ENGINEERING TRIPOS PART IIB
ELECTRICAL AND INFORMATION SCIENCES TRIPOS PART II

Thursday 1 May 2003 2.30 to 4

Module 4D7

CONCRETE AND MASONRY STRUCTURES

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.*

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

(TURN OVER

1 (a) Discuss briefly the philosophy underlying limit state design for reinforced concrete structures. By considering the example of a long-span concrete box girder bridge, list some limit states that a designer might wish to consider. Discuss the importance of these limit states to the safety and whole life performance of the bridge and explain the role partial safety factors play in limit state design. [30%]

(b) In practice, structural failure is extremely rare. Comment on how limit state design accounts for these extremely rare events and the validity of the assumptions involved. [10%]

(c) A designer specifies that steel bars in a particular project should have a *characteristic* strength f_{yk} of 460 MPa. The steel yield strength may be assumed normally distributed with a coefficient of variation of 10%. The bars are all 16 mm diameter and the variability in this diameter can be assumed negligible.

(i) Determine the *design* yield strength f_{yd} for the bars and hence calculate the probability that a bar chosen at random will have less than this design strength. [10%]

(ii) The *design* value of tensile load to be applied to the bars is specified to equal the design value of the strength of the bars calculated in (i) above. The load, which is composed of dead load only, can be assumed to be normally distributed with standard deviation of 10 kN. What is the reliability index β and hence probability of failure in tension for any randomly selected bar subjected to this loading? [20%]

(iii) When the bars arrive on site the mill certificate for the steel states that the mean strength is actually 500 MPa with a standard deviation of 23 MPa. Do the bars supplied comply with the specification? A site survey indicates that the actual dead loads will have both mean and standard deviation 20% greater than that assumed in part (ii) above. What is the reliability index and probability of failure for the actual bars subjected to this revised loading? The bar strengths and loading are assumed to remain normally distributed. [20%]

(iv) As an alternative to specifying that the design load should equal the design strength, the engineer decides to specify a target reliability index of $\beta = 3.5$ in order to determine the dead loads that could be carried safely by the steel bars. If the standard deviation of the loads is 10 kN and the originally specified steel properties are assumed, what would be the value of the *characteristic* load and the *design* load? What is the probability of failure for the bars under this loading? [10%]

2 (a) What major factors should be considered in the specification of a reinforced concrete structure if a designer wishes to ensure high quality, durable concrete? Explain why each of the factors listed is important for the performance of the final structure. [20%]

(b) Cement replacement materials are widely used in the production of concrete. Name some examples and explain their function and the mechanism by which this functionality is achieved. [10%]

(c) The two primary mechanisms of deterioration which concern the owners of the concrete infrastructure are firstly chloride induced corrosion and secondly carbonation.

(i) Explain briefly the deterioration process in each case and discuss how one might prevent or minimise the likelihood of occurrence. [20%]

(ii) Once corrosion has been initiated, describe the procedures you might employ to confirm its presence and then remedy the problem. [20%]

(d) Due to corrosion, an important reinforced concrete highway bridge is estimated to require major repairs costing £250,000 every 25 years. A specialist proposes a cathodic protection (CP) system which would eliminate corrosion completely but cost £60,000 to install and £3,000 per year to operate. All costs are in 2003 prices.

(i) Assuming a discount rate of 6 % per annum for discounting in annual steps, and using continuous discounting where appropriate, determine whether the protection system can be recommended on economic grounds if the required life of the structure is 75 years. [20%]

(ii) To make CP more competitive the specialist subsequently offers to reduce the installation costs to £50,000 and suggests that savings could also be made on running costs. To what level must the running costs be reduced for the CP system to compete on economic grounds with the original option to undertake major repairs every 25 years? [10%]

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3 A 5 m long inverted U-shaped reinforced concrete cantilever beam is shown in Fig.1. A uniformly (unfactored) distributed live load $w = 6$ kN/m is to be supported by the beam over its full length. The concrete has characteristic cube strength $f_{ck} = 30$ MPa, effective Young's Modulus $E_{ce} = 30$ GPa, modulus of rupture $f_{tk} = 4$ MPa, design shear strength $\tau_{Rd} = 0.5$ MPa and density 24 kN/m^3. The steel reinforcing bars are high yield deformed bars with Young's Modulus $E_s = 210$ GPa and yield strength $f_{yk} = 460$ MPa.

