Version SAS/2

EGT3
ENGINEERING TRIPOS PART IIB

Friday 6 May 09.30 to 11.10

Module 4D9

OFFSHORE GEOTECHNICAL 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
Engineering Data Book
CUED approved calculator allowed
4D9: Offshore Geotechnical Engineering Data Book (20 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.

You may not remove any stationery from the Examination Room.

1 A deep water location is being considered for the development of a floating offshore wind farm, consisting of an array of floating turbines moored by anchors embedded in soft normally-consolidated clay with an effective unit weight γ' of 5 kN.m^{-3}. An initial site investigation has been performed, which included in-situ vane shear and cone penetrometer tests performed with a cone with cone area ratio α of 0.2. Additional samples were recovered and used for cyclic simple shear testing in the laboratory.

(a) For the peak torque measurements derived by the vane shear tests given in Table 1, calculate the intact undrained shear strength, s_u. Assume a vane height, h, of 60 mm and a diameter, d, of 30 mm. [20%]

(b) Using the corresponding cone resistance measurements given in Table 2 and the vane shear derived undrained shear strength determined in part (a), estimate an appropriate value for the cone factor N_{kt}. [30%]

(c) Comment on the suitability of the cone penetrometer for measuring the undrained shear strength of soft clay soil, and compare and contrast it with full flow penetrometers. Give three reasons why full flow penetrometers are better suited to performing such measurements. [20%]

(d) Using the shear strain accumulation plot provided in Figure 1 and the reorganised storm data given in Table 3, calculate the equivalent number of cycles that is representative of the design storm at a shear stress ratio τ_{cy}/σ'_{vc} = 0.2 and determine the corresponding accumulated shear strain. For each step in the accumulation procedure record the equivalent number of cycles and accumulated strain in tabular form. [30%]

Table 1

Depth, z (m)	Vane torque, T (Nm)
2.0	0.49
6.0	1.34
12.0	2.74

Table 2

Depth, z (m)	Cone resistance, q_c (kPa)	Pore pressure, u_2 (kPa)
2.0	53	50
6.0	155	150
12.0	322	260

Table 3

Stress ratio, $\tau_{cy}/\sigma'_{vc}(-)$	Number of cycles, $N(-)$
0.075	400
0.10	60
0.12	40
0.15	6
0.20	2

