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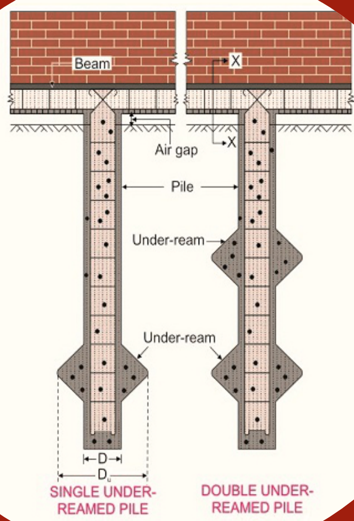


CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

Text Book : Theory with worked out Examples and Practice Questions

9 Geotechnical Engineering

(Solutions for Volume : I Classroom Practice Questions)

02. Definitions and Properties of Soil

01. Ans: (c)

Sol: Volume of solids in sample A:

Total volume $V = V_s + V_v$

Void ratio, $e = \dfrac{V_v}{V_s}$

$V_s = V_v$

Total volume $V = 1\ m^3$

$\therefore\ V_s = 1 - V_s$

$$V_s = \frac{1}{2} m^3$$

Volume of solids in sample B:

Total volume, $V = V_s + V_v$

$$1 = V_s + V_v$$

$$V_v = 1 - V_s$$

Void ratio, $e = \dfrac{V_v}{V_s}$

$1.5\ V_s = V_v$

$1.5\ V_s = 1 - V_s$

$2.5\ V_s = 1$

$$V_s = \frac{1}{2.5} = 0.4\,m^3$$

After compaction solids volume cannot change total volume after compaction

$V = 1\ m^3$

$V_s = 0.4 + 0.5 = 0.9\ m^3$

Porosity, $n = \dfrac{V_v}{V} = \dfrac{0.1}{1} = 0.1$

02. Ans: (a)

Sol: Water content of mixed sample $= \dfrac{W_w}{W_{solids}}$

Weight of solids cannot change weight of solids in sample of water content 50%

Water content, $w = \dfrac{W_{w_1}}{W_{solid_1}}$

$$0.5 = \frac{W_w}{W_{solids_1}}$$

$$0.5\,W_{solids_1} = W_w$$

Total weight of sample, W = 1 kg

$W_s + W_W = 1$ kg

$0.5\ W_s = 1 - W_s$

$$W_s = \frac{1}{1.5} = 0.667\,kg$$

Weight of solids in sample of water content 80%

$$w = \frac{W_w}{W_s} \Rightarrow 0.8\,W_s = W_w$$

$0.8\ W_s = 1 - W_s$

$$W_s = \frac{1}{1.8} = 0.556\,kg$$

$\therefore$ Total weight of mix = 2 kg

Solids weight of mix = 0.667 + 0.556

= 1.223

$\therefore$ water content of mix $= \dfrac{W_w}{W_s} = \dfrac{2-1.223}{1.223}$

= 63.6%

03. Ans: (d)

Sol: $\gamma = \gamma_d (1 + w)$ γ_d is constant

$\gamma \propto 1 + w$

$$\frac{\gamma_2}{\gamma_1} = \frac{1+w_2}{1+w_1} \Rightarrow \frac{\gamma_2}{1.8} = \frac{1.1}{1.05}$$

$\gamma_2 = 1.88$ gm/cc

Common data for Questions 04 & 05

04. Ans: (b)

Sol: In Borrow pit

$\gamma = 1.75$ g/cc, $w_1 = 12\%$

$G = 2.7$; $V_1 = ?$

After compaction

$w_2 = 18\%$

$\gamma_{d_2} = 1.65\ g/cc$

$V_2 = 1000\ m^3$

$$\frac{V_1}{V_2} = \frac{\gamma_{d_2}}{\gamma_{d_1}}$$

$$\gamma_{d_1} = \frac{\gamma}{1+w} = \frac{1.75}{1+0.12} = 1.56$$

$$\frac{V_1}{1000} = \frac{1.65}{1.56}$$

$\therefore V_1 = 1056\ m^3$

05. Ans: (c)

Sol: Amount of water to be added

$= \gamma_{d_2} V[w_2 - w_1]$

$= 1.65 \times 1000\ [0.18 - 0.12]$

$= 99$ tons $\quad (\because 1g/cc = 1t/m^3)$

06. Ans: (c)

Sol: $\gamma_1 = 1.66$;

$w_1 = 8\%$

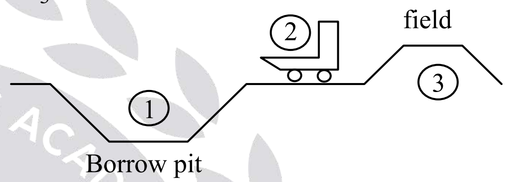
$\gamma_2 = 1.15$

$w_2 = 6\%$

$\gamma_3 = 1.82$

$w_3 = 14\%$

$v_3 = 100\ m^3$



$$\frac{v_1}{v_3} = \frac{1+e_1}{1+e_3} = \frac{\gamma_{d_3}}{\gamma_{d_1}}$$

$$\gamma_{d_1} = \frac{\gamma_1}{1+w_1} = \frac{1.66}{1+0.08} = 1.537$$

$$\gamma_{d_2} = \frac{1.15}{1+0.06} = 1.084$$

$$\gamma_{d_3} = \frac{1.82}{1+0.14} = 1.59$$

$$\frac{V_1}{V_3} = \frac{\gamma_{d_3}}{\gamma_{d_1}}$$

$$\frac{V_1}{100} = \frac{1.59}{1.54}$$

$V_1 = 104.3\ m^3$

$$V_2 = \frac{1.596}{1.084} \times 100 = 147.2\ m^3$$

No. of truck load $= \frac{147.2}{6} = 24.5 = 25$ nos.

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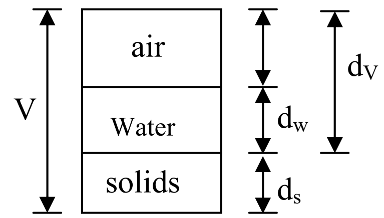
07. Ans: (c)

Sol:



$e = 0.51$

$S_r = 80\%$

$d_w = 1$ m

$$S_r = \frac{d_w}{d_v} = \frac{1}{d_v} = 0.80$$

$\therefore d_v = 1.25$

$$e = \frac{d_v}{d_s} = \frac{1.25}{d_s} = 0.5$$

$d_s = 2.5$

$\therefore$ Total $d = d_s + d_v = 2.5 + 1.25$

$= 3.75$ m

Common data for Questions 08 & 09

08. Ans: (d)

Sol: Volume of cube $= 5^3 = 125\ cm^3$

$W_d = 135$ g ; $W = 195$ g

$$\text{water content } = \frac{W - W_d}{W_d} \times 100$$

$e \times S_r = wG$

$\therefore e = 0.44\ G$

$$\frac{\gamma_{sat}}{\gamma_w} = \frac{G + e}{1 + e}$$

$$\gamma_{sat} = \frac{\text{Saturated wt of cube}}{\text{volume of cube}}$$

$$= \frac{195}{5^3} = \frac{195}{125}\ g/cc$$

$$\therefore \frac{195}{125} = \frac{G + 0.44G}{1 + 0.44G}$$

$\therefore G = 2.07$

09. Ans: (c)

Sol: $e \times S_r = 0.44\ G$

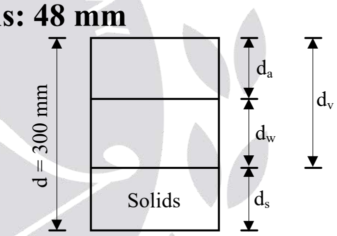
$e = 0.44\ G$

$e = 0.44 \times 2.07$

$\therefore e = 0.92$

10. Ans: 48 mm

Sol:



$$n = \frac{e}{1 + e} = 0.4$$

$d_v = nd = 0.4 \times 300 = 1200$ mm

$$s = \frac{d_w}{d_v}$$

$d_w = sd_v = 0.6 \times 120 = 72$ mm

$d_a = d_v - d_w = 120 - 72 = 48$ mm

$\therefore$ rainfall depth required = 48 mm

11. Ans: 11.87%

Sol: To find initial porosity

$$\gamma_d = \frac{\gamma_w . G}{1 + e}$$

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$$16 = \frac{9.80 \times 2.67}{1+e}$$

$e = 0.637$

$$n_1 = \frac{e}{1+e} = \frac{0.637}{1+0.637} = 0.388 \approx 38.8\%$$

$$e = \frac{V_v}{V_s} = 0.637$$

$$n = \frac{V_v}{V} \Rightarrow 0.388 = \frac{V_v}{1} \Rightarrow V_v = 0.388$$

Coarse sand

$V_s = V - V_v = 1 - 0.388 = 0.611\ m^3$

Dry silty soil:

$\gamma_s = G.\ \gamma_w$

$= 2.67 \times 9.80 = 26.16\ kN/m^3$

$$V_s = \frac{W_s}{\gamma_s} = \frac{5.5}{26.16} = 0.21\ m^3$$

Wet Clay:

Water content, $w = \dfrac{W_w}{W_s}$

$$0.1 = \frac{W - W_s}{W_s}$$

$W_s = 1.3636\ kN$

$$V_s = \frac{1.3636}{2.55 \times 9.8}$$

$= 0.0545\ m^3$

After compaction:

Total volume, $V = 1.2\ m^3$

$V_s = 0.611 + 0.21 + 0.0545 = 0.875\ m^3$

$V_s + V_v = V$

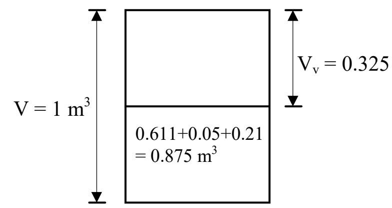
$V_v = V - V_s$

$= 1.2 - 0.875$

$= 0.325$

Final porosity, $n_2 = \dfrac{0.325}{1.2} \times 100 = 27\%$

Reduction in porosity = 38.8% – 27% = 11.8 %



12. Ans: (126.66 × 10^6**)**

Sol: (i) $\dfrac{e_1 + 1}{e_2 + 1} = \dfrac{V_1}{V_2}$

$$\frac{0.8+1}{0.9+1} = \frac{60 \times 10^6}{V_2}$$

$V_2 = 63.33 \times 10^6\ m^3$

$Cost_2 = 63.33 \times 2 \times 10^6$ Rs

$= 126.66 \times 10^6$

(ii) $\dfrac{e_1 + 1}{e_3 + 1} = \dfrac{V_1}{V_3}$

$$\frac{0.8+1}{1.2+1} = \frac{60 \times 10^6}{V_3}$$

$V_3 = 73.33 \times 10^6$

$Cost_3 = 73.33 \times 1.8 \times 10^6$

$= 132 \times 10^6$ Rs

(iii) $\dfrac{0.8+1}{1.6+1} = \dfrac{60 \times 10^6}{V_4}$

$V_4 = 86.66 \times 10^6$

$Cost_4 = 1.7 \times 86.66 \times 10^6$

$= 147.33 \times 10^6$ Rs

(iv) $\dfrac{0.8+1}{2+1} = \dfrac{60 \times 10^6}{V_5}$

$V_5 = 100 \times 10^6$

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$Cost_5 = 1.6 \times 100 \times 10^6$

$= 160 \times 10^6$ Rs

Lesser cost is 126.66×10^6

Assignment Solutions

01. Ans: (a)

Sol: $\gamma \propto 1 + w$

$$\frac{\gamma_2}{\gamma_1} = \frac{1+w_2}{1+w_1}$$

$$\frac{2.12}{2.24} = \frac{1+w_2}{1.12}$$

$w_2 = 0.06 = 6\%$

02. Ans: (b)

Sol: wt of sample = 0.18 kg

Volume = $10^{-4} m^3$

$\gamma_d = 1600 \ kg/m^3$

water added additionally = 0.02 kg

$$\gamma_d = \frac{W_S}{V} \Rightarrow 1600 = \frac{W_S}{10^{-4}}$$

$\therefore W_s = 0.16$ kg

wt of water present initially = 0.18 – 0.16

= 0.02 kg

Total wt of water present = 0.02 + 0.02 kg

= 0.04 kg

Final water content $= \frac{W_w}{W_s} \times 100$

$= \frac{0.04}{0.16} \times 100 = 25\%$

Common data for Questions 03 & 04

03. Ans: (c)

Sol: Wt of clay = 34.62 gm = W

Given dry wt = 20.36 gm = W_d

Volume = 24.66 cc

G = 2.68

Net wt = 34.62 – 20.36

W= 14.26 gms

$$\text{Water content of soil} = \frac{W - W_d}{W_d} \times 100$$

$$w = \frac{14.26}{20.36} \times 100 = 70\%$$

$$\gamma = \frac{W}{V} = \frac{34.62}{24.66} = 1.403$$

$$e = \frac{wG}{S_r}$$

$\therefore e.s_r = 0.70 \times 2.68 = 1.876$

$$\gamma = \gamma_w \left[\frac{G + e.S_r}{1+e}\right]$$

$$1.403 = 1\left[\frac{2.68 + 1.876}{1+e}\right]$$

$\therefore e = 2.25$

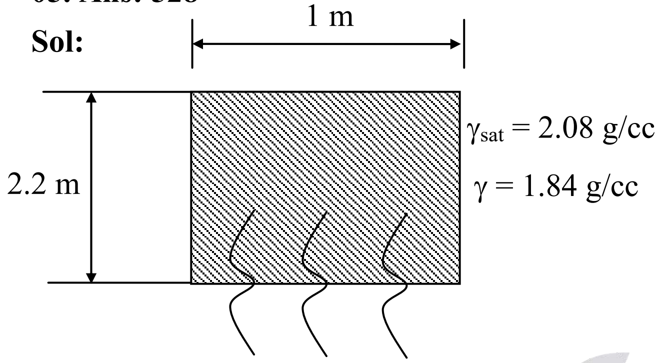
04. Ans: (d)

Sol: $S_r = \frac{1.876}{2.25} = 0.8345$

$S_r = 83.45\%$

05. Ans: 528

Sol:



Volume of soil $= 1 \times 2.2$

$= 2.2 \times 10^6\ cm^3$

Initial cut of soil = $V\gamma_1$

Final cut of soil = $V\gamma_2$

Draining of water (change in weight)

$= V(\gamma_1 - \gamma_2)$

$= 2.2 \times 10^6 (2.08 - 1.84)$

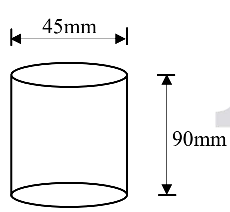
$= 528 \times 10^3$ gm

Volume of water = $528 \times 10^3\ cm^3$

= 528 lit

06. Ans: $W_d = 240.45$ and $W_w = 28.85$

Sol:



Volume of soil

$$= \frac{\pi}{4} \times 45^2 \times 90 = 143138.81\ mm^3$$

$= 143.13\ cm^3$

$\rho_w = 1$ gm/cc

$$\rho_d = (1 - n_a)\frac{\rho_w.G}{1 + w.G}$$

$$= (1 - 0.18)\frac{1 \times 2.72}{1 + 0.12 \times 2.72} = 1.68 \text{ gm/cc}$$

$\therefore\ \rho = 1.68(1 + 0.12) = 1.88$ gm/cc

$\therefore$ weight of dry solids

$W_d = \rho_d \times V$

$= 1.68 \times 143.13$

$= 240.45$ gm

Weight of soil

$= \rho \times V$

$= 1.68 \times 143.13$

$= 269.3$ gm

Weight of water

$W_w = w \times W_s$

$= 0.12 \times 240.45$

$= 28.85$ gm

04. Index Properties of Soil

01. Ans: (a)

Sol: At L.L $w_L = 60\%$,

$$e_1 = \frac{w_L.G}{S} = 0.6G$$

$w_s = 25\%$, $e_2 = 0.25\ G$

$$\frac{V_1}{V_2} = \frac{1 + e_1}{1 + e_2}$$

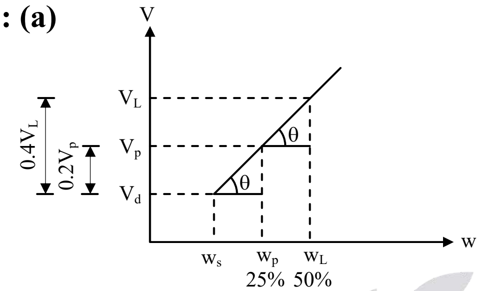
$$\frac{10}{6.5} = \frac{1 + 0.6G}{1 + 0.25G}$$

$G = 2.5$

Common data for Questions 02 & 03

02. Ans: (a)

Sol:



$$V_L - V_p = 0.4\,V_L - 0.2\,V_p$$

$$0.6V_L = 0.8\,V_p$$

$$\therefore\ V_L = \frac{0.8}{0.6}V_p$$

$$\therefore\ V_L = 1.33V_p$$

$$V_p = 0.2\,V_p + V_d$$

$$0.8\,V_p = V_d$$

$$\frac{w_p - w_s}{V_p - V_d} = \frac{w_L - w_p}{V_L - V_P}$$

$$\frac{25 - w_s}{0.2V_P} = \frac{50-25}{0.4V_L - 0.2V_P}$$

$$\frac{25 - w_s}{0.2V_p} = \frac{25}{0.53V_p - 0.2V_p}$$

$$\frac{25 - w_s}{0.2V_p} = \frac{25}{0.33V_p}$$

$$w_s = 9.9 \simeq 10\%$$

03. Ans: (c)

Sol:

$$S.R = \frac{\dfrac{V_1 - V_d}{V_d}\times 100}{w_1 - w_s}$$

$$= \frac{\dfrac{V_p - V_d}{V_d}}{w_p - w_s}\times 100$$

$$= \frac{\dfrac{V_p - 0.8V_p}{0.8V_p}}{25-10}\times 100$$

$$= \frac{\dfrac{0.2V_p}{0.8V_p}}{25-10}\times 100$$

$$= \frac{0.2}{15\times 0.8}\times 100$$

$$= \frac{0.2}{12}\times 100 = \frac{20}{12} = 1.66$$

Common data for Questions 04, 05 & 06

04. Ans: (c)

Sol: G_m = Mass specific gravity = 1.88

Water content, w = 40%

On oven drying, mass specific gravity drops to = 1.74

G of clay =?

$$e = \frac{w_s.G}{S_r} = 0.40\times G$$

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

$$1.88 = \frac{G + 0.40G}{1+.4G}$$

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$$1+0.4G=\frac{G(1+0.4)}{1.88}$$

$$G = 2.90$$

05. Ans: (a)

Sol: w_s =?

