ENGINEERING TRIPOS PART IIA

Wednesday 2 May 2012 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.*

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

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

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

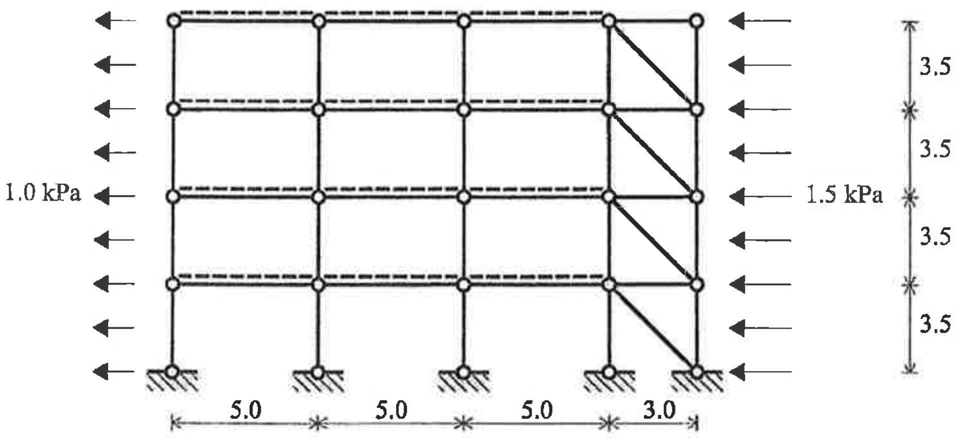
FINAL version

1 A multi-storey building is constructed from a series of primary pin-jointed frames such as that shown in Fig. 1 and spaced 4 m apart along the building. The frame is made of grade S355 steel. The floor at each level consists of 250 mm thick concrete slabs, of density 2400 kgm^{-3}, spanning between the primary frames. A uniformly distributed live load of 5 kNm^{-2} is applied to the floor. The external cladding spans vertically between the floor beams and is subjected to unfactored wind loads as shown in the figure.

(a) By assuming that the slab provides negligible restraint against lateral torsional buckling of the beams, that the SLS deflection limit is span/360 and that the load combination at ULS is: (1.4 · dead load) + (1.6 · live load), select a suitable UB section that satisfies ULS and SLS requirements for the 5 m span. State any assumptions you make in your calculations. [50%]

(b) By considering vertical and horizontal loads with a ULS combination of 1.2 · (dead load + live load + wind load), select a suitable UC section for the ground floor columns in the braced core. [40%]

(c) The client wishes to create a 15m clear space at ground floor by removing the two internal columns at this level. Without doing any detailed calculations, sketch two viable options for achieving this. [10%



Typical frame

(all dimensions in metres)
(---- indicates concrete floor slabs)

Fig. 1

2 (a) By considering the stresses in the rectangular reinforced concrete section shown in Fig. 2(a) and assuming that the concrete compression zone has a mean stress of $0.6f_{cu}$ and a depth of $0.5d$., show that the ultimate bending moment governed by failure of the compression zone is given by $M_u = 0.225f_{cu}bd^2/\gamma_c + f_yA'_s(d-d')/\gamma_s$. [20%]

(b) The 300 mm wide by 500 mm deep by 8 m long reinforced concrete beam shown in Fig. 2(b) is simply supported at A and B. The beam carries a uniformly distributed working live load of 45 kNm^{-1} and its self-weight. Reinforced concrete has a density of 2400 kgm^{-3} and the concrete cube strength is 40 MPa. The longitudinal top reinforcement bars have a diameter 20 mm, the bottom reinforcement bars have a diameter of 25 mm and the shear reinforcement bars have a diameter of 12 mm. All bars have a yield stress of 460 MPa and the cover is 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 and identify the salient values. [20%]

(ii) Design a layout for the longitudinal reinforcement based on the critical cross-section. [20%]

(iii) By assuming that the concrete can provide sufficient strut resistance, design the shear reinforcement based on the critical cross-section. [20%]

(iv) By considering the variations in bending moment and shear force along the beam, suggest an optimised reinforcement layout. [20%]

