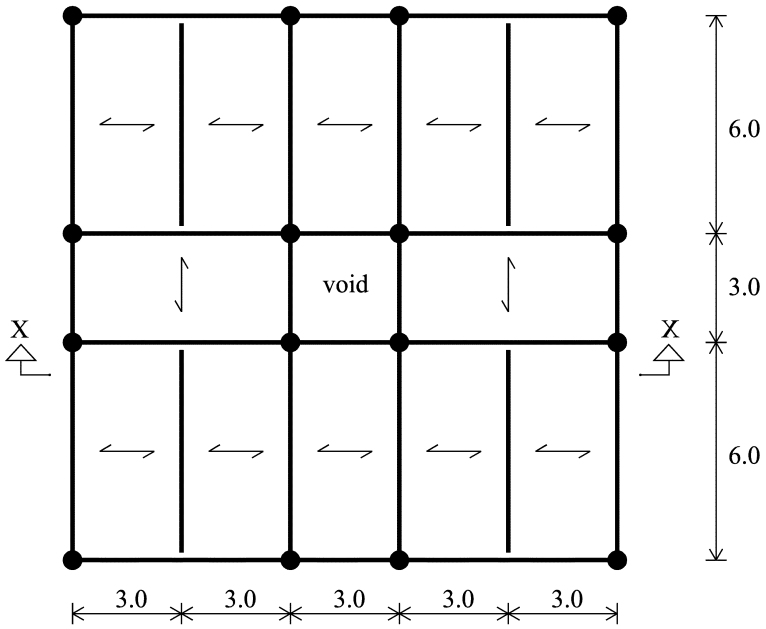
You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 A multi-storey building (Fig. 1) consists of a grade S355 steel frame with pin-jointed connections. The floors consist of one-way spanning simply-supported slabs that have an unfactored self-weight of 0.375 kN m^{-2} and an unfactored superimposed live load of 3 kN m^{-2}.

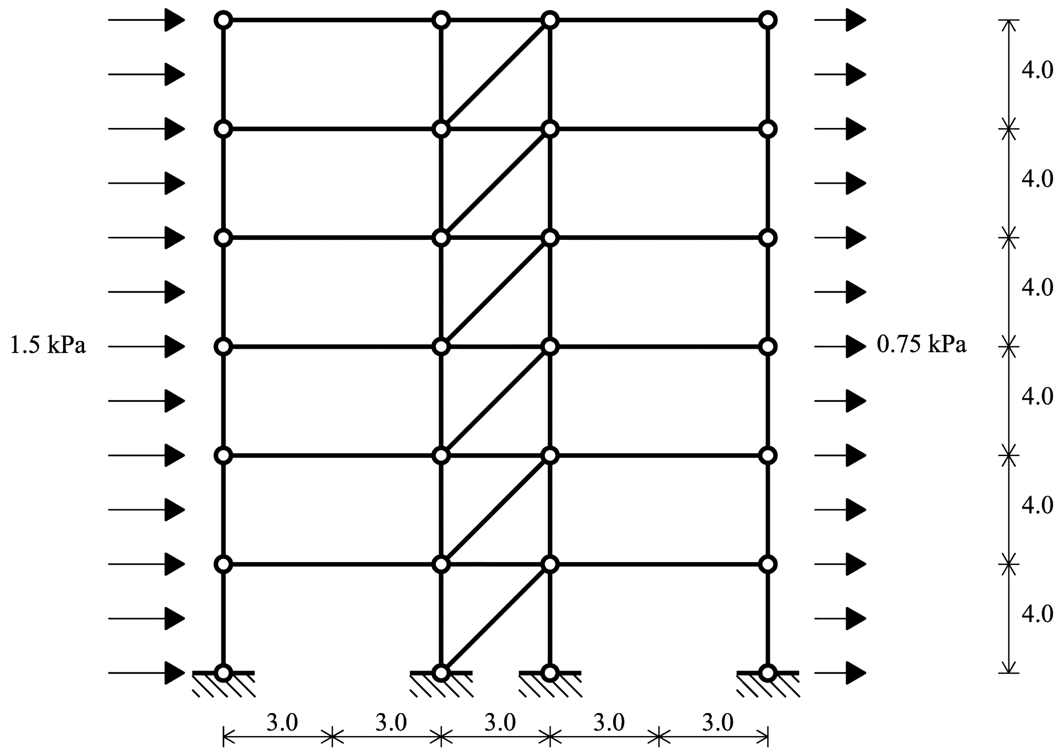
(a) With the aid of sketches, where appropriate, describe the load path for vertical loads and the load path for horizontal loads in the structure. [20%]

(b) By assuming that the floor slabs provide full restraint against lateral torsional buckling of 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 sizes of UB sections required for the floor beams. [50%]

(c) By assuming that the load combination at ULS is the greater of: (1.2 × dead load) + (1.2 × live load) + (1.2 × wind load) **or** (1.4 × dead load) + (1.6 × live load), select a suitable size of UC section for the four internal, centrally located columns around the void, at ground floor level. [30%]



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



Section XX
(all dimensions in metres)

