EGT2
ENGINEERING TRIPOS PART IIB

Thursday 4 May 2017 14.00 to 15.30

Module 4D7

CONCRETE AND MASONRY STRUCTURES

*Answer not more than **three** questions.*

*The **approximate** number 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
Engineering Data Book
4D7 Data sheets

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) What are the main limit states that need to be considered when designing reinforced concrete structures. Illustrate your answers by comparing and contrasting the relevant limit states for (i) a motorway overbridge with spans of about 20 m, and (ii) a major teaching hospital that contains wards and laboratory spaces. [15%]

(b) A designer specifies that the concrete for a reinforced concrete beam is to have a characteristic cube strength f_{ck} of 50 MPa. The quality control at the batching plant is such that the compressive strength of concrete, for any grade of concrete, may be assumed to be normally distributed with a standard deviation of 8 MPa.

(i) Find the mean compressive strength of the mix and the design strength f_{cd} . [10%]

(ii) Calculate the probability that any cube sample chosen at random will have a strength less than f_{cd} . [10%]

(iii) The permanent loads on the beam result in a *design* compressive stress in the concrete equal to the *design* compressive strength of the concrete mix calculated in (i) above. Assume that the value of the permanent load is normally distributed, with a variability equivalent to a standard deviation in the applied stress of 6 MPa at the critical position. What is the reliability index β and hence probability of failure in compression of the concrete subjected to this loading? [30%]

(iv) The client subsequently modifies the brief and now requires a target reliability index of $\beta = 3.5$ for the structure. For the loading specified in (iii) above, what characteristic strength should the designer now specify in order to just achieve this target? [20%]

(v) If you wished to design a machine to test the concrete, what concrete strength should you assume to ensure that 99.99% of the specimens will fail when tested. [15%]

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. [10%]

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

(i) Explain briefly the deterioration process in each case and discuss how the likelihood of occurrence might be minimised. [15%]

(ii) Once corrosion has been initiated, describe the procedures you might employ to confirm its presence and then remedy the problem. [15%]

(c) 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 that would eliminate corrosion completely but cost £60,000 to install and £3,000 per year to operate. All costs are at current prices.

(i) Assuming a discount rate of 3% 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 lifetime of the structure is 75 years. [30%]

(ii) Your accountant advises you that because of BREXIT the cost of borrowing money will increase and a discount rate of 6% is more appropriate. Does this change your decision? Justify your answer. [30%]

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3 (a) Plot a schematic stress versus axial-strain curve for a normal-strength concrete cylinder subjected to uniaxial compression, identifying salient features. How would the behaviour of a high strength concrete specimen differ from that of a normal strength concrete specimen? Add a typical stress-strain curve for high strength concrete. [20%]

(b) A reinforced concrete T-beam is shown in Fig. 1. The effective depth to the centroid of the longitudinal reinforcing steel is 460 mm. The steel reinforcement at midspan (point A) consists of three 25 mm diameter bars and at support B there are four 16 mm diameter bars as shown. In both cases the steel has a Young's modulus of 210 GPa and factored design yield stress f_{yd} = 440 MPa. The concrete has a Young's modulus of 30 GPa and a factored design compressive cube strength f_{cd} = 30 MPa. The concrete is assumed to fail in compression at a uniform stress of $0.6f_{cd}$. The concrete tensile strength is 3.5 MPa. Assume the section is bending about its major axis.

(i) Calculate the maximum bending moment that the cross-section at point A can sustain at the ultimate limit state, assuming it is under-reinforced. [30%]

(ii) Evaluate the uncracked second moment of area of the section at point B by transforming the steel to concrete. Find the bending moment at first cracking. [30%]

(iii) Assuming the concrete carries no tension but is linear-elastic in compression, and that the reinforcing steel exhibits linear-elastic behaviour, find the cracked second moment of area of the section at point B. [20%]