(a) Given that before cracking the centroid is at the bottom surface of the top flange, and the second moment of area of the uncracked section $I_{un} = 0.006$ m^4, determine the magnitude of the live load at which you would first expect the beam to crack. The steel has been ignored when determining the gross section properties. [10%]

(b) Calculate the maximum stress in the concrete cantilever beam at the serviceability limit state using elastic no-tension theory. Hence estimate the strain in the reinforcing bars at SLS. [20%]

(c) Estimate the deflection of the tip of the cantilever under short term SLS loading assuming:

(i) the beam behaves as if *uncracked* over its full length; [10%]

(ii) the beam behaves as if *cracked* over its full length. [10%]

(d) Use the appropriate interpolation formula to allow for tension stiffening and hence give a better estimate of the tip deflection. Explain why this will still be an overestimate of the actual tip deflection. [30%]

(e) Determine the shear capacity of the beam. Would you expect to include shear links in this beam? If so, explain your decision and, without calculation, sketch on a cross-section of the U-beam how you might detail such shear reinforcement. [20%]

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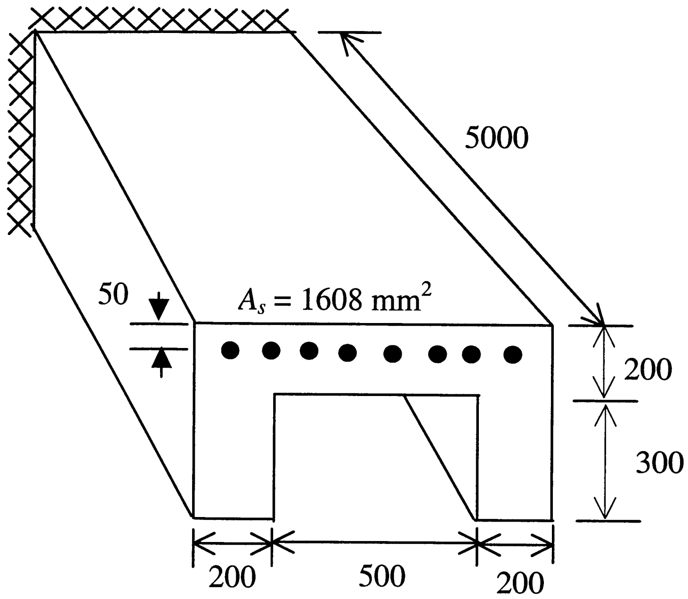

All dimensions in mm unless shown otherwise

Fig. 1

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4 (a) A vertical brick wall 3.5 m in height and 300 mm in thickness is constructed using English bond as shown in Fig. 2. It is subjected to a permanent vertical force n of 900 kN (per unit length of wall) where n is the characteristic dead load from above.

(i) By considering the "vertical arching" method, or otherwise, estimate the characteristic lateral load q_{lat} that can be carried safely by this wall. Suggest an appropriate factor of safety and how it might be applied in this example. [20%]

(ii) What class of brick and mortar designation would be required if partial safety factors on material strength of 3.0 and on loading of 1.5 are assumed? [10%]

(b) Outline the assumptions about material properties underlying Heyman's plastic theory of the strength of masonry arches. Briefly discuss their validity and the resulting two theorems. [20%]

