ENGINEERING TRIPOS PART IIA

Monday 19 April 2010 2.30 to 4

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.*

Unless otherwise indicated, the given loads in all questions are already factored and no partial material factors need to be applied, and self-weight can be ignored.

Where indicated, "ULS" denotes Ultimate Limit State.

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

STATIONERY REQUIREMENTS
Single-sided script 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

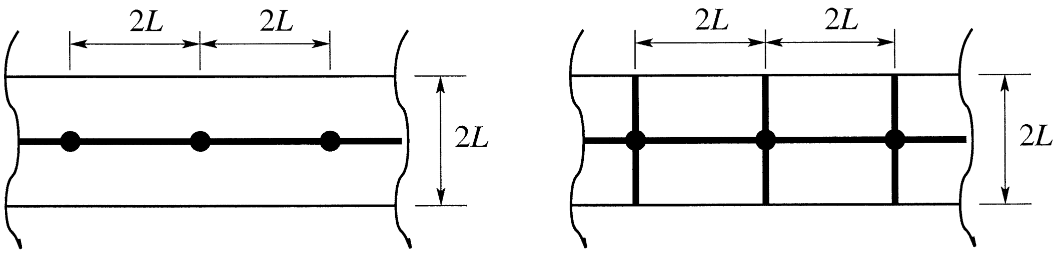
1 (a) Describe briefly what is meant by a load path and its connection to the application of the Lower Bound Theorem. [10%]

(b) A preliminary design for a continuous bridge is shown in plan in Fig. 1(a). It consists of a long plate of width $2L$, rigidly connected on top of a central, continuous horizontal beam that, in turn, rests on top of discrete vertical columns spaced $2L$ apart. The floor and beam are uniform, and the floor carries a transverse distributed load, w, per unit area. The fully plastic bending moment per unit width of a given strip of plate is M_p.

(i) Using the Lower Bound Theorem, show that the floor can safely carry a load of $2M_p/L^2$ per unit area if w is assumed to be carried by a single set of strips running *across* the width of the bridge. Calculate the corresponding force in each column. [20%]

(ii) Show that the maximum bending moment in the horizontal beam lies in the *range* from $wL^3/2$ to wL^3. [30%]

(iii) The designer believes that the safe load found in (b.i) can be improved by adding additional horizontal beams, which span *across* the width of the bridge and over the columns, as shown in Fig. 1(b). Show that the original safe load can be increased threefold. [40%]



(a) ● denotes vertical column (b)

Fig. 1

2 A 400 mm deep by 250 mm wide continuous reinforced concrete beam is supported at A, B and C as shown in Fig. 2. The beam in turn supports a slab that imposes a dead load of 32 kNm^{-1} and a live load of 15 kNm^{-1} on the beam. The concrete cube strength is 50 MPa. The longitudinal reinforcement bars have a diameter of 20 mm and a yield stress of 460 MPa. The shear reinforcement bars have a diameter of 8 mm and a yield stress of 250 MPa. The cover is 40 mm. The material 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.

(a) By assuming that that spans AB and BC are both subjected to the maximum design load:

(i) show that the maximum sagging moment, the maximum hogging moment and the maximum shear force are 79.4 kNm, 141.1 kNm and 176.4 kN, respectively. Sketch the bending moment and the shear force diagrams and identify the locations at which the maxima occur; [25%]

(ii) design a layout for the longitudinal reinforcement for maximum hogging and another layout for maximum sagging; [35%]

(iii) determine the amount of shear reinforcement required at the critical cross section; [20%]

(iv) support B is provided by a square reinforced concrete column of side-length 250 mm. Determine the vertical reinforcement required in the column. [10%]

(b) Without carrying out further calculations describe how removal of the live load from span BC would affect the answers found in (a). [10%]

