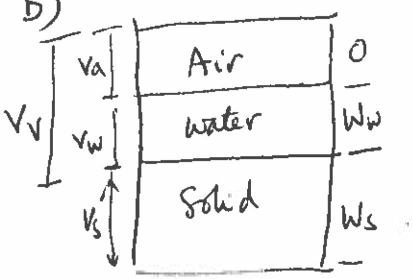
3D1 - 2022/23

Q 1 a) When rocks are subjected freeze/thaw cycles water entering the cracks can expand on freezing and open up the cracks. The rocks can eventually split forming smaller rocks. This process can continue and soil particles of different sizes are formed.

The soil particles can be transported either by water or wind. When soil particles are transported by water in rivers, larger sized particles remain in the upper reaches while smaller particles are transported further downstream and settle based on their sizes. Very fine particles can be transported until confluence of river with sea, where the flow velocity is small, causing them to settle and even form river delta's. Flowing water also removes angularities in the soil particles form of rounded or sub-rounded shapes.

Relatively smaller particles of soil can be transported by wind and form aeolian deposits. These particles can retain their sharp angular features giving larger friction angles and more specifically dilation angles. [15%]

b)



Bulk density is total weight of soil by total volume

$$\gamma_b = \frac{W_T}{V_T} = \frac{W_w + W_s}{V_a + V_w + V_s} = \frac{W_w + W_s}{V_v + V_s}$$

$$W_w = \gamma_w V_w \; ; \quad e = \frac{V_v}{V_s} \; ; \quad S_r = \frac{V_w}{V_v} \; ;$$
$$W_s = G_s \gamma_w V_s \; ;$$

$$\therefore \gamma_b = \frac{\gamma_w V_w + G_s \gamma_w V_s}{V_s + V_v} = \frac{\gamma_w [V_v S_r + G_s V_s]}{V_s + e V_s}$$

$$= \frac{\gamma_w [e \cancel{V_s} S_r + G_s \cancel{V_s}]}{(1+e) \cancel{V_s}}$$

$$\gamma_b = \frac{[G_s + e S_r]}{(1+e)} \gamma_w \qquad \text{QED}$$

[15%]

1 c) i) $G_s = 2.65$

$e_{max} = 1.015$

$e_{min} = 0.55$

$RD = 40\%$

Sample $\phi = 76$ mm

$h = 20$ mm.

$$RD = \frac{e_{max} - e}{e_{max} - e_{min}}.$$

$$0.4 = \frac{1.015 - e}{(1.015 - 0.55)} \Rightarrow e = 0.829$$

Note: RD of 40% indicates loose packing.

As the sample is fully saturated $S_r = 100\% = 1$

$$\therefore \gamma_{sat} = \frac{(G_s + e)\gamma_w}{1+e}$$

$$= \frac{(2.65 + 0.829)}{1.829} \times 9.81$$

$$= \underline{18.66} \text{ kN/m}^3.$$

Using $w G_s = e S_r$.

$$w = \frac{0.829 \times 1}{2.65} = 31.283\% \simeq \underline{31.3\%}.$$ [10%]

ii) Volume of sample $V = \frac{\pi}{4}\left(\frac{76}{1000}\right)^2\left(\frac{20}{1000}\right) = 9.0729 \times 10^{-5}$ m^3.

$\phi = 76$ mm

$h = 20$ mm

$e = \frac{V_v}{V_s} = 0.829$ $\quad V = V_v + V_s = (1+e) V_s$

$V_s = \frac{9.0729 \times 10^{-5}}{1.829} = 4.96059 \times 10^{-5}$ m^3

$V_v = V - V_s = 4.112329 \times 10^{-5}$ m^3.

weight of the soil grains $= (G_s \gamma_w) V_s = 2.65 \times 9.81 \times 10^3 \times 4.96059 \times 10^{-5}$

$= 1.2896$ N

Mass of the soil grains $= \underline{131.455}$ grams

weight of the water in sample $= \gamma_w \cdot V_v = 9.81 \times 10^3 \times 4.1123 \times 10^{-5}$

$= 0.4034$ N

Mass of water $= \underline{40.34}$ grams.

