409 Offshore Geotechnical Engineering 2023 Exam Crib. – sas229

Q.1. a. The sediments along the route were formed from a combination of detrital material from land erosion and the remains of marine organisms. (5%) Material that comes from the land is "terrigeneous" material whereas that which settles through the water column is "pelagic" material. (5%) Terrigeneous material comes from river systems, coastal erosion or glacial activity and is predominantly granular and silicate based – ie. sands, and so is most likely to be found in shallower coastal waters. (5%) Pelagic sediments are fine-grained and can be transported over large distances by wind or currents prior to deposition, hence fine-grained soils are often found in deeper water. (5%) Along the export cable route the sands are likely to be found close to shore, the silts along the descent towards the Celtic Deep, and the soft muds in Celtic Deep itself. (10%)

[Total 30%]

Q.1. b. For the sands a box-corer or grab-corer would be most appropriate to facilitate disturbed sub-sampling that could be tested in the laboratory using suitable element tests (e.g. triaxial, shear box). (10%) For the silts the cone penetrometer is most appropriate as correlations can be used to give an indication of sediment type, and it is robust in more sandy zones. (10%) After identifying more sandy zones with the cone penetrometer, a T-bar or ball penetrometer can be used to characterise the softer muddier sediments, because the increased projected bearing area of these probes provides more accurate measurements of strength in soft sediments as well as sensitivity. (10%)

[Total 30%]

Q.1.c. Five relevant offshore geohazards :

① - Slope failure could apply significant drag loads to the shallowly buried subsea export cable. (5%)

② - The slope failure could trigger debris flows, resulting in deposits and turbidites. (5%)

③ - Sand waves along the route could present significant difficulties for cable trenching and seabed mobility could result in cable stability being undermined, (5%)

④ - Strong tidal currents could present challenging hydrodynamic loading conditions for the subsea cable at exposed locations (i.e. at terminals and due to subsea mobility). (5%)

⑤ - Scour induced by strong tidal currents and waves in shallow water could result in reduced embedment of the shallowly buried cable and thus instability. (5%)

Or - Exposed rock causing abrasion of cable.

[Total 25%]

Q.1.d. For a drained slope : $F = \dfrac{\tan\phi_{cr}}{\tan\alpha}$

Assume $F \geq 1$ $\therefore$ $1 \leq \dfrac{\tan\phi_{cr}}{\tan\alpha} \rightarrow \tan\phi_{cr} \geq \tan\alpha$

Hence $\phi \geq \alpha = 15°$ (5%)

For undrained conditions: $F = \dfrac{2k}{\sin 2\alpha}$ where $k = \dfrac{s_u}{\sigma_v'}$

Assume $F \geq 1$ $\therefore$ $1 \leq \dfrac{2s_u}{\sin 2\alpha \, \sigma_v'} \rightarrow \dfrac{s_u}{\sigma_v'} \geq \dfrac{\sin 2\alpha}{2}$

Hence $\dfrac{s_u}{\sigma_v'} \geq 0.25$ (5%)

Q.1. d. (cont.). It is not possible to infer the soil type from these calculations because a slope of 15° is likely to be stable in either a sand or a soft fine-grained sediment. The calculations merely indicate the minimum strength parameters required to satisfy stability in either scenario. (5%)

[Total 15%]

Q.2.a $W' = (SG - 1)\left(\frac{\pi D^2}{4}\right)\gamma_w$

$= (3 - 1)\left(\frac{\pi\ 0.4^2}{4}\right) \cdot 10$

$= 2.5$ kN m^{-1} [Total 5%]

Q.2.b. $I \approx \frac{\pi}{8} D^3 t = \frac{\pi}{8} 0.4^3\ 0.02 = 0.0005$ m^4

[Total 5%]

Q.2.c. On diameter: $V_{max} = N_c D s_u + f_b A' \gamma'$ (5%)

where $N_c = 6\left(\frac{w}{D}\right)^{0.25}$ and $f_b \approx 1.5$

Use remoulded strength → $s_{u,rem} = \frac{s_u}{S_t} = \frac{15}{3} = 5$ kN m^{-2} (5%)