$e = 0.4 \times 2.90$

$e = 1.16 \quad \Rightarrow \; e = w_S\,G$

$$w_s=\left(\frac{1}{G_m}-\frac{1}{G}\right)\times 100$$

$$=\left(\frac{1}{1.74}-\frac{1}{2.90}\right)\times 100$$

$= 22.98\%$

$w_s = 23\%$

Common Data for Questions 06, 07 & 08

06. Ans: (b)

Sol: Initial weight of saturated soil,

$W_1 = 95.6$ gm

Initial volume of saturated soil,

$V_1 = 68.5$cc

Final dry weight = 43.5 gm = W_d

Final dry volume = 24.1 cc = V_d

w_s = ?

$$w_s=\left[\frac{W_1-W_d}{W_d}-\left(\frac{v_1-v_d}{W_d}\right)\gamma_w\right]\times 100$$

$$=\left[\frac{95.6-43.5}{43.5}-\left(\frac{68.5-24.1}{43.3}\right)\right]\times 100$$

$w_s = 17.7\%$

07. Ans: (c)

Sol: $\gamma_d=\frac{W_d}{V_d}=\frac{43.5}{24.1}=1.80\,\text{gm/cc}$

$$G_m=\frac{\gamma_d}{\gamma_w}=\frac{1.80}{1}=1.80$$

$$W_S=\left(\frac{1}{G_m}-\frac{1}{G}\right)\times 100$$

$$17.7=\left(\frac{1}{1.80}-\frac{1}{G}\right)\times 100$$

$G = 2.65$

08. Ans: (c)

Sol: To find initial and final void ratio = ?

To find e_1:

$$\gamma_{sat}=\frac{w_1}{v_1}=\frac{95.6}{68.5}=1.39\text{ g/cc}$$

$$1.39=\frac{2.67+e_1}{1+e_1}$$

$e_1 = 3.28 \simeq 3.15$

To find e_2:

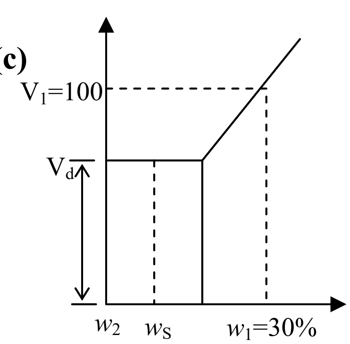
$e_2 = w_s G$

$= 0.17 \times 2.65$

$= 0.47$

09. Ans: (c)

Sol:



Given:

$V_1 = 100$ cc,

$w_1 = 30\%$

$w_s = 18\%$

$G = 2.72$

$V_2 = ?$

$w = 15\%$

Let e_1 be void ratio at water content of 30%

$$e_1 = \frac{w_1 G}{S_r} = \frac{0.30 \times 2.72}{1} = 0.816$$

Let e_2 be void ratio, at w_s

$$e_2 = \frac{w_s G}{S_r} = \frac{0.18 \times 2.72}{1} = 0.489$$

$$\frac{V_1}{V_2} = \frac{1+e_1}{1+e_2}$$

$$V_2 = \frac{100 \times (1+0.489)}{1+0.816} = 82 \text{ cc}$$

10. Ans: 21.63%. 347 kN and w = 25.24%

Sol: $n = 36\%$

$$e = \frac{n}{1-n} = \frac{0.36}{1-0.36} = 0.563$$

$G = 2.6$

$w_1 = 11\%$

Let w_2 be w.c @ full saturation

$$e = \frac{w_2 . G}{s} = w_2 = 0.216 = 21.6\%$$

$$\gamma_d = \gamma_w \left(\frac{G}{1+e} \right)$$

$$= 9.81 \left(\frac{2.6}{1+0.563} \right) = 16.31 \text{ kN/m}^3$$

To rise w.c w_1 to w_2

The weight of water to be added additionally

$= w_s(w_2 - w_1)$

$= \gamma_d . v(w_2 - w_1)$

$= 16.31 \times 200\ (0.216 - 0.11)$

$= 346$ kN

$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_1} \Rightarrow V_2 = 1.06 V_1$$

$$\frac{1.06 V_1}{V_1} = \frac{1+e_2}{1+e_1}$$

$e_2 = 0.657$

$$e_2 = \frac{w_3 G}{s}$$

$$0.657 = \frac{w_3 \times 2.6}{1}$$

$w_3 = 0.254 = 25.4\%$

11. Ans: 15.71 kN/m², ΔH = 10.1 cm

Sol: (a) $$I_D = \frac{e_{max} - e}{e_{max} - e_{min}}$$

$$0.36 = \frac{0.91 - e}{0.91 - 0.42}$$

$e = 0.734$

$$\gamma_d = \frac{\gamma_w . G}{1+e} = \frac{9.81 \times 2.68}{1+0.734}$$

$= 15.71$ kN/m^3

(b)

$$0.66 = \frac{0.91 - e}{0.91 - 0.42}$$

$e = 0.587$

$$\frac{V_2}{V_1} = \frac{1+e_2}{1+e_1}$$

$$\frac{AH_2}{AH_1} = \frac{1+e_2}{1+e_1}$$

$$\frac{H_2}{1.2} = \frac{1+0.587}{1+0.734}$$

$$H_2 = \left(\frac{1.587}{1.734}\right)\times 1.2 = 1.098 \text{ m}$$

$\Delta H = H_2 - H_2$

$= 10.1$ cm

12. Ans: (40.11 cc and 16.06cc)

Sol: $W = 30\%$; $V = 90$ cm^3 $G = 2.68$

$W_S = 18\%$

$GW_S = es_r$

$2.68 \times 0.18 = e$

$e_2 = 0.482$

$$\frac{V_1}{V_2} = \frac{1+e_1}{1+e_2}$$

$GW_S = es_r$

$2.68 \times 0.3 = e_1$

$e_1 = 0.804$

$V_1 = 90$ cm^3

$$\frac{90}{V_2} = \frac{1+0.804}{1+0.482}$$

$V_d = 73.93$ cm^3

To find V_s :

$$V_V + V_S = V_d, \frac{V_V}{V_S} = e$$

$$0.482 = \frac{V_V}{V_S}$$

$V_V = 43.38$ m^3

$1.482\ V_S = 73.93$

$V_S = 49.88$ m^3

Total volume of reduction of soil

$= 90 - 73.93 = 16.06$ cc

Volume of water evaporated $= V_1 - V_s$

$= 90 - 49.88 = 40.11$ cc

Assignment Solutions

04. Ans: 1.75

Sol: 20% of its portion fines than 0.002 mm

$W_L - W_P$

$I_P = 60 - 25 = 35$

$$A = \frac{I_P}{f} = \frac{35}{20} = 1.75$$

05. Ans: 85%

Sol:
$$I_P = \frac{\gamma_{d\,max}\left[\gamma_d - (\gamma_d)_{min}\right]}{\gamma_d\left[(\gamma_d)_{max} - (\gamma_d)_{min}\right]}$$

$$I_P = \frac{(1.90)[1.816 - 1.413]}{(1.816)[1.90 - 1.413]} = 85\%$$

06. Ans: 0.33, 15, 10

Sol: $W_L = 35$, $W_P = 20$, $W_s = 10$, W.C = 25%

$$I_L = \frac{W - W_p}{I_P} = \frac{25-20}{35-20} = \frac{5}{15} = \frac{1}{3}$$

$= 0.33$

$I_p = W_L - W_P = 35 - 20 = 15$

$I_s = W_p - W_s = 20 - 10 = 10$

07. Ans: 15.65

Sol: $\gamma_{min} = 14.71$

$\gamma_{max} = 16.68 \text{ kN/m}^3$

$I_D = 50\%$

$$I_b = \frac{e_{max} - e}{e_{max} - e_{min}}$$

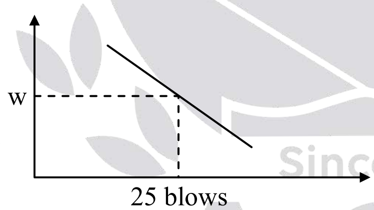
$$50\% = \frac{\frac{1}{\gamma_{d\,min}} - \frac{1}{\gamma_d}}{\frac{1}{\gamma_{d\,min}} - \frac{1}{\gamma_{d\,max}}}$$

$$= \frac{\frac{1}{14.71} - \frac{1}{\gamma_d}}{\frac{1}{14.71} - \frac{1}{16.68}}$$

$\gamma_d = 15.633 \text{ kN/m}^3$

08. Ans: (a)

Sol:



$w = 20 - \log_{10} 25$

$w = 18.6\%$

05. Soil Classification

01. Ans: (c)

Sol: $w_L = 60\%$

$w_P = 20\%$

I_P of soil $= w_L - w_P$

$= 60 - 20 = 40\%$

I_P of A line $= 0.73(w_L - 20\%)$

$= 0.73(60 - 20)$

$= 29.2$

As the soil lies above A line chart and its liquid limit is 60%

The given soil is CH.

02. Ans: GW-GM

Sol: $C_u = 18$, $C_c = 2$, $I_p = 6$

From question it is given as gravelly soil.

For GW, $C_u > 4$ and $C_c = 1 - 3$

$18 > 4$ and $C_c = 2$

∴ Soil is GW

But lines lies 5% and 12%, border line cases require dual symbol

For GM Atterberg limits fall below A line or $I_p < 4$

For GC Atterberg limits above A-line and $I_p > 7$

Here $I_p = 6$ for GC IP must be greater

∴ Soil is GW-GM

03. Ans: (GM)

Sol: Fine fraction = 45%

Coarse fraction = 100 – 45 = 55%

∴ Soil is coarse grained

% passing 4.75 mm since = 58% (out of total soil)

% retained or 4.75 mm since = 100 – 58%

= 42% (out of total)

Gravel + sand = 55%

% of Gravel = 42% (out of total soil)

∴ % retaining on 4.75 mm sieve out of coarse fraction

$$= \frac{42}{55} \times 100 = 76\%$$

(out of coarse fraction)

∴ it is gravel

$w_L = 40\%$, $w_p = 30\%$

A-line = $0.73\ (w_L - 20)$

$= 0.73\ (40 - 20) = 14.6\%$

$I_p = 40 - 30 = 10\%$

Point plots below A-line silty gravel (GM)

Assignment Solutions

01. Ans: (b)

Sol: $w_L = 38\%$, $w_p = 25\%$

$I_p = w_L - w_p = 13$

a = 60 – 35 = 25 = a

b = 60 – 15 = 45 but b = 40

c = 38 – 40 ⇒ C = 0

d = 13 – 10 = 3 ≈ d = 3

GI = 0.2 × 25 + 0.005 × 25 × 0 + 0 0.01 × 40 × 3 = 6.2 ≈ 6

02. Ans: (c)

Sol: $w_L = 20\%$ $w_P = 15\%$

$W_L < 35\%$ → Low compressible

$I_p = w_L - w_p = 20 - 15 = 5\%$

$I_p = 0.73\ (w_L - 20) = 0.73\ (20 - 20) = 0$

∴ from graph CL – ML

03. Ans: (c)

Sol:

	% Finer	% Finer	% retained
4.75 mm	850/1000	0.85	25%
75 μ	250/1000	0.25	85%

$w_L = 42\%$, $w_P = 20\%$

$I_p = w_L - w_P$

$= 42 - 20 = 22\%$

$I_p = 0.73\ (42 - 40) = 16.06$

CI

04. Ans: (b)

Sol: $w_L = 48\%$, $w_P = 26\%$

C = 25%, w = 29%

$I_p = w_L - w_P = 48 - 26 = 22\%$

$I_p = 0.73\ (w_L - 20) = 0.73\ (48 - 20)$

$I_p = 20.44\%$

From chart CI

06. Ans: (b)

Sol: $D_{10} = 0.23$ mm; $D_{30} = 0.3$ mm

$D_{60} = 0.41$ mm

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} \qquad C_u = \frac{D_{60}}{D_{10}}$$

$C_c = 0.954$ $C_u = 1.78$

$C_u < 2$

∴ uniformly graded

09. Ans: ML

Sol: $w_L = 0$, $w_P = 0$

$I_p = 0$, $I_p = 0.73\ (0 - 20) = 0$

ML (from chart)

06. Permeability

01. Ans: (b)

Sol: temperature increases, γ_w decreases to 90% & μ decreases to 90%

$$\gamma_{w_2} = \frac{90}{100}\gamma_{w_1}\ ; \qquad \left[K \propto \frac{\gamma_w}{\mu}\right]$$

$$\mu_2 = \frac{75}{100}\mu_1$$

$$\frac{K_2}{K_1} = \frac{\gamma_{w_2}}{\gamma_{w_1}} \times \frac{\mu_1}{\mu_2}$$

$$\frac{K_2}{K_1} = \frac{90}{100} \times \frac{100}{75}$$

$K_2 = 1.2\ K_1$

$K_2 = 20\%$ (increases by 20%)

02. Ans: 1.35×10^{-4} m³/sec/m

Sol: $H = 7$ m, $H_1 = 2$ m, $h = 3$ m, $L = 40$ m

$$i = \frac{h}{L} = \frac{3}{40} = 0.075$$

$k = 0.09$ cm/sec $= 0.09 \times 10^{-2}$ m/sec

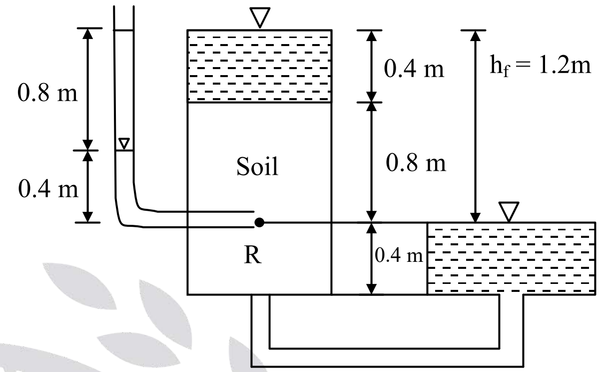
$$\frac{Q}{1m} = ki\frac{A}{1}$$

$$= \frac{0.09 \times 10^{-2} \times 0.075 \times 2 \times 1}{1m}$$

$= 1.35 \times 10^{-4}$ m³/sec/m

Common data for Questions.Q03 & Q04

03. Ans: (c)



$$i = \frac{h_f}{L} = \frac{1.2}{1.2} = 1$$

Loss of head for a seepage length of 0.8 m is $h_f = i \times L = 1 \times 0.8 = 0.8$ m

Pressure head at R is 0.4 m

Assuming datum at d/s water surface,

Elevation head at R is zero

i.e., Datum head = 0

$$\text{Total head at R} = \frac{P}{\gamma_w} + Z$$

$= 0.4 + 0 = 0.4$

If Datum head is chosen at bottom of soil, then Datum (or) Elevation head = 0.4 m

Pressure head = 0.4

Total head at R = 0.4 + 0.4 = 0.8

04. Ans: (a)

Sol: Discharge velocity, $V = k.\ i = k \times 1 = k$

$$\text{Seepage velocity, } V_s = \frac{V}{n} = \frac{k}{0.50} = 2\,k$$

05. Ans: 0.183 cm/sec and 0.094 cm/sec

Sol: Weight of water collected in 1 minute

= 6.18 N

Weight = volume × density

6.18 = volume × 9810

$$\text{Volume} = \frac{6.18}{9810} = 6.3\times10^{-4}\ \text{m}^3/\text{min}$$

Q = 1.05 × 10^{-5} m^3/sec

Q = kiA

$$1.05\times10^{-5} = k\times\frac{26}{20}\times\frac{\pi}{4}\times0.075^2$$

$$k_{at\,25°C} = 1.83\times10^{-3}\ \text{m/sec} = 0.183\ \text{cm/sec}$$

$$k \propto \left(\frac{e^3}{1+e}\right)\times\frac{1}{\mu}$$

At 25°C	at 20°C
K = 0.183 cm/sec	k_2 =?
n = 40%	n_2 = 35%
$e = \frac{n}{n-1}$	$e_2 = \frac{0.35}{0.65} = 0.5384$
$v_1 = 0.9v_{20°C}$	$v_{20°C}$

$$\therefore\ \frac{k_2}{k_1} = \left(\frac{e^3}{1+e}\right)_2\left(\frac{1+e}{e^3}\right)_1\times\frac{\mu_1}{\mu_2}$$

$$= \frac{0.5384^3}{1.5384}\times\frac{1.667}{0.667^3}\times0.9$$

k_2 = 0.094 cm/sec

Assignment Solutions

01. Ans: (d)

Sol:
$$k \propto \frac{e^3}{1+e}$$

$$\frac{k_2}{k_1} = \frac{0.6^3}{1.6}\times\frac{1.48}{0.48^3}$$

k_2 = 1.80 × 0.02 = 0.036 cm/sec

02. Ans: (b)

Sol: $Z_1 = Z_2 = Z_3 = Z$

$k_1 = 1 \times 10^{-2}$ cm/sec

$k_2 = 1 \times 10^{-1}$ cm/sec

$k_3 = 1 \times 10^{-2}$ cm/sec

$$k_H = \frac{k_1z_1 + k_2z_2 + k_3z_3}{z_1+z_2+z_3}$$

$$= \frac{1\times10^{-2} + 1\times10^{-1} + 1\times10^{-2}}{3} = 0.04$$

$K_H = 0.04$

$$k_v = \frac{z_1+z_2+z_3}{\frac{z_1}{k_1}+\frac{z_2}{k_2}+\frac{z_3}{k_3}}$$

$$= \frac{z+z+z}{\frac{z}{10^{-2}}+\frac{z}{10^{-1}}+\frac{z}{10^{-2}}} = \frac{3}{10^2+10+10^2}$$

$k_v = 0.0143$

$$\frac{k_H}{k_v} = \frac{0.04}{0.0143} = 2.79 = 2.8$$

04. Ans: 20%

Sol: k = 8.0 m/day,

h = 21.6 m,

Q = 162 lit/day

L = 96.3 m,

A = 180 cm^2 , x = ?