(c) Figure 3 (which is also available as a separate sheet) represents a simplified model of a masonry arch entrance to a church side chapel. The left hand wall abuts the main church structure and can be assumed immovable, as can the foundation supporting the arch. It is assumed that there is no slip between the stones. A new ornamental cross, which can be represented as a concentrated load *P*, is to be added at the pinnacle of the arch. What is the maximum weight of cross, in terms of the weight *W* of the right hand wall stone, that can be carried safely by the arch assuming an overall factor of safety against collapse of two? Initially assume the density of all the stones is the same, γ_{stone} , and the thickness of the arch (into the page) is constant. [30%]

(d) If the wall stone on the right hand side of Fig. 3 is found to have a density half that assumed in part (c) above (i.e. $\gamma_{stone}/2$), what height H of triangular shaped pinnacle (of full density γ_{stone}) as shown dotted in Fig. 3, would be required to ensure the same weight of cross as determined in part (c) could be safely carried by the arch? [20%]

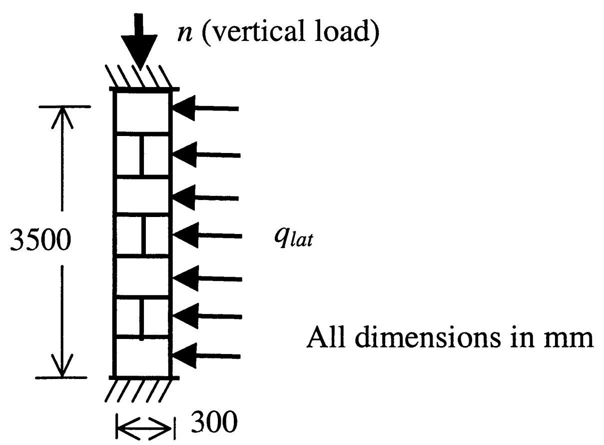

Fig. 2

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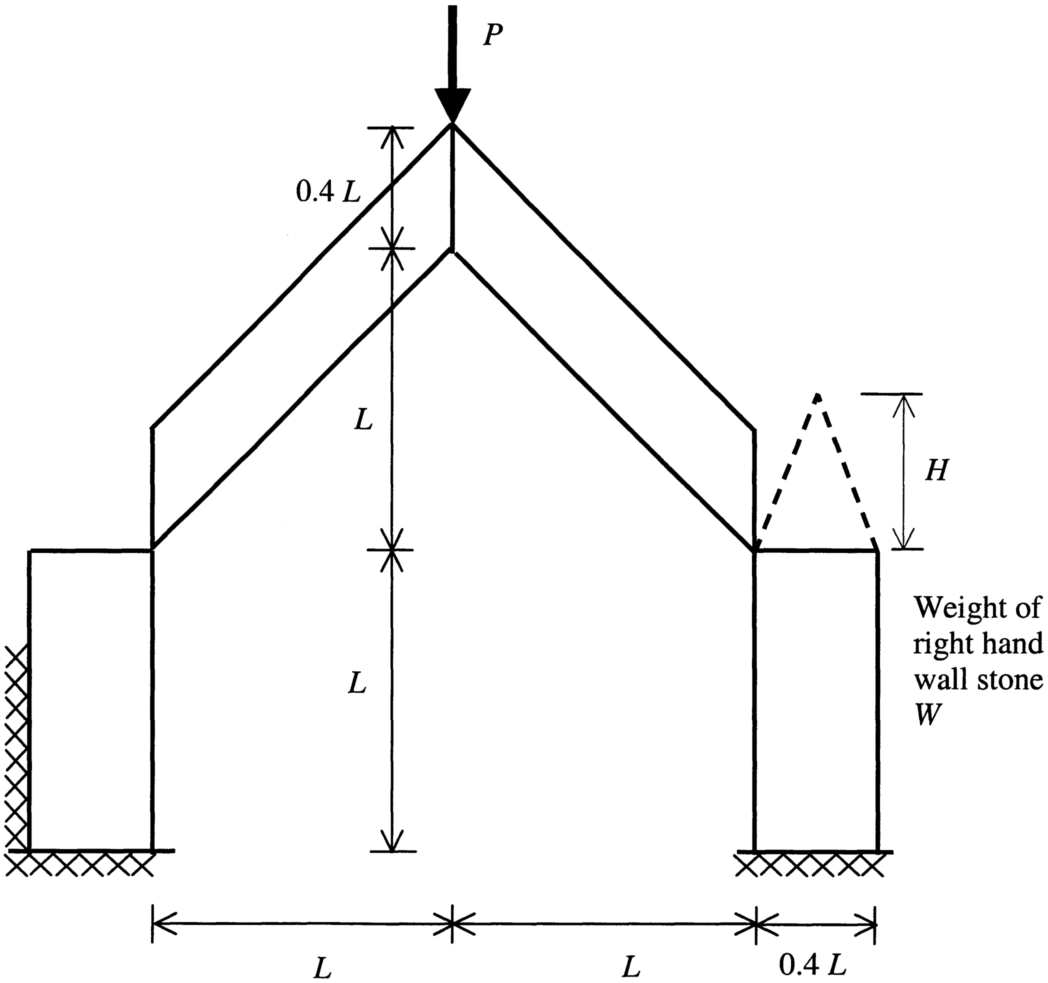