$\theta = \cos^{-1}\left(1 - 2\frac{w}{D}\right) \rightarrow \theta = 1.37$ radians. (5%)

$f W' = V_{max} = 6(0.4)^{0.25} \times 0.4 \times 5 + 1.5 \times \frac{0.4^2}{4}(\theta - \sin\theta\cos\theta)\gamma'$

$2.51 f = 9.54 + 0.34 = 9.88 \rightarrow f = 3.93$ (10%)

[Total 25%]

Q.2.d. $f = 3.93 = f_{lay} f_{dyn}$ (5%)

$f_{lay} \approx 0.6 + 0.4\left(\frac{\lambda^2 k}{T_0}\right)^{0.25}$ and $\lambda = \sqrt{\frac{EI}{T_0}}$

$T_0 = \left(\frac{\cos\phi}{1 - \cos\phi}\right) z_w W' \rightarrow \phi = 90 - 15 = 75°$ (5%)

$\therefore T_0 = 0.35 \times 100 \times 2.51 = 87.7$ kN (5%)

Q.2.d (cont.) $$\lambda = \sqrt{\frac{2e8 \times 0.0005}{87.7}} = 33.77 \quad (10\ \%)$$

$k = \frac{V}{W}$ where $V = 9.88$ and $W = 0.4 \times 0.4 = 0.16\ m$

$\therefore\ k = 61.75\ KN\,m^{-1}$ (10%)

$$flay \approx 0.6 + 0.4 \left(\frac{33.77^2 \times 61.75}{87.7} \right)^{0.25}$$

$$= 2.79 \quad (10\ \%)$$

$$\therefore\ fdyn = \frac{3.93}{2.79} = 1.44 \quad (5\%)$$

[Total 50%]

Q.2.e. Weather conditions were likely to have been benign as a typical range for fdyn is 1-10 and the value calculated sits at the lower end of that spectrum.

[Total 15%]

QUESTION 3 - DRAG ANCHORS :

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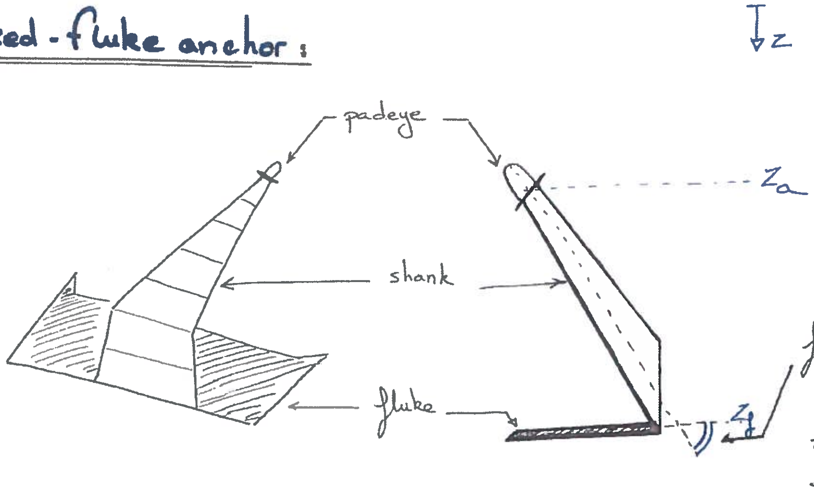
3.a. Fixed-fluke anchor :



fixed fluke angle chosen depending on soil type :
hard clay or sand ~ 30°
soft clay ~50°

[1pt]

- Drag anchors comprise a broad fluke rigidly connected to the shank. The angle between the shank and the fluke is pre-determined and is typically chosen based on the soil type the anchor is to be installed in. Drag anchors are installed by dragging the anchor until the anchor "bites" into the soil and embeds itself until its ultimate penetration depth. [1pt]
- Traditional fixed-fluke anchors are not designed to take large vertical loads and are suitable for catenary mooring lines and taut & semi-taut lines at relatively shallow to medium depths. [1pt] ③

Note : In this question, calculation is proposed at $z = z_f$ but the calculation at $z = z_a$ is (also) correct and was accepted.