Q = kiA

$$162\times10^{-3}=8\times\frac{h}{x}.180\left(10^{-4}\right)$$

$$162\times10^{-3}=8\times\frac{21.6}{x}\times180\times10^{-4}$$

x = 19.2 m

$$\%=\frac{x}{\ell}\times100=\frac{19.2}{96.3}\times100$$

% of length of the pipe is filled with sand

= 19.33

% ≃20%

05. Ans: (d)

Sol: Permeability, $k=\frac{CD_{10}^2}{1+e}\left(\frac{\gamma_w}{\mu}\right)$

$$k=k_o\left(\frac{\gamma_w}{\mu}\right)$$

k_o = absolute/incitric permeability

$$4\times10^{-7}=k_o\times\frac{1}{0.091\times10^{-4}}$$

k_o = 0.36 × 10^{-11}

Conventional Practice Solutions

01.

Sol: Using the relation

$$\left(\frac{x_2^2-x_1^2}{t_2-t_1}\right)=\frac{2k_u}{S.n}\left[h_1+h_c\right]$$

$$\left(\frac{12^2-4^2}{9}\right)=\frac{2k_u}{S.n}\ [\ 60+h_c\ ]\ \rightarrow(1)$$

Similarly $\frac{25^2-12^2}{22}=\frac{2k_u}{S.n}\left[210+h_c\right]$

$\rightarrow(2)$

Dividing the equation (1) by equation (2)

$$\frac{14.22}{21.86}=\frac{60+h_c}{210+h_c}$$

Solving, we get h_c = 219.2 cm

To find k_u

$$\frac{12^2-4^2}{9}=\frac{2k_u}{0.93\times0.3}\left[60+219.2\right]$$

k_u = 7.1 × 10^{-3} cm/min

02.

Sol: Given Soil has three layers and the water is drained perpendicular to the layers

∴ Average permeability in vertical direction

$$k_v=\frac{z_1+z_2+z_3}{\frac{z_1}{k_1}+\frac{z_2}{k_2}+\frac{z_3}{k_3}}$$

$$=\frac{3+4+3}{\frac{3}{1\times10^{-6}}+\frac{4}{2.5\times10^{-8}}+\frac{3}{1.5\times10^{-5}}}$$

$= 6.127 \times 10^{-8}$ m/s

$$k_v = \frac{2.3aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

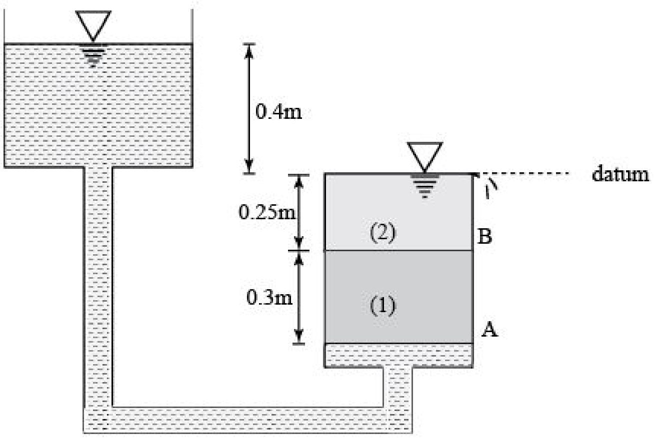
$$\Rightarrow 6.127\times10^{-8} = \frac{2.3\times10}{t}\log_{10}\left(\frac{10.5}{10}\right)$$

$$\Rightarrow 6.127\times10^{-8} = \frac{0.48735}{t}$$

$\Rightarrow t = 7.954 \times 10^{6}$ S = 92.06 days

03.

Sol:



Total head loss = 0.4 m

Let h_1 & h_2 be total head loss in soil (1) and soil (2)

$h_1 + h_2 = h$

$h_1 + h_2 = 40$ cm ………. (i)

$h_1 = 40\%$ of h (given)

$\therefore h_1 = 0.4h = 0.4 \times 40 = 16$ cm

$16 + h_2 = 40$

$\therefore h_2 = 24$ cm

At Point A:

Pressure head, $\frac{P}{\gamma_w} = 0.95$ m

Elevation head, Z = – 0.55 m

$\therefore$ Total head (Hydraulic head) = $\frac{p}{\gamma_w} + z$

$= 0.95 – 0.55$

$= 0.40$ m

At Point B:

Loss of head from A to B, $h_1 = 0.16$ m

Total head at B = total head @ A (–) head loss from A to B

$= 0.4 – 0.16$

$= 0.24$ m

Pressure head @ B = Tsotal head at B (–) Elevation head at B

$= 0.24 – (– 0.25)$

$= 0.49$ m

$Q_1 = Q_2 = Q$

$Q_1 = k_i\, i_i A$

$= k_i . \frac{h_1}{z_1} .A$

$= 0.04 \times \frac{0.16}{0.3} \times 1$

$= 0.0213 \frac{cm^3}{sec.m^2}$

Discharge velocity is same through soil (1) & soil (2)

$V_1 = V_2 = K_1 .i_1$

$= 0.0213$ cm/sec

Seepage velocity (Vs)

in soil (1) $V_{s_1} = \dfrac{V_1}{\eta_1} = \dfrac{0.0213}{\frac{0.55}{1+0.55}} = 0.06$ cm/sec

in soil (2) $V_{s_2} = \dfrac{V_2}{\eta_2}$

$= \dfrac{0.0213}{\frac{0.65}{1+0.65}} = 0.054$ cm/sec

Let y be the head at which instability occurs in soil (1) (i.e. $\sigma_1 = 0$ at bottom of soil (1))

At bottom of soil (1):

$\sigma = 0.25\ \gamma_{sat2} + 0.3\ \gamma_{sat1}$

$u = \gamma_w\ (0.3 + 0.25 + y_1)$

$\gamma_{sat1} = \gamma_w\left(\dfrac{G+e_1}{1+e_1}\right)$

$= 9.81\left(\dfrac{2.65+0.55}{1+0.55}\right) = 20.25\ kN/m^3$

$\gamma_{sat2} = \gamma_w\left(\dfrac{G+e_2}{1+e_2}\right)$

$= 9.81\left(\dfrac{2.7+0.65}{1+0.65}\right) = 19.917\ kN/m^3$

$\sigma' = \sigma - u = (0.25\gamma_{sat2} + 0.3\gamma_{sat1})(-)\gamma_w(0.55+y_1)$

$= 0$

$\Rightarrow (0.25 \times 19.917 + 0.3 \times 20.25) - 9.81(0.55 + y_1)$

$= 0$

$\Rightarrow y_1 = 0.57$ m

Let y_2 be the head at which instability occurs in soil (2) (i.e. $\sigma' = 0$ at the bottom of soil (2))

$\sigma = \gamma_{sat2} \times 0.25$

$= 0.25 \times 19.917 = 4.98\ kN/m^2$

$v = \gamma_w\ (0.25 + 0.6y_2)$

$\sigma' = \sigma - v = 0$

$\Rightarrow 4.98 - 9.81\ (0.25 + 0.6y_2) = 0$

$\Rightarrow y_2 = 0.43$ m

$\therefore$ The minimum head required to create instability is 0.43 m at which instability occurs at bottom of soil (2).

07. Effective Stress

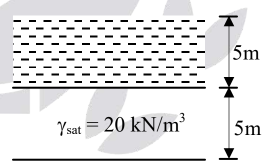
01. Ans: (d)

Sol: For wider area, effective stress remain same with the increase of depth.

$\therefore$ Effective stress at 2 m = 36 kN/m^2

02. Ans: (a)

Sol:



Effective vertical stress at 5 m depth below

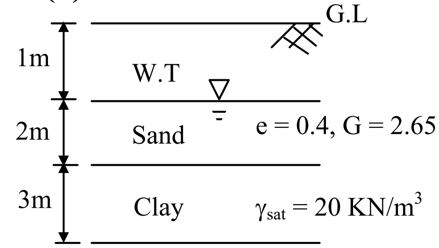
$\sigma' = (\gamma_{sat} - \gamma_w)\ h$

$= (20 - 10)5$

$= 50$ kPa

03. Ans: (d)

Sol:



$$\gamma_{sat} \text{ of sand} = \frac{\gamma_w (G+e)}{1+e}$$

$$= \frac{10(2.65+0.4)}{1+0.4} = 21.785\,kN/m^3$$

γ_d of soil above water table = ?

$$\gamma_d = \frac{\gamma_w G}{1+e} = \frac{10\times 2.65}{1+0.4} = 18.92\,kN/m^3$$

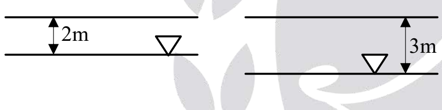
Effective stress below G.L =?

$\sigma' = \sigma - u$

$= (1\times18.92)+(2\times21.785)+(20\times3) - (5\times10)$

$= 72.49\ kN/m^2$

04. Ans: (d)



Increase in effective stresses = final effective stress – initial effective stress

= change in effective stresses

$= (\gamma_d - \gamma_w)(3-2)$

$= (16-10)\ 1$

$= 6$ kPa

05. Ans: (c)

Sol: $h_c \propto \frac{1}{D_{10}}$ where D_{10} in cm, h_c = cm

$$\frac{h_{c_2}}{h_{c_1}} = \frac{(D_{10})_1}{(D_{10})_2} = \frac{0.006}{0.01}$$

$h_{c_2} = 0.6\times 60$

$= 36$ cm

06. Ans: –750

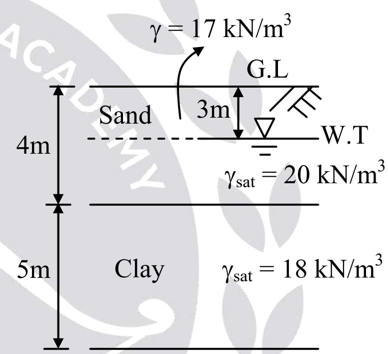
Sol: Take dia of voids 20% of effective grain size.

$$d = \frac{20}{100}(0.002) = 0.0004\,mm = 0.00004\,cm$$

$$h_c = \frac{0.3}{d} = \frac{0.3}{0.00004} = 7500\,cm = 75\,m$$

$P = -\gamma_w h = -75\times10 = -750\ kN/m^2$

Common Data for Questions Q 07 & Q 08



07. Ans: (b)

Sol: σ' at 9m depth below G.L = ?

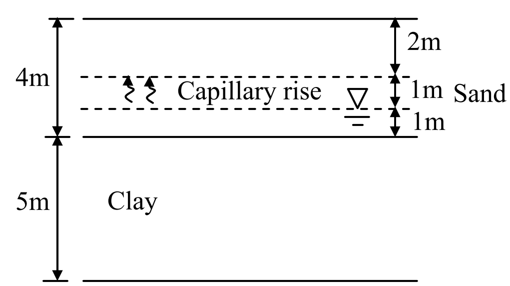
$\sigma' = \sigma - u$

$= (17\times3)+(20\times1)+(18\times5)-(6\times9.81)$

$\sigma' = 102.14\ kN/m^2$

08. Ans: (a)

Sol:



$\Delta\sigma'$ at 9 m depth of soil below G.L = ?

Effective stress after capillary rise at 9m = σ'

$\sigma' = \sigma - u$

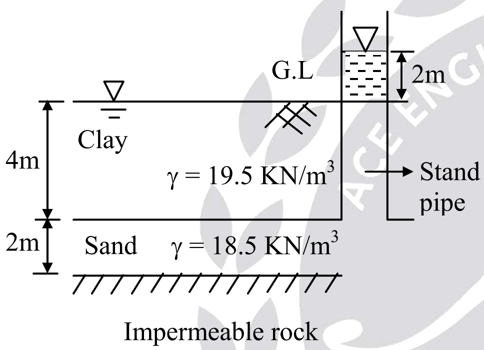
$= (2\times17)+(2\times20)+(18\times5)-6\times9.81$

$\sigma' = 105.14$

Increase in effective stress = 105.14 – 102.14

$\Delta\sigma' = 3\ kN/m^2$

Common Data for Questions Q 09 & Q 10



09. Ans: (d)

Sol: Effective stress at a depth of 6m =?

$\gamma_w = 10\ kN/m^2$

$\sigma' = \sigma - u$

$= (19.5)\times 4 + (18.5\times2)-(8\times10)$

$\sigma' = 35\ kN/m^2$

10. Ans: (a)

Sol: $\Delta\sigma'$ =? when artesian head in the stand is reduced by 1m

Total stress remains same.

Pore water pressure decreases by10 kN/m^2

$\therefore$ Effective stress increases by 10 kN/m^2

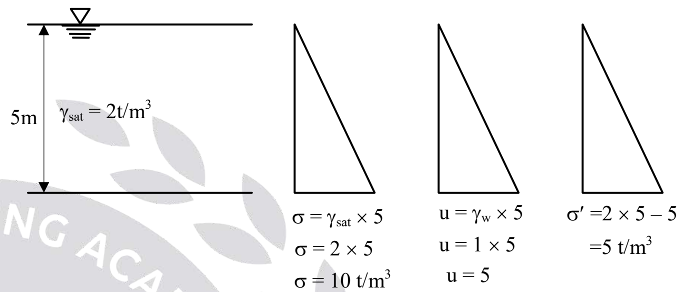
$\Delta\sigma' = 10\ kN/m^2$

Assignment Solutions

02. Ans: (d)

2. σ, u, σ' t/m^2

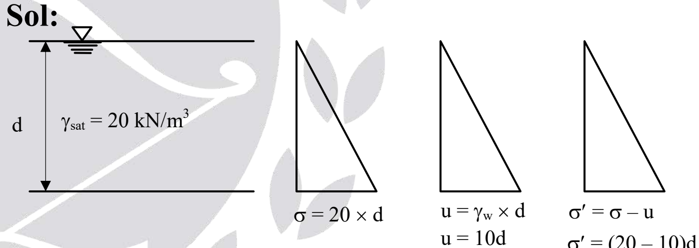
$\gamma_{sat} = 2t/m^3$ depth = 5m



$\sigma = 10\ t/m^3$, $u = 5t/m^3$, $\sigma' = 5\ t/m^3$

05. Ans: (b)

Sol:

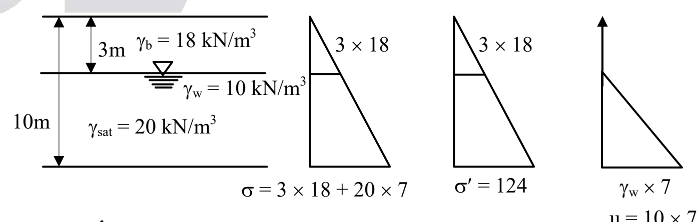


$\sigma' = 100 = (20-10)d$

$d = 10\ m$

06. Ans: (b)

Sol:



$\sigma' = \sigma - u$

$\sigma = 3\times18 + 20\times7 = 194\ kN/m^2$

$u = 7\times10 = 70\ kN/m^2$

$\sigma' = 194 - 70 = 124\ kN/m^2$

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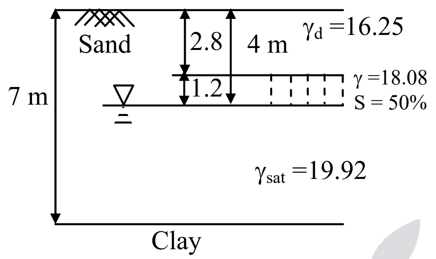
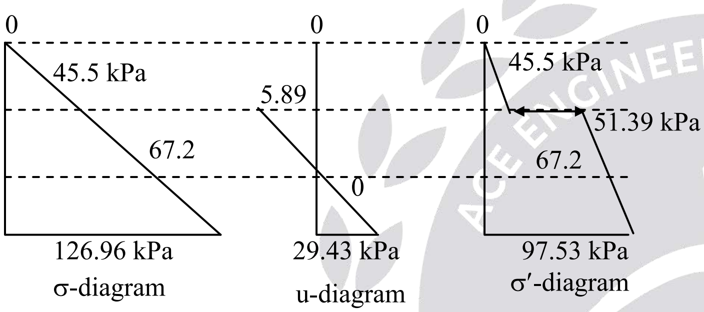
Conventional Practice Solutions

01.

Sol:





$$\gamma_d = \frac{\gamma_w.G}{1+e} = 16.25\ kN/m^3$$

$$\gamma = \gamma_w\left[\frac{G+e.S}{1+e}\right] = 18.08 kN/m^3$$

$$\gamma_{sat} = \gamma_w.\left[\frac{G+e}{1+e}\right] = 19.92\ kN/m^3$$

At ground level: σ = 0, u = 0, σ′ = 0

At 2.8 m depth

just above

$\sigma = 2.8 \times \gamma_d = 2.8 \times 16.25 = 45.5$ kPa

u = 0

σ′ = σ –u = 45.5 kPa

@Just below

σ = 45.5 kPa

$u = -\gamma_w . h_e. S$

$= -9.81 \times 1.2 \times 0.5 = -5.89$ kPa

σ′ = σ –u = 45.5–(–5.89) = 51.39 kPa

At 4 m depth

$\sigma = 2.8\ \gamma_d + 1.2\gamma$

$= 2.8 \times 16.25 + 1.2 \times 18.08$

= 67.20 kPa

u = 0

σ′ = σ –u = 67.20 kPa

At 7 m depth

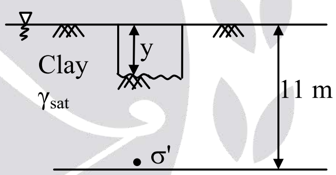
$\sigma = 2.8\gamma_d + 1.2\gamma + 3\ \gamma_{sat} = 126.96$ kPa

$u = 3\gamma_w = 29.43$ kPa

σ′ = σ–u = 97.53 kPa

02.

Sol:



$$\gamma_{sat} = \gamma_w\left[\frac{G+e}{1+e}\right]$$

eS = wG

$e.1 = 0.43 \times 2.7$

e = 1.161

$$\gamma_{sat} = 9.81\left[\frac{2.7+1.161}{1+1.161}\right]$$

$\gamma_{sat} = 17.527$

(i) At 11 m depth

σ' = γ' Z = (17.527 – 9.81) × 11 = 84.89 kPa

(ii) σ' = γ' [11 – y]

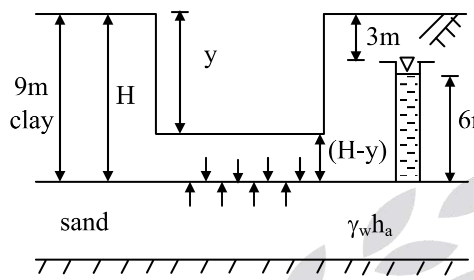
48 = 7.717 (11 – y)

⇒ y = 4.78 m

08. Seepage Pressure and Critical Hydraulic Gradient

01. Ans: (c)

Sol:



To find depth of safe excavation:

$$\gamma = 20 \text{ kN-m}^3$$

Downward pressure = uplift pressure

$$\gamma (H - y) = \gamma_w h_a$$

$$20 (9 - y) = 10 \times 6$$

$$y = 6 \text{ m}$$

∴ Maximum depth of trench will be excavated without failure is 6 m.