Check: $\gamma_{sat} = \frac{W}{V} = \frac{1.2896 + 0.4034}{9.0729 \times 10^{-5}} = 18.66$ kN/m^3. [10%]

iii) Average sized particle $D_{20} = 0.15$ mm.
Assuming spherical shape of particles

$$v_p = \frac{4}{3}\pi r^3 = \frac{4}{3}\pi \times \left(\frac{0.15}{2\times1000}\right)^3 = 1.76715\times10^{-12}$$

$$\text{No of particles} = \frac{v_s}{v_p} = \frac{4.96059\times10^{-5}}{1.76715\times10^{-12}} = 28,071,198.6$$

$\simeq$ 28 million particles!

If D_{50} was used.
$v_p = 1.41372\times10^{-11}$. } no of particles = 3,508,899
$\simeq$ 3 million particles.
still quite a large number. [10 %]

1 d) Hostun Sand is similar to Ham River sand.

i) $\lambda = 0.163$
$\kappa_0 = 0.015$
$\Gamma^* = 3.026$
$\sigma_c^* = 2500$ kPa

NCL:- $v = \Gamma - \lambda \ln \sigma'_v$ But loose sand cannot exist in this state

From 1kPa → 2500 kPa κ_0 line is followed.

$v_{initial} = 1 + e = 1.829$.

$$\therefore v_{\sigma_c^*} \simeq 1.829 - \kappa_0 \ln\left[\frac{2500}{1}\right] = 1.7116$$

From 2500 kPa → 3000 kPa λ line is followed

$$v_{3\,MPa} = 1.7116 - \lambda \ln\left[\frac{3000}{2500}\right] = 1.6819$$

$$\varepsilon_v = \frac{\delta v}{v} = \frac{1.829 - 1.6819}{1.829} \simeq 0.08 \quad (8\%)$$

In oedometer volumetric strain = vertical strain ∴ change in height = 8% of 20mm.

$\therefore h_{sample} = 18.3916$ mm
$\simeq$ 18.4 mm [15%]

ii) unloading from 3 MPa → 1 MPa - will follow κ_0 line.

$v_{3MPa} = 1.6819$

$$v_{1MPa} = 1.6819 + \kappa_0 \ln\left[\frac{3000}{1000}\right] = 1.6983.$$

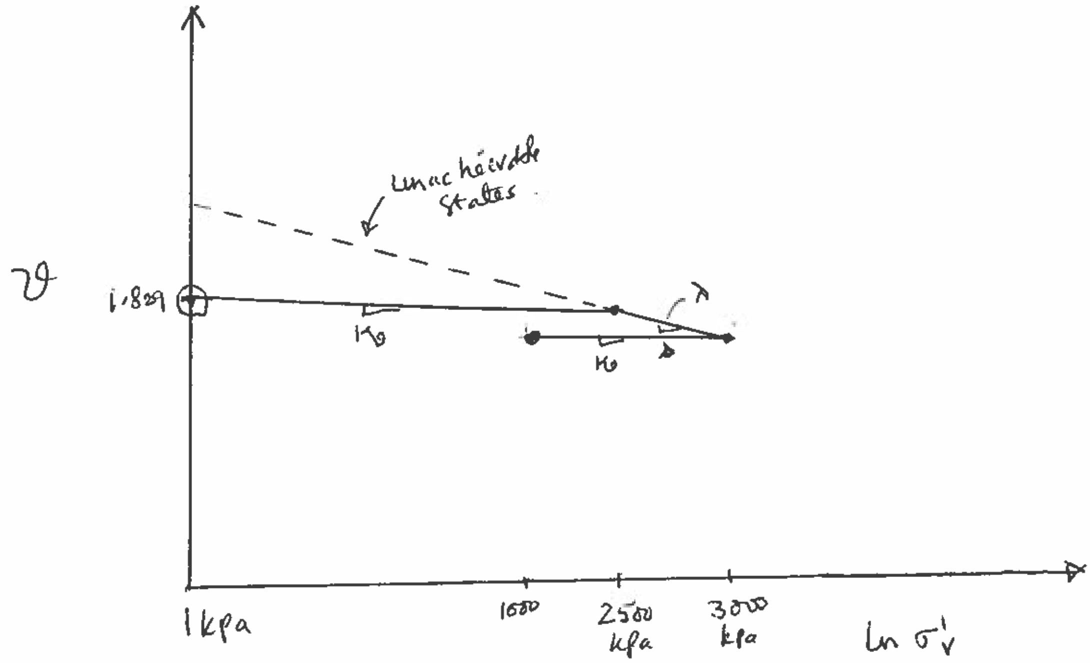
$\varepsilon_v = \frac{\Delta V}{V} = 0.00979$ or 0.979%