3.b. Calculation of Anchor Resisting Force :

- The horizontal geotechnical resisting force T_p is given by :

$$T_p = (f A_f)\, N_c\, s_u = 1.1 \times 16.4 \times 9 \times (4 + 1.5\, z_f)$$

- Using the Design Chart from the manufacturer to obtain the ultimate embedment depth of the anchor (fluke) z_f, we obtain : at W = 40 tonnes, $z_f = 24$ m. ∴ [1pt]
  And Replacing in T_p, we then have : $T_p = 6.5$ MN ∴ [1pt]
- The submerged Weight of the Anchor is : $W_s = W \dfrac{\rho_{steel} - \rho_w}{\rho_{steel}} = 342$ kN ∴ [1pt]
- The Chain angle at the padeye is given by $\theta_w' - \beta = \theta_a$; with $\beta \to 0$ when the anchor is fully installed ⇒ $\theta_w' = \theta_a$ = angle of resultant anchor line tension T_a to the fluke
  And θ_a is given by :

$$\theta_a = \tan^{-1}\left(\frac{W_s + T_p \tan\theta_w}{T_p}\right) \quad \text{with } \theta_w = 50° = 0.87 \text{ rad.}$$

$$\Rightarrow \theta_a = 51° = 0.89 \text{ rad.} \quad \therefore$$

[1pt]

- The expression of the resisting anchor force T_a is then obtained by:

$$T_a = \frac{T_p}{\cos\theta'_w} = \frac{T_p}{\cos\theta_a} = 10.4 \text{ MN} \therefore$$ [1pt]

3. c. Resultant Anchor Line Tension T_a :

⑤

- The ultimate embedment depth z_f is equal to $z_f = z_a + z_{anchor\ a\to f} = z_a + 6.2$ where z_a is the depth of the padeye. $\Rightarrow$ $z_a = 17.8$ m if $z_f = 24$ m $\therefore$ [1pt]
- From the chain geometry: $d = 0.5$ m and $b = 3.0 \times d = 1.5$ m [1pt]
- The bearing resistance is then expressed by:

Assuming $z_f = 24$m $\Rightarrow$ $\cancel{z_a} Q_{av} = b\,N_c \int_0^{z_a} s_u\,dz = bN_c \int_0^{z_a} (4 + 1.5z)\,dz = \left(4\cancel{z_a} + 1.5\frac{z_a^{\cancel{2}}}{2}\right) bN_c$

$$\Rightarrow Q_{av} = \left(4 + \frac{3}{4} z_a\right) \times 1.5 \times 7.6 = 198 \text{ kPa}.$$ [3pts]

- The Chain solution then gives the anchor line tension at the padeye.

$$T_{a,chain} = \frac{2 z_a Q_{av}}{(\theta_a^2 - \theta_m^2)} \quad \text{with } \theta_m = 20° = 0.35 \text{ rad}.$$ [1pt]

Value calculated in previous question 3(b)

- At ultimate penetration depth, the anchor has to be in equilibrium and therefore $T_{a,chain} = \overline{T_{a,3(b)}}$

Here, we calculate: $T_{a,chain} = 10.4$ MN $= T_{a,\text{ question } 3(b)}$

Which is only true when z = final penetration depth of anchor.