Fig. 3

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5 (a) Describe briefly how to plot an interaction diagram relating the values of axial compressive force N and moment M about the central axis of a rectangular member at failure and discuss how such a diagram may be used in design. Explain why it is necessary to measure the moment about a fixed axis, usually at mid-depth. [30%]

(b) Why is the ratio $\varepsilon_y/\varepsilon_{cm}$ so important in determining the shape of the interaction diagram? [10%]

(c) Figure 4(a) shows a pinned-foot rectangular reinforced concrete portal frame under test in the laboratory with applied load in its own plane. The model has uniform inner and outer bending reinforcement, so that the cross-section throughout is as shown in Fig. 4(b). The concrete has cube strength f_{cd} = 30 MPa and the 10 mm diameter reinforcing bars have yield strength f_{yd} = 400 MPa in tension and compression. Adequate extra reinforcement, not shown in the figures and not affecting the bending strength, prevents shear failure and premature failure in the corners. The self-weight of the frame can be ignored. All dimensions in Fig. 4 are in mm.

(i) Assume that all the steel yields at failure unless it is at the neutral axis and that steel which is on the neutral axis and not yielding can carry stress of magnitude less than f_{yd}. Evaluate the ultimate moment of resistance M_u at a typical cross-section with zero axial force. Hence estimate the load W at collapse. [30%]

(ii) Estimate the axial forces in the frame at collapse and hence re-estimate the bending strength and find an improved estimate for the collapse value W. [30%]

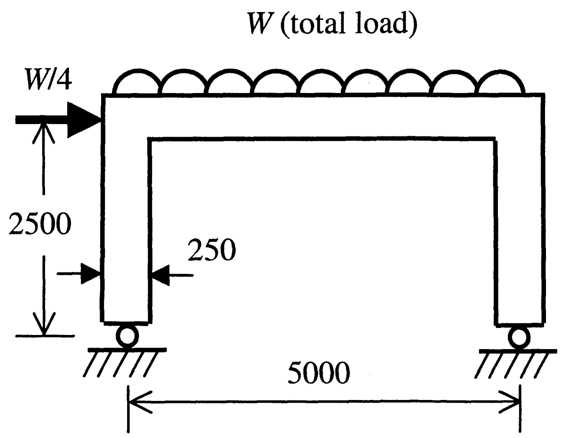

Fig. 4(a)

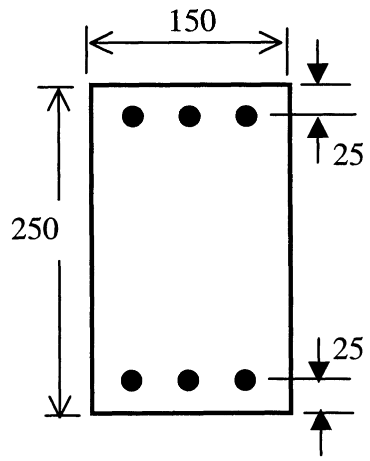

Fig. 4(b)

