CE 330 – Geotechnical Engineering II, 2016-2017; Semester 2
Solutions of Practice Problems on Subsurface Investigation

1. The subsurface profile at a particular site is shown in Figure 1. Calculate the following quantities at point A.
    a. effective vertical geostatic stress
    b. total vertical geostatic stress
    c. lateral (horizontal) effective stress; given the coefficient of lateral earth pressure at rest $K_0 = 0.4$
    d. lateral total stress
    e. mean effective stress
    f. total mean stress
    g. overconsolidation ratio (OCR) if in the past the ground surface were at a level 2 m higher than the present level (with water table at the same location).

   [Hint: Mean effective stress at any point $\sigma'_m = (\sigma'_v+2\,\sigma'_h)/3$; $\sigma'_h = K_0\sigma'_v$; $\sigma_v=\sigma'_v+u$; $\sigma_h=\sigma'_h+u$]

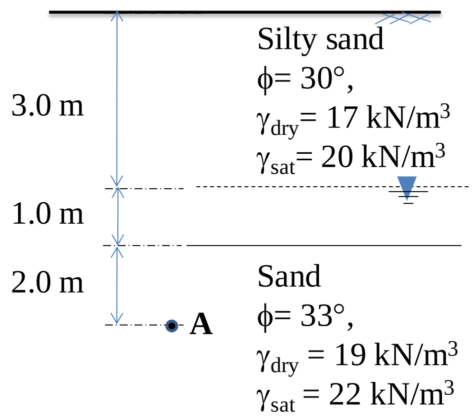


Fig. 1. Subsurface profile for use in Problem 1

Answer:

In subsurface profile shown in Figure 1,

$$\gamma_w = 9.81\text{ kN/m}^3$$

for silty sand -

$$\gamma_{dry,1} = 17\text{ kN/m}^3,\ \gamma_{sat,1} = 20\text{ kN/m}^3\text{ and }\phi_1 = 30°$$

for sand -

$$\gamma_{dry,2} = 19\text{ kN/m}^3,\ \gamma_{sat,2} = 22\text{ kN/m}^3\text{ and }\phi_2 = 33°$$

At point A:

(a) Effective vertical geostatic stress;

$$\sigma_{v,A}' = 3\,m\,(\gamma_{dry,1}) + 1\text{ m }(\gamma_{sat,1} - \gamma_w) + 2\text{ m }(\gamma_{sat,2} - \gamma_w)$$

$$= 3\,m\,(17\text{ kN/m}^3) + 1\text{ m }(20\text{ kN/m}^3 - 9.81\text{ kN/m}^3) + 2\text{ m }(22\text{ kN/m}^3 - 9.81\text{ kN/m}^3)$$

$$\sigma_{v,A}' = 3\,m\,(17\text{ kN/m}^3) + 1\text{ m }(10.19\text{ kN/m}^3) + 2\text{ m }(12.19\text{ kN/m}^3)$$

$\sigma_{v,A}' = 85.57 \text{ kPa}$

(b) Total vertical geostatic stress;

$\sigma_{v,A} = \sigma_{v,A}' + u_A = 85.57 + 3 \text{ m } (\gamma_w)$

$= 85.57 + 3 \text{ m } (9.81 \text{ kN/m}^3)$

$\sigma_{v,A} = 115 \text{ kPa}$

(c) Lateral (horizontal) effective stress;

Here, the coefficient of lateral earth pressure at rest $K_0 = 0.4$

$\sigma_{h,A}' = K_0(\sigma_{v,A}') = 0.4 \text{ (85.57 kPa)}$

$\sigma_{h,A}' = 34.228 \text{ kPa}$

(d) Lateral (horizontal) total stress;

$\sigma_{h,A} = \sigma_{h,A}' + u_A = 34.228 \text{ kPa} + 3 \text{ m } (9.81 \text{ kN/m}^3)$

