EGT3
ENGINEERING TRIPOS PART IIB

Friday 22 April 2016 9.30 to 11

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.

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

1 A floor consists of a reinforced concrete slab cast on a series of beams spaced at 2 m centres as shown in Fig. 1. The beams are simply supported with a 5 m span. The main longitudinal reinforcement in the beams is four 32 mm diameter bars. The centroid of this reinforcement is located 375 mm below the top of the slab. At the ultimate limit state, the concrete carries a uniform stress of 0.6 f_{cd} where f_{cd} = 30 MPa. The design yield stress of all steel is 400 MPa and the density of the concrete is 24 kN/m^3. Assume that the slab includes negligible longitudinal steel but is adequately reinforced transversely to sustain the applied loads. When the concrete in the slab sets, full composite action is developed between the beam and the slab to form a T-beam-and-slab structural floor system.

(a) (i) Calculate the maximum design bending moment for a T-beam section. [20%]

(ii) Use a variable angle truss analogy to design the vertical steel links to sustain a shear load associated with the maximum possible concrete shear force contribution. Use an effectiveness factor of ν = 0.5 and a maximum strut capacity $f_{c,max} = \nu f_{cd}$. Assume the shear stress is carried only by the web of the T-beams. [20%]

(iii) Using your answers to parts a(i) and (ii), find the maximum allowable live load (kN/m^2) that could be applied to this beam-and-slab floor system in addition to the concrete self-weight. [20%]

(b) (i) Explain how the modified compressive field theory (MCFT) takes into account the influence of co-existing principal tensile strains on the compressive stress-strain behaviour of cracked concrete struts resisting shear forces. [25%]

(ii) Explain the basis for the V_s+V_c approach for the shear design of reinforced concrete and discuss any limitations. [15%]

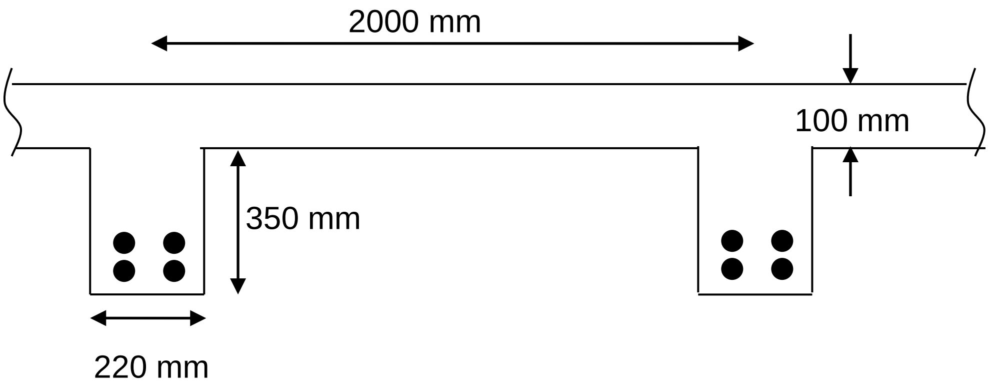

Fig. 1 (not to scale) T-Beam-and-slab cross-section

2 A rectangular reinforced concrete beam has a cross-section with a width of 200 mm and overall height of 400 mm as shown in Fig. 2. The Young's modulus of elasticity of the steel and concrete are 210 GPa and 30 GPa respectively. The concrete tensile strength is 3 MPa. The areas of the top and bottom longitudinal steel are the same. In each case there is a single layer of reinforcement whose centroid is located 40 mm from the adjacent top and bottom surfaces respectively.