02. Ans: (c)

Sol: $20 (9 - 7) = \gamma_w h_a$

$$h_a = \frac{20 \times 2}{10} = 4 \text{ m}$$

Water table to be lowered = 6 – 4 = 2m

03. Ans: 35

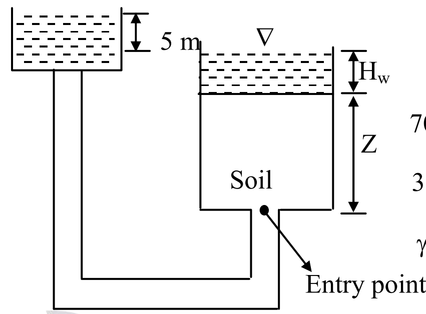
Sol: Given

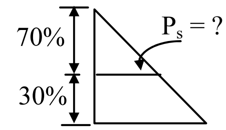
Net head causing flow h = 5 m

Hydraulic gradient $i = \frac{h}{Z} = \frac{5}{Z} = 1$

$\Rightarrow \quad Z = 5$ m

Seepage length Z = 5 m





$\gamma_w h = 10 \times 5 = 50$ kPa

For 100% → 50 kPa

For 70% → $\frac{50}{100} \times 70 = 35$kPa

04. Ans: 1.91 m

Sol: Depth of soil layer = 1200 mm

FOS against piping = $\frac{i_c}{i}$

$$z = \frac{(G-1)(1-n)}{i}$$

$$i = \frac{1.65 \times 0.7}{2}$$

$$\frac{h}{z} = 0.5775$$

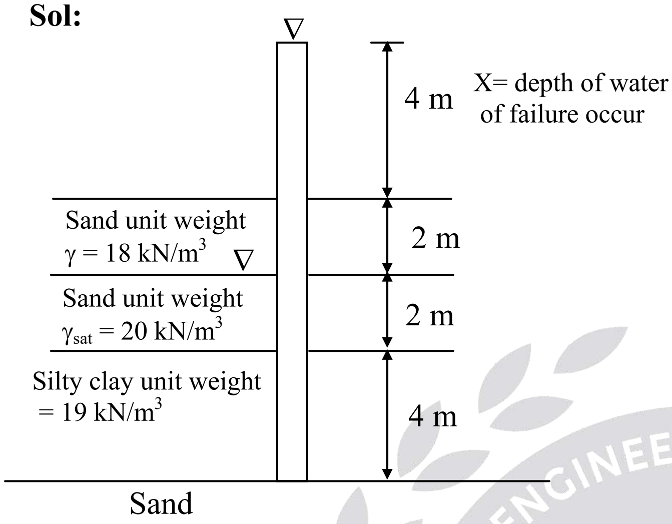
$$z = 3.1168 \text{ m}$$

Additional depth of coarse sand

= 3.1168 – 1.2 = 1.9168 m

05. Ans: 32 kPa & 7.2m

Sol:



I. At bottom of silty clay

Total stress

$\sigma = 18 \times 2 + 20 \times 2 + 4 \times 19$

$= 152$ kPa

Pore water pressure

$U = (4 + 2 + 2 + 4) \times 10 = 120$ kPa

Effective stress $\sigma' = \sigma - u$

$= 152 - 120 = 32$ kPa

II. At x m of water failure occur. That is effective stress = 0

Total stress $\sigma = 152$ kPa

Pore water pressure $u = 10\,(x + 2 + 2 + 4)$

$\sigma' = 0$

$\therefore \sigma - u = 0$

$\Rightarrow 152 = 10\,[x + 2 + 2 + 4]$

$\therefore x = 7.2$ m

06. Ans: 2.2 & 10.38 kN/m^3

Sol: $V_s = \dfrac{V}{n}$

$V = V_s .n = 2.4 \times 10^{-4}$ cm/sec

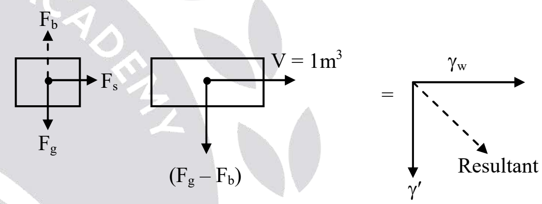
$V = k.i$

$$V = k\left(\frac{h_A - h_B}{L}\right)$$

$$2.4\times10^{-4} = 1.2\times10^{-3}\left(\frac{5-h_B}{14}\right)$$

$h_B = 2.2$ m

$i = 0.2$



Resultant $= \sqrt{\gamma'^2 + (i\gamma_w)^2} = 10.377\,\text{kN}$

07. Ans: (d)

Sol: Total stress at point A

$= 0.7 \times 9.81 + 20.6 \times 1$

$= 27.467$ KPa

Neutral stress at point A $= \gamma_w h$

h = total head at point A

$h = 1 + 0.7 + 0.75 = 2.45$

$\therefore$ Effective stresses at point A, $\sigma' = \sigma - u$

$= 27.467 - 9.81 \times 2.45$

$= 3.4325$ KPa

08. Ans: (c)

Sol: Upward seepage force per unit volume

$$=\frac{\gamma_w h\times A}{\text{volume}}=\frac{\gamma_w h\times A}{A\times z}=\gamma_w i$$

$= 9.81 \times 0.75$

$= 7.3575\ \text{kN/m}^3$

09. Ans: (c)

Sol: Critical state

Down ward force = upward seepage force

$\gamma_{sat} \times 2 + \gamma_w h = \gamma_w \times 4.5$

$19 \times 2 + \gamma_w h = \gamma_w \times 4.5$

$\gamma_w (4.5 - h) = 38$

$h = 0.63$ m

04. Ans: (c)

Sol: $i_c = (G - 1)(1 - n)$

$= (1.6 (1 - 0.375)$

$= 1$

Assignment Solutions

01. Ans: (d)

Sol: $\text{F.O.S}=\frac{i_c}{i}$

$$i_c=\frac{G-1}{1+e}=(G-1)(1-n)$$

$= 1.65 \times 0.65$

$= 1.0725$

$$i=\frac{h}{z}=\frac{0.85}{1.25}=0.68$$

$$F=\frac{1.0725}{0.68}=1.577$$

02. Ans: (c)

Sol: $G = 2.62$, $e = 0.62$, $z = 2.5$ m

$$i_c=\frac{G-1}{1+e}=\frac{2.62-1}{1+0.62}=1$$

Hydraulic head = 1 × 2.5 m = 2.5 m

09. Seepage Analysis

01. Ans: 0.0086

Sol: The quantity of flow into the pond per m^2 area

$Q = ki$

$$i=\frac{h}{z}=\frac{\text{head loss}}{\text{depth of clay}}=\frac{5\text{m}}{5\text{m}}=1$$

$\therefore\ Q = 10^{-5} \times 10^{-2} \times 1 = 10^{-7}\ \text{m}^3/\text{sec}$

$= 10^{-7} \times 3600 \times 24\ \text{m}^3/\text{day}$

$= 0.0086\ \text{m}^3/\text{day}$

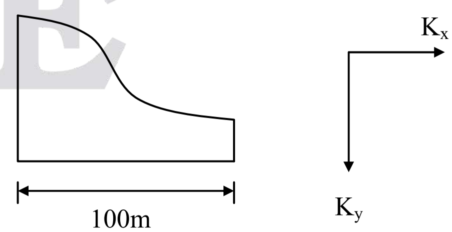
02. Ans: (a)

Sol: **Given:**

$K_x = 3.45$ m/day; $K_y = 1.5$ m/day

$B = 100$ m

Scale factor = 1:25 in vertical direction



$$b=B\sqrt{\frac{K_y}{K_x}}\qquad b=100\sqrt{\frac{1.5}{3.45}}=65.93\,\text{m}$$

For scale 1:25, $b=\frac{65.93}{25}=2.63\,\text{m}$

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03. Ans: (b)

Sol: $H = 18$, $N_d = 9$, $n = 3$, $h = ?$

$$\Delta H = \frac{H}{N_d}$$

$$h = H - n.\ \Delta H = 18 - 3 \times \frac{18}{9} = 12\,m$$

04. Ans: (d)

Sol: Equivalent permeability $k = \sqrt{k_x k_y}$

$$= \sqrt{6 \times 1.39 \times 1.39}$$

= 3.404 m/day

∴ Seepage per unit width, $q = kH\frac{N_f}{N_d}$

$$= 3.404 \times 9 \times \frac{5}{8}$$

= 19.152 m^3/day/m

∴ Total seepage = q × b = 19.152 × 50

= 957.6 m^3/day

05. Ans: 3.933 , 3.367, 1.666, 1.6667,
$\Delta Q = 2.2667 \times 10^{-5}$ m^3/sec/m

Sol:

(A) Total head loss h = (4.5 – 1.1) = 3.4

Head loss per one flow net $= \frac{3.4}{6} = 0.566\,m$

∴ Piezeometric head at point

a = 4.5 – 0.566

= 3.933 m

∴ Piezeometric head at point

b = 4.5 – 2 × 0.566

= 3.367 m

∴ Piezeometric head at point

c = 4.5 – 5 × 0.566

= 1. 6667 m

∴ Piezeometric head at point

d = 4.5 – 5 × 0.566

= 1.6667 m

(B) The rate of seepage through channel II per unit length

$$q = kH\frac{N_f}{N_d}$$

$N_f = 1$, $N_d = 6$

$$q = 4 \times 10^{-3} \times 10^{-2} \times 3.4 \times \frac{1}{6}$$

= 2.266 × 10^{-5} m^3/sec/m

06. Ans: (a)

Sol: FOS against piping $= \frac{i_c}{i_{exit}}$

$$i_c = \frac{G-1}{1+e} = 1.083$$

$$i_{exit} = \frac{\Delta H}{b}$$

$$\Delta H = \frac{H}{N_d} = \frac{4.2}{8} = 0.525$$

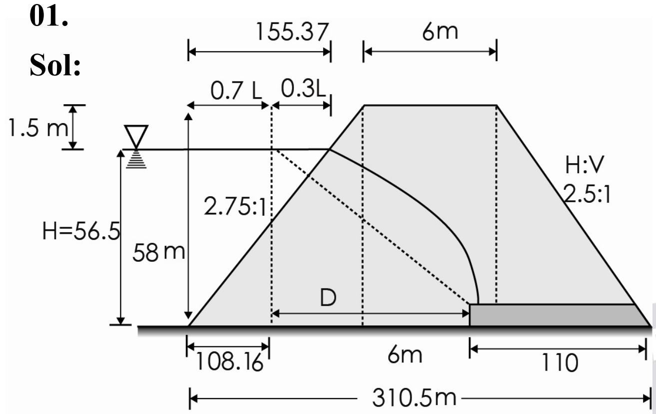
$$i_{exit} = \frac{0.525}{1.65} = 0.3181$$

$$FOS = \frac{1.083}{0.3181} = 3.4$$

Conventional Practice Solutions

01.

Sol:



$L = 2.75 \times 56.5 = 155.375$

$0.7L = 0.7 \times 155.375 = 108.78$

$D = 310.5 - 108.78 - 110 = 91.72$ m

$H = 56.5$ m

$S = \sqrt{D^2 + H^2} - D = 16\,\text{m}$

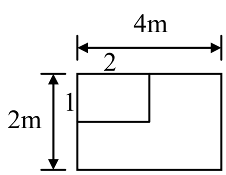
$Q = K.S$

$= \sqrt{K_x.K_y}.S = 48 \times 10^{-7}$ m^3/sec/m

10. Stress Distribution

01. Ans: (b)

Sol:



At centre:

$\sigma_Z = I\,q$

$Z = 5$ m

To Calculate I:

$m = \dfrac{L}{Z} \quad n = \dfrac{B}{Z}$

$m = \dfrac{2}{5} \quad n = \dfrac{1}{5}$

$m = 0.4 n = 0.2$

From Table, I = 0.0328

$$\left.\begin{aligned}\sigma_Z &= 0.0328 \times 8 \\ &= 0.2624\end{aligned}\right\} \text{At corner of } 1 \times 2 \text{ rectangle}$$

σ_Z at centre = 0.2624 × 4 = 1.05 t/m^2

At corner:

From given table, I = 0.0931

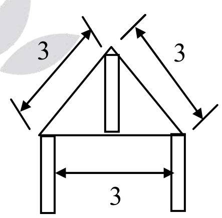
$m = \dfrac{4}{5} = 0.8$

$n = \dfrac{2}{5} = 0.4$

$\sigma_Z = 0.0931 \times 8 = 0.744$ t/m^2

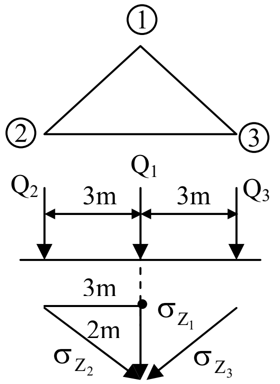
02. Ans: (d)

Sol:



Total load = 200t

Load on each column = $\dfrac{200}{3} = 66.66\,\text{t}$



$$\sigma_Z = \sigma_{Z_1} + \sigma_{Z_2} + \sigma_{Z_3}$$

$$\sigma_{Z_1} = \frac{Q}{Z^2}\frac{3}{2\pi} = \frac{66.66}{2^2}\frac{3}{2\pi} = 7.95\,t/m^2$$

$$\sigma_{Z_2} = \frac{Q}{Z^2}\frac{3}{2\pi}\left(\frac{1}{1+\left(\frac{r}{Z}\right)^2}\right)^{(5/2)}$$

$$= \frac{66.66}{2^2}\frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{3}{2}\right)^2}\right]^{(5/2)}$$

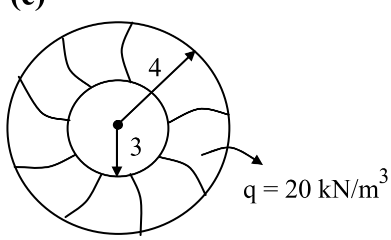
$\sigma_{Z_2} = 0.417\ t/m^2 = \sigma_{Z_3}$

$\sigma_Z = 7.95 + 0.417 + 0.417$

$\sigma_Z = 8.78\ t/m^2$

03. Ans: (c)

Sol:



σ_Z at centre =?

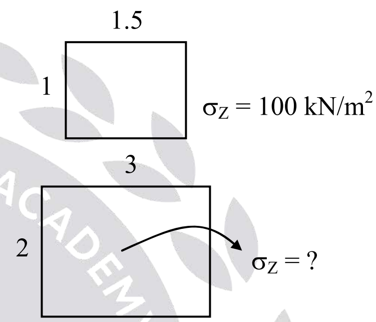
Z = 10 m

$$\sigma_Z = 20\left[1-\left(\frac{1}{1+\left(\frac{4}{10}\right)^2}\right)^{3/2}\right] - 20\left[1-\left(\frac{1}{1+\left(\frac{3}{10}\right)^2}\right)^{3/2}\right]$$

$\sigma_Z = 1.56\ kPa = 1.56\ kN/m^2$

04. Ans: (d)

Sol:



$\sigma_Z = 4 \times \sigma_Z$ of small rectangle (1×1.5)

$= 4 \times 100 = 400\ kN/m^2$

05. Ans: 7.41 m

Sol: Vertical stress due to circular loaded area

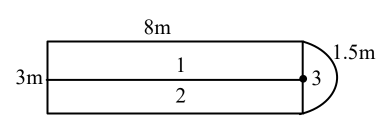
$$\sigma = q\left[1-\left(\frac{1}{1+(r/z)^2}\right)^{3/2}\right]$$

$$0.1q = q\left[1-\left(\frac{1}{1+(2/z)^2}\right)^{3/2}\right]$$

Z = 7.41 m

06. Ans: 83.05 kPa

Sol:



Total vertical stress

= stresses at 1 + stresses at 2 + stresses at section 3

$= \sigma_{v_1} + \sigma_{v_2} + \sigma_{v_3}$

$\sigma_{v_1} = \sigma_{v_2} = qI$

$n = \frac{L}{z} = \frac{8}{3} = 2.67$

$m = \frac{B}{Z} = \frac{1.5}{3} = 0.5$

$\therefore$ m = 0.5, n = 2.67 $\Rightarrow$ I = 0.1365

$\sigma_{v_1} = \sigma_{v_2} = 0.1365 \times 200 = 27.3$

Vertical stress in circular area

$$\sigma_{v_3} = q\left[1 - \left(\frac{1}{1+(r/z)^2}\right)^{3/2}\right]$$

$$= 200\left[1 - \left(\frac{1}{1+\left(\frac{1.5}{3}\right)^2}\right)^{3/2}\right]$$

= 56.89 KPa

Vertical stress in semi-circular area

$$= \frac{\sigma_{V_3}}{2} = 28.44 \text{ KPa}$$

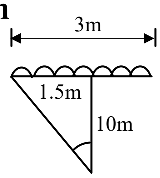
$\therefore$ Total vertical stresses

= 27.3 + 27.3 + 28.44

= 83.05 KPa

07. Ans:18.7 kPa

Sol: Take h = 10 m



$$\theta = \tan^{-1}\left(\frac{1.5}{10}\right) = 8.53$$

= 0.148 radians

$$\sigma_z = \frac{q}{\pi}(2\alpha + \sin 2\alpha)$$

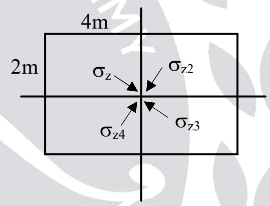
$$= \frac{100}{\pi}(2 \times 0.148 + \sin 2(8.53))$$

= 18.76 kPa

Assignment Solutions

01. Ans: (a)

Sol:



$m = \frac{L}{z} = \frac{4}{5} = 0.8$

$n = \frac{B}{z} = \frac{2}{5} = 0.4$

$\sigma_z = \sigma_{z_1} + \sigma_{z_2} + \sigma_{z_3} + \sigma_{z_4}$

$\sigma_{z_1} = Iq$

m = 0.8, n = 0.4, I = 0.0931

$q = \frac{600}{8 \times 4} = 18.75 \text{kN/m}^2$

$\therefore \sigma_{z_1} = 0.0931 \times 18.75$

= 1.7456 kN/m^2

$\therefore$ Total pressure σ_z = 4 × 1.7456

= 7 kN/m^2

11. Consolidation

01. Ans: 147.86 mm & 2.86 years

Sol: d = H = 8 m = 800 cm

For a settlement 120 mm in 2 years

$C_v = 6 \times 10^{-3}$ cm^2/s

S_f =?, t_{90} = ?

$$T_v = \frac{C_v t}{d^2}$$

$$= \frac{6\times10^{-3}\times2\times365\times24\times60\times60}{800^2} = 0.5913$$

Since $T_v > 0.282$

$T_v = 1.781 - 0.933 \log_{10}(100 - U\%)$

$0.5913 = 1.781 - 0.933 \log_{10}(100 - U\%)$

U = 81.16%

$$\Rightarrow U = \frac{s}{s_f}$$

$$\Rightarrow 81.16 = \frac{120}{s_f}\times100$$

s_f = 147.86 mm

(b) $T_v = 1.781 - 0.953\log_{10}(100-90\%)$

= 0.848

$$T_v = \frac{C_v t}{d^2} \Rightarrow 0.848 = \frac{6\times10^{-3}\times t}{120^2}$$

⇒ t = 2.86 years

02. Ans: (a)

Sol: ΔH_1 = 1 cm,

$\sigma'_{f_1} = 2\ kg/cm^2$, $\sigma'_{0_1} = 1 kg/cm^2$,

ΔH_2 = ?