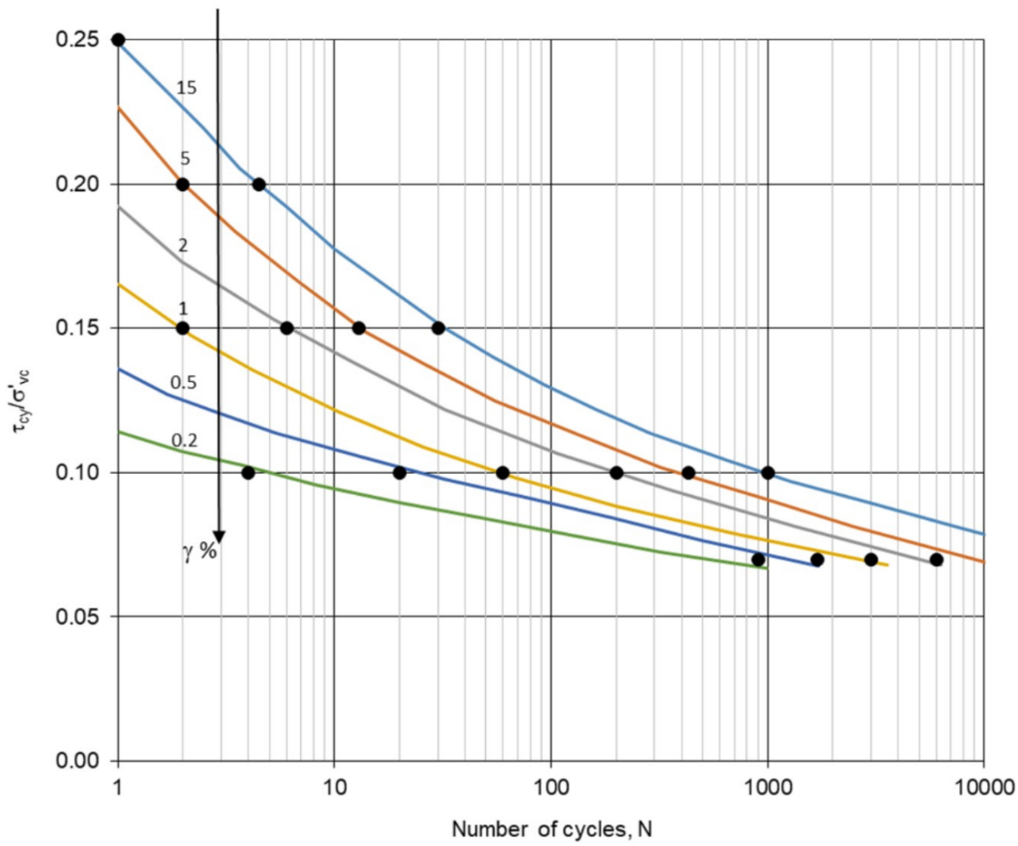

Fig. 1

2 A subsea cable, with diameter D of 0.3 m and specific gravity of 3, is embedded in sand to a normalised embedment w/D of 0.5. The sand has a critical friction angle ϕ_{cv} of 33°, relative density I_D of 0.3, natural logarithm of grain crushing stress Q of 10, and effective unit weight γ' of 10 kN.m^{-3}. Assume that seawater has a density ρ of 1020 kg.m^{-3} and that appropriate coefficients of drag C_D and lift C_L for the partially embedded cable are 0.7 and 0.9, respectively.

(a) Calculate the horizontal drag force and vertical lift force acting on the cable due to a steady current velocity v of 2 m/s. [20%]

(b) Estimate the peak friction angle ϕ_{peak} accounting for stress-dilatancy. [20%]

(c) Calculate the maximum vertical penetration resistance V_{max}. [20%]

(d) Check that the horizontal breakout capacity is sufficient for the cable to remain in a stable state. [30%]

(e) Comment on the validity of the peak friction angle calculation and suggest what an improved estimate would need to account for. [10%]

3 The installation and uplift capacity of a set of steel tubular piles is being considered to tether vertically a tension leg platform.

(a) Describe the two critical driveability issues that can be encountered during pile hammering and their consequences. [15%]

(b) For a soil profile of $s_u = 2z$ kPa, where z is the depth below the mudline, explain why the shaft capacity of a pile increases with the square of the pile embedment. [10%]

(c) The selected piles have a diameter of $D = 3$ m and are driven to an embedded depth of $L = 30$ m. The site comprises normally-consolidated soft clay, with an undrained shear strength $s_u = 2z$ kPa, where z is the depth below the mudline in metres. The effective unit weight of the soil is $\gamma' = 7.3$ kN.m^{-3}. Estimate the uplift capacity available at the head of each pile when used to anchor the floating platform, explaining your calculations and assumptions. Assume that the pile is plugged. [25%]

(d) The estimation of the number of blows needed for installation is achieved using the pile driving formula below (Gates, 1957):

$$Q_{ult} = 104.5\sqrt{\eta_H E_H}\,(2.4 - log\,(s))$$

where:

Q_{ult}	[kN]	Predicted pile ultimate capacity
η_H	[-]	Hammer efficiency
E_H	[kJ]	Maximum driving energy of the hammer
s	[m/bl]	Pile set per blow

The hammers considered for installations are the IGC-280 and the IHC-S500, with a maximum rated energy on the pile of 280 kJ and 500 kJ respectively. These both have a blowrate of 42 bl.min^{-1}. At this location, refusal is encountered when 600 bl.m^{-1} is reached. Determine which hammer is most suited to install the pile to the required penetration depth and an upper-bound estimate of the installation time needed for installation. Assume a hammer efficiency of $\eta_H = 0.82$ for both hammers. [35%]

(e) List two counteractive effects caused by cyclic loading on the axial response of the pile. [15%]

4 Suction caissons are to be used to anchor a tension-leg platform supporting a small offshore wind turbine. The site comprises soft clay, with a uniform shear strength $s_u = 16$ kPa.

The proposed caissons have a diameter $D = 3$ m, length $L = 12$ m and wall thickness $t_w = 0.06$ m. The buoyant weight of each caisson is 720 kN and the effective unit weight of the soil, γ' is 6.3 kN.m^{-3}.

Take vertical bearing capacity factors on tip bearing $N_c = 7.5$ and on plug bearing $N_c = 9$, and take an interface roughness coefficient $\alpha = 0.3$ for installation.

(a) Prove that it is safe to apply suction and that the caisson is not going to fail by uplift of the plug into the caisson during installation. [25%]

(b) Describe possible modes of undrained uplift failure mechanisms of a suction anchor. Draw a diagram indicating the components that contribute to capacity for each of them. [20%]

(c) Evaluate the uplift capacity of each caisson and conclude on the mode of failure expected at this site. [40%]

(d) Why can you neglect the overburden term in the calculation of uplift resistance with passive suction? [10%]

(e) How would scour affect the results obtained in part (c)? [5%]

END OF PAPER