ENGINEERING TRIPOS   PART IIB

Monday 9 May 2011   9 to 10.30

Module 4D5

FOUNDATION 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.*

Attachments: 4D5 Databook (18 pages)

STATIONERY REQUIREMENTS
Single-sided script 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

SKH02

1 Pad foundations are to be designed to support a large industrial building over a substantial thickness of stiff, overconsolidated clay. Both triaxial tests and oedometer tests were conducted on block samples of the clay taken from a depth of 1 m below the level ground surface. They offered values of undrained peak shear strength $c_u = 80$ kPa ± 20 kPa which were first achieved at a shear strain $\gamma_u \approx 4\%$, and an oedometer modulus $E_o = 10000$ kPa ± 2000 kPa for a stress increment of 200 kPa on top of the initial effective vertical stress of 20 kPa. In addition, SPT probes were conducted which suggested that below 1 m depth c_u could be taken to increase at a typical rate of 10 kPa/m. Use the Foundation Engineering Data Book to make the following calculations pertinent to the design of 2 m square footings each carrying a vertical load of 800 kN, and founded at 1 m depth, which is just below the zone of seasonal swelling and shrinkage.

(a) Using the uncertainty in the design parameters, estimate the expected range of factors of safety against complete bearing failure and the expected range of immediate undrained settlements, assuming that stress-strain curves are parabolic up to peak strength. [25%]

(b) Estimate the vertical stress increments due to foundation loading at suitable vertical intervals below the centrelines of the 2 m square footings and calculate the corresponding range of expected ultimate settlements based directly on the oedometer data. [25%]

(c) Make an alternative estimate of the ranges of expected immediate and ultimate settlements based on the use of linear elastic solutions for the settlement below loaded areas, by selecting whatever values you deem most appropriate for elastic shear modulus G and Poisson's ratio ν. [25%]

(d) Discuss the shortcomings and limitations of the estimates made in (a), (b) and (c), and suggest appropriate estimates of immediate and long term *differential* settlement to be used in this design case study. [25%]

2 An engineer has previously assumed a permissible bearing stress of 300 kPa for conventional, shallow foundations sited over a deep, dense sand stratum. She now wishes to perform calculations relating both to ultimate limit states and to serviceability limit states (i.e. settlements). The sand is a fine to medium-coarse quartz sand with a uniformity coefficient $U_C = 4$, a critical state angle of friction $\phi_{crit} \approx 34°$, a bulk unit weight $\gamma \approx 20$ kN/m^3 and an in situ voids ratio $e \approx 0.55$ providing a relative density $I_D \approx 80\%$. The water table is deep.

Make the following calculations by selecting appropriate parameters and calculation procedures from the Foundation Engineering Databook. In each case, make brief comments to explain and justify your decisions.

(a) Assuming that the design bearing pressure will be 300 kPa, sketch a typical plastic deformation mechanism for a 1 m square pad footing located at 0.5 m depth in the sand and estimate an average value for the mean effective stress p' within the mechanism under working load. Estimate the net ultimate bearing capacity of the footing, allowing approximately for the effect of p' increasing beyond working load. Express the working state of the footing in two ways, by calculating the approximate load factor to collapse and by estimating an average mobilised angle of friction ϕ_{mob}. [35%]

(b) Deduce the equation of an approximate hyperbolic stress-strain curve that could represent the average secant shear stiffness of the sand within the assumed zone of deformation while the footing is being loaded up to 300 kPa. Calculate an equivalent linear-elastic value of shear modulus which should offer corresponding shear strains. [40%]

(c) Dense sands are found to suffer volumetric strains during drained triaxial compression tests. At small strains the volume reduces under load with a secant Poisson's ratio $\nu \approx 0.2$ but this value increases steadily at larger strains, reaching 0.5 after about 1% to 2% shear strain. At greater shear strains the volume of the sample exceeds its initial value. Explain briefly why this is so. Use elastic solutions for a rigid punch to estimate the settlement of the conventional 1 m square footings. [15%]

(d) Advise the engineer on whether the conventionally loaded footing is likely to be safe and serviceable. Make design recommendations based on your calculations, including suggestions for additional field or laboratory tests that may be required to substantiate them. [10%]

3 (a) Describe four methods of pile load testing. What are the advantages and disadvantages of each method? [40%]

(b) A 20 m long 0.5 m diameter pile is hammer driven into a soft clay layer. The clay layer is normally consolidated, having a peak undrained strength profile with depth given by $c_u = 14z$ kPa where z(m) is the depth below the ground surface. The effective unit weight of the clay γ' is 7 kN/m^3.

(i) Calculate the pile capacity using the API (2000) design method. [25%]

(ii) Describe the changes in total and effective stress around the pile during the life of the pile. How do these changes affect the short and long-term pile capacity? [35%]

4 An offshore wind-turbine is to be supported on a 4 m diameter steel monopile driven into a uniform clay layer. The pile loading consists of a vertical load of 6 MN and a horizontal load of 4 MN at a height of 16 m above the mud-line. The clay has a uniform undrained shear strength of 40 kPa and a buoyant unit weight of 8 kN/m^3.

The steel can be assumed to have a yield stress σ_y of 200 MPa and a Young's modulus E of 210 GPa.

(a) Estimate the minimum pile thickness that would be able to carry the moment load at the mudline without yield. [15%]

(b) Assuming a wall thickness of 40 mm, estimate the minimum pile length below the mudline that can provide the required lateral capacity. [35%]

(c) Assuming that the monopile does not plug, estimate the minimum pile length below the mudline that can provide the required axial capacity. [30%]

(d) What alternative foundation systems could be used for an offshore wind-turbine? What are their advantages and disadvantages over a monopile foundation? [20%]

END OF PAPER

IIB 2011 4D5 Numerical answers

Q1:	a)	FoS 2 to 3.2
		Settlements: 15 mm to 6 mm
	b)	32 mm to 47 mm
	c)	16 mm undrained
		26 mm drained
	d)	8.6 mm undrained
		27 mm drained
Q2	a)	FoS 7.6 ϕ_{mob}=28 degrees
	b)	10 MPa
	c)	11 mm
Q3	b)	2344 kN
Q4	a)	26 mm
	b)	22 m
	c)	11.3 m