$\sigma'_{f_2} = 4 kg/cm^2, \sigma'_{0_2} = 2 kg/cm^2$

$$\Delta H \propto \log_{10}\left(\frac{\sigma'_f}{\sigma'_0}\right)$$

$$\frac{\Delta H_1}{\Delta H_2} = \frac{\log_{10}\left(\frac{\sigma'_{f_1}}{\sigma'_{0_1}}\right)}{\log_{10}\left(\frac{\sigma'_{f_2}}{\sigma'_{0_2}}\right)}$$

$$\frac{1}{\Delta H} = \frac{\log_{10}\left(\frac{2}{1}\right)}{\log_{10}\left(\frac{4}{2}\right)} \Rightarrow \Delta H = 1\text{cm}$$

03. Ans: (c)

Sol: t_1 = 4 yrs, S_1 = 80 mm

t_2 = 9 yrs, S_2 = ?

For both conditions, soil is same

(Degree of consolidation).

$$U = \frac{S}{S_f}\times100$$

$S_f \rightarrow$ same for both

ΔH = 80 mm ; t_1 = 4 yrs

= 60% (less than)

t_2 = 9 yrs

$$U = \frac{S}{S_f}\times100 \Rightarrow T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

$$\Rightarrow C_v\frac{t}{d^2} = \frac{\pi}{4}U^2$$

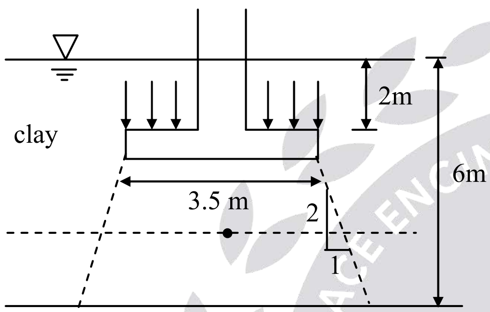
$$\Rightarrow t \propto U^2 \Rightarrow t \propto s^2$$

$$\Rightarrow \frac{t_1}{t_2} = \left[\frac{S_1}{S_2}\right]^2$$

$$\Rightarrow \frac{4}{9} = \left[\frac{80^2}{S_2^2}\right]^2 \Rightarrow S_2 = 120\,\text{mm}$$

04. Ans: 120 mm

Sol:



$\gamma_w = 10$ kN/m^3, $\gamma_{sat} = 19.3$ kN/m^3, q = 500 kN

$C_C = 0.36$, $e_0 = 0.92$, $S_f = 120$

$$S_f = H_0 \frac{C_C}{1+e_0}\log_{10}\left(\frac{\sigma'_f}{\sigma'_0}\right)$$

$$S_f = 4 \times \frac{0.36}{1+0.92}\log_{10}\left(\frac{\sigma'_f}{\sigma'_0}\right)$$

$$\Delta\sigma' = \frac{q}{(B+Z)^2} = \frac{500}{(3.5+2)^2}$$

$\Delta\sigma' = 16.528$ kN/m^2

$\sigma_f' = \sigma_o' + \Delta\sigma'$

$= 37.2 + 16.528$

$= 53.728$ kN/m^2

$$S_f' = 4 \times \frac{0.36}{1.92} \times \log_{10}\left[\frac{53.728}{16.528}\right] = 120 \text{ mm}$$

05. Ans: (c)

Sol: $t \propto \dfrac{d^2 m_v}{K}$

$$\frac{t_2}{t_1} = \left(\frac{d_2}{d_1}\right)^2\left(\frac{m_{v2}}{m_{v1}}\right)\left(\frac{K_1}{K_2}\right)$$

$t_1 = 15$ yrs, $d_2 = 2\,d_1$, $K_2 = 3K_1$,

$m_{v2} = 4\,m_{v1}$

$$t_2 = 15 \times \left(\frac{2}{1}\right)^2\left(\frac{4}{1}\right)\left(\frac{1}{3}\right)$$

$t_2 = 80$ yrs

Common data for Questions 06 & 07

06. Ans: (a)

Sol: $d_1 = \dfrac{20}{2} = 10\text{mm}$, U_1=50%, t_1= 45min [lab]

$d_2 = 5000$ mm, U_2=50%, t_2 =? [field]

Same U, T_v

$t \propto d^2$

$$\frac{t_2}{t_1} = \frac{d_2^2}{d_1^2}$$

$$t_2 = 45\left(\frac{5000}{10}\right)^2 = 11250000\,\text{min}$$

= 21.4 years

07. Ans: (b)

Sol: $t_2 = 4 \times 21.4 = 85.6$ yrs

Common data for Questions 08 & 09

$$U = \frac{80}{300} = 26.6\%$$

$$T_v = \frac{C_v t}{d^2}$$

$$\frac{\pi}{4}(26.6)^2 = \frac{C_v t}{d^2}$$

$$\frac{C_v}{d^2} = \frac{\pi}{225}$$

08. Ans: (b)

Sol: $T_v = \frac{C_v}{d^2} \times t = \frac{\pi}{225} \times 25 = 0.35$

$U = 65\%$

$$\frac{S}{300} \times 100 = 0.65$$

$S = 195$ mm

09. Ans: (d)

Sol: At U% = 70%, $T_v = 0.403$

$$T_v = \frac{C_v}{d^2} \times t$$

$$0.403 = \frac{\pi}{225} \times t \Rightarrow t = 28.8\text{yrs}$$

10. Ans: (c)

Sol: **NOTE:** The time is measured from middle of construction period

t = 5 yrs,

S = 90 mm,

$S_f = 360$

$$T_v = \frac{C_v t}{d^2}$$

$$\frac{t_1}{t_2} = \frac{T_{v_1}}{T_{v_2}} = \frac{(S/360)^2}{(90/360)^2}$$

$$S^2 = 90^2 \times \frac{9}{4}$$

S = 135 mm

Common data for Questions 11 & 12

11. Ans: (b)

Sol: $\gamma_{sat} = 18$ kN/m^3

$\gamma_{sat} = 20$ kN/m^3

$\gamma_w = 10$ kN/m^3

Depth = 4 m ; $\gamma = 19$ kN/m^3

a) Immedidately after load

$\sigma = q + (18 \times 5) + (20 \times 3)$

$= 226$ kPa

$U = U_{static} + U_{dynamic}$

$= 8\gamma_w + q = 156$

$\sigma' = 70$ kPa $= 70$ kN/m^2

12. Ans: (c)

Sol: Many years after (At the end of consolidation)

$\sigma = 226$ kPa

$U = 80 \quad (\because \overline{U} = 0)$

$\sigma' = 146$ kPa

13. Ans: 422.7 mm

Sol:

Preliminary analysis	**Detailed investigation**
H_1	$H_2 = 1.2H_1$
$\Delta\sigma'_1 = 24KPa$	$\Delta\sigma'_2 = \Delta\sigma' + 1\times\gamma_w$ $= 24 + 9.81$ $= 33.81$ KPa
$Sf_1 = 250$ mm	$Sf_2 = ?$

$S_f = m_v H\Delta\sigma'$

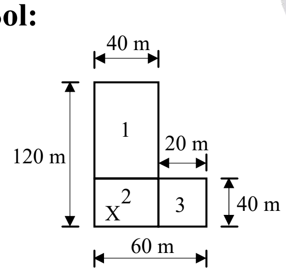
$S_f \propto H.\ \Delta\sigma'$ assuming 'm_v' remains same

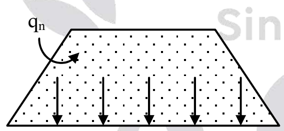
$$\frac{s_{f_1}}{s_{f_2}} = \frac{H_1\Delta\sigma'}{H_2\Delta\sigma'}$$

$$\frac{250}{S_{f_2}} = \frac{H_1 24}{1.2H33.81} = S_{f_2} = 422\,mm$$

14. Ans: 514.5 mm

Sol:





$q_n = 150$ KPa

$\mu = 0.5$ (for soft clay)

$E_s = 15\ MN/m^2 = 15 \times 10^6\ N/m^2$

$= 15 \times 10^3\ kN/m^2$

Rec (1)

$$= \frac{L}{B} = \frac{80}{40} = 2$$

$I = 0.77$

$$S_i = \frac{q_n}{E_s} B(1-\mu^2)I$$

$$= \frac{150}{15\times10^3} 40(1-0.5^2)0.77 = 0.231$$

Rec (2)

$$= \frac{L}{B} = 1$$

$$S_i = \frac{150}{15\times10^3} \times 40(1-0.5^2) = 0.56$$

Rec (3)

$$\frac{L}{B} = \frac{40}{20} = 2$$

$S_i = 0.115$

$\therefore$ Total settlement

$$S_i = S_{i_1} + S_{i_2} + S_{i_3} = 0.514\,m$$

Assignment Solutions

01. Ans: (b)

Sol: $$s_f = H\frac{C_c}{1+e_o}\log\left(\frac{\sigma'f}{\sigma'_o}\right)$$

$$s_f \propto \log\left(\frac{\sigma'f}{\sigma'o}\right)$$

$$\frac{s_{f_2}}{s_{f_1}} = \frac{\log\left(\frac{200}{50}\right)}{\log\left(\frac{50}{25}\right)} = \frac{\log 4}{\log 2} = 2$$

$$s_{f_2} = 2\times16 = 32\,mm$$

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02. Ans: (c)

Sol: $a_v = \dfrac{\Delta e}{\Delta\sigma'} = \dfrac{0.7-0.6}{17.5-17} = 0.2\,m^2/t$

03. Ans: (d)

Sol: $T_v = \dfrac{C_v t}{d^2}$

Degree of consolidation is same $T_{v_1} = T_{v_2}$

$$\frac{C_v t}{d^2} = \frac{C_v t}{d^2}$$

$$\frac{t}{d^2} = \frac{t}{d^2}$$

$$\frac{300}{(2.5)^2} = \frac{t}{5^2}$$

t = 4 × 300 = 1200 days

05. Ans: (a)

Sol: $C_c = \dfrac{\Delta e}{\log\left(\dfrac{\sigma'}{\sigma'o}\right)} = \dfrac{0.3}{\log\left(\dfrac{100}{10}\right)} = 0.3$

06. Ans : (c)

Sol: For same degree of consolidation, $t \propto d^2$

$$\therefore \frac{t_2}{t_1} = \left(\frac{d_2}{d_1}\right)^2$$

Site x	Site y
d_1=10 m t_1= 36	d_2 = 2.5 m for top half clay d_2 = 5 m for bottom half clay $\therefore d_2$ = 5 m (higher value is considered)

$$\frac{t_2}{36} = \left(\frac{5}{10}\right)^2$$

t_2 = 9 months

Conventional Practice Solutions

01.

Sol: $\sigma'_o = 30\,kPa$

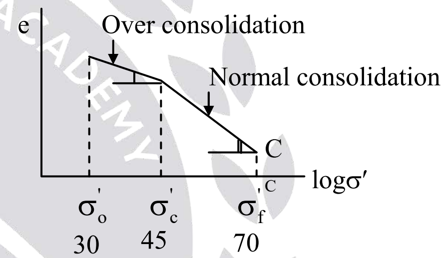
$\sigma'_c = 45\,kPa$

If $\sigma'_0 < \sigma'_c$ it is in over consolidation state

Given

$\Delta\sigma' = 40$

$\sigma'_f = \sigma'_o + \Delta\sigma' = 70\,kPa$



$$S_f = H.\frac{C_R}{1+e_o}.\log_{10}\left[\frac{\sigma'_c}{\sigma'_o}\right] + H.\frac{C_C}{1+e_o}\log_{10}\left[\frac{\sigma'_f}{\sigma'_c}\right]$$

$$= 2.\frac{0.04}{1+e_o}\log_{10}\left[\frac{45}{30}\right] + 2\frac{0.25}{1+e_o}\times\log_{10}\left[\frac{70}{45}\right]$$

= 0.05m = 50 mm

02.

Sol: $d = \dfrac{6}{2} = 3\,m$

For U = 50%, t = 1 year

$T_{V(50)} = 0.197$

$T_V = \dfrac{C_v.t}{d^2} \Rightarrow C_v = 1.773\ m^2/year$

$$C_v = \frac{k}{m_v.\gamma_w}$$

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$$\therefore\ m_v = \frac{k}{C_v.\gamma_w} = \frac{0.03}{1.773\times 9.81}$$

$$= 1.7\times 10^{-3}\ m^2/kN$$

Ultimate settlement $S_f = m_v.\ H.\ \Delta\sigma'$

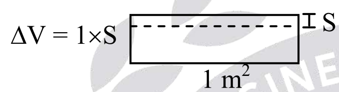
$$= 1.7\times 10^{-3}\times 6\times 70$$

$$= 0.724\ m$$

$\therefore$ Settlement in 1 year, $S = US_f$

$\Rightarrow S = 0.5\times 0.724 = 0.362$ m

$\Delta V = 1\times S$



$$T_V = \frac{\pi}{4}U^2$$

$$C_v.\frac{t}{d^2} = \frac{\pi}{4}\left[\frac{S}{S_f}\right]^2$$

$\therefore\ t\ \alpha\ S^2$

$t = C.S^2$

$1 = C.\ (0.362)^2$

$$C = \frac{1}{(0.362)^2} = 7.631$$

$t = C.S^2$

$t = 7.631\ S^2$

$$\text{(or) } S^2 = \frac{1}{7.631}.t$$

Differentiate

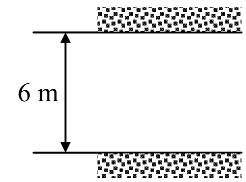
$$2.S.\ \frac{d.S}{dt} = \frac{1}{7.631}$$

$$\frac{dS}{dt} = \frac{1}{7.631\times 2\times S} = \frac{1}{7.631\times 2\times 0.362}$$

$= 181$ m/year (or) $0.181\ m^3/m^2$ year

03.

Sol:



$H = 6$ m

$$d = \frac{6}{2} = 3\ m\ \text{(double drainage)}$$

$S = 30$ mm

$t = 3$ years

$S_f = 120$ mm

$$U = \frac{S}{S_f} = \frac{30}{120}\times 100 = 25\%$$

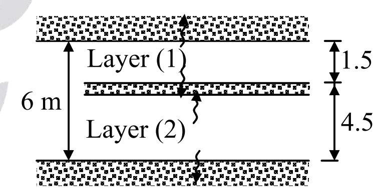
$$T_v = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2 = \frac{\pi}{4}\left(\frac{25}{100}\right)^2$$

$$= 0.049$$

$$T_v = \frac{C_v.t}{d^2}$$

$$0.049 = \frac{C_v\times 3}{3^2}$$

$C_v = 0.147\ m^2$/year



Layer (1):

$$d = \frac{1.5}{2} = 0.75\ m$$

$t = 3$ year

$$T_v = \frac{C_v.t}{d^2} = \frac{0.147\times 3}{0.75^2} = 0.784$$

Since $T_v > 0.28$,

$T_v = 1.781 - 0.933\ \log_{10}[100 - U\%]$

$\Rightarrow 0.784 = 1.781 - 0.933\ \log_{10}\ [100 - U]$

$\therefore\ U_1 = 88.3\%$

Layer (2):

$$d = \frac{4.5}{2} = 2.25\,m$$

t = 3 year

$$T_v = \frac{C_v.t}{d^2} = \frac{0.147\times 3}{2.25^2} = 0.087$$

Since $T_v < 0.28$,

$$T_v = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

$$\Rightarrow 0.087 = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

$\Rightarrow U_2 = 33.33\%$

For $H_1 = 1.5$ m, $U_1 = 88.3\%$

$H_2 = 4.5$ m, $U_2 = 33.3\%$

$\therefore$ Average degree of consolidation (overall)

$$U = \frac{U_1H_1 + U_2H_2}{H_1 + H_2} = 47.05\%$$

$$U = \frac{S}{S_f}$$

$\therefore S = U \times S_f$

$= 0.4705 \times 120 = 56.4$ mm

04.

