Version JJO/4

EGT3
ENGINEERING TRIPOS PART IIB

Wednesday 1 May 2019 14.00 to 15.40

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
Engineering Data Book
Attachment: 4D7 Concrete Structures data sheet (4 pages)

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 The 15 m long T-Beam shown in elevation and cross section in Fig. 1 is to support a uniformly distributed live load of $w_q = 5$ kN m^{-1} (unfactored). The concrete has a design cube strength $f_{cd} = 45$ MPa, and the reinforcing steel has design yield strength $f_{yd} = 435$ MPa. Longitudinal reinforcement of $A_s = 1257$ mm^2 is provided.

(a) Draw factored shear force and bending moment diagrams. You may assume $\gamma_g = 1.35$ for permanent loads and $\gamma_q = 1.50$ for live loads. [10%]

(b) Calculate the design flexural resistance, M_d, for the beam cross section shown in Fig. 1. Include in your working a plot of the assumed strain profile and identify the neutral axis depth. [20%]

(c) The beam shown in Fig. 1 is taken to a laboratory to be tested under a uniformly distributed load. This applied load is increased linearly from 0 kN m^{-1} until an ultimate limit state failure is reached. What is the failure mode? At what value of applied load in the laboratory do you predict that it will occur? [40%]

(d) What changes might be made to reduce the total embodied energy of this beam, whilst also ensuring it can safely carry the intended *design* loads? You may assume that the embodied energy of concrete is 1 MJ kg^{-1} and the embodied energy of reinforcing steel is 20 MJ kg^{-1}. [30%]

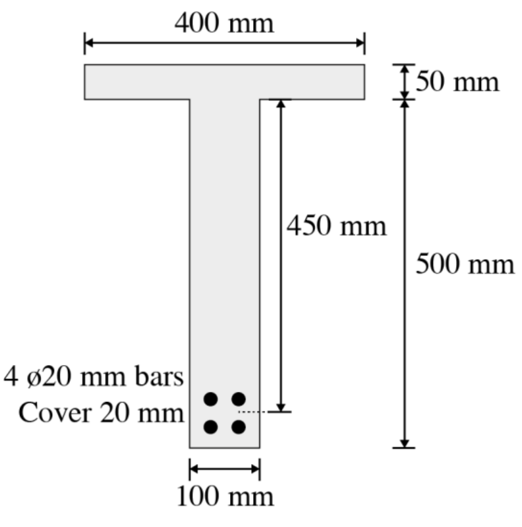

Fig. 1(a)

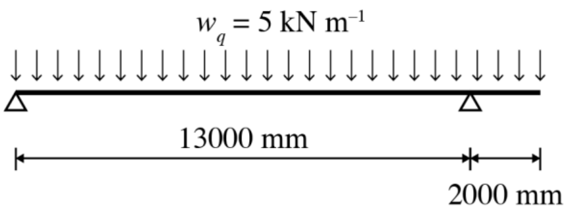

Fig. 1(b)

2 The U-beam shown in Fig. 2 cantilevers a distance of 5 m over the edge of the Grand Canyon and is used as a viewing platform for very brave people. The concrete has a characteristic cube strength of $f_{ck} = 45$MPa, Young's Modulus $E = 30$ GPa, modulus of rupture $f_{tk} = 4$ MPa and density 24 kN m^{-3}. The steel reinforcing bars have a total cross sectional area of $A_s = 3142$ mm^2, Young's Modulus $E_s = 200$ GPa and characteristic yield strength $f_{yk} = 500$ MPa.

(a) (i) Ignoring the steel reinforcement, calculate the uncracked elastic second moment of area of the cantilever beam. [5%]

(ii) At what value of live load would you expect the beam to first crack? [15%]

(b) The cantilever is designed to support a uniformly distributed live load of $w_q = 8$ kN m^{-1} (unfactored) over its span.