$\therefore$ This proves that the estimated depth from manufacturer is correct. [1pt]

⑦

Note: Another way to prove this is to write the total equation:

$$T_{a,anchor} = \frac{T_p}{\cos\theta_a} = \frac{(f A_p) N_c s_u}{\cos\theta_a} = \underbrace{1.1 \times 16.4 \times 9 \times (4 + 1.5 z_f)}_{T_p\ 649.5 + 243.5 z_f} \times \left[\tan^{-1}\left(\frac{W_s + T_p\tan(0.87)}{T_p}\right)\right]^{-1}$$

$$T_{a,anchor} = (649.5 + 243.5 z_f)\left[\cos\left(\tan^{-1}\left(\frac{342 + (649.5 + 243.5 z_f)\tan(0.87)}{649.5 + 243.5 z_f}\right)\right)\right]^{-1} = T_{a,chain}$$

$$= \frac{2(z_f - z_{a\to f}) \times 1.5 \times 7.6 \times \left(4 + \frac{3}{4}(z_f - z_{a\to f})\right)}{\tan^{-1}\left(\frac{342 + (649.5 + 243.5 z_f)\tan(0.87)}{649.5 + 243.5 z_f}\right)^2 - 0.35^2}$$

And replace with $z_f = 24$ and show it works. However, this is longer and redundant as it repeats calculations of Q.3(b).

3. d. Holding Capacity:

- From Chain Solution, the anchor line tension at the mudline T_m is obtained by:

$$T_m = T_a \, e^{\mu(\Theta_a - \Theta_m)} = 12.5 \text{ MN} \therefore = UHC. \quad [1pt]$$

- Thus gives an anchor efficiency of:

$$\eta = \frac{UHC}{W_{dry}} = \frac{T_m}{W_{dry}} \approx 32 \therefore \quad [1pt]$$

- Compared with the tension line, this gives a factor of safety of:

$$FOS = \frac{T_{line}}{UHC} = \frac{12.5}{21} = 0.6 < 1.35 \longrightarrow \underline{\overset{\text{NOT}}{\text{OK}}} \quad [1pt]$$

③

3. e. UHC from manufacturer:

- Using graph from manufacturer, we get $UHC \approx 15$ MN
  Very similar to value calculated but slightly higher. [1pt]
  Method used for calculating T_m above simplifies the geometry of the anchor and assumes the fluke is rectangular and does not account for shank resistance. Although minimal, these might have been accounted for by manufacturer. [1pt]

②

QUESTION 4 . MOBILE JACK-UP & SPUDCAN FOUNDATIONS

4.a. To install a mobile jack-up, the following installation procedure is followed:

1) The jack-up is towed or driven to site with legs elevated out of the water.

2) On location, the legs are lowered onto the seabed, where they continue to be jacked until adequate bearing capacity is reached. [1pt]

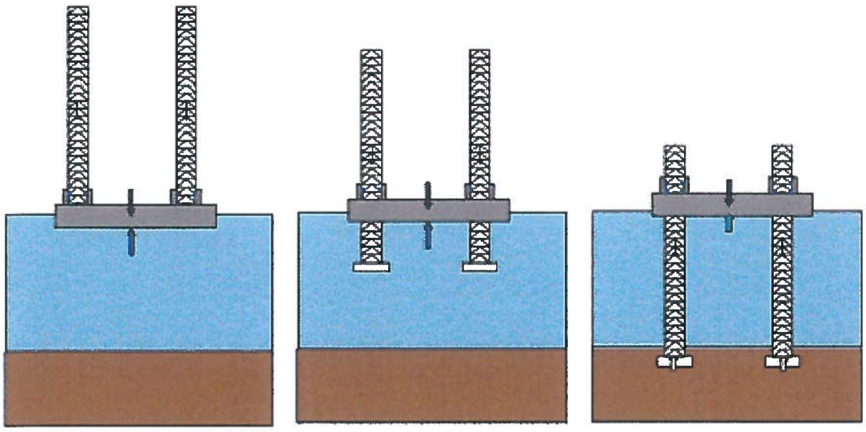
[1pt] 3) The hull is lifted clear of the water.

4) The spudcan foundations are pre-loaded by pumping sea-water into ballast tanks in the hull. This is the proof-test phase or pre-load phase to strengthen the foundation bearing capacity by exposing them to a larger vertical load than would be expected during service, such that the combined pre-load (jack-up + water) is between 1·3 & 2 times the weight of the jackup

[1pt] 5) The ballast tanks are emptied before operation of the jackup begins.