Sol: Effective stress at the middle of clay layer

(a) Before pumping,

$\sigma_1' = \gamma_s \times 1.8 + \gamma_s' \times 10.2 + \gamma_c' \times 3$

$\Rightarrow \sigma_1' = 18 \times 1.8 + (19.6 - 9.81) \times 10.2 + (19 - 9.81) \times 3$

$\Rightarrow \sigma_1' = 159.83$ kN/m^2

Corresponding 'e' from interpolation

$e_1 = 0.8$

(b) After pumping,

$\sigma_2' = \gamma_s \times 5.8 + \gamma_s' \times 6.2 + \gamma_c' \times 3$

$\Rightarrow \sigma_2' = 18 \times 5.8 + (19.6 - 9.81) \times 6.2 + (19 - 9.81) \times 3$

$\Rightarrow \sigma_2' = 192.7$ kN/m^2

Corresponding 'e' from interpolation

$$e_2 = 0.76 - \frac{(0.76 - 0.7)}{(190 - 210)}(190 - 192.7)$$

$\Rightarrow e_2 = 0.7519$

$$\therefore \frac{\Delta H}{H} = \frac{\Delta e}{1 + e_o}$$

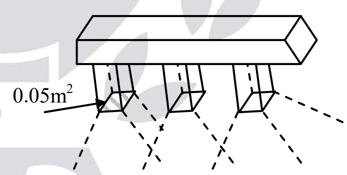
$$\Rightarrow \Delta H = \left(\frac{0.8 - 0.7519}{1 + 0.8}\right) \times 6$$

$\Rightarrow \Delta H = 0.160$ m = 160 mm

12. Compaction

01. Ans: (c)

Sol:



Energy given by rammer per m^3 of soil in the field

$$= \frac{40\times 1.5}{0.05\times 0.3} = 4000 \text{ kgm/m}^3$$

Energy given in IS light compaction test in kg-m/m^3 of volume of soil

Satandard value 595 kJ/m^3

= 60673.11 kg-m/m^3

$\therefore$ No. of purses required

$$= \frac{60673.11}{4000} = 15.16 \approx 16\,\text{No's}$$

02. Ans: (b)

Sol: $e_{max} = 0.75$, $e = 0.50$, $e_{min} = 0.35$

$G = 2.67$

$$\gamma_d \text{ field } = \frac{\gamma_{w.}G}{1+e}$$

$$= \frac{10\times 2.67}{1+0.5} = 17.8\,\text{kN.m}$$

$$\gamma_d \text{ lab} = \frac{\gamma_w G}{1+e_{min}} = \frac{10\times 2.67}{1+0.35} = 19.77\,\text{kN.m}$$

$$\text{Relation compaction} = \frac{17.8}{19.77}\times 100$$

$$= 90\%$$

Assignment Solutions

01. Ans: (d)

Sol:

Maximum dry density that can be achieved without air voids.

$$\gamma_d = \frac{\gamma_w G}{1+wG}$$

$$= \frac{10\times 2.6}{1+0.14\times 2.6}$$

$= 19.06\ \text{kN/m}^3$

02. Ans: 1.1

Sol: $$d = \frac{(1-n_a)\rho_w G}{1+wG}$$

$$1.85 = \frac{(1-n_a)\times 1\times 2.67}{1+0.16\times 2.67}$$

$n_a = 1.1\%$

13. Shear Strength

01. Ans: (a)

Sol: Direct stress, $\sigma_1 = 5\ \text{Kg/cm}^2$

All round stress, $\sigma_3 = 3.2\ \text{Kg/cm}^2$

Shear on failure plane, $\tau_f = 0.9$

$\phi = ?$

$$\tau_{max} = \frac{\sigma_1 - \sigma_3}{2} = 0.9$$

$$\because \tau_f = \tau_{max} \Rightarrow \phi = 0$$

Another method:

$$\tau_f = \frac{\sigma_1 - \sigma_3}{2}\sin 2\alpha_f$$

$$0.9 = \frac{5-3.2}{2}\sin 2\left(45+\frac{\phi}{2}\right)$$

$$1 = \sin 2\left[45+\frac{\phi}{2}\right]$$

$1 = \cos\phi$

$\phi = 0$

02. Ans: 34.37 kN/m²

Sol: UCC test

An undrained test ($\Delta V = 0$)

$$A_2 = \frac{V_1}{L_1 - \Delta L}$$

Divided by L_1

$$A_2 = \frac{A_1}{1 - \frac{\Delta L}{L_1}} = \frac{A_1}{1-\varepsilon} = \frac{A_1}{1-0.1}$$

$$A_2 = \frac{\pi/4 \times d^2}{1-0.1} = 21.81 \text{ cm}^2$$

$$q_u = \frac{Q}{A_2} = \frac{150}{21.81} = 6.87 \text{ N/cm}^2$$

$$= 68.7 \text{ kN/m}^2$$

$$C_u = \frac{q_u}{2} = 34.37 \text{ kN/m}^2$$

Common data for Questions 03 & 04

03 & 04 Ans: (c) & (b)

Sol: Given:

Unconfined compressive test ($\phi = 0$)

$q_u = 1.2$ kg/cm^2

$\alpha_f = 50$

Cohesion of soil =?

$$\alpha_f = \left(45 + \frac{\phi}{2}\right)$$

$$\sigma_1 = \sigma_3 \tan^2\left(45 + \frac{\phi}{2}\right) + 2C \tan\left(45 + \frac{\phi}{2}\right)$$

$\because\ \alpha_f = 50$

$$50 = 45 + \frac{\phi}{2}$$

$$5 \times 2 = \phi$$

$$\phi = 10°$$

$$q_u = 2\, C_u \tan\left(45 + \frac{\phi}{2}\right) \text{ if } \phi > 0$$

$$q_u = 2\, C_u \tan\left(45 + \frac{\phi}{2}\right) \text{ if } \phi = 0$$

$$1.20 = 2\, C_u \tan\left(45 + \frac{10}{2}\right)$$

$$C_u = 0.5 \text{ kg/cm}^2$$

05. Ans: $\alpha = 55.4°$, $\sigma_n = 338.72$ kN/m^2

$\tau = 128.56$ kN/m^2

Sol: $\sigma_3 = 250$ kN/m^2

$\sigma_d = 275$ kN/m^2

$\sigma_1 = \sigma_3 + \sigma_d$

$= 250 + 275 = 525$ kN/m^2

$C' = 0$ (for N.C clay in C.D test)

$$\sigma_1' = \sigma_3' + \sigma_d' = 525 \text{ kN/m}^2$$

$$\sigma_1' = \sigma_3' \tan^2(45 + \phi/2) + 2C' \tan(45 + \phi/2)$$

$$\sigma_1' = \sigma_3' \tan^2(45 + \phi/2)$$

$$525 = 250 \times \tan^2(45 + \phi/2)$$

$$45° + \phi/2 = 55.4°$$

On the failure plane

$$\sigma = \frac{\sigma_1 + \sigma_3}{2} + \frac{\sigma_1 - \sigma_3}{2} \cos 2\alpha_f$$

$$= 338.72 \text{ kN/m}^2$$

$$\tau_f = \frac{\sigma_1 - \sigma_3}{2} \sin 2\alpha_f$$

$$= 128.56 \text{ kN/m}^2$$

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06. Ans: $C_u = 0$, $\phi_u = 15.8°$, $C' = 0$, $\phi' = 22°$

Sol: $\sigma_3 = 200$ kN/m^2

$\sigma_d = 150$ kN/m^2

$u_f = 75$ kN/m^2

NCC in Cu test $C_u = 0$ & $C' = 0$

To find, ϕ_u^1 & ϕ_u^{11} =?

$\sigma_1 = \sigma_3 + \sigma_d = 200 + 150$

$= 350$ kN/m^2

$$350 = 200 \tan^2\left(45 + \frac{\phi_u}{2}\right) + 2(0)$$

$$\frac{350}{200} = \tan^2\left(45 + \frac{\phi_u}{2}\right)$$

$\phi_u = 15.8°$

To find ϕ'

$$\sigma_1^1 = \sigma_3^1\left(45 + \frac{\phi}{2}\right)$$

$$(\sigma_1 - u) = (\sigma_3 - u)\tan^2\left(45 + \frac{\phi}{2}\right)$$

$$275 = (125)\tan^2\left(45 + \frac{\phi}{2}\right)$$

$\phi = 22^o$

07. Ans: B = 0.70 & A = –0.228

Sol: Change = final value – Initial value

In consolidation stage:

$\Delta u_3 = 10 - (-60) = 70$ kN/m^2

$\Delta \sigma_3 = 100 - 0 = 100$ kN/m^2

$\Delta u_3 = B \times \Delta\sigma_3 \Rightarrow B = 0.7$

In shearing stage (or) failure stage

$\Delta u_d = -70 - 10 = -80$ kN/m^2

$\because$ u = Pore water pressure

$\Delta\sigma_d = 500$ kN/m^2

$\Delta u_d = AB\,\Delta\sigma_d$

$-80 = A \times 0.7 \times 500$

$\Rightarrow A = -0.228$

08. Ans: B = 0.95 & A = 0.357

Sol: $\Delta\sigma_3 = 800 - 700 = 100$

$\Delta u_3 = 445 - 350 = 95$

$\Delta u_3 = B\,\Delta\sigma_3$

$B = 0.95$

$\Delta\sigma_d = 575$ kN/m^2

$\Delta u_d = 640 - 445 = 195$ kN/m^2

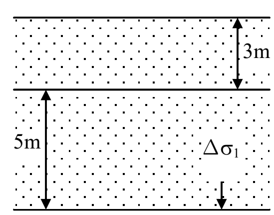
$\Delta u_d = AB \times \Delta\sigma_d$

$195 = A \times 0.95 \times 575$

$A = 0.357$

09. Ans: 78.20 kN/m^2

Sol:



$\Delta\sigma_3 = ½\,\Delta\sigma_1$

$\Delta\sigma_1 = 3\gamma = 48.6$ KPa

$\Delta\sigma_3 = ½\,\Delta\sigma_1 = 24.3$

$\Delta\sigma_d = (\Delta\sigma_1 - \Delta\sigma_3)$

$= 48.6 - 24.3 = 24.3$

$\Delta u = B\,(\Delta\sigma_3 + A\,\Delta\sigma_d)$

$= 31.29$ KPa

To find $\sigma' = \sigma - u$

$= 8 \times 16.2 - 31.29 = 98.31$ KPa

$S = C' + \sigma' \tan$

$= 50 + 98.31 \times \tan(16°)$

$= 78.18$ KPa

Assignment Solutions

01. Ans: (4, 41.37 kPa & 10.35kPa)

Sol: D = 75 mm, L = 150 mm; T = 64 N-m

T = 16 N.m

$$T = C_u \pi d^2\left[\frac{H}{2}+\frac{d}{6}\right]$$

$$64\times10^3\,N-mm = C_u\pi\times75^2\left[\frac{150}{2}+\frac{75}{6}\right]$$

$$64\times10^3 = C_u\pi 75^2\left[75+\frac{75}{6}\right]$$

$C_u = 4.139$ N/mm^2

$$=\frac{4.139\times10^3}{10^{-6}}\,kN/m^2$$

$\therefore$ $C_u = 41.39$ kPa (undisturbed)

Similarly

$$16\times10^3\,N\text{-}mm = C_u\,\pi\times75^2\left[\frac{150}{2}+\frac{75}{6}\right]$$

$C_u = 10.347$ KPa

(remoulded)

$$\therefore\ \text{Sensitivity} = \frac{\text{undisturbed strength}}{\text{Remoulded strength}}$$

$$=\frac{41.39}{10.347}=4$$

02. Ans: (a)

Sol: $\Delta u_d = 130$ kN/m^2

$\Delta\sigma_3 = 250 - 100 = 150$ kN/m^2

$\Delta u_3 = B\,\Delta\sigma_3$ $\qquad \dfrac{130}{150} = B$

B = 0.87

03. Ans: (b)

Sol: $q_u = 100$, $C_u = \dfrac{q_u}{2} = 50$

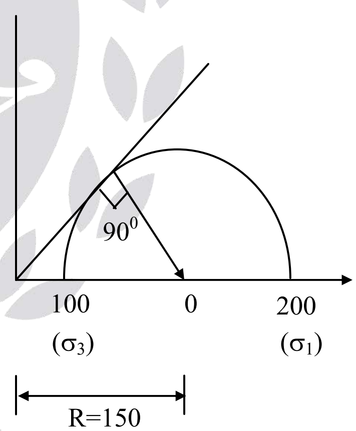
$\sigma_3 = 100$; For UU test, $\phi_u = 0$ or $\tan\alpha_f = 1$

$\sigma_1 = \sigma_3 + 2C_u$

$= 100+2\times50 = 200$

07. Ans: (a)

Sol:



Angle of internal friction (ϕ) = ?

Direction of failure envelop in CD test of NCC

$$\sin\phi = \frac{50}{150}$$

$$\phi = \sin^{-1}\left(\frac{1}{3}\right)$$

Conventional Practice Solutions

01.

Sol: $S = C_u + \sigma.\tan\phi_u$

From test : 1

$118 = C_u + 220\tan\phi_u \rightarrow (1)$

From Test: 2

$145 = C_u + 324\tan\phi_u \rightarrow (2)$

Solving (1) & (2) we get

$\phi_u = 14.55°$

$C_u = 60.88$ kPa

For unconfined compression test

$\sigma_3 = 0$, $\sigma_1 = q_u$ (unconfined compression strength)

$q_u = 2\, c_u \tan\alpha_f$

$$= 2\times 60.88 \tan\left[45+\frac{14.55°}{2}\right] = 157.4 \text{ kPa}$$

Apparent cohesion of unconfined compression test

$$C_u = \frac{q_u}{2}$$

$$= \frac{157.4}{2} = 78.7\,\text{kPa}$$

For triaxial test

Given $\sigma_3 = 360$ kPa, $\phi_u = 14.55°$,

$C_u = 60.88$ kPa

To find σ_1

$\sigma_1 = \sigma_3\tan^2\alpha_f + 2\,Cu\tan\alpha_f$

$$= 360.\tan^2\left[45+\frac{14.55°}{2}\right] + 2\times 60.88\tan\left[45+\frac{14.55°}{2}\right]$$

$= 758.97$ kPa

02.

Sol: $\sigma = 80$ kPa, $\tau_f = 48$ kPa

$\tau_f = C + \sigma.\tan\phi$

$\Rightarrow 48 = 0 + 80.\tan\phi$

$\Rightarrow \phi = 30.96^o$

To find σ_3 & σ_1

$$\sigma = \frac{\sigma_1+\sigma_3}{2} + \frac{\sigma_1-\sigma_3}{2}\cos 2\alpha_f$$

$$80 = \frac{\sigma_1+\sigma_3}{2} + \frac{\sigma_1-\sigma_3}{2}\cos 2\left[45+\frac{30.96^o}{2}\right] \quad \text{….(i)}$$

$$\tau_f = \frac{\sigma_1-\sigma_3}{2}\sin 2\alpha_f$$

$$48 = \frac{\sigma_1-\sigma_3}{2}\sin 2\left[45+\frac{30.96^o}{2}\right] \quad \text{……… (ii)}$$

Solving equation (i) and (ii)s

$160 = \sigma_1 + \sigma_3 + (\sigma_1 - \sigma_3)\,(-0.514)$

$96 = (\sigma_1 - \sigma_3)\,0.857$

$\sigma_1 = 164.7$ kPa

$\sigma_3 = 52.8$ kPa

Failure plane makes angle of $45+\frac{\phi}{2}$ w.r.t major principal plane

$$45+\frac{\phi}{2} = 45+\frac{30.96}{2} = 60.48^o$$

$\therefore$ Major principal plane makes 60.48^o with the horizontal.

Minor principal plane makes $90 - 60.48^o = 29.52^o$ with horizontal.

14. Earth Pressure

01. Ans: 316.7 kN

Sol: Given:

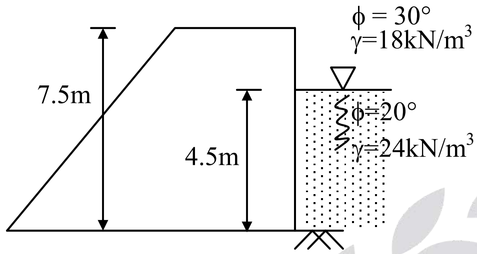


Fig. (1)

$k_a = \frac{1}{3}$, $\quad k_{a_1} = \frac{1-\sin 20}{1+\sin 20} = 0.49$

$\therefore$ at top $\sigma_v = 0, P_a = 0$

$\therefore$ at 3 m below,

$\sigma_v = 18 \times 3 = 54$ kN/m^2

$P_a = 54 \times \frac{1}{3} = 18$ kN/m^2

$\therefore$ at 3m just below $P_{a_1} = 54 \times 0.49 = 26.46$

At 7.5 m,

$\sigma_v = 18 \times 3 + 4.5 \times 14 = 117$ kN/m^2

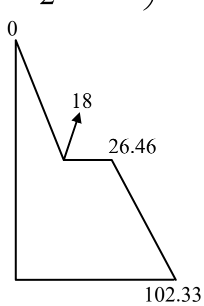
$P_{a_2} = 0.49(117) + 10 \times 4.5$

$= 102.33$ kN/m^2

Total active thrust

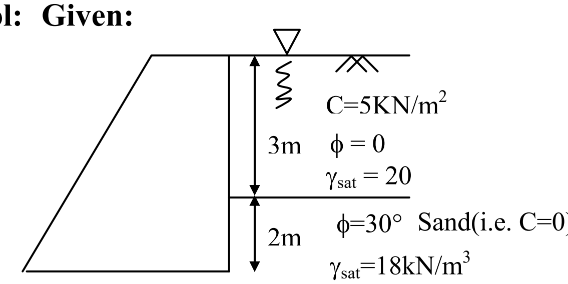
$= \frac{1}{2} \times 18 \times 3 + \left(\frac{26.46+102.33}{2}\right)4.5$

$= 316.77$ kN/m



02. Ans: (167 kN/m)

Sol: Given:



To find: Total active thrust on the back

a) At top:

As there is water $K_{a_1} = 1, K_{a_2} = 0.33$

So $\sigma'_v = 0$

$\sigma_h = K_a (0)$

$\sigma_h = 0$

$P_a = K_{a_1}\sigma_v - 2C_1\sqrt{K_{a_1}} = -10\,\text{kPa}$

b) At 3 m depth:

a) Just above:

$\sigma'_v = 3\gamma' = 3(20-10) = 30\,\text{kPa}$

$P_a = K_{a_1}\sigma'_v - 2C_1\sqrt{K_{a_1}} + \gamma_w h$

$= 1\ (30) - 2\ (5)\ (1) + 10 \times 3$

$= 50$ kPa

b) Just below:

$P_a = K_{a_2}\sigma'_v - 2C_2\sqrt{K_{a_2}} + \gamma_w h$

$= 0.33\ (30) - 2\ (0)\sqrt{0.33} + 10 \times 3$

$= 39.9 \cong 40$ kPa

c) At bottom:

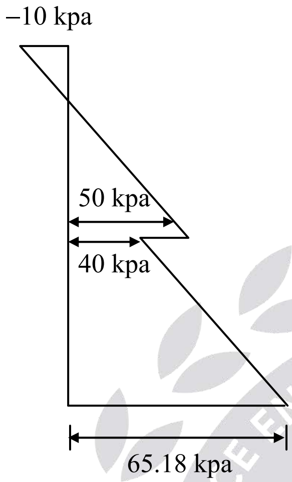
$\sigma'_v = 3\gamma' + 2\gamma'$

$\sigma'_v = 3(20-10) + 2(18-10) = 46\,\text{kpa}$

$P_a = K_{a_2}\sigma'_v - 2C_2\sqrt{K_{a_2}} + \gamma_w h$

$= 0.33\ (46) - 2\ (0)\ \sqrt{K_{a_2}} + 10 \times 5$

$= 65.18$ kPa



To compute force:

$F = P_a \times A$

$Z_C = \frac{2C}{\gamma}\sqrt{K_a}$ } where there is no water

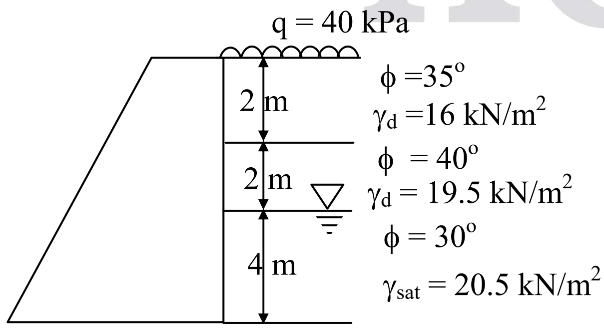
$F = P_a$ = area of +ve portion of diagram

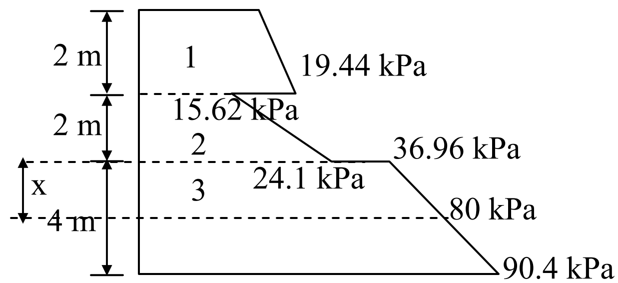
$= \left(\frac{1}{2} \times 50 \times 2.5\right) + \frac{1}{2}(40 + 65.4) \times 2$

$F = 167$ kN/m

03. Ans. 7.23 m

Sol:





Active Pressure distribution

$$K_{a_1} = \frac{1 - \sin 35^o}{1 + \sin 35^o} = 0.27$$

$$K_{a_2} = \frac{1 - \sin 40^o}{1 + \sin 40^o} = 0.217$$

$$K_{a_3} = \frac{1 - \sin 30^o}{1 + \sin 30^o} = \frac{1}{3}$$

Pressure at top:

$\sigma_v = q$

$P_a = \sigma_v \times K_{a_1} = 10.8$ kPa

Pressure at a depth 2 m

Case (a): Just above the 2 m depth

$\sigma_v = q + \gamma_a \times 2$

$= 40 + 16 \times 2 = 72$ kPa

$P_a = \sigma_v\ K_{a_2} = 72 \times 0.27$

$= 19.44$ kPa

Case (b): Just below 2 m depth

$\sigma_v = 72$ kPa

$P_a = \sigma_v\ ka_2 = 72 \times 0.217$

$= 15.62$ kPa

Pressure at a depth 4 m depth

Case (a) : Just above the 4 m depth

$\sigma_v = q + \gamma_{d_1} \times 2 + \gamma_{d_2} \times 2$

$= 40 + 16 \times 2 + 19.5 \times 2 = 111$ kPa

$P_a = \sigma_v K_{a_2} = 111 \times 0.217 = 24.1$ kPa

Case(b) : Just below the 4 m depth

$\sigma_v = 111$ kPa

$P_a = \sigma_v K_{a_3} = 111 \times \frac{1}{3} = 36.96$ kPa

Pressure at base:

$\sigma_v = q + \gamma_{d_1} \times 2 + \gamma_{d_2} \times 2 + \gamma' \times 4$

$= 40 + 16 \times 2 + 19.5 \times 2 + (20.5 - 9.81) \times 4$

$= 153.76$ kPa

$P_a = \sigma_v K_{a_3} + \gamma_w \times 4 = 90.4$ kPa

In the third layer : At $P_a = 80$ kPa

$\sigma'_v = 40 + 2[16 + 19.5] + [20.5 - 9.81]x$

$= 111 + 10.69x$ (x = depth in the third layer at which $p_a = 80$ kPa)

$80 = \sigma'_v \times K_{a_3} + \gamma_w \times x$

$80 = \frac{1}{3}[111 + 10.69x] + 9.81x$

$\Rightarrow x = 3.23$ m

From top $= 2 + 2 + x = 7.23$ m

Assignment Solutions

01. Ans: (a)

Sol: $P_a = \sigma_v k_a = 2c\sqrt{k_a} = 0$

$\sigma_v k_a = 2c\sqrt{k_a}$

$\therefore \quad \sigma_v = \frac{2c}{\sqrt{k_a}} = 2c \tan\alpha$

$k_a = \frac{1}{\tan^2 \alpha}$

02. Ans: 161.66 kN/m

Sol: $\phi_1 = 30^o$; $\quad k_{a1} = \frac{1 - \sin\phi_1}{1 + \sin\phi_1} = 0.333$

$\phi_2 = 10^o$; $\quad k_{a2} = \frac{1 - \sin\phi_2}{1 + \sin\phi_2} = 0.704$

At top: $\sigma_v = q = 10 \text{ kN/m}^2$

$P_a = k_{a1}\sigma_v - 2c_1\sqrt{k_{a1}}$

$= 0.333 \times 10 - 0 = 3.33 \text{ kN/m}^2$

At 3 m depth: $\sigma_v = q + \gamma_1 z_1$

$= 10 + 15 \times 3 = 55 \text{ kN/m}^2$

(a) Just above the 3 m depth,

$P_a = k_{a1}\sigma_v - 2C_1\sqrt{k_{a1}}$

$= 0.333 \times 55 - 0 = 18.32 \text{ kN/m}^2$

(b) Just below the 3 m depth,

$P_a = k_{a2}\sigma_v - 2C_2\sqrt{k_{a2}}$

$= 0.704 \times 55 - 2 \times 10\sqrt{0.704} = 21.94 \text{ kN/m}^2$

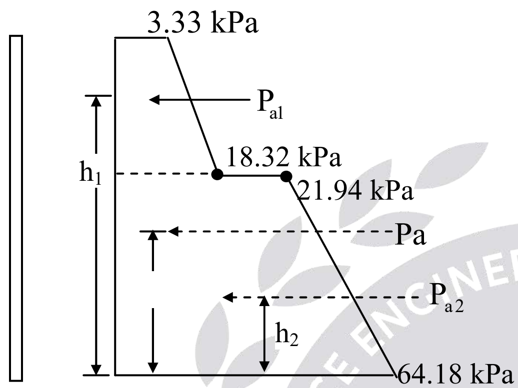
At 6 m depth: $\sigma_v = q + \gamma_1 z_1 + \gamma_2 z_2$

$= 10 + 15 \times 3 + 20 \times 3 = 115 \text{ kN/m}^2$

$P_a = k_{a2}\sigma_v - 2C_2\sqrt{k_{a2}}$

$= 0.704 \times 115 - 2 \times 10\sqrt{0.704}$

$= 64.18\ kN/m^2$



The active pressure diagram is shown in the figure. Total active force,

$P_a = P_{a1} + P_{a2}$

$= \frac{1}{2}[3.33 + 18.32] \times 3 + \frac{1}{2}[21.94 + 64.18]3$

$= 32.48 + 129.18 = 161.66\ kN/m$

03. Ans: (d)

Sol: $k_o = 0.5$, $\frac{k_p}{k_a} = ?$

$k_o = 1 - \sin\phi = 0.5$

$\phi = 30°$

$k_a = \frac{1-\sin\phi}{1+\sin\phi}$

$k_p = \frac{1+\sin\phi}{1-\sin\phi} = \frac{1+1/2}{1-1/2} = \frac{3/2}{1/2} = 3$

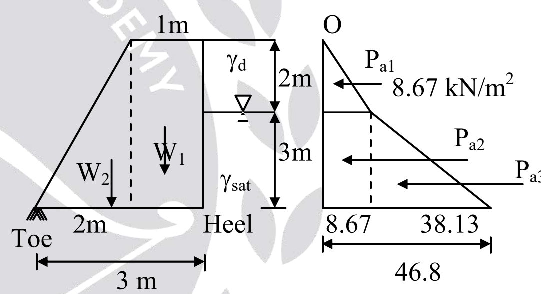
$k_a = \frac{1-1/2}{1+1/2} = \frac{1/2}{3/2} = \frac{1}{3}$

$\frac{k_p}{k_a} = \frac{3}{1/3} = 9$

Conventional Practice Solutions

01.

Sol:



$K_a = \frac{1-\sin\phi}{1+\sin\phi} = 0.271$

At a depth of 2m, $p_a = K_a.\sigma_v$

$p_a = K_a(\gamma_d \times 2) = 8.67$ kPa

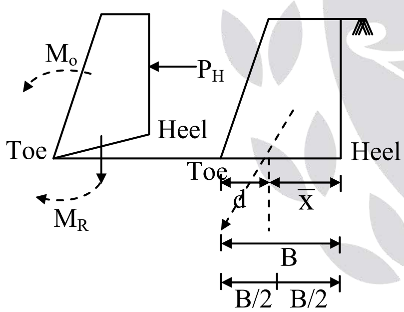
At a depth sof 5m, $p_a = K_a\ \sigma_v' + \gamma_w h$

$p_A = k_A\ [\ 2\gamma_d + 3\gamma'] + \gamma_w\ h$

$p_a = 46.8$ kPa

Force due to	Force	Distance form Toe	Moment about toe (C.W,+ve)
W_1	$1\times5\times1\times24 = 120$	$2+0.5 = 2.5$	+300
W_2	$\frac{1}{2}\times2\times5\times24=120$	$\frac{2}{3}\times2=\frac{4}{3}$	+160
	$\sum P_V = 240$ kN		$\sum M_R = 460$ kNm
P_{a1}	$\frac{1}{2}\times8.67\times2=8.67$	$3+\frac{1}{3}\times2=3.667$	–31.73
P_{a2}	$3\times8.67 = 26.01$	$\frac{3}{2}=1.5$	–39.01
P_{a3}	$\frac{1}{2}\times38.13\times3 = 57.19$	$\frac{1}{3}\times3=1$	–57.19
	$\sum P_H = 91.87$ kN		$\sum M = -128$ kNm

Overturning moment



$$B = \bar{x} + \bar{d}$$

For $\bar{x} = \dfrac{\sum M \text{ about heal}}{\sum P_V}$

For $\bar{d} = \dfrac{\sum M \text{ about toe}}{\sum P_V}$

Safety against overturining moment:

Distance from toe, $\bar{d} = \dfrac{\sum M \text{ about toe}}{\sum P_V}$

$$= \frac{(460-128)}{240}$$

$$\bar{d} = \frac{332}{240}$$

$\bar{d}$ = 1.38 m

$\therefore$ Eccentricity, $e = \dfrac{B}{2} - \bar{d}$ = 1.5–1.38

e = 0.12 m

To avoid tension,

$e \le \dfrac{B}{6}$

Hence no tension occurs

Factor of safety against lateral sliding

$$F_S = \mu.\frac{\sum P_V}{\sum P_H} \qquad (\mu = 0.47)$$

$$F_s = \frac{0.47\times240}{91.87} = 1.22$$

Comment: Theoretically it is safe against sliding. However for practical design a minimum of 1.5 is recommended.

2. Factor of safety against overturning about toe only:

Resisting moments, M_R = Self weight

$$M_R = W_1 + W_2$$

$$M_R = 460 \text{ kN.m}$$

Overturning moments, M_o = Pressure

$$M_o = P_{a_1} + P_{a_2} + P_{a_3}$$

$$M_o = 128 \text{ kN.m}$$

$$F_o = \frac{M_R}{M_o} = 3.59$$

3. Bearing pressure on foundation soil using Usually,

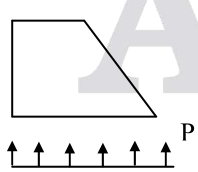
$$P = \frac{\sum P_V}{B \times 1}\left[1 + \frac{6e}{B}\right]$$

$$P = \frac{240}{3}\left[1 + \frac{6(0.12)}{3}\right]$$

P = 99.2 kPa

As per Meyerhof's Method: Assumes uniform pressure.

$$P = \frac{\sum P_V}{(B - 2e) \times 1}$$



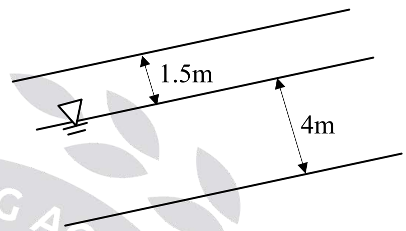
P = 86.96 kPa

15. Stability of Slopes

01. Ans: (d)

Sol: $\phi' = 35°$, $\gamma_{sat} = 19 \text{ kN/m}^3$

$i = 28°$, $\gamma_w = 9.8 \text{ kN/m}^3$



Against translational failure,

$$FOS = \frac{C + \gamma z \tan\phi \cos i}{\gamma z \cos i \sin i}$$

$$= \frac{0 + (\gamma 1.5 + (4 - 1.5)\gamma')\tan\phi \cos^2 i}{(\gamma 1.5 + (4.15)\gamma')\cos i \sin i}$$

$$= \frac{(19 \times 1.5 + 2.5 \times (19 - 9.8))\tan 35 \cos^2 28}{(19 \times 1.5 + 2.5 \times 19)\cos 28 \sin 28}$$

= 0.89

02. Ans: 4.77

Sol:

Infinite slope, seepage parallel to slope

$$F = \frac{C' + \gamma z \cos^2 i \tan\phi'}{\gamma_{sat} z \cos i \sin i} \qquad Z = H_c$$

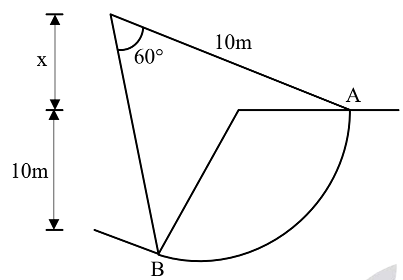
$$1 = \frac{25 + 8 \times H_c \cos^2(35°)\tan(28°)}{18 \times H_c \cos(35°)\sin(35°)}$$

$H_c = 4.77$

03. Ans: 1.184, 2.66

Sol: C = 50 kN/m^2

$\phi = 10^o$ $\sigma' = 255$ kN/m^2 , t = 840 kN



$N = \sigma' I.1$

$= 255 \times 1.04 \times 1 = 265.2$

$$\hat{L} = \frac{(2\pi r)\times 60}{360} = 10.47$$

$$F = \frac{C.\hat{L} + \Sigma N \tan\phi}{\Sigma T} = \frac{C.\hat{L} + N\tan\phi}{T}$$

$$F = \frac{50\times 10.47 + 255(10.47)\tan 10}{840}$$

$= 1.1836$

w.r. to height

$$H_C = \frac{4C}{\gamma\sqrt{k_a}}$$

$$= \frac{4C}{\gamma}\tan\left[45 + \frac{\phi}{2}\right] = \frac{4\times 50}{18}\tan 50 = 13.24\,m$$

$H = R - x$

$= 10 - R\cos 60^o = 5$

$$F = \frac{H_C}{H} = \frac{13.24}{5} = 2.67$$

04. Ans: $F_c = 1.16$ & $F_\phi = 1.2$

Sol: Given:

Cutting is to be made in soil

Slope of soil = 25°

Depth of soil = 25 m

Cohesion soil C = 0.35 kg/cm^2

Angle ϕ = 15°

Bulk density γ = 2 gm/cc

a) FOS w.r.t cohesion, if FOS desired with respect to friction = 1.5

As we know

$$F_S = \frac{\tan\phi}{\tan\phi_m} \Rightarrow 1.5 = \frac{\tan 15^\circ}{\tan\phi_m}$$

$$\tan\phi_m = \frac{\tan 15^\circ}{1.5}$$

$\phi_m = 10°$, $S_n = 0.06$

$$S_n = \frac{C}{F_C\,\gamma\,H}$$

$$0.06 = \frac{3500}{F_C \times 2000 \times 25} \qquad F_C = 1.16$$

b) If FOS with respect to cohesion is 1.5, then what is FOS with respect to friction = ? (F_ϕ = ?)

$$S_n = \frac{C}{F_C\,\gamma\,H}$$

$$S_n = \frac{3500}{1.5 \times 2000 \times 25}$$

$S_n = 0.049 \cong 0.05$

$\because \phi_m = 12.5°$

$$F_\phi = \frac{\tan\phi}{\tan\phi_m} = \frac{\tan 15^\circ}{\tan 12^\circ 5'} = 1.2$$

05. Ans: 3.56 & 1.18

Sol: Given:

A new canal is excavated with

Depth of canal h = 5 m

C = 1.4 t/m^2 ; $\phi = 15°$

$\gamma_{sat} = 1.945$ t/m^3

Slope of bank = 1 : 1

To find:

a) FOS w.r.t cohesion when canal runs full = ?

b) If it is suddenly emptied, FOS = ?

a) $$S_n = \frac{C}{F_c \gamma^1 H}$$

$$0.083 = \frac{1.4}{F_C(1.945-1)5} \Rightarrow F_C = 3.56$$

For $\phi = 15^0$; $S_n = 0.083$

For $\phi = 7.5^0$; $S_n = 0.122$

b) $$\phi_m = \frac{\gamma}{\gamma_{sat}} \times 15 = 7.5$$

$$S_n = \frac{C}{F_C\,\gamma_{sat}\,H}$$

$$F_C = \frac{1.4}{0.122 \times 1.945 \times 5} = 1.179$$

06. Ans: $F_c = 2.4$ & $F_\phi = 2.89$

Sol: Given:

Embankment is to be made of a soil

Shear parameters of soil:

$C' = 30$ KN/m^2 ; $\phi' = 15°$

To find F_ϕ if $F_C = 1$

$$S_m = \frac{C'}{F_C} + \frac{\sigma' \tan\phi}{F_\phi} \;;\; (\phi' = 15')$$

$$39.25 = \frac{30}{1} + \frac{100 \times \tan 15}{F_\phi}$$

$$F_\phi = 2.89$$

To find F_C if $F_\phi = 1$

$$S_m = \frac{C'}{F_C} + \frac{\sigma' \tan\phi'}{F_\phi}$$

$$39.25 = \frac{30}{F_C} + \frac{26.79}{1} \Rightarrow F_C = 2.40$$

Assignment Solutions

01. Ans: (a)

Sol: Taylor's stability number

$$S_n = \frac{c}{F\gamma H}$$

When running full condition $\gamma' = \gamma_{submerged}$

$$0.046 = \frac{15}{1.5 \times 9 \times H}$$

$\gamma_{submerged} = \gamma_{sat} - \gamma_w = 19 - 10 = 9$ kN/m^3

H = 24 m

02. Ans: (d)

Sol: $$FOS = \frac{S}{T} = \frac{C + \sigma\tan\phi}{T}$$

$$= \frac{C' + \gamma' z \cos^2 i \tan\phi'}{\gamma_{sat} z \cos i \sin i}$$

$$= -\frac{10 + 10 \times 5 \times \cos^2 10 \times \tan 25}{20 \times 5 \cos 10 \times \sin 10} = 1.90$$

03. Ans: 1.06

Sol: $F.O.S = \frac{\text{Resisting moment}}{\text{Driving moment}}$

$$= \frac{C_u LR}{W.x}$$

$$= \frac{50 \times 18 \times \frac{\pi}{180} \times 68° \times 18}{2060 \times 8.8} = 1.06$$

Conventional Practice Solutions

01.