$\sigma_{h,A}' = 63.658 \text{ kPa}$

(e) Mean effective stress;

$$\sigma_{m,A}' = \frac{\sigma_{v,A}' + 2\sigma_{h,A}'}{3}$$

$$\sigma_{m,A}' = \frac{85.57 \text{ kPa} + 2(34.228 \text{ kPa})}{3}$$

$\sigma_{m,A}' = 51.342 \text{ kPa}$

(f) Total mean stress;

$\sigma_{m,A} = \sigma_{m,A}' + u_A = 51.342 \text{ kPa} + 3 \text{ m } (9.81 \text{ kN/m}^3)$

$\sigma_{m,A} = 80.772 \text{ kPa}$

(g) Overconsolidation ratio (OCR);

In the past, ground surface were at a level 2 m higher than the present level (with water table at the same location). Therefore, thickness of silty sand layer was 5 m (3 m +2 m) in the past.

$\therefore$ past maximum effective stress = $5 \text{ m } (\gamma_{dry,1}) + 1 \text{ m } (\gamma_{sat,1} - \gamma_w) + 2 \text{ m } (\gamma_{sat,2} - \gamma_w)$

$= 5\ m\ (17 \text{ kN/m}^3) + 1 \text{ m } (20 \text{ kN/m}^3 - 9.81 \text{ kN/m}^3) + 2 \text{ m } (22 \text{ kN/m}^3 - 9.81 \text{ kN/m}^3)$

$= 5\ m\ (17 \text{ kN/m}^3) + 1 \text{ m } (10.19 \text{ kN/m}^3) + 2 \text{ m } (12.19 \text{ kN/m}^3)$

$= 119.57 \text{ kPa}$

present effective stress $= 3\ m\ (17 \text{ kN/m}^3) + 1 \text{ m } (10.19 \text{ kN/m}^3) + 2 \text{ m } (12.19 \text{ kN/m}^3)$

$= 85.57 \text{ kPa}$

$$OCR = \frac{\text{Past maximum effective stress}}{\text{Present effective stress}}$$

$$= \frac{119.57 \text{ kPa}}{85.57 \text{ kPa}}$$

$OCR = 1.397$

2. SPT blow counts (N) obtained at intervals of 1 m at a sandy site are given below. A donut hammer and a liner sampler without the liner were used. Every care was taken to connect the rod segments firmly and to follow standard procedure. The water table is at a depth of 3 m, and the site is lightly overconsolidated (OC) because approximately 2 m of soil (average total unit weight approximately equal to 17 kN/m^3) were removed before the SPT was performed. The K_0 of this soil in a normally consolidated state ($K_{0,NC}$) would be 0.48. Calculate energy corrected N_{60} and corresponding stress-normalized, energy-corrected blow counts $(N_1)_{60}$ at depth 1, 4 and 6 m. Use the relation $K_0 = K_{0,NC}(OCR)^{0.5}$. Use the following table to guide you through the calculations.

Depth (m)	1	2	3	4	5	6
Field SPT blow count (N)	15	18	22	23	25	28

Depth (m)	N_{SPT}	N_{60}	$\sigma'_{v,present}$ (kPa)	$\sigma'_{v,past}$ (kPa)	OCR	K_0	$(N_1)_{60}$
1	15						
4	23						
6	28						

Answer:

We know energy corrected (standardized) value of SPT blow count

$$N_{60} = C_N \eta_r \eta_s \eta_b N$$

For a donut hammer η_H=45% → $C_N = \frac{45}{60} = 0.75$

For rod length (i.e. depth of sampling) < 4m →η_r=0.75

4m to 6 m →η_r=0.85

A liner sampler without a liner was used thus η_s=1.2

For standard borehole diameter η_b=1.0

Thus N_{60} values for all depths

@ 1 m N_{60} = (0.75) (0.75) (1.2) (1.0) 15=10.1

@ 4m N_{60} = (0.75) (0.85) (1.2) (1.0) 23=17.6

@ 6m N_{60} = (0.75) (0.95) (1.2) (1.0) 28=23.9

Now we need to normalize N60 values to get (N1)60

$$(N_1)_{60} = N_{60}\sqrt{\frac{P_A}{\sigma'_v}\frac{K_{0,NC}}{K_0}}$$

Where $K_0 = K_{0,NC}\sqrt{OCR}$

Sample Calculations at 4m:-

$$\sigma'_{v,present} = (17)(4) - (9.81)(1) = 58.2kPa$$
$$\sigma'_{v,past\ max.} = 58.2 + (17)(2) = 92.2kPa$$
$$OCR = \frac{92.2}{58.2} = 1.58$$
$$K_0 = \mathrm{K}_{0,\mathrm{NC}}\sqrt{\mathrm{OCR}} = (0.48)\sqrt{1.58} = 0.6$$
$$(\mathrm{N}_1)_{60} = (17.6)\sqrt{\left(\frac{100}{58.2}\right)\left(\frac{0.48}{0.6}\right)} = 20.6$$

Similar calculations are done to obtain the following table:

Depth 'm'	N_{SPT}	N_{60}	$\sigma'_{v,present}$ 'kPa'	$\sigma'_{v,past}$ 'kPa'	OCR	K_0	$(N_1)_{60}$
1	15	10.1	17	51	3	0.83	18.6
4	23	17.6	58.2	92.2	1.58	0.6	20.6
6	28	23.9	72.6	106.6	1.47	0.58	25.5

3. The results of SPT tests performed with an automatic trip hammer (hammer efficiency = 80%) using the standard ASTM split spoon sampler with a liner are shown in the following table. The borehole diameter was within the recommended range. The soil profile consists of a normally consolidated (NC) sand with average total unit weight equal to 20 kN/m^3. The water table is located at 4.5 m below the ground surface. Estimate the relative density D_R using correlation proposed by Meyerhof and Skempton (1986) at depths 4m and 6m. Use A = 36.5 in your calculations.

Depth (m)	4	5	6
Field SPT value (N)	25	30	35

Answer:

For automatic trip hammer η_H=80%→ $C_N = \frac{80}{60} = 1.33$

A liner sampler with a liner was used thus η_s=1.0
Borehole diameter was within recommended limits so η_b=1.0

Rod Length correction η_r
@ 4m η_r=0.85
@ 6m η_r=0.95

Therefore

@ 4 m N_{60} = (1.33) (0.85) (1.0) (1.0) 25=28.3
@ 6 m N_{60} = (1.33) (0.95) (1.0) (1.0) 35=44.2

Following Meyerhof and Skempton (1986) method

$$D_R(\%) = \sqrt{\frac{N_{60}}{A + BC\frac{\sigma'_v}{P_R}}}$$

Given:

A=36.5, B=27, and C=1 for NC sand
So using the above equation

σ'_v@ 4m =69.8%
σ'_v@6m =82.5%

4. The cone resistance q_c for a clean sand at 6 m has been measured at 11 MPa. The average total unit weight of the soil column above 6 m is 21 kN/m^3. The water table is 3 m below the surface. The soil is normally consolidated, with K_0 = 0.45. The soil has ϕ_c = 30˚. Estimate the relative density D_R of the sand at 6 m using relationships proposed by (a) Kulhawy and Mayne (1990) and (b) Salgado and Prezzi (2007).

Answer:

Given:

q_c at 6 m = 11MPa

Average total unit weight above 6 m = 21kN/m^3

Water table is 3 m below surface

Soil- NC with $K_o = 0.45$, $\phi_c = 30°$

(a) Following the equation proposed by Lancellotta (1983); Jamiolkowski et al. (1985) Kulhawy and Mayne (1990)

$$D_R = 68\left[\log\left(\frac{q_c}{\sqrt{p_a \sigma'_{vo}}}\right) - 1\right]$$

Now, $\sigma'_{vo} = 6(21) - 3(9.81) = 96.6$ kPa

$q_c = 11$ MPa

$$D_R = 68\left[\log\left(\frac{11 \times 10^3}{\sqrt{100(96.6)}}\right) - 1\right]$$

