EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 1 May 2018 2.00 to 3.40

Module 4D7

CONCRETE 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.*

*Write your candidate number **not** your name on the cover sheet.*

STATIONERY REQUIREMENTS
Single-sided script paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 4D7 Concrete Structures Formula and Data Sheet (4 pages)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

1 (a) Describe how to plot an interaction diagram that relates values of axial compressive force *N* and moment *M* for a rectangular member in uniaxial bending. Discuss how such diagrams are used in design. [30%]

(b) Why is the ratio of steel to concrete strains important in determining the shape of the interaction diagram? [10%]

(c) Fig. 1 shows a reinforced concrete portal frame to be tested in the laboratory with load applied in its own plane. The structure has a constant cross section with equal top and bottom reinforcement throughout. The concrete cylinder strength f_{cd} = 40 MPa and the 12 mm diameter reinforcing bars used have a yield strength f_{yd} = 475 MPa in tension and compression. The structure has sufficient additional reinforcement, not shown in Fig. 1, to prevent premature shear failure.

(i) Evaluate the moment of resistance M_u of a typical cross section with zero axial force. Assume that all the steel yields *unless* it is on the neutral axis. [10%]

(ii) Using an appropriate plastic collapse mechanism estimate the uniformly distributed load *w* at failure. [15%]

(iii) Estimate the axial forces in the frame and re-evaluate the moment of resistance of the beam *BC*. Find an improved estimate for the failure load *w*. [25%]

(iv) Sketch, but do not undertake any calculations, a feasible alternative geometry for this frame that would reduce the total concrete volume while maintaining the load capacity *w* calculated in part (ii). Comment on your proposal. [10%]

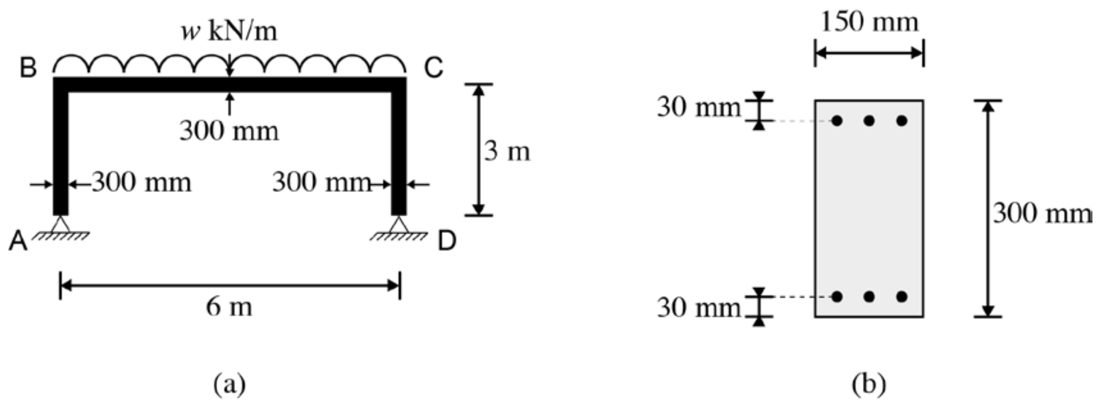

Fig. 1

2 (a) Describe the main features of the 'variable angle truss analogy' when applied to the design of the internal transverse reinforcing steel in a reinforced concrete beam subjected to both vertical shear and torsion. Include free body diagrams indicating how the force is assumed to be transferred using this analogy. [35%]

(b) The deep beam shown in Fig. 2 spans 19 m and is 4 m tall and 250 mm thick. It is loaded by one point load applied 7 m from Support A. Longitudinal reinforcement has a total area of 6,300 mm^2, yield stress in tension and compression of 575 MPa, and an effective depth of 3,840 mm. The beam has a self-weight of 23.5 kN/m. The actual concrete cylinder strength, f_c, is 40 MPa. The two supports and loading point are 400 mm wide.