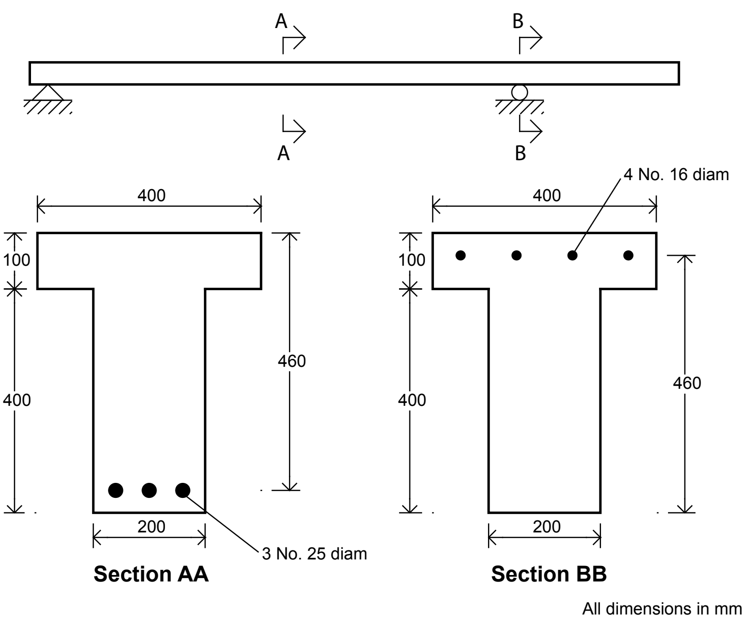

Fig. 1

4 (a) Describe how the bond properties of steel reinforcement influence the crack width and why no further cracks develop after a certain loading stage. Illustrate your answer by sketching how the bond stress, the stress in the reinforcement, and the stress in the concrete develop in a tension region bounded by two cracks for:

(i) a constant bond-stress slip relationship and [15%]

(ii) a non-linear bond-stress slip model [15%]

(b) An axial load, N, of 480 kN is applied to the centre of a 300 mm x 300 mm square reinforced concrete column. The internal longitudinal reinforcement consists of 4 reinforcing bars as shown in Fig. 2. The cover to the centroid of the reinforcing steel is 35 mm. The factored design yield stress of the longitudinal steel is 440 MPa. The concrete has a factored design compressive cube strength of $f_{cd} = 30$ MPa. The concrete is assumed to fail in compression at a uniform stress of 0.6 f_{cd}. The column is stocky and all the steel can be assumed to yield ($\varepsilon_y/\varepsilon_{cu}$ is small).

(i) If the column is subjected to a uniaxial bending moment about the x-x axis of 150 kNm at the ultimate limit state, find the minimum reinforcing bar diameter required. [20%]

(ii) In addition to bending about the x-x axis, the column is also subjected to bending about the y-y axis. When the bending moment about the y-y axis is fixed at 15 kNm, find the location of the neutral axis at failure and the corresponding value of M_{xx}. Discuss how approximations of bi-axial failure surfaces can be used in design. [50%]

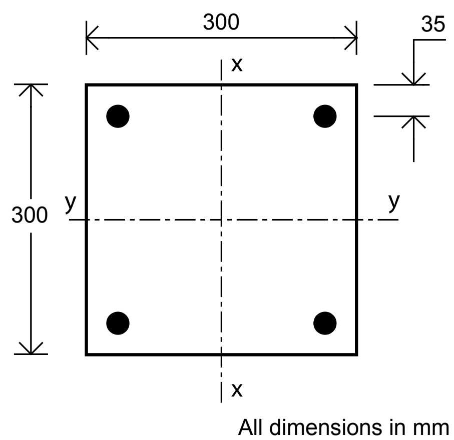

Fig. 2

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Numerical answers

1. (b) (i) 63.2 MPa, 33.3 MPa (ii) 95.7×10^{-6} (iii) 4.93 (iv) 35.7 MPa (v) 78.6 MPa
3. (b) (i) 268.9 kNm (ii) 48.5 kNm (iii) 758.4×10^{6} mm^4
4. (b) (i) 25 mm (ii) 147.2 kNm