Version CRM/8

EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 30 April 2014 2 to 3.30

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
Graph paper

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

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

1 (a) Adopting reinforced concrete as the primary structural material in construction results in a considerable carbon footprint. Explain how this could be reduced and what effects, if any, such actions would have on the whole life performance of the final product. [45%]

(b) A concrete bridge was constructed in 1960 and assumed to be initially free of chloride contamination. The design specified the cover to the steel reinforcement to be 35 mm.

Five years after construction a core was taken into an exposed face of a bridge abutment and phenolphthalein indicator solution applied. The outer 12 mm region of concrete in the core was clear and the remaining region turned a deep pink colour.

In addition, concrete dust samples were taken from this same region of the abutment at a depth of 10 mm from the surface and tested in the lab at regular intervals after construction. Two years after construction these tests showed that the chloride concentration per unit weight of cement was 0.2%; after eight years it was 0.6%. The diffusion coefficient D for the concrete is assumed to be constant. Critical thresholds for depassivation of the steel (and hence initiation of corrosion) are assumed to be Cl^{-} = 0.4% by weight of cement or $pH = 12$.

(i) Estimate the age at which corrosion of the steel will first be initiated. [40%]

(ii) What factors might affect the time to initiation and rate of corrosion? [15%]

2 (a) Most structural failures are found to be the result of several contributing factors. List 3 examples of concrete structures that have collapsed. For each identify the contributing factors that led to the failure. Outline what measures might have been taken to prevent these failures. Would current codes of practice reduce the likelihood of each of these failures today? [25%]

(b) (i) The nuclear industry is extremely focussed on quality and long term performance. What measures would you include in a specification for a nuclear containment vessel made from reinforced concrete to enhance the whole life performance of the structure? [25%]

(ii) Describe problems that might arise during and after a mass concrete pour for a large dam and suggest what might be included in the specification to address these issues. [25%]

(c) (i) Plot a schematic stress versus axial-strain curve for a normal strength concrete cylinder subject to uniaxial compression. Describe how the behaviour of this cylinder would differ if it was constrained against lateral expansion by a radial compressive stress, σ_3 . Add additional curves to the plot to show the effects of applying increasing lateral stress to the cylinder specimen. [15%]

(ii) A circular concrete column with diameter 600 mm has vertical steel reinforcing bars distributed around its perimeter. In addition, the column has transverse shear links in the form of circular hoops which provide lateral confinement to the concrete. The shear links are made from 16 mm diameter reinforcing steel with yield strength of 500 MPa. The hoops are spaced at 100 mm centres over the height of the column. The cover to the centreline of the shear links is 50 mm. The column is loaded axially until the steel shear links just yield. Estimate the magnitude of the lateral compressive stress that would be generated by the shear links alone. [10%]

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3 A rectangular reinforced concrete beam with a width of 150 mm, an overall height of 350 mm and an effective depth to the steel reinforcement of 300 mm is reinforced with 2 × 20 mm diameter steel bars. The Young's moduli of the steel and concrete are 210 GPa and 30 GPa respectively. During construction, the applied bending moment can be represented by a probability density function which is uniform between 6 kNm and 8 kNm.

(a) (i) For a given value of concrete tensile strength, f_{ct} , find the bending moment associated with first cracking. For this calculation, the contribution of the steel to the uncracked second moment of area can be neglected. [10%]

(ii) Using cracked elastic no-tension theory, find the strain in the steel, ε_s , for an applied moment, M_a . [30%]

(b) The concrete tensile strength can be represented by a uniform probability density function between 1 MPa and 3 MPa. Determine the probability that the cross-section will crack during construction. [40%]

(c) In addition to cracking due to the application of external loads, briefly discuss four other possible sources of cracking and the characteristics of the associated crack patterns. [20%]

4 The cross-section of a reinforced concrete beam is rectangular with width, *b*. When subjected to bending, the concrete in the compression zone is designed to fail in compression at a design uniform stress of 0.6 f_{cd} = 20 MPa. The concrete compressive strength of a strut resisting shear can be taken as f_{cmax} = 10 MPa. The design anchorage bond strength is 3 MPa. All the steel reinforcement has a design yield stress of 430 MPa. The effective depth to the 4 × 25 mm longitudinal bars is 400 mm. The transverse reinforcement consists of 8 mm diameter bars at spacing, *s*, throughout the shear spans.

(a) When s = 150 mm and b = 250 mm then:

(i) assuming under-reinforced behaviour, calculate the maximum design bending moment that the cross-section can sustain at the ultimate limit state and; [10%]

(ii) using the Eurocode 2 variable angle truss approach, find the maximum design shear force that can be sustained by the beam. [20%]

(iii) If the beam is simply supported with a clear span of 2400 mm and subjected to a factored concentrated load P = 400 kN at mid-span, determine the minimum anchorage length for the longitudinal reinforcement beyond the supports. How could the anchorage length be reduced? Discuss, without doing detailed calculations, how you would determine whether the longitudinal steel in the shear spans could be reduced to two reinforcement bars. [40%]

(b) Calculate the minimum width, *b,* required for the cross-section to sustain an applied shear force of 200 kN. Briefly discuss the implications for the transverse steel design and two other factors that might lead to constraints on the minimum beam width. [30%]

END OF PAPER

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List of numerical answers

Q1(b)(i)	T(carbonation) = 42.5 years; T (chlorides) = 50 years; T (initiation) = 42.5 years
Q2(c)(ii)	$\sigma_3 = 4$ MPa
Q3(a)(i)	$M_{cr} = 3.06 \times 10^6 \times f_{ct}$ Nmm
Q3(a)(ii)	x = 106.5mm , $I_{cr} = 225.1 \times 10^6$ mm^4 ; $\varepsilon_s = 2.87 \times 10^{-11} \times M_a$
Q3(b)	$P_f = 0.642$
Q4(a) (i)	$M_u = 266.4$ kNm
Q4(a)(ii)	Max V = $V_{Rd,S} = 259.4$ kN
Q4(a)(iii)	Min. anchorage length: $l_a = 896$ mm for yield of bar; $l_a = 265$ mm for extra shear force
Q4(b)	$b_w = 111.1$ mm