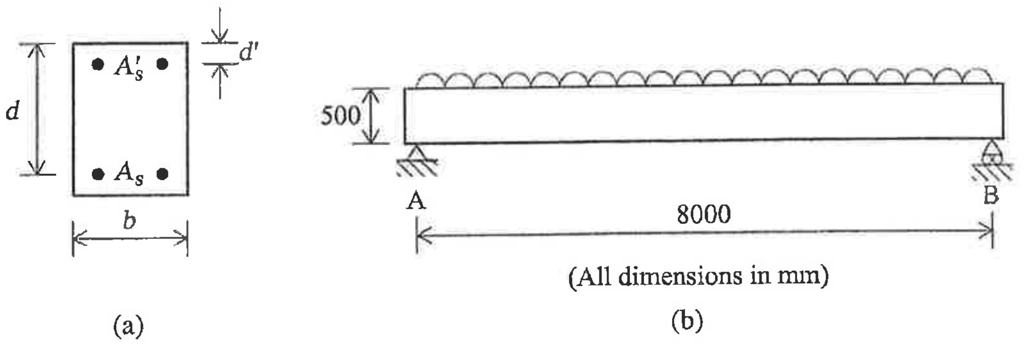


Fig 2

3 (a) Describe, with sketches where appropriate, the two principal ways of joining structural steel components and list their advantages and disadvantages. [15%]

(b) Fig. 3 shows a 2 m by 1.5 m roadway sign supported by a 150·150·10 mm square hollow section. The hollow section is welded to a grade S355 base plate that is in turn fixed to the foundations by means of four holding down bolts that have a yield strength of 460 MPa. The sign and the hollow section have a negligible self-weight and the sign is subjected to a factored wind load of 5 kPa.

(i) Determine the forces acting on the baseplate. [15%]

(ii) Calculate the resultant shear forces acting in the horizontal plane in the bolts and determine the diameter of the bolts required. [30%]

(iii) By considering the average shear stress, the maximum elastic bending stress in the horizontal plane of the baseplate, and the maximum bolt bearing stress, determine the thickness of the baseplate. Without carrying out further calculations suggest modifications for improving the proposed baseplate. [30%]

(iv) Describe briefly, with sketches where appropriate, the other design checks required to complete the design of the baseplate and holding down bolt system. [10%]