(a) If first cracking is to occur at a moment of approximately 22.5 kNm, find the required areas of top and bottom reinforcement. [30%]

(b) At the ultimate limit state in flexure, the concrete carries a uniform design stress of 0.6 f_{cd} where f_{cd} = 30 MPa. The design steel yield stress is 400 MPa. The concrete strain at failure can be taken as 0.0035, the steel yield strain as 0.0022 and γ_s = 1.15. Find the ultimate moment capacity of the cross-section assuming the reinforcement steel calculated in part (a) is provided. [45%]

(c) An additional axial load consisting of a longitudinal compressive force of 80 kN is applied at the centroid of the beam cross-section. Calculate how this additional force would change the area of steel required for part (a) if the required cracking moment is unchanged. Comment on the result. [25%]

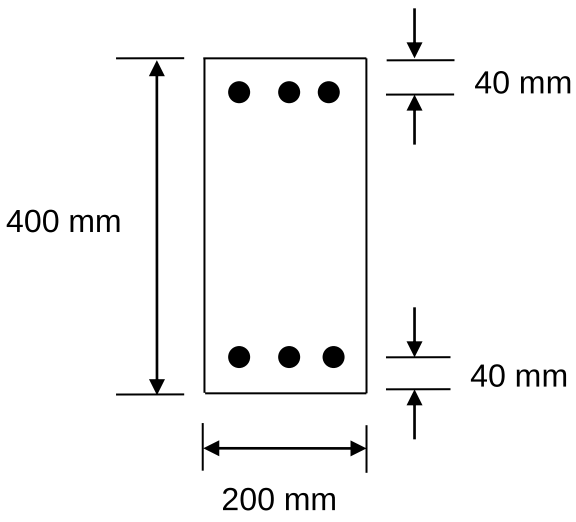

Fig. 2 (not to scale)

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3 A consulting engineer wishes to check the capacity of a reinforced concrete cantilever beam which extends out for a distance of 5 m from a fully fixed support. The flexural strength of the beam in hogging at the support is assumed to have a mean value of 30 kNm. Self-weight of the beam can be ignored. The tip of the cantilever is required to carry a downward point-load *P* with mean value 3 kN. Assume the partial safety factors on material strength and load at ULS are γ_m = 1.3 and γ_f = l .2 respectively.

Assume that the load effect *S* and flexural strength *R* are normally distributed with both having coefficient of variation of 0.1.

(a) (i) Determine the mean, characteristic and design load effect at the root of the cantilever, and also the characteristic and design flexural strength for this beam. [12%]

(ii) Determine the reliability index β and hence the probability of failure for this cantilever beam. Sketch the probability density functions for both the flexural load effect and the flexural strength at the support, marking on the sketch the mean, characteristic and design values for both strength and load effect. [15%]

(iii) Would this cantilever beam be considered safe in flexure under this applied loading? Justify your answer. [8%]

(b) The consulting engineer now decides to specify a target reliability index of β = 3.8 for this cantilever beam. What would be the mean value of the point load that could be applied at the tip of the cantilever to comply with this safety requirement, assuming all other parameters remain as before? [15%]

(c) Outline briefly the mechanical properties of ordinary concrete under uniaxial, biaxial and triaxial stress, and describe two situations in which the triaxial properties are exploited in design. Sketch a graph of uniaxial stress versus strain for a range of concrete strengths; include plots of volumetric strain and lateral strain for a uniaxial cylinder compression test at one of the chosen concrete strengths. [50%]

4 You are employed as a consultant to assess four reinforced concrete bridges. The bridges all have three spans, each of which consists of a simply supported reinforced concrete slab on reinforced concrete piers and abutments.

Each bridge has been subjected to one of the damage scenarios listed below:

(i) severe flooding by a river passing under the bridge;

(ii) fire resulting from a petrol lorry crashing into one reinforced concrete pier supporting the bridge above;

(iii) earthquake;

(iv) spalling of several large chunks of concrete from the deck soffit onto the road underneath.

(a) For each of the four scenarios listed above, describe:

(i) the cause and type of damage that might result;

(ii) the effect the incident might have on the longer term durability;

(iii) the remedial measures you might employ to refurbish the bridge and reduce the risk of a similar event happening again in the future;

(iv) the NDT techniques you might employ to assist in your evaluation and how these would be used in each case. [80%]

(b) Describe at least two real historical examples of failure of concrete structures, describing the differing primary cause(s) of failure of each. Discuss the implications for, and effects on, the Codes of Practice, and whether the failure could have been avoided if the designer had used larger factors of safety on the primary loading. [20%]

END OF PAPER

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