$\frac{\Delta h}{h} = 0.00979$ $\Delta h = 0.00979 \times 18.3916 = 0.1802$ mm.

$18.3916 + 0.1802 = 18.5718$ mm

∴ Rebounded height of sample = $\simeq$ 18.6 mm [15%]

1d iii)


unachievable states
v
1.829
κ_0
λ
κ_0
1kpa
1000
2500 kpa
3000 kpa
$\ln \sigma'_v$

[10%]

3D1 2023 Exam Crib – sas 229

Q.2.a. Silt: $s_\infty = \dfrac{h\,\Delta\sigma_v}{E_o} = \dfrac{10 \times 100}{5000} = 0.2$ m (5%)

Clay: $s_\infty = \dfrac{h\,\Delta\sigma_v}{E_o} = \dfrac{10 \times 100}{2000} = 0.5$ m (5%)

[Total 10%]

Q.2.b. Silt: $c_v = \dfrac{E_o k}{\gamma_w} = \dfrac{5000 \times 1 \times 10^{-8}}{9.81}$

$= 5.1 \times 10^{-6}$ m^2/s $= 160$ m^2/yr (5%)

Clay: $c_v = \dfrac{E_o k}{\gamma_w} = \dfrac{2000 \times 1 \times 10^{-9}}{9.81}$

$= 2 \times 10^{-7}$ m^2/s $= 6.42$ m^2/yr (5%)

[Total 10%]

Q.2.c. Silt: $\tilde{T} = \dfrac{c_v t}{L^2} = \dfrac{160 \times 1/12}{5^2} = 0.53$ ← (Double drained)

$\tilde{T} \geq 1/12 \longrightarrow$ 2nd stage parabolic isochrone. (5%)

$\therefore$ $\tilde{L} = 1$ and $\tilde{U}_L = \exp\left(-3\left(\tilde{T} - 1/12\right)\right) = 0.26$

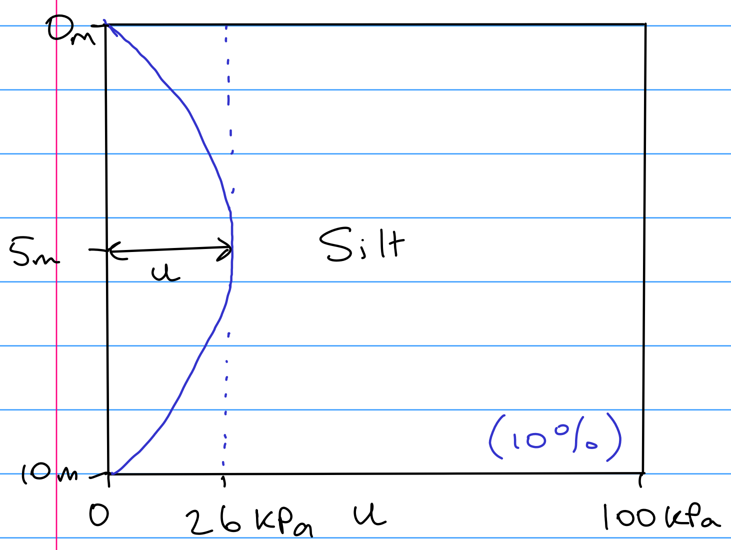
$\hookrightarrow$ $u = \tilde{U}_L \sigma_v = 26$ kNm^{-2} (5%)