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Thursday 1 May 2003 2.30 to 4

Module 4D7

CONCRETE AND MASONRY STRUCTURES

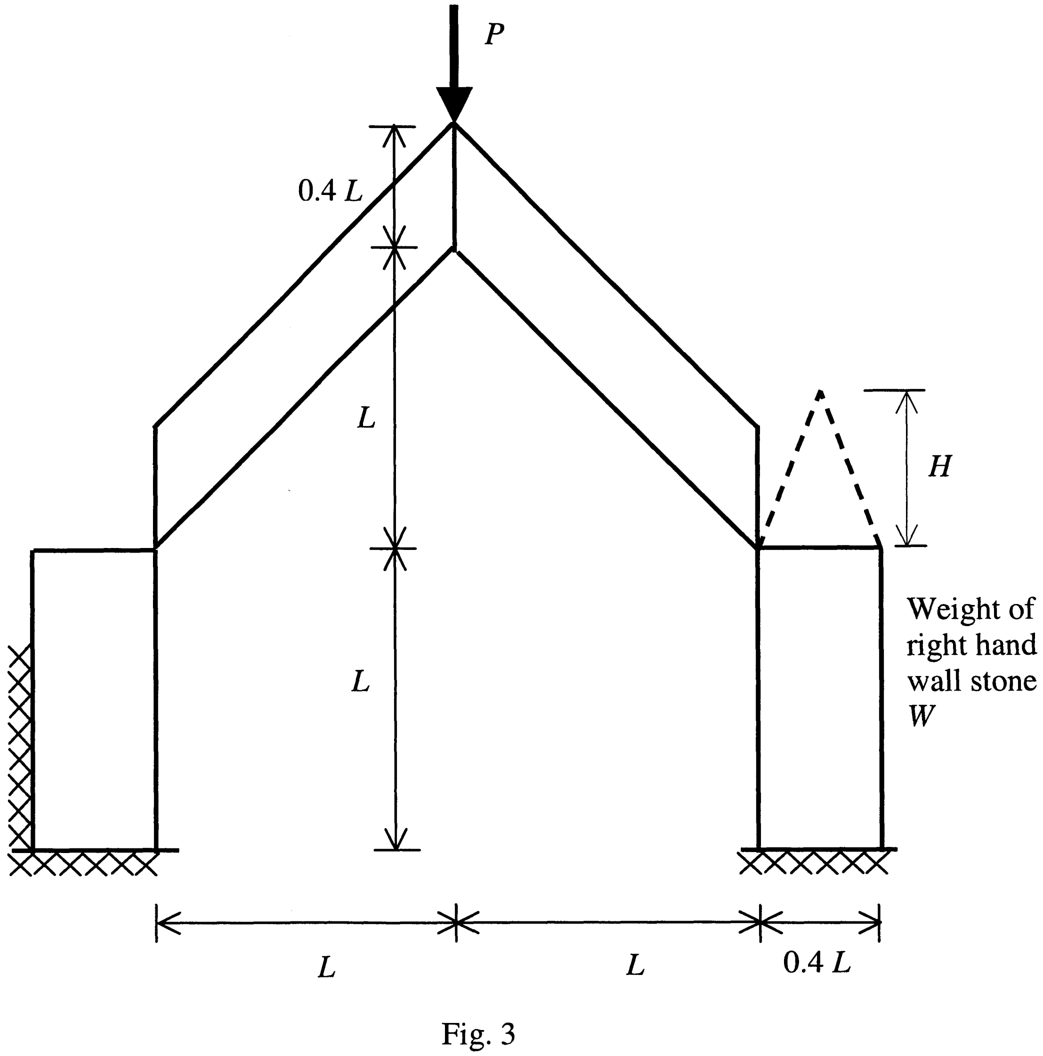

Fig. 3

Working sheet for Question 4
(may be handed in with your script)