(i) Calculate the maximum stress in the concrete and the maximum strain in the steel at the serviceability limit state. [20%]

(ii) Estimate upper and lower bounds to the deflection at the tip of the cantilever under serviceability limit state loading. [30%]

(iii) Use the appropriate interpolation formula to improve the accuracy of your deflection calculation under this short term loading. [20%]

(iv) Why will the result from part (iii) still be an overestimate? [10%]

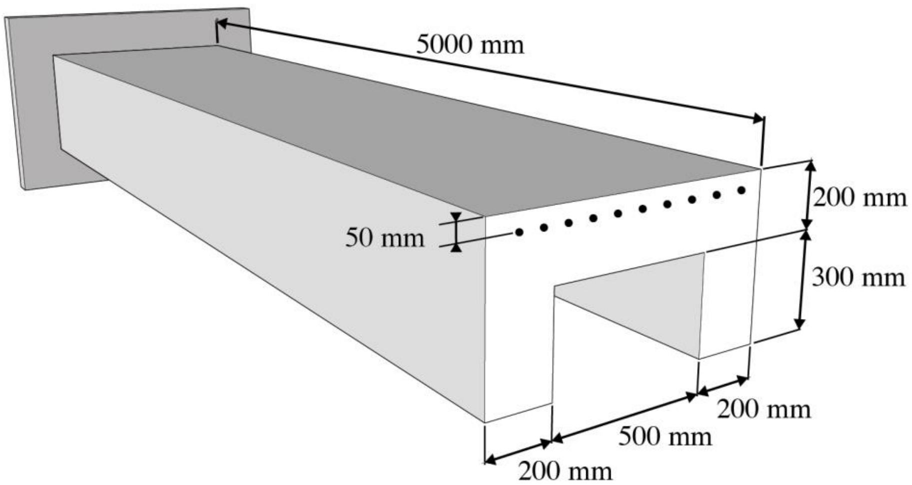

Fig. 2

3 (a) You are designing a vehicular road bridge over a river in Montreal, Canada. In the period 1981-2010 the city experienced temperatures ranging from -38ºC to +46ºC and receives about 800 mm of rainfall per year. What major factors should be considered in the specification of a reinforced concrete structure to minimise whole life cost. Explain why each of the factors you list is important for the performance of the final structure. [25%]

(b) (i) Two important mechanisms of deterioration in normal reinforced concrete structures are carbonation and chloride ingress. Briefly explain the deterioration process in each case and discuss how one might prevent or minimise the likelihood of occurrence. [15%]

(ii) The steel reinforcement in the structural frame of a tall reinforced concrete office tower built in 1966 is suffering from corrosion. What procedures might you employ to identify the extent of the problem, and to remedy it where required? [25%]

(c) (i) You are procuring a new bridge and have received tenders for construction. You have asked for the tenders to minimise whole life costs. You have received two tender packs. One proposes to install a cathodic protection system that will eliminate all corrosion but will cost £75,000 to install and £4,500 per year to operate. The second proposes major repairs costing £300,000 every 25 years. Over a 125-year lifetime, assuming a 4% discount rate per year, and using continuous discounting where appropriate, which tender would you select? [25%]

(ii) Comment on your results. [10%]

4 (a) The Eurocodes are based on a philosophy of limit state design. In the context of the design of a tall building in London:

(i) List some limit states that the designer should normally consider. [5%]

(ii) Discuss the importance of each to the safety and whole life performance of the structure. [15%]

(iii) What role do partial factors of safety play in limit state design? [10%]

(b) Partial safety factors are normally determined largely by calibration against historic design codes. What are the implications of this for the assumptions of reliability in design to the Eurocodes? [10%]

(c) Structural failures are thankfully rare. Using an example of a real-life structural failure, explain what went wrong and why. How did the failure influence subsequent structural designs? [25%]

(d) The construction sector is responsible for a large percentage of total carbon dioxide emissions. Simply supported, 4 m long, precast beams are mass produced in a factory in Swansea. Their flexural strength has a mean value of 40 kNm and coefficient of variation of 0.18. When placed in a building they are loaded by a single point load placed at the mid-span of the beam. The point load has a mean value of 10 kN and coefficient of variation of 0.20. Assuming partial factors on materials of $\gamma_m = 1.5$ and on load of $\gamma_g = 1.35$, and ignoring self-weight:

(i) Determine the design load effect and design strength of the beam. [20%]

(ii) Determine the reliability index, β, for this beam assuming that the load and strength are normally distributed. [10%]

(iii) Comment on your results. [5%]

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4D7 NUMERICAL ANSWERS

Q1(b) M_d = 263kNm
Q1(c) w_q = 10.55kN/m
Q2(a)(i) $I_u = 6x10^9$ mm^4
Q2(a)(ii) w = 2.4kN/m
Q2(b)(i) σ_c = 14MPa; σ_s = 154MPa
Q2(b)(ii) δ_u = 17.2mm; δ_l = 6.6mm
Q3(c)(i) Option 1 £189k, Option 2: £184k