$D_R = 71.3\%$

(b) From the equation based on cavity expansion analysis,

$$D_R = \frac{\ln\left(\frac{q_c}{p_a}\right) - 0.4947 - 0.1041\phi_c - 0.841\ln\left(\frac{\sigma_h'}{p_a}\right)}{0.0264 - 0.0002\phi_c - 0.0047\ln\left(\frac{\sigma_h'}{p_a}\right)}$$

Now, $\sigma'_h = K_o \sigma'_{vo} = (0.45)(96.6) = 43.5$ kPa

$$D_R = \frac{\ln\left(\frac{11}{0.1}\right) - 0.4947 - 0.1041(30) - 0.841\ln\left(\frac{43.5}{100}\right)}{0.0264 - 0.0002(30) - 0.0047\ln\left(\frac{43.5}{100}\right)}$$

$D_R = 73\%$

5. A CPT was performed in a deposit of soft clay with the water table at a depth of 1 m. The cone resistance at a depth of 10 m was equal to 0.6 MPa. What is the minimum and maximum value of s_u of the clay at what depth would expect based on a range of values of N_k varying from 10 to 15? The average total unit weight of this clay is 17 kN/m^3. Consider that the clay layer to be fully saturated due to capillary rise.

Answer:

Given, $q_c = 0.6$ MPa @ 10m depth

Range of $N_k = 10$ to 15

Average total unit weight = 17 kN/m^3

Water table is at 1 m depth, fully saturated clay due to capillary rise

We know, $q_c = N_k s_u + \sigma_v$

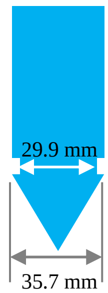
$$\Rightarrow s_u = \frac{q_c - \sigma_v}{N_k}$$

Now at 10m $\sigma_v = (17)(10) = 170$ kPa

For $N_k = 10,\ s_u = \dfrac{600-170}{10} = 43$ kPa

For $N_k = 15,\ s_u = \dfrac{600-170}{15} = 29$ kPa

6. Penetration resistance q_c, sleeve friction f_s and pore pressure u_2 measured during a CPT at a depth of 20 m below ground surface are summarized in the table below. The dimensions of the cone are as displayed in Fig. 2. Piezoprobe tests have shown that in situ pressures are hydrostatic and index tests have indicated the unit weight of the soil γ = 18 kN/m^3. What sort of material is likely being encountered? Use Robertson's chart and consider that the soil layer is fully saturated.



z (m)	q_c (kPa)	f_s (kPa)	u_2 (kPa)
20	2000	25	320

Fig. 2. Cone dimensions for use in Problem 6

Answer:

Given, @ 20m depth, $q_c = 2000$ kPa, $f_s = 2000$ kPa, $u_2 = 2000$ kPa

Unit weight of soil, γ=18 kN/m^3

Unit weight of water, γ_w=9.81 kN/m^3

Diameter of shoulder & cone = 29.9 mm & 35.7 mm respectively

$$\therefore \ \alpha = \frac{\text{Area of load cell}}{\text{Area of cone}} = \frac{29.9^2}{35.7^2} = 0.7$$

Total stress at 20m , $\sigma_{vo} = 18 \times 20 = 360$ kPa

Effective stress at 20m , $\sigma'_{vo} = 360 - 9.81 \times 20 = 163.8$ kPa

$q_{net} = q_t - \sigma_{vo}$

Now, $q_t = q_c + (1-\alpha)u_2$

= 2000 + (1-0.7)$\times$320

=2096 kPa

$\therefore q_{net} = 2096 - 360 = 1736$ kPa =1.7 MPa

Normalized cone tip resistance, $Q = \dfrac{q_{net}}{\sigma'_{vo}} = \dfrac{1736}{163.8} = 10.6$

Friction ratio, $F = \dfrac{f_s}{q_{net}}(\%) = \dfrac{25 \times 100}{1736} = 1.44\%$

Pore pressure ratio, $B_q = \dfrac{u_2 - u_o}{q_{net}} = \dfrac{320 - 9.81 \times 20}{1736} = 0.071$

Using Robertson chart, it is found that the soil is of clayey silt to silty clay type.