Fig. 1

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2 (a) Figure 2(a) shows simplified strain and stress blocks in a reinforced concrete beam. By assuming that failure occurs with a compression zone equal to half the effective depth, and by considering equilibrium of moments and longitudinal forces, show that the areas of reinforcement required to resist an applied bending moment M are:

$$A'_s = \frac{M - \left(0.225 f_{cu}\, bd^2 / \gamma_c\right)}{f_y (d - d') / \gamma_s} \quad \text{and} \quad A_s = A'_s + \frac{0.3 f_{cu} bd / \gamma_c}{f_y / \gamma_s}$$

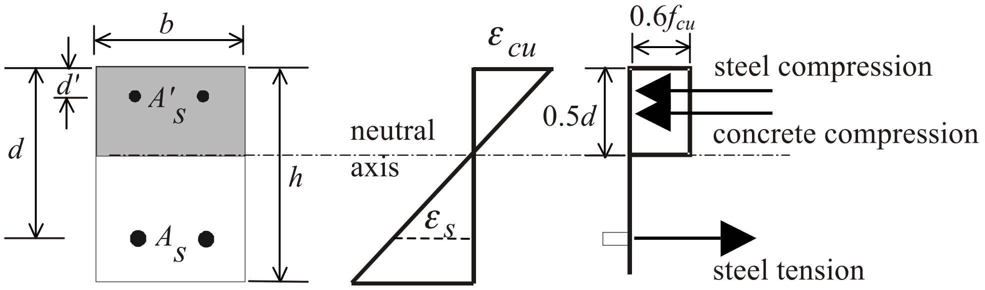
where A'_s and A_s are the area of compression steel reinforcement and the tension steel reinforcement, respectively, and where γ_s and γ_c are the material safety factors for steel and concrete, respectively. [20%]

(b) A 10 m long reinforced concrete beam is supported at A and B as shown in Fig. 2(b). The beam is required to carry a uniformly distributed working live load of 60 kN m^{-1} and its self-weight. The concrete cube strength is 50 MPa and the beam cross-section is 300 mm wide by 500 mm deep with 40 mm cover. The longitudinal reinforcement bars have a diameter of 25 mm or 16 mm and the shear reinforcement bars have a diameter of 8 mm. All bars have a yield stress of 460 MPa. 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. By assuming that the full length of the beam is subjected to the maximum design load:

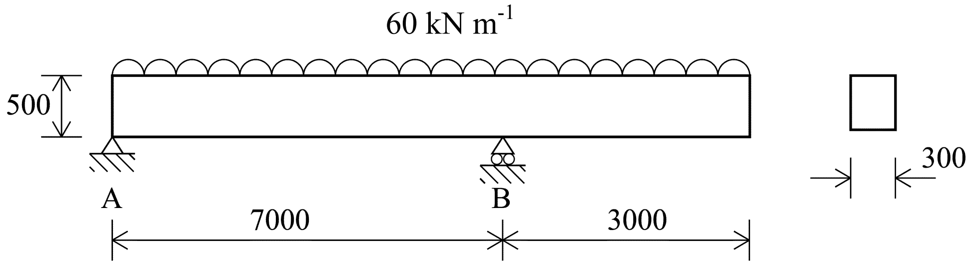
(i) Show that the maximum sagging moment, the maximum hogging moment and the maximum shear force are 454.5 kN m, 412.7 kN m and 418.4 kN, respectively. Sketch the bending moment and shear force diagrams in the beam and identify the locations at which these maxima occur. [30%]

(ii) Calculate the amount of longitudinal and shear reinforcement required at critical sections of the beam and show how this would be laid in the cross-section of the beam. State any assumptions you make. [30%]

(iii) Without carrying out further detailed calculations, indicate an efficient layout of longitudinal and shear reinforcement along the beam. [20%]


b
d'
A's
d
As
h
neutral
axis
εcu
εs
0.6fcu
0.5d
steel compression
concrete compression
steel tension

(a)


60 kN m-1
500
A
B
7000
3000
300
(all dimensions in mm)

(b)

Fig. 2

3 (a) Describe, with sketches where appropriate, the limit state design approach in terms of characteristic loads and characteristic resistances. In your answer explain why the material safety factor for glass is significantly higher than that for steel. [20%]