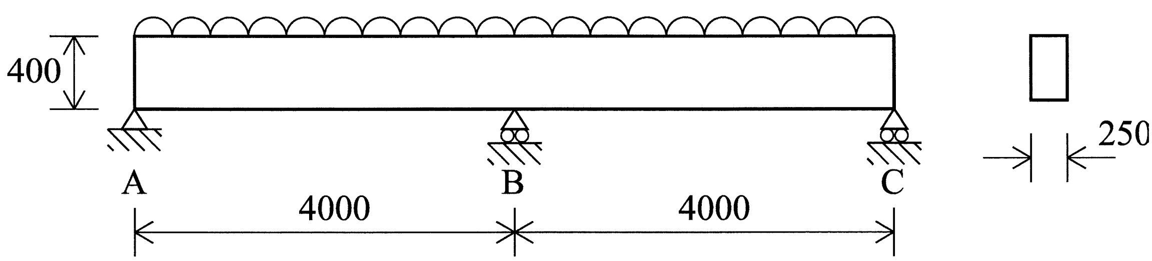


Fig. 2

3 The timber frame, shown in elevation in Fig. 3(a), consists of 4000 mm long by 150 mm wide softwood timber beams that are simply supported between timber columns. A typical timber beam carries a uniformly distributed vertical load of 4 kNm^{-1} from a floor slab in addition to a 102.5 mm thick by 2500 mm high brick wall along its full length. The brick wall is in turn subjected to an unfactored lateral load of 0.25 kPa and is restrained from vertical in-plane translation by the timber beams at its head and foot. The self-weight of the brick wall is negligible and C24 timber is used throughout. You may also assume that $k_{mod} = k_h = 1.0$, $k_{ls} = k_{c90} = 1.1$, $\gamma_m = 1.3$, and the load factor for ULS is 1.5.

(a) Show that when the brick wall is subjected to the lateral load of 0.25 kPa, it generates a vertical thrust of 7.6 kN. [15%]

(b) Determine the minimum depth d of the timber beams required to satisfy shear and flexural strength requirements as well as an instantaneous deflection limit equal to the span/300. [40%]

(c) Determine the minimum bearing length c required at the support ends of the beams. [15%]

(d) A variation of the original design consists of suspending the timber beam at mid-span by means of inclined steel ties and steel bracketry as shown in Fig. 3(b). Assuming that 30 mm diameter through-bolts are used, that they are rigid, *i.e.* no hinges form in the bolt, and that all the flexural forces are transmitted through the bolts, use Johanson's theory to determine the required number of bolts. [30%]

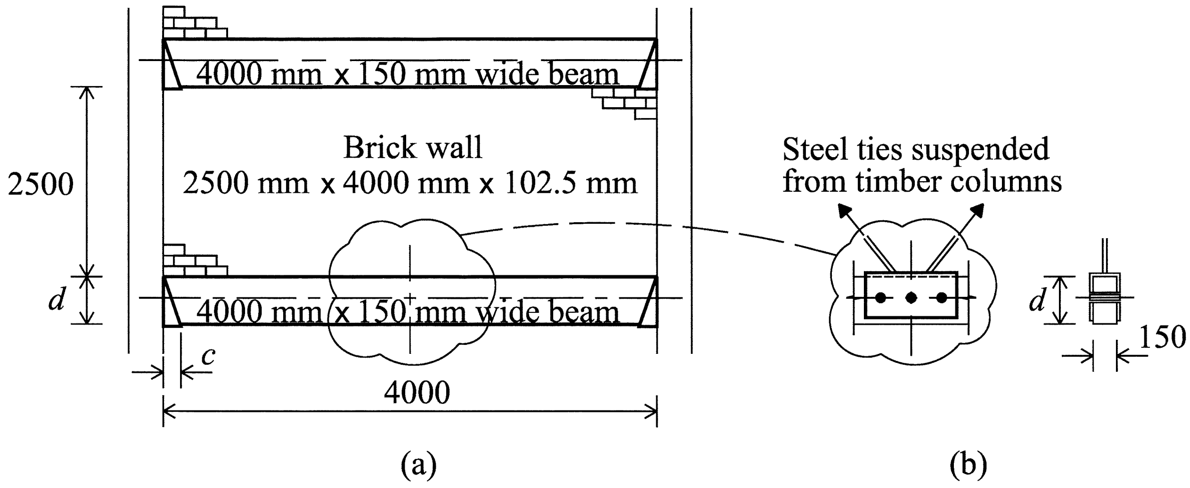


Fig. 3

4 (a) When designing a cross-section for bending strength up to first yield, show that the shape efficiency factor, denoted usually as ϕ_f , is equal to $6Z/A^{3/2}$ and carefully explain the meaning of these symbols. How does this factor change when designing for fully plastic behaviour? [30%]

(b) Determine the ratio of the two factors found in (a) for each of:

(i) 914 × 419 × 388 Universal Beam in steel bending about its major axis, and;

(ii) a thin-walled square hollow section;

and comment briefly on your findings. [20%]

(c) Describe briefly why the span-to-depth ratio plays a key role in the design of beams made from different materials. A uniform fixed-ended beam has span L and overall depth d , and carries a central point load $\gamma_f W$. Determine an expression for the limiting span-to-depth ratio if the beam is expected to reach full yield, assuming a maximum elastic deflection L/F under a load cW , where F and c are known constants. How could this formula be modified for a brittle material? [50%]

END OF PAPER

Final version