Version JPT/2

EGT3
ENGINEERING TRIPOS PART IIB

Tuesday 25 April 2017   14.00 to 15:30

Module 4D6

DYNAMICS IN CIVIL ENGINEERING

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: 4D6 Dynamics in Civil Engineering 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 Figure 1(a) shows a three-legged offshore drilling rig, consisting of a deck of mass M supported on three identical legs, each of bending stiffness EI and effective mass per unit length m. The legs are of length l and are assumed to be rigidly connected to both the deck and the seabed. Assuming the amplitude of motion is small enough to neglect the vertical component, an approximation to the fundamental, sway mode shape of the rig is

$$\bar{u} = 1 - \cos\left(\frac{\pi x}{l}\right) ,$$

where x is the vertical coordinate measured from the seabed.

(a) Explain why the above mode shape represents a good approximation. [10%]

(b) Use Rayleigh's method to estimate the fundamental natural frequency of the rig. Assume the mass of the entrained water is included in the effective mass of the legs. [40%]

(c) Storm conditions result in a wave load that may be idealised as a horizontal point force applied to the deck, with the triangular force pulse shown in Fig. 1(b). Estimate the peak displacement of the deck, assuming the response is dominated by the fundamental sway mode. It may be assumed that M = 4.6 × 10^6 kg, EI = 1.8 × 10^{11} N m^2, m = 25 × 10^3 kg m^{-1} and l = 80 m. [40%]

(d) If the mean height of the sea lies significantly below the deck, exposing the upper portion of the legs, qualitatively, how would you expect the response to change? [10%]

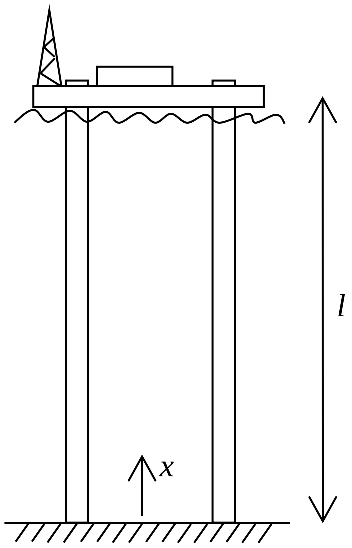

Fig. 1(a)

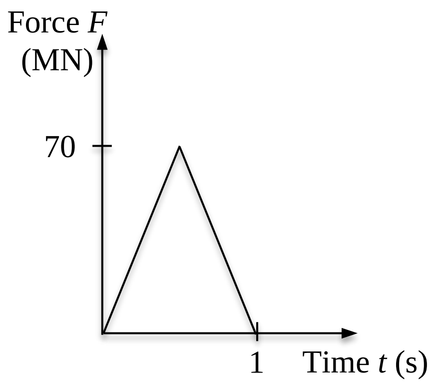

Fig. 1(b)

2 Figure 2(a) shows a two-storey sway-frame that supports a slender tower of uniform cross-section and flexural stiffness EI_{tower} = 200 MN m^2. The mass of the tower is 6000 kg, the mass of each storey is 10000 kg, and all frame columns have a flexural stiffness of EI = 30 MN m^2.

(a) Simplify the entire structure to a three-degree-of-freedom model.

(i) Using a mode shape of {1, 2, 5}, estimate the fundamental natural frequency. [35%]

(ii) Find a more accurate approximation of the fundamental mode shape and natural frequency. [15%]

(b) The storeys have an elastic shear capacity of 100 kN. Assume the tower remains elastic. Using the mode shape {1, 2, 5} and the design spectrum in Fig. 2(b):

(i) Calculate the maximum ground acceleration for which the structure would remain elastic. How do you expect this calculation to compare with the actual value for the real structure? Justify your answer. [30%]

(ii) Calculate the ductility required if the design PGA is 0.5g. [20%]

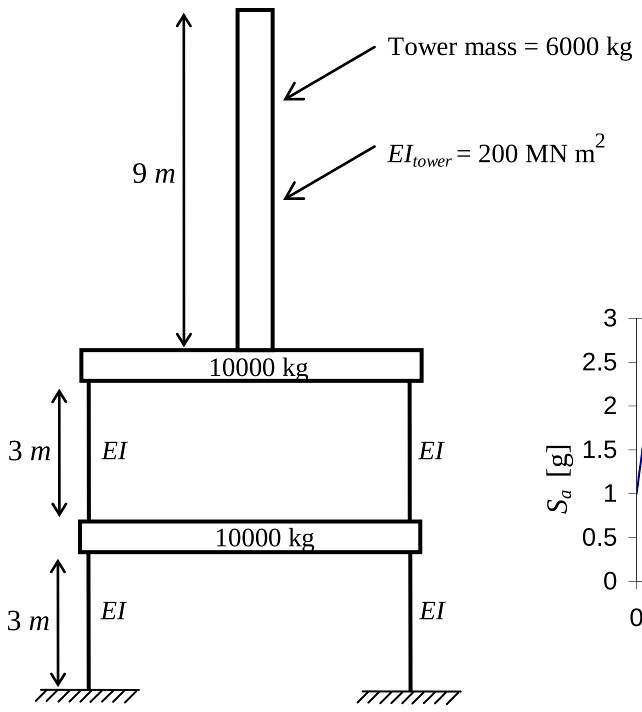

Fig. 2(a)