(i) Assuming failure occurs in the region *without* shear reinforcement, sketch a feasible strut and tie model for this beam indicating tension and compression members and their geometry. Show the values of reactions at *A* and *B* and derive expressions for the forces in your strut and tie model in terms of the unknown applied point load, *P*. [15%]

(ii) In the region *without* shear reinforcement, use your strut and tie model to estimate the collapse load of the beam, *P* (kN), assuming the allowable stress in cracked concrete struts is limited by Eurocode 2 to:

$$\sigma_{Rd,\max} = 0.6\left(1-\frac{f_c}{250}\right)f_c$$

[35%]

(iii) The real beam when tested in the laboratory failed at an applied load of P = 685 kN. Failure was a shear mode occurring in the span *without* shear reinforcement. Comment on your prediction from part (ii). [15%]

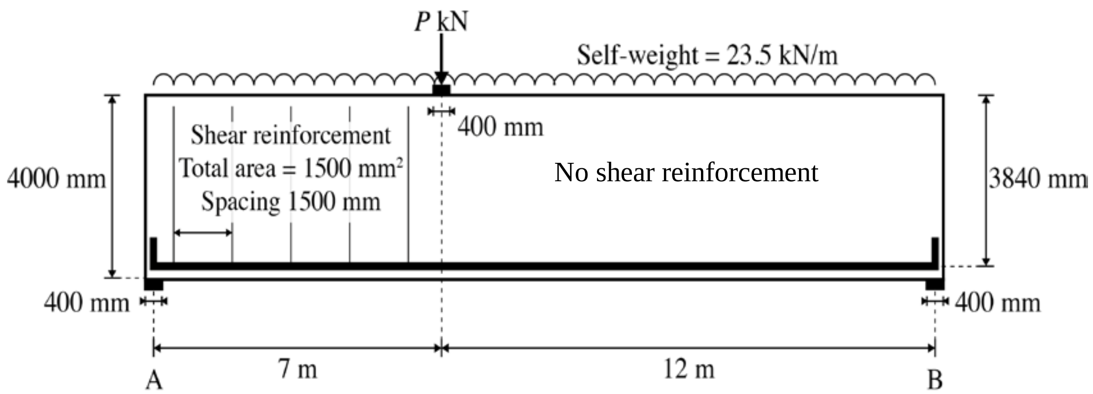

Fig. 2

3 (a) Describe briefly three major failures of *concrete* structures which each resulted from a different primary cause. In each instance outline the reason(s) for the failure and discuss the implications for, and effects on Codes of Practice, and whether the failure could have been avoided if the designer had used larger factors of safety on the main design loadings. [45%]

(b) On inspection a concrete structure of uncertain age is found to have carbonated to a depth of 6 mm, and to have chloride content of 1% (by weight of cement) at 10 mm below the surface. Four years later, the carbonation depth is 9 mm, and chloride content is 1.5% at a depth of 10 mm. The cover to the surface of the reinforcing bars is 25 mm.

(i) How long after the second inspection would you expect reinforcement corrosion to begin, if the cause is reduction in pH value due to carbonation of the concrete? [20%]

(ii) Assuming the concrete initially had zero chloride content and infiltration of ions is occurring from the surface, estimate the timing of the onset of chloride-induced corrosion which is assumed to initiate when Cl = 0.4% by weight of cement at the bar surface. Explain which deterioration mechanism is critical, chloride ingress or carbonation? [35%]

4 (a) (i) Cement replacement materials offer the design engineer the scope to provide a variety of enhanced properties in a concrete mix design. List three cement replacement materials and explain the origin of each. [10%]

(ii) There is a wide variety of specialist cements available in the construction industry. Name 4 different types of cement and detail the different properties of the concrete produced using each when compared to mix designs which only contain Ordinary Portland Cement (OPC). How are these changes achieved? [15%]

(iii) Why is gypsum added in the final stages of production of OPC? [5%]

(iv) Tricalcium aluminate (C3A) can have detrimental effects on concrete. What are these and how can they be mitigated? [10%]

(b) A simply-supported, precast, reinforced concrete beam spanning 8 m is loaded at mid-span by a point load P with mean value 5 kN. Self-weight of the beam can be ignored.

(i) The load P applied to this beam during its design life is thought to be best represented by a probability density function which is uniform from 3 to 7 kN and zero elsewhere. Sketch the equivalent probability density function for the flexural *load effect* at mid-span and hence find its characteristic value. [15%]

(ii) The beam is designed such that a population of identical beams would have a flexural strength with a probability density distribution which is uniform from R to l.2R and zero elsewhere, where R is a measure of flexural strength. What is the probability of failure, under the loading given in part (i), for such a beam which is designed to have a characteristic strength equal to the characteristic load effect? [45%]

END OF PAPER

List of numerical answers

Q1(c)
(i) M_u = 40.3 kNm
(ii) w = 17.9 kN/m
(iii) M_u = 41.9 kNm ; w = 18.6 kN/m

Q2(b)
(ii) P = 1204 kN

Q3(b)
(i) T (carbonation) = 48.4 years after second inspection
(ii) T (chlorides) = 0 years after second inspection

Q4(b)
(i) S_k = 13.6 kNm
(ii) P_f = 0.00653