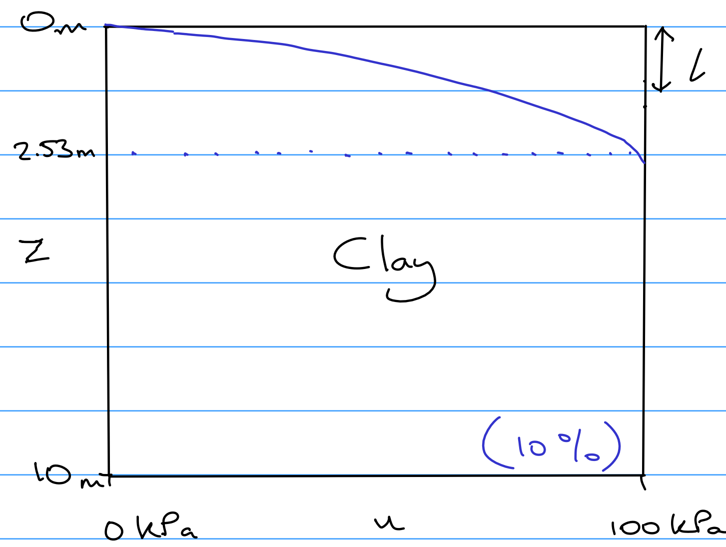
Clay: $\tilde{T} = \dfrac{c_v t}{L^2} = \dfrac{6.42 \times 1/12}{10^2} = 0.00535$ ← (Single drained)

$\tilde{T} < 1/12 \longrightarrow$ 1st stage parabolic isochrone. (5%)

$\therefore$ $\tilde{U}_L = 1$ and $\tilde{L} = \sqrt{12\tilde{T}} = 0.25$

$\hookrightarrow$ $L = 10 \times 0.25 = 2.53$ m (5%)





[Total 40%]

Q.2.d. Silt : $\tilde{T} = \frac{c_v t}{L^2} = \frac{160 \times 1}{5^2} = 6.4$

$\tilde{S} = 1 - \frac{2}{3} \exp\left(-3\left(\tilde{T} - 1/12\right)\right) = 1$ ∴ Fully consolidated!

↳ ∴ $S_{silt} = 1 \times 0.2 = 0.2m$ (5%)

Clay : $\tilde{T} = \frac{c_v t}{L^2} = \frac{6.42 \times 1}{10^2} = 0.064$

$\tilde{S} = 1 - \frac{2}{3} \exp\left(-3\left(\tilde{T} - 1/12\right)\right) = 0.29$

↳ $S_{clay} = 0.29 \times 0.5 = 0.15$ m (5%)

$\Sigma S = 0.2 + 0.15 = 0.35$ m (5%)

$\Sigma S_{\infty} = 0.2 + 0.5 = 0.7$ m

$\frac{\Sigma S}{\Sigma S_{\infty}} = \frac{0.35}{0.7} = 0.5$

∴ 50% of total settlement will have occurred 1 year after construction is finished. (5%)

[Total 20%]

Q.2.e. Vertical drains or pre-loading could have been employed to accelerate the rate of consolidation. The former entails adding high permeability vertical drains at spacings less than the layer drainage height so as to reduce the effective drainage path length. The latter by accelerating the consolidation process prior to unloading to the target stress state. Vacuum consolidation also an acceptable suggestion where negative excess pore pressures are used to extract pore water resulting in consolidation.