(Schematic not required).

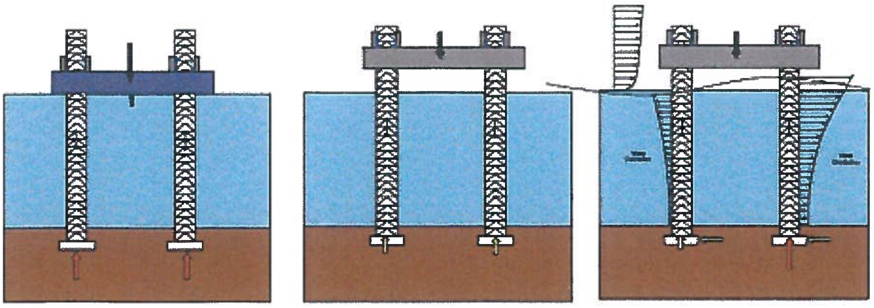
③



Arriving on location
(a)

Lowering legs
(b)

Coming out of the water
(c)

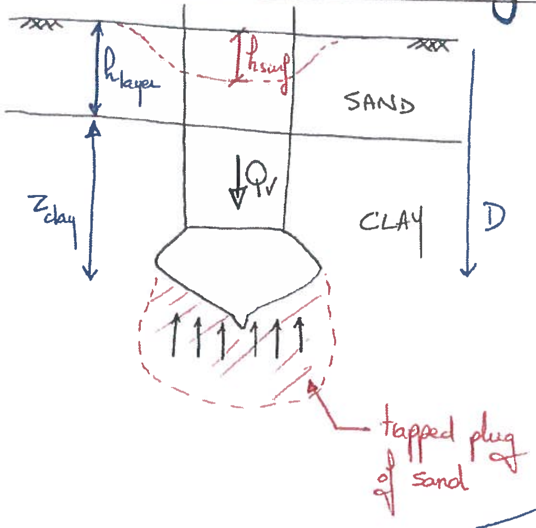


Preloading
(d)

At full airgap
(e)

With environmental loads

4. e "Punch-through" case : Deep Bearing Capacity



$$Q_v^{deep} = \left(N_c s_u + \gamma'_{sand} \cdot h_{layer} + \gamma'_{clay} z_{clay}\right) A' \quad [1pt]$$

$$= \left[7.7 \times 30 + 10 \times 5 + 7.3 \times (10-5)\right] \times 76$$

$$= 24.43 \text{ kN} \therefore \quad [1pt]$$

The trapped sand plug underneath the spudcan will increase the predicted bearing capacity. This increase is due to the side friction on the sand plug. [1pt]

We Assume that the upper sand layer simply contributes to the overburden stress.

Note A Value of $N_c = 7.1$ obtained from shallow foundations bearing capacity was also accepted here.

③

4.f. Shallow Bearing Capacity : Punching shear failure mechanism

$$Q_v^{shallow} = N_c s_u A' + \gamma'_{sand} K_s \tan\phi \int_{h}^{h_{layer}} z \times \pi B \, dz + \underbrace{\cancel{W_{spudcan}}}_{\text{weight of spudcan}} + \underbrace{\cancel{W_{soil}}}_{\text{weight of backfill soil that rests on the spudcan}} + q_0 A' \quad [1pt]$$

with q_0 = effective overburden pressure from sand at depth h

$$\Rightarrow q_0 = \gamma'_{sand} h A' \quad [1pt]$$

$$\Rightarrow Q_v^{shallow} = N_c s_u A' + \frac{\gamma'_{sand}}{2}\left[3 \frac{s_u}{\gamma'_{sand} B}\right] \pi B \left(h_{layer}^2 - h^2\right) + \gamma'_{sand} h A' \therefore \quad [1pt]$$

$$= 9 \times 22.5 \times 76 + \frac{10}{2} \times \left(3 \times \frac{22.5}{20 \times 10}\right) \times \pi \times 10 \times \left(5^2 - 2^2\right) + 10 \times 2 \times 76$$

$$Q_v^{shallow} = 19.1 \text{ kN} \therefore \quad [1pt]$$

④

4. b - Capacity pre and post - preload:

