ENGINEERING TRIPOS PART IIB

Thursday 02 May 2013 2 to 3.30

Module 4D7

CONCRETE STRUCTURES

*Answer any **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.*

Attachments:
4D7 Data Sheets (4 pages)

STATIONERY REQUIREMENTS
Single-sided script paper
Graph Paper

SPECIAL REQUIREMENTS
Engineering Data Book
CUED approved calculator allowed

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

2. Whole life costing (WLC) principles are to be used to decide between two options for installing a new expansion joint for an existing short-span concrete bridge.

Option 1 involves installing a stainless steel joint with capital cost of £80,000. This joint is expected to last 20 years before requiring replacement. Installation requires closure of the bridge for 5 days. Maintenance costs for this joint are estimated at £10,000 per annum throughout its life.

Option 2 would involve installing a new FRP (fibre reinforced polymer) joint that is lightweight and quicker to install requiring only two days' bridge closure, but is more expensive at £130,000 and has a shorter predicted life expectancy of 15 years. Maintenance costs for this joint are estimated at £6000 per annum.

The traffic delay cost incurred for each day of closure of the bridge during installation is £50,000 but increases by 2% per annum in real terms because of increased traffic loadings. Both the capital cost of the joints and the traffic delay costs may be assumed to be incurred at the start of the accounting years in which the joint is replaced. Traffic delay cost during maintenance may be neglected. All costs are in 2013 prices.

(a) Assuming a discount rate of 3.5% per annum for discounting in annual steps, and using continuous discounting for the maintenance costs, determine whether the stainless steel or FRP expansion joint should be recommended on economic grounds if the required remaining design life for the bridge is 60 years. [60]%

(b) How would you allow for traffic delay costs during annual maintenance? Would it make any difference if the traffic delay costs were not borne by the bridge owner? [40%]

3. A 150 mm thick reinforced concrete slab to carry a single point load at the centre is shown in Fig. 1. The slab is square with side length of 2 m and is supported on two of the four sides. The supports allow rotation and it can be assumed there is no axial force applied to the slab. The reinforcement consists of a layer of 12 mm diameter bars at 100 mm centres and a layer of 12 mm diameter bars at 200 mm centres. The layers are oriented in perpendicular directions and aligned with the slab axes. The reinforcement is well anchored. The design yield stress of the reinforcement is 400 MPa. The cover to the centroid of the outer steel layer is 30 mm from the tension face of the slab. The concrete has a characteristic strength of $f_{ck} =$ 40 MPa and $\gamma_c = 1.5$. At the ultimate limit state the concrete compression zone carries a uniform stress of $0.6 f_{cd}$ There is no shear reinforcement.

(a) Using the upper bound theory of plasticity and the possible collapse mechanism shown in Fig. 1, calculate the maximum point load that can be applied to the centre of the slab. [40%]

(b) Find an alternative estimate of the collapse load by considering a single yield line at mid-span. [15%]

(c) If the load is actually applied through a square 150 × 150 mm column located in the centre of the slab, determine whether a punching shear failure is likely to occur at a basic control perimeter of $2d$ before the collapse loads from (a) or (b) could be reached. [30%]

(d) How would your responses above be altered if the slab supports could generate axial forces? Do not carry out any further calculations. [15%]

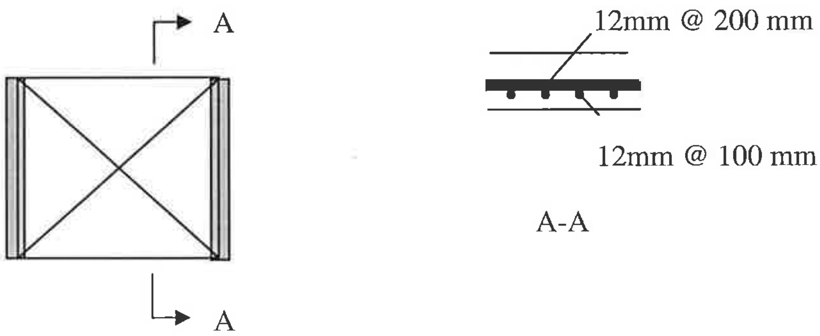

Fig. 1 (not to scale)

4. (a) Describe how the bond properties of steel reinforcement influence the crack width and why no further cracks develop after a certain stage. Sketch 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 [20%]

(b) A reinforced concrete column with a 475 mm × 475 mm square cross section is subjected to axial load combined with a bending moment about one diagonal of the cross-section. The column reinforcement consists of eight bars of 32 mm diameter, one in each corner and one in the middle of each side of the cross-section. The concrete cover is 50 mm. The design concrete cube strength is 30 MPa and at the ultimate limit state the concrete compression zone carries a uniform stress of 0.6 f_{cd}. The ultimate concrete compressive strain is 0.0035. The steel reinforcement is linear perfectly-plastic with a design yield stress in tension and compression of 400 MPa and $E_s = 200$ GPa. The neutral axis at failure goes through the column centre.

i) Find the value of axial force N and applied bending moment M associated with failure. [40%]

ii) The column is loaded between rollers so that the compressive force has an eccentricity of 100 mm from the column centre as shown in Fig. 2. This is the only load applied to the column. If the column is to take the compressive force found in b(i) calculate an estimate of the maximum allowable column height assuming simple supports. [25%]

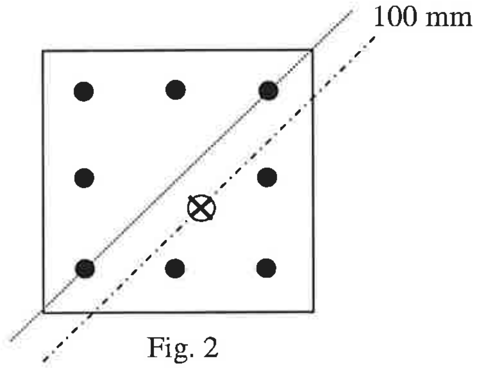

Fig. 2

END OF PAPER

4D7 2013. Numerical Answers

1 (a) 550 MPa; 400 MPa

(b) 240 MPa; 43.7%

(c) 525 MPa; 4.46; 263 MPa

3 (a) 283 kN

(b) 191.5 kN

4 (b) (i) 2031 kN; 571 kNm

(ii) 13.1 m

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May 2013