[Total 20%]

Q.3.a. $\frac{V_{ult}}{A} = S_c d_c N_c s_u + \gamma h$ where $s_u = 25\,kPa$

$S_c = 1 + 0.2 \frac{B}{L} \rightarrow \frac{B}{L} = 1$ (circular)

$\therefore = 1.2$ (5%)

$d_c = 1 + 0.33 \tan^{-1}(h/D)$

$= 1 + 0.33 \tan^{-1}(1/20) = 1.02$ (5%)

$N_c = 2 + \pi$ (5%)

$A = \frac{\pi D^2}{4} = \frac{\pi \times 20^2}{4} = 314.2\ m^2$ (5%)

$\rightarrow \frac{V_{ult}}{A} = 172\ kPa \therefore V_{ult} = 53921\ kN$ (5%)

[Total 25%]

Q.3.b. $H_{ult} = A s_u = 314.2 \times 25 = 7855\ kN$ (5%)

$M_{ult} = 0.67\, A D s_u$

$= 0.67 \times 314.2 \times 20 \times 25$

$= 105257\ kNm$ (5%)

[Total 10%]

Q.3. c. $M = 75H$ (Moment due to wind force @ hub height). (5 %)

$$\left(\frac{V}{V_{ult}}\right)^2 + \left[\frac{M}{M_{ult}}\left(1 - 0.3\left(\frac{H}{H_{ult}}\right)\right)\right]^2 + \left|\left(\frac{H}{H_{ult}}\right)^3\right| - 1 = 0$$

$$\left(\frac{10000}{53921}\right)^2 + \left[\frac{75H}{105257}\left(1 - 0.3\left(\frac{H}{7855}\right)\right)\right]^2 + \left|\left(\frac{H}{7855}\right)^3\right| - 1 = 0$$

$$0.0344 + \left[7.12 \times 10^{-4} H - 3.82 \times 10^{-5} H\right]^2 + \left|\left(1.27 \times 10^{-4} H\right)^3\right| - 1 = 0$$

$$\left|2.06 \times 10^{-12} H^3\right| + 4.55 \times 10^{-7} H^2 - 0.9656 = 0$$ (20%)

Solve by trial and error $\rightarrow$ $H \approx 1452$ kN

(10%)

$\therefore \dfrac{H}{H_{ult}} = \dfrac{1452}{7855} = 0.19$ (5 %)

$\therefore \dfrac{M}{M_{ult}} = \dfrac{75H}{M_{ult}} = \dfrac{75 \times 1452}{105257} = 1.03$ (5 %)

$M/M_{ult} > 1.0$ is permissible using this approach for low values of V/V_{ult} and H/H_{ult}, as is the case here. The failure mode will be moment induced rotation in this case. (5 %)

[Total 50%]

Q.3. d. Assuming that lift-off does not occur implies that negative excess pore pressures at the soil-foundation interface do not have sufficient time during loading to dissipate. (5%) Under sustained loading it is likely they will eventually dissipate, reducing the moment capacity of the foundation. (5%) To account for lift-off a combination of the Green (V-H) and Meyerhoff effective area approaches could be used. (5%)

[Total 15%]

Q.4. a. The steps required to perform a drained triaxial test are as follows:

1. Create a sample within the rubber membrane at the target relative density using a split-mold.
2. Place the specimen on the triaxial pedestal and enclose in the triaxial cell.
3. Apply cell pressure and back pressure such that the difference between the two represents the target cell pressure.
4. Check the "B" value. If less than 0.95 increase cell and back pressure.
5. Open the drainage taps to the sample and apply axial strain at a rate that results in no excess pore pressure. Optionally measure the volume change.