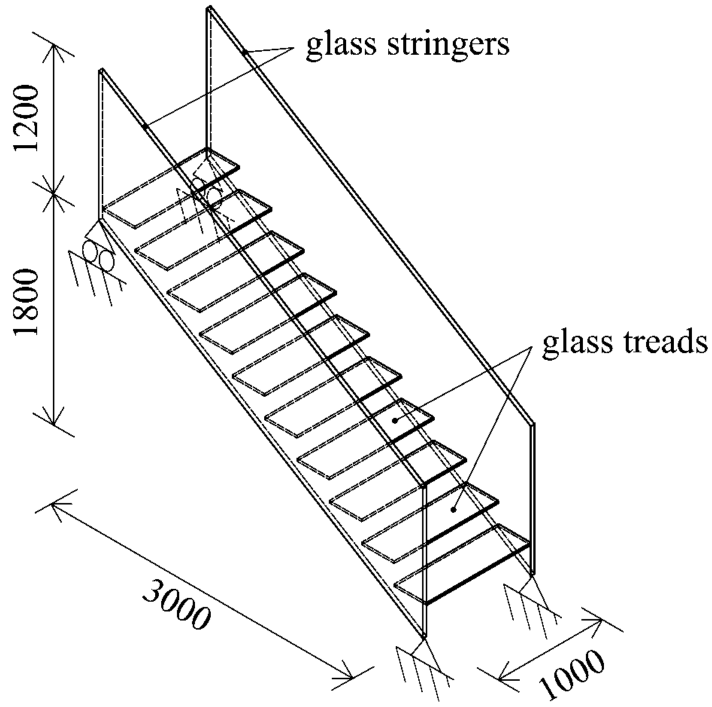
(b) A glass staircase (Fig. 3) consists of 1 m long monolithic glass treads that are simply supported by the two monolithic glass stringers. The stringers act as simply supported beams spanning between the bottom and top ends of the staircase. The glass treads are subjected to a live load of 4 kNm^{-1}. The load factors for dead and live loads are 1.4 and 1.6 respectively and the glass has the following characteristics: $m = 6.5$ and $k = 7 \times 10^{-53}\ m^{-2}\ Pa^{-7}$.

(i) Calculate the long, medium and short term strengths of both annealed and fully toughened glass for a probability of failure of 1/1000. In your calculation you may assume that the surface pre-stress from toughening is 90 MPa; $A = k_A = 1$; k_{mod} is 1.0, 0.5 and 0.3 for short, medium and long term loads, respectively. [20%]

(ii) By assuming that 10 mm thick glass is used for the threads and stringers, determine the maximum bending moments in the threads and the stringers for the short and long duration loads. Use these values to establish the type of glass required for the threads and the stringers. [30%]

(iii) Without performing further detailed calculations, explain, with the aid of sketches, how you would improve your calculations in b(ii) to account for the variation in bending moments along the span of the thread and stringer. [15%]

(iv) Describe the further design checks and design measures you would consider in order to produce a stable and robust staircase. [15%]



(all dimensions in mm)

Fig. 3

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4 A flitch beam consisting of two rectangular 75 × 300 C24 timber sections bolted to a central rectangular steel section is shown in Fig. 4(a). The steel and the timber can be assumed to be perfectly bonded. The steel section has a thickness of 25 mm, Young's modulus 210 GPa and a yield stress of 345 MPa. The partial material safety factors for steel and timber are 1.15 and 1.3, respectively. A solid C24 timber beam with equal overall dimensions is shown in Fig. 4(b). Both structures are located in an environment corresponding to service class 3 and subjected to short-term loading. Relevant timber properties can be found in the 3D3 Structural Materials and Design Datasheets. Use $E_{0,mean}$, $k_h = 1$, $k_{ls} = 1$ and, in the first instance assume $k_{crit} = 1$.

(a) By transforming the steel to timber, calculate EI_{XX} and EI_{YY} for the flitch beam. Calculate EI_{XX} and EI_{YY} for the solid timber structure. What do you conclude about the relative values? [30%]

(b) If the flitch beam is subjected to bending about the X-X axis, determine whether the steel will yield before the timber fails. Compare the ultimate bending moment capacity about X-X of the flitch beam with that of the solid timber section. [30%]

(c) Briefly describe the phenomenon of lateral torsional buckling. Compare qualitatively the anticipated lateral torsional buckling performance of the flitch beam with that of an equal solid timber section. In design, how can the likelihood of lateral torsional buckling be reduced? [40%]

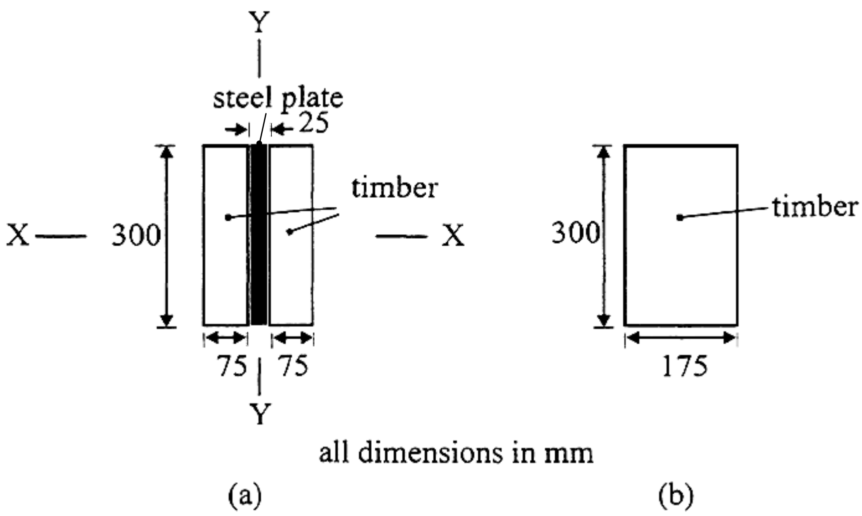

Fig. 4

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