- From data - book: $Q_v = (N_c s_u + \sigma'_{v0})A'$

↦ Initial: $z = 0 \Rightarrow D$ = embedment depth of spudcan $= 0 \Rightarrow \frac{D}{B} = 0 \Rightarrow \underbrace{N_c = 6}_{\text{Data Book}}$

And therefore $Q_v^0 = (N_c s_{u0} + 0) \times A'$

$s_u = s_{u0} + kz$, at $z = 10m$. $s_u = 30\,kPa \Rightarrow s_{u0} = 30 - 1.5 \times 10 = 15\,kPa$ ∴

$$\Rightarrow Q_v^0 = (6 \times 15) \times 76$$
$$= 6.8\,kN \therefore \quad [1pt]$$

↦ With the pre - load, $D\ 1.0\ m \Rightarrow \frac{D}{B} = 1.0 \Rightarrow N_c = 7.7$ (Data Book)

And therefore $Q_v^{PL} = (N_c s_u + \sigma'_{v0})A'$

$$= (7.7 \times 30 + 7.3 \times 10) \times 76 = 23.1\,kN \therefore \quad [1pt]$$

⇒ The bearing capacity is increased by a factor of 3.4 after pre - loading. [1pt]

4. c - Deep Penetration failure Mechanism:

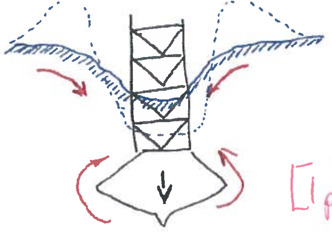
③

- Backflow failure occurs if:

$$\frac{D}{B} > \left(\frac{s_{u0}}{\gamma' B}\right)^{0.55} - \frac{1}{4}\left(\frac{s_{u0}}{\gamma' B}\right)$$

Here $\frac{D}{B} = 1.0 > \left[\left(\frac{s_{u0}}{\gamma' B}\right)^{0.55} - \frac{1}{4}\left(\frac{s_{u0}}{\gamma' B}\right)\right] = 0.51$ [1pt]

⇒ Deep penetration failure mechanism [1pt] - also called backflow failure - occurs: a flow failure of the soil creating backflow during further penetration of the spudcan into soft clay occurs until wall failure occurs, creating an infill above the supdcan [1pt] ④

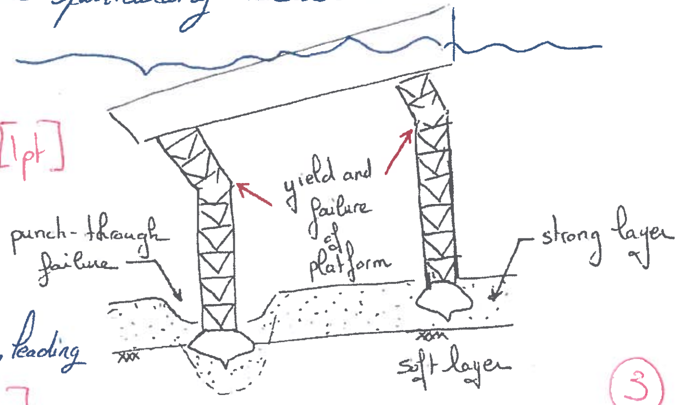


[1pt]

Thin layers of sand overlying a weaker layer of clay are particularly hazardous.

4. d - Punch - through failure:

Unexpected punch - through failure of a mobile jackup [1pt] platform can occur during installation when the spudcan uncontrollably pushes a locally strong zone of soil [1pt] into underlying softer material. Such failure can lead to buckling of the jack - up leg and toppling of the unit, leading to catastrophic failures - [1pt]



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