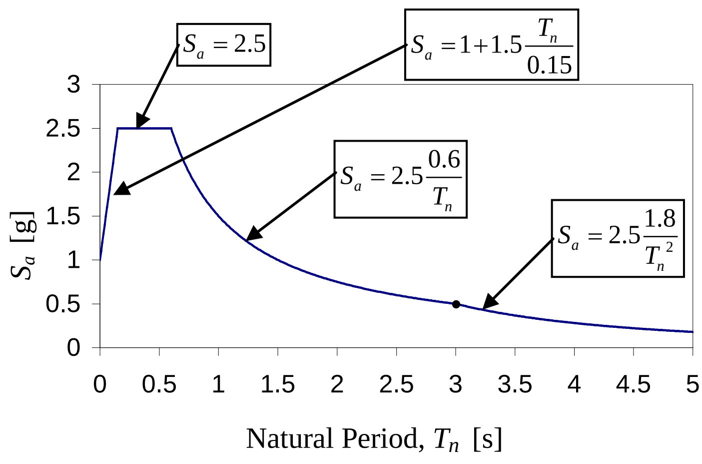

Fig. 2(b)

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3 (a) Explain briefly the terms 'frequency domain' and 'time domain' analyses. [15%]

(b) Why is 'time domain analysis' required when dealing with soils subjected to earthquake loading? [10%]

(c) The long, box tunnel structure with 8 m × 4 m cross-section shown in Fig. 3 is embedded to a depth of 4 m. The tunnel is made of concrete with a unit weight of 24 kN m^{-3} and the walls have a thickness of 0.25 m. This tunnel is located in dry sandy soil that has a unit weight of 15 kN m^{-3}, friction angle of 33^o and a void ratio of 0.67. The expected direction of ground shaking is shown in Fig. 3. The reference plane can be taken as 4 m below the ground surface and the Poisson's ratio of sand may be taken as 0.3. Consider a 1 m length of the tunnel perpendicular to the plane of the paper. Assuming the tunnel structure remains rigid, determine the horizontal, vertical and rotational stiffness due to the soil. [25%]

(d) It is estimated that the soil participating with the tunnel is 30 times the mass of the tunnel in the horizontal direction, and only 10 times the mass of the tunnel in the vertical direction. The mass moment of inertia of the tunnel and participating soil around it is determined to be 984,600 kg m^2 about the expected axis of rotation. Determine the natural frequencies of vibration for the horizontal, vertical and rotational degrees of freedom for the tunnel structure. [20%]

(e) Heavy rains saturate the sand and bring the water table to the ground surface. A strong earthquake is experienced by the tunnel. Due to the large cyclic strains and excess pore pressure generation, the shear wave velocity in the sand is reduced to 20 m s^{-1}. How does this affect the natural frequencies of vibration? [15%]

(f) Discuss the possible ways in which this tunnel could suffer damage during the earthquake event described in part (d) above. [15%]

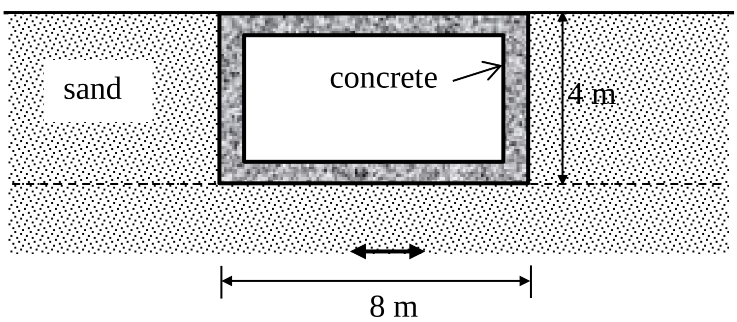

Fig. 3

4 (a) Write down the equations of motion that describe flutter of bridge decks and explain flutter using these equations and sketches. [20%]

(b) Explain single-degree-of-freedom flutter of bridge decks using equations and sketches. [10%]

(c) The main span of a suspension bridge has a length of 1200 m, a deck width of 30 m, a mass per unit length of 16 tonnes m^{-1}, a mass radius-of-gyration of 9.5 m, a natural period in torsion of 3.7 s, and a moment slope of $dC_m/d\alpha = 1.1$. Assume the density of air is 1.23 kg m^{-3}. Recalling that the aerodynamic moment can be defined as $0.5C_m\rho V^2b^2L$, estimate the critical wind speed for static torsional divergence. [70%]

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Numerical Answers

Q1

(b) $K_{eq} = \frac{3\pi^4 EI}{2l^3}$ $M_{eq} = \frac{9ml}{2} + 4M$ $\omega_n = \sqrt{\frac{3\pi^4 EI}{l^3(9ml+8M)}}$

(c) 3.54 m

Q2

(a) (i) 3.55 Hz (ii) [1 2 6]; 3.50 Hz

(b) (i) 0.25g (ii) 2.5

Q3

(c) 2426.78 MN/m; 401.18 MN/m; 29703.27 MNm/rad

(d) 12.07 Hz; 8.50 Hz; 27.64 Hz

(e) 1.63 Hz; 1.15 Hz; 3.73 Hz

Q4

(c) 73.3 m/s

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