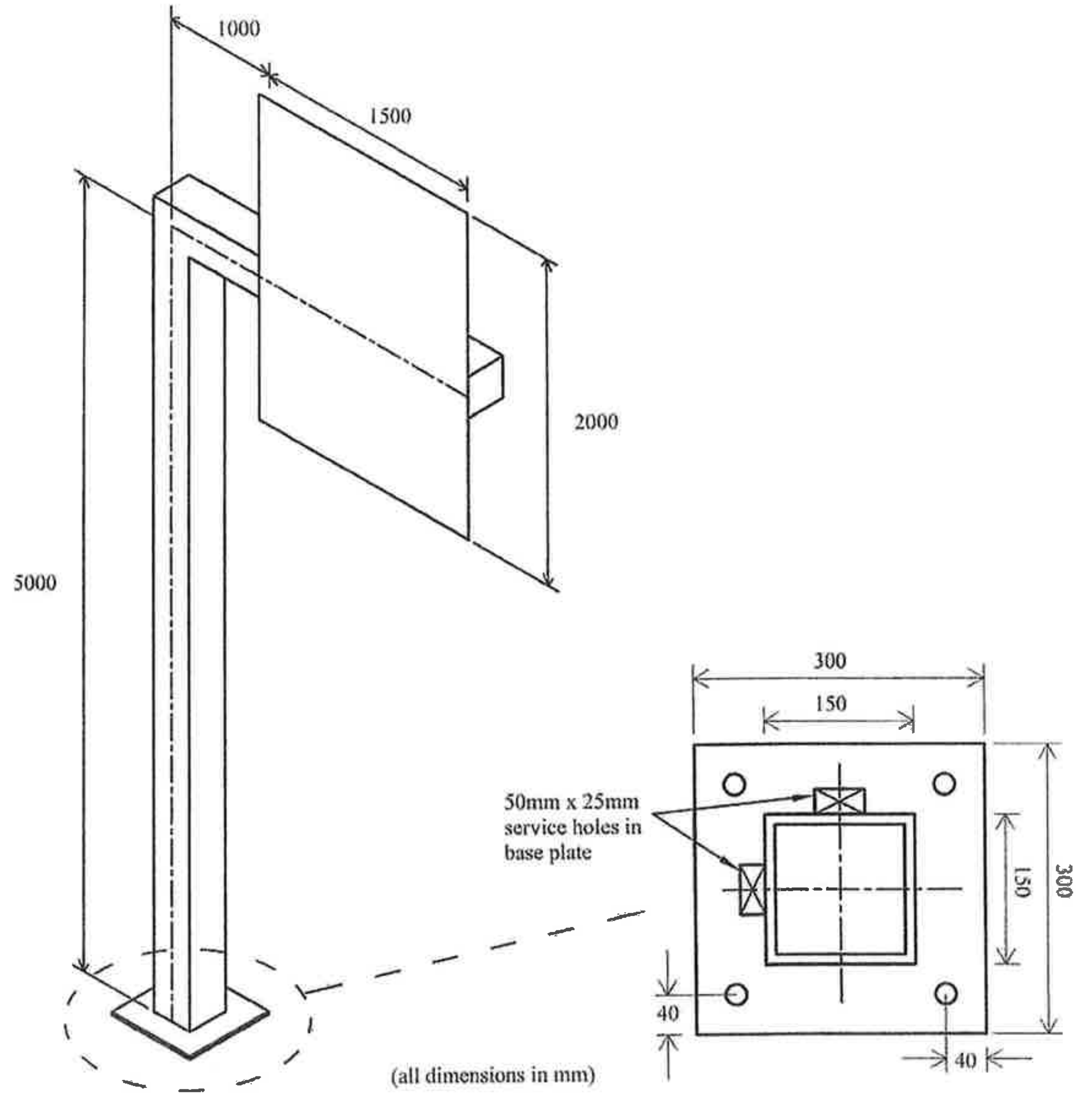

1000
1500
2000
5000
300
150
50mm x 25mm
service holes in
base plate
150
300
40
40
(all dimensions in mm)

Fig. 3

4 (a) By considering both shear and flexural deformations, show that the maximum deflection of a cantilevered beam of depth h and width b subjected to a uniformly distributed load of total magnitude W is given by:

$$v_{tot} = \frac{3Wl^3}{2Ebh^3}\left(1+\frac{Eh^2}{2Gl^2}\right)$$ [30%]

(b) A 3000 mm long by 175 mm wide C24 timber beam shown in Fig. 4(a) carries a characteristic uniformly distributed load of 20 kN. The beam is restrained laterally. Assume $k_{mod} = k_h = k_{ls} = 1.0$, $\gamma_m = 1.3$ and take the load factor for ULS as 1.5.

(i) Determine the minimum depth h of a timber beam required to satisfy shear strength requirements, bending strength requirements and an instantaneous deflection limit of span/200 at the free end. [30%]

(ii) Two options are being considered that would introduce a simple support at B: (a) a 2.5m high by 0.5m long brick wall or; (b) a vertical steel tie from a structure above that is connected to the timber beam by means of a single steel bolt as shown in Fig. 4(b). Determine the diameter of the steel bolt and the thickness of the masonry wall for these two alternative options. In your calculations you should assume that the yield strength and the material safety factor for the bolt are 355 MPa and 1.15, respectively. The compressive strength of the masonry is 5 MPa and the material safety factor for the masonry wall is 2.8. [40%]

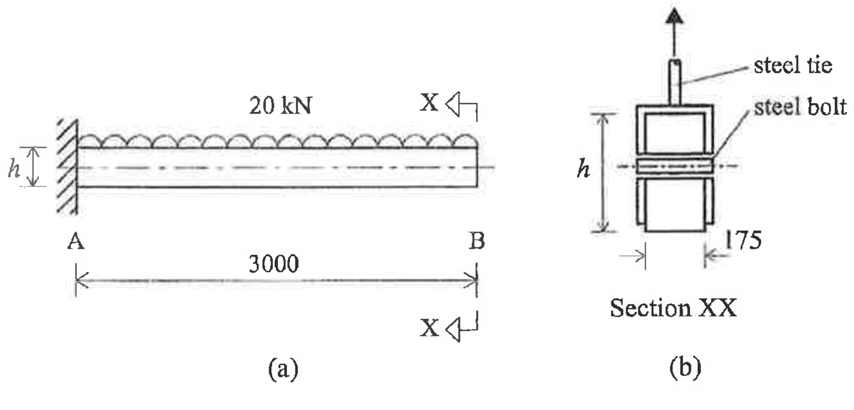


Fig. 4

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