Version MJD/4

EGT3
ENGINEERING TRIPOS PART IIB

Monday 4 May 2015 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 data sheets (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 the dynamic model used as the basis for designing the tower of an onshore wind turbine. This comprises a uniform cantilever beam of length L, flexural rigidity EI and mass per unit length m, representing the tower structure, together with a point mass $M = mL$, representing the generator and blades.

(a) Using Rayleigh's principle and assuming a third-degree polynomial for the fundamental mode shape, estimate the fundamental natural frequency of the tower. [40%]

(b) Wind gust loading may be modelled as a spatially distributed time-varying force

$$F(x, t) = f(x)q(t)$$

where $f(x)$ describes a linearly distributed force per unit length, with a peak magnitude of 60 kN/m at the top of the tower, and $q(t)$ describes the rectangular time-history shown in Fig. 1(b). Estimate the resulting peak displacement of a tower with parameter values L = 60 m, $EI = 2 \times 10^{11}$ N m^2 and m = 3000 kg/m. [40%]

(c) The design is to be developed for offshore use by doubling the height of the tower and mounting it on the sea bed at a water depth of L. Comment on the suitability of the design for offshore use with regard to its dynamic performance. [20%]

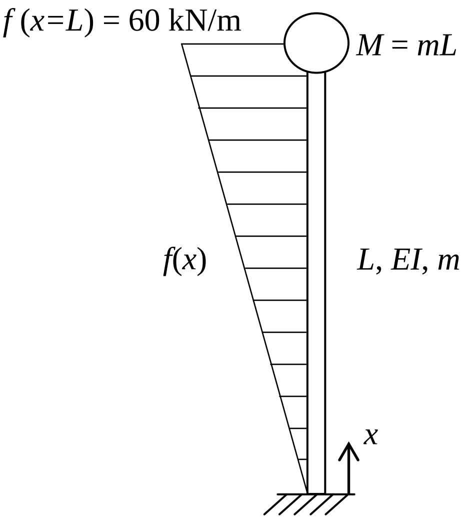

Fig. 1(a)

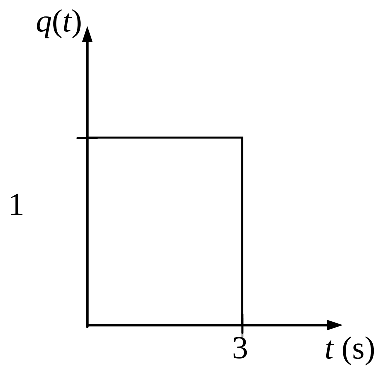

Fig. 1(b)

2 Figure 2(a) shows the design spectrum to be used for this question.

(a) Find the design ground acceleration, the design ground displacement, and the maximum spectral displacement. [15%]

(b) A structure has a natural period in the range 0.15 s < T_n < 0.6 s. Assume that when the structure yields, the maximum deformation energy is the same as if the structure remained elastic. Derive an equation for the required yield displacement as a function of the ductility, μ, and the natural period, T_n. [35%]

(c) A two-storey sway frame is shown in Fig. 2(b). All columns have a lateral stiffness of k, and the first mode shape is {1, 1.62}. Note that the mode shape is not dependent on k. Using the design spectrum in Fig. 2(a), find the minimum value of k required to ensure that the maximum displacement of the first floor does not exceed 0.5 m. In this case, assume that if the structure yields, the maximum displacement is the same as if the structure remained elastic. Only consider the first mode response. [50%]

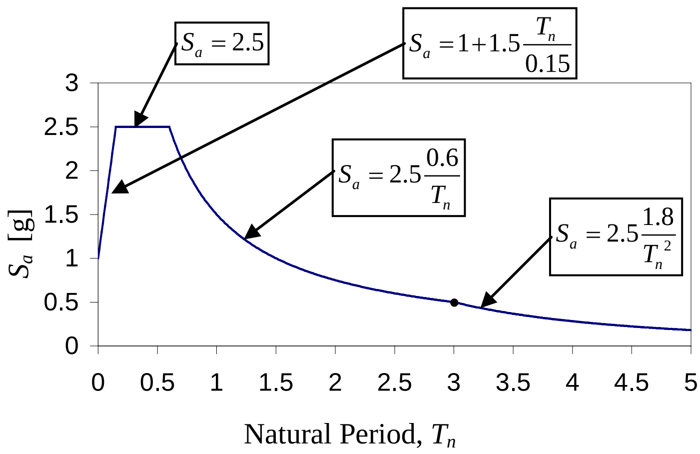

Fig. 2(a)

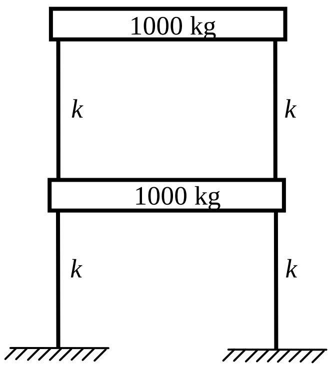

Fig. 2(b)

3 (a) In the context of dynamic problems in civil engineering, explain briefly the terms *frequency domain* and *time domain* analyses. Why is *time domain* analysis preferred when considering soil-structure interaction problems? [15%]

(b) Describe two causes that can lead to degradation of soil stiffness of a fully saturated, loose sand bed during earthquake loading. [15%]

(c) A new shallow foundation is to be designed on a dry, horizontal sand bed that is 10 m thick and underlain by bedrock. The shallow foundation exerts a bearing pressure of 30 kPa and is embedded 0.5 m below the ground surface. The sand has void ratio of 0.7 and Poisson's ratio of 0.3. Considering the reference plane to be 4.5 m below the ground surface, calculate the shear modulus of the sand and the shear wave velocity. You may take the specific gravity of sand particles to be 2.65 and the friction angle of sand to be 33^{o}. [20%]

(d) During an earthquake event the shear wave velocity was recorded as 120 m s^{-1} in the sand bed described in part (c). The earthquake has 5 cycles of strong shaking. Show that the magnitude of the cyclic shear strain generated by this earthquake is approximately 0.1%. [25%]

(e) Following heavy rains the water table has moved to the ground surface, fully saturating the sand bed. The same earthquake event as in part (d) has now resulted in an excess pore pressure of 65 kPa at the reference plane. Estimate the shear modulus and hence the shear wave velocity in the sand under these conditions. [25%]

4 (a) Explain the relevance of the Strouhal Number and the Scruton Number to vortex-induced vibrations. Briefly discuss whether such concepts may be relevant to pedestrian-induced vibration of footbridges. [20%]

(b) Explain what is meant by a flutter derivative, and how it might be measured in wind tunnel tests. [20%]

(c) Earthquake engineers make use of a technique called Response Spectrum Analysis. Explain how calculating the spectrum of the response of a structure to wind buffeting differs from this. [20%]

(d) Briefly describe the main principles of blast-resistant structural design. [20%]

(e) Explain how the wind-induced vibrations of cables can be affected by rain. [20%]

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Part IIB 4D6 - 2015

Answers

1. (a) $f_1 = 0.25\sqrt{\frac{EI}{mL^4}}$; (b) 0.713 m

2. (a) $u_{g,\max} = 1.12$ m , $\ddot{u}_{g,\max} = 1g$, $S_{d,\max} = 1.12$ m ; (b) $u_g = \frac{2.5T_n^{\ 2}}{4\pi^2\sqrt{2\mu - 1}}$; (c) k = 15 kN m^{-1}

3. (c) G_{max} = 73.9 MPa , v_s = 217.8 m/s ; (e) G_{max} = 3.6 MPa , v_s = 42.6 m/s ;

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