[Total 15%]

Q.1. b. $\sin\phi = \dfrac{(\sigma_1' - \sigma_3')}{(\sigma_1' + \sigma_3')} \Rightarrow \phi = \sin^{-1}\left(\dfrac{(\sigma_1' - \sigma_3')}{(\sigma_1' + \sigma_3')}\right)$

$q = \sigma_3' - \sigma_1'$ and $\sigma_c = \sigma_1'$

$\therefore \sigma_1' = c$ and $\sigma_3' = q + \sigma_c$

Value	Peak			Residual		
σ_c (kPa)	100	200	300	100	200	300
q (kPa)	340	610	840	245	500	730
σ_1' (kPa)	100	200	300	100	200	300
σ_3' (kPa)	440	810	1140	345	700	1030
ϕ' (°)	39.0	37.2	35.7	33.4	33.8	33.3

(10%)

$$\overline{\phi'_{peak}} = \frac{39.0 + 37.2 + 35.7}{3} = 37.3^\circ \quad (5\%)$$

$$\overline{\phi'_{crit}} = \frac{33.4 + 33.8 + 33.3}{3} = 33.5^\circ \quad (5\%)$$

[Total 20%]

Q.4.c. The appropriate friction angle is ϕ'_{crit} for conservatism. [Ideally the value from part (b) would be used, however 32° for Ham River Sand from the databook would also be accepted] (5%)

$$\frac{V_{ult}}{A} = q_f = s_q N_q \sigma'_{vo} + s_\gamma N_\gamma \frac{\gamma' B}{2}$$

$$s_q = 1 + (B/L)\sin\phi'$$
$$= 1 + (3/4)\sin\phi'$$
$$= 1.41 \quad (5\%)$$

$$N_q = \tan^2(\pi/4 + \phi'/2)\, e^{(\pi \tan\phi)}$$

$$= 27.07 \quad (5\%)$$

$$\sigma'_{vo} = \gamma_d$$ [Note: 1 metre embedment]

$$\gamma_d = \left(\frac{G_s}{1+e}\right)\gamma_w = \left(\frac{2.65}{1+1.05}\right) 9.81 = 12.68\ \text{kNm}^{-3} \quad (5\%)$$

$$\therefore \sigma'_{vo} = 12.68\ \text{kNm}^{-2}$$

$$S_\gamma = 1 - 0.3\, B/L$$
$$= 1 - 0.3 \times 3/4$$
$$= 0.78$$ (5%)

$$N_\gamma = 2(N_q - 1)\tan\phi'$$
$$= 2(27.07 - 1)\tan(33.5)$$
$$= 34.51$$ (5%)

For dry soil $\gamma' = \gamma_d \therefore \dfrac{\gamma' B}{2} = \dfrac{12.68 \times 3}{2}$

$$= 19.0 \text{ KN m}^{-2}$$ (5%)

$\Rightarrow q_f = 1.41 \times 27.07 \times 12.68 + 0.78 \times 34.51 \times 19.0$

$= 1017.9 \text{ kN m}^{-2}$

$\Rightarrow A = 3 \times 4 = 12 \text{ m}^2$

$\Rightarrow V_{ult} = q_f A = 1017.9 \times 12 = 12216 \text{ kN}$

$= 12.2 \text{ MN}$ (5%)

[Total 40%]

Q.4.c. $\sigma'_{vo} = \gamma' = \left(\dfrac{G_s - 1}{1 + e}\right)\gamma_w = \left(\dfrac{2.65 - 1}{1 + 1.05}\right) 9.81$

$= 7.89 \text{ kN m}^{-3}$ (5%)

$\dfrac{\gamma' B}{2} = \dfrac{7.89 \times 3}{2} = 11.8 \text{ KN m}^{-2}$ (5%)

S_q, N_q, S_γ and N_γ remain unchanged...

$\Rightarrow q_f = 1.41 \times 27.07 \times 7.89 + 0.78 \times 34.51 \times 11.8$

$= 618.8 \text{ kN m}^{-2}$ (5%)

$\Rightarrow V_{ult} = q_f A = 618.8 \times 12 = 7425 \text{ kN}$

$= 7.4 \text{ MN}$ (5%)

Percentage reduction in capacity:

$$100 \times \left[1 - \left(\frac{12.2 - 7.4}{12.2} \right) \right] \approx 60 \%$$ (5%)

Note: could also account for buoyancy and side friction.

[Total 25%]