Sol: For critical height

$$FOS = 1 = \frac{C' + \gamma' z \cos^2 i \tan\phi}{\gamma z \cos i \sin i}$$

$\Rightarrow 25 + (18 - 9.8)z \cos^2 35 \tan 28$

$= 18 \times z \times \cos 35 \sin 35$

$25 + 2.9256z = 8.4572z$

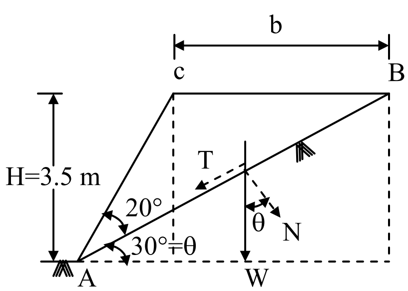
$\Rightarrow z = 4.519$ m

Critical height < actual height

$\therefore$ The slope is unstable

02.

Sol: Wedge failure:



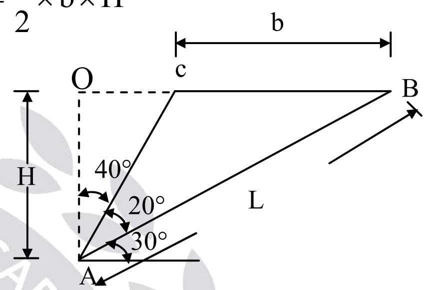
$N = W\cos\theta \qquad T = W\sin\theta$

$$F = \frac{C.L \times 1 + N.\tan\phi}{T}$$

L = length of AB

Area of wedge

$$A = \frac{1}{2} \times b \times H$$



Δ AOB, $\tan 60° = \frac{OC + CB}{H}$

Δ AOC, $\tan 40° = \frac{OC}{H}$

OC = H tan 40°

$\therefore$ CB = H tan 60° – H tan 40°

b = 3.125 m [$\because$ H = 3.5 m]

$$\frac{H}{AB} = \cos 60°$$

$$\frac{H}{\cos 60°} = L$$

L = 7 m

Area of wedge $A = \frac{1}{2} \times b \times H$

$$A = \frac{1}{2} \times 3.125 \times 3.5$$

$A = 5.469$ m^2

Self weight

$W = A \times 1 \times \gamma = 103.93$ kN

$N = W\cos 30° = 90$ kN

$T = W \sin 30° = 51.97$ kN

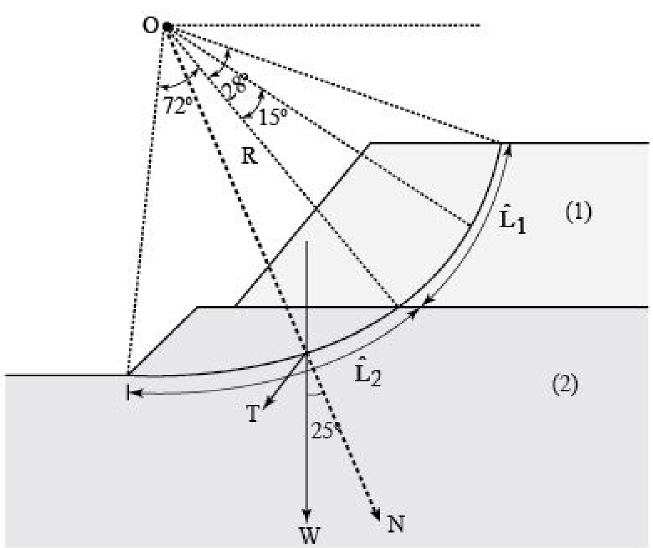
Factor of safety

$$F = \frac{C\hat{L} + N\tan\phi}{T} = \frac{8\times 7 + 90\times\tan 20^o}{51.97}$$

F = 1.71

03.

Sol:



$$F = \frac{C_u\hat{L}R}{W.x}$$

$$F = \frac{C_1\hat{L}_1R + C_2\hat{L}_2R}{T.R}$$

$W = a \times 1 \times \gamma$

$= 41.8 \times 1 \times 19 = 794.2$ kN

$T = W \sin 25^o$

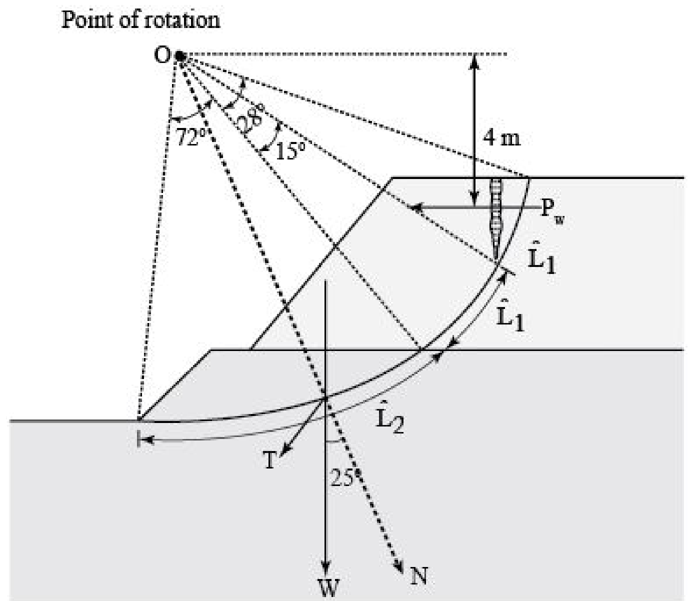
$= 335.64$ kN

$$\hat{L}_1 = R\times 28^o\times\frac{\pi}{180} = 9\times 28\times\frac{\pi}{180} = 4.39$$

$$\hat{L}_2 = R\times 72^o\times\frac{\pi}{180} = 9\times 72\times\frac{\pi}{180} = 11.30$$

$$F = \frac{(20\times 4.39\times 9) + (35\times 11.30\times 9)}{335.64\times 9} = 1.44$$

F = 1.44



$$F = \frac{C_1\hat{L}_1R + C_2\hat{L}_2R}{T.R + P_w\times 4}$$

$$\hat{L}_1 = R\times 15^o\times\frac{\pi}{180} = 2.356$$

$a = (41.8 - 0.6) = 41.2\ m^2$

$W = a \times 1 \times \gamma$

$= 41.2 \times 1 \times 19$

$= 782.8$ kN

$T = W. \sin 25^o$

$= 330.82$ kN

Crack depth $z_c = \frac{2C_1}{\gamma\sqrt{K_a}} = \frac{2\times 20}{19\sqrt{1}} = 2.1$ m

Force due to water, $P_w = \gamma_w.\frac{Z_c}{2}$

$$= 9.81 \times \frac{2.1^2}{2} = 21.63 \text{ kN}$$

$$F = \frac{(20 \times 2.356 \times 9) + (35 \times 11.30 \times 9)}{330.82 \times 9 + 21.63 \times 4} = 1.30$$

F = 1.30

∴ Due to the tension crack formation the F.O.S get reduced.

04.

Sol: Consider width = 1 m

Weight of wedge = 70 × 20 = 1400 kN

Driving moment = $W\bar{x}$ = 1400 × 4.5

= 6300 kN-m

Resisting moment $= C\hat{L}R$

$$= 60\left(12 \times 90 \times \frac{\pi}{180}\right) \times 12$$

= 13571.7 kN-m

$$FOS = \frac{M_R}{M_D} = \frac{13571.7}{6300} = 2.15$$

Minimum value of FOS, $F_c = \frac{C}{S_n \gamma H}$

$$= \frac{60}{0.181 \times 20 \times 8}$$

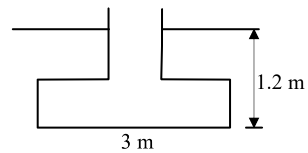
$\Rightarrow F_c = 2.07$

16. Bearing Capacity of Soil

01. Ans: 2.54, 2.03

Sol:

(a)



Net ultimate bearing capacity

$q_{nu} = CN_c + (N_q - 1)\,\gamma_D + 0.4\,\gamma B N_\gamma$

$C = 0,\ N_q = 22,\ N_\gamma = 20$

q_{nu} = 21 × 17 × 1.2 + 0.4 × 17 × 3 × 20

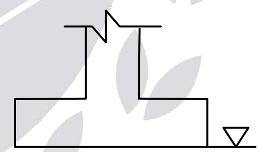
= 836.4 KPa

Safe bearing capacity $q_s = \frac{q_{nu}}{F} + \gamma_D$

$$350 = \frac{836.4}{F} + 17 \times 1.2$$

F = 2.54

(b)



$q_{nu} = (N_q - 1)\gamma D + 0.4\,\gamma' B N_\gamma$

= 21 × 17 × 1.2 + 0.4 (20 – 9.81) 3 × 20

= 672.96

Safe bearing capacity

$$q_s = \frac{q_{nu}}{F} + \gamma D$$

$$350 = \frac{672.96}{F} + 17 \times 1.2$$

F = 2.04

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02. Ans: (b)

Sol: Given:

Depth = 1m

Square plate = 30 cm^2

Load = 7.2 tones

S_p settlement = 25 mm

To find:

If settlement is limited for 10 mm

Allowable bearing pressure=?

$$q_1 = \frac{7.2}{(0.3)^2} = 80\, t/m^2$$

S_2 = 10 mm

q = ?

($S \propto q$ in case of granular soils)

$$\frac{S_2}{S_1} = \frac{q_2}{q_1}$$

$$\frac{10}{25} = \frac{q_2}{80}$$

$q_2 = 32$ t/m^2

03. Ans: 442.88 kN

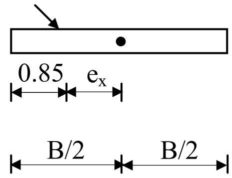
Sol: q_n =?

Q = P cos 30

$B' = B - 2e_x = 1.7$ m

$L' = L - 2e_y = 2$ m

$A' = B'L' = 3.4$ m^2



$$e_x = \frac{B}{2} - 0.85 = 1 - 0.85 = 0.15 \text{ m}$$

$e_y = 0$

Mayer of's equation:

$$q_u = CN_cS_cd_ci_c + \gamma D_f N_q s_q d_q i_q + 0.5\gamma B N_\gamma S_\gamma d_\gamma i_\gamma$$

$q_u = 0 + 18 \times 1 \times 33.3 \times 1.314 \times 1.113 \times 0.444 + 0.5 \times 18 \times 2 \times 37.16 \times 1.314 \times 1.113 \times 0.02$

= 408.78 kPa

$q_{nu} = q_u - \gamma D_f = 408.78 - 18 \times 1$

= 390.78 kPa

$$q_{ns} = \frac{q_{nu}}{F} = \frac{390.78}{3} = 130.26\, \text{kPa}$$

Net sate load

$Q_{na} = A'q_{ns} = 3.4 \times 130.26 = 442.88$ kN

04. Ans: 5.01 m

Sol: For design safety, $q_n \le q_{na}$

(smaller of q_{ns} and q_{np})

If q_{np} is not given, then $q_{na} = q_{ns}$

$q_n \le q_{ns}$

or $q_g \le q_s$

Gross load = co. load + 5% col.load

$$= 1962 + \frac{5}{100}1962$$

= 2060.1 kN

$$q_g = \frac{Q_s}{A} = \frac{2060.1}{1.5^2} \text{ kN/m}^2$$

= 915.6 kPa

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$$q_s = \frac{q_n - \gamma D_f}{F} + \gamma D_f$$

$$q_s = \frac{1.3N_c + \gamma D_f(N_q - 1) + 0.4\gamma BN_r}{F} + \gamma D_f$$

$$915.6 = q_s = \frac{0 + 20.6 \times D_f \times (22-1) + 0.4 \times 20.60 \times 2.5 \times 20}{3}$$
$$+ 20.6 \times 17$$

equate $q_g = q_s$

$D_f = 5.01$ m

05. Ans: 1.07 m

Sol: $Q_n = 152$ kN/m, $d = 1.2$ m,

$\gamma = 18.8$ kN/m^2, $q_u = 150$ kN/m^2

$$C_u = \frac{q_u}{2} = \frac{150}{2} = 75 \text{ kN/m}^2$$

$$\therefore \; q_n = \frac{152}{B \times 1} \text{ kN-m}^2$$

C = 1/2 of unconfined compressive Strength

$$q_{ns} = \frac{q_{nu}}{F} = \frac{1}{F}(CN_c) = \frac{(75 \times 5.7)}{3} = 142.5$$

$N_c = 5.7$ (for pure clay terzagi)

Equate $q_n = q_{ns}$

$$\therefore \; \frac{152}{B} = 142.5 \qquad B = 1.07 \text{ m}$$

06. Ans: 6.55 m

Sol: Given:

Size of foundation = 14m×21m

Unconfined compressive strength = 15 kN/m^2

$$C_u = \frac{15}{2} = 7.5 \text{ kN/m}^2$$

Gross pressure intensity $q_u = 140$ kN/m^2

FOS = 3; $\gamma_{clay} = 19$ kN/m^3

For safety $q_n \le q_{na}$

Where, $q_{na} \rightarrow$ net allowable bearing capacity of soil which is smaller of q_{ns} & q_{np}

According to skemptons;

$q_{nu} = CN_c$

For Rectangular footing;

$$N_c = 5\left[1 + 0.2\frac{D}{B}\right]\left[1 + 0.2\frac{B}{L}\right]$$

$$q_{ns} = \frac{q_{nu}}{F.O.S}$$

$$N_c = 5\left[1 + 0.2\frac{D}{14}\right]\left[1 + 0.2 \times \frac{14}{21}\right]$$

$$N_c = \frac{17}{3}\left(1 + 0.2\frac{D}{14}\right)$$

$$q_{nu} = 7.5 \times \frac{17}{3}\left(1 + 0.2\frac{D}{14}\right)$$

$$= 42.5\left(1 + 0.2\frac{D}{14}\right)$$

$$q_{ns} = \frac{q_{nu}}{FOS} = \frac{42.5}{3}\left(1 + 0.2\frac{D}{14}\right)$$

$$= 14.17\left(1 + 0.2\frac{D}{14}\right)$$

Since there is a provision for basement floor, the footing is not back filled. Hence,

$q_n = q_u - \gamma D$

$= 140 - 19 \times D$

$$140 - 19 \times D = 14.17\left(1 + 0.2\frac{D}{14}\right)$$

$140 - 19 \times D = 14.17 + 0.202D$

$125.83 = 19.202D$

$D = 6.55$ m

Assignment Solutions

01. Ans: (c)

Sol: Unconfined compressive strength $q = 2C_u$

$100 = 2C_u$

$C_u = 50\ kN/m^2$

$\therefore$ According to skempton's theory

Net ultimate bearing capacity

$q_{nu} = CN_c$

for rectangular footing

$$N_C = 5\left(1+0.2\frac{0}{B}\right)\left(1+0.2\frac{B}{L}\right)$$

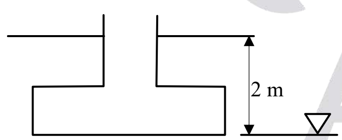
$$N_C = 5\left(1+0.2\left(\frac{2}{1}\right)\right)\left(1+0.2\frac{1}{2}\right)$$

$= 7.7$

$\therefore q_{nu} = 50 \times 5.7$

$= 385\ kN/m^2$

06. Ans: 211 kPa; 201 kPa; 4.74%



$$C = \frac{q}{2} = \frac{60}{2} = 30\,KPa$$

Ultimate bearing capacity

$q_u = CN_c + \gamma DN_q + 0.5\,\gamma BN_\gamma$

$\phi_u = 0,\ N_c = 5.7,\ N_q = 1,\ N_\gamma = 0$

$\therefore$ q_u at W.T 2 m below the G.L

$= 30 \times 5.7 + 20 \times 2 \times 1$

$= 211$ KPa

q_u at W.T 1 m below the G.L

$= CN_c + \gamma_a DN_q$

$$\gamma_a = \frac{20\times1+(20-9.81)}{2}$$

$= 15.095$

$q_u = 30 \times 5.7 + 15.095 \times 2$

$= 201.19$ KPa

% reduction in ultimate bearing capacity

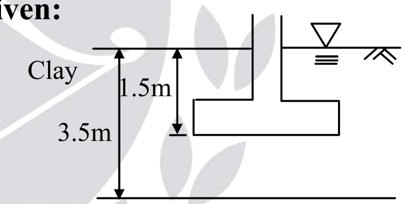
$$= \frac{211-201.19}{211}\times100$$

$= 4.64\%$

Conventional Practice Solutions

01.

Sol: Given:



Square footing

Size of the footing = 2 m × 2m

$w_L = 30\%$

$w_n = 40\%$, $G_s = 2.7$

$C_u = 50$ kPa

$$\gamma_{sat} = \frac{\gamma_w[G+Se]}{1+e}; \quad S_r e = wG$$

$$= \frac{\gamma_w[G+wG]}{1+wG}$$

$$= \frac{10[2.7+0.4\times2.7]}{1+0.4\times2.7} = 18.17\ kN/m^3$$

To find: Net safe bearing capacity of the footing

According to Skepmton's approach,

$q_{nu} = CN_c$

Where, $N_c = 6\left[1+0.2\dfrac{D}{B}\right]$

→ for square footing

$$N_c = 6\left[1+0.2\frac{1.5}{2}\right] = 6.9$$

$q_{nu} = 50 \times 6.9 \quad \because N_c \le 9$

$= 345\ \text{kN/m}^2$

$$q_{ns} = \frac{q_{nu}}{F}$$

$= 115\ \text{kN/m}^2$

∴ Net safe Bearing capacity of soil

$= 115\ \text{kN/m}^2$

$\sigma_o' = \sigma - u$

$= 18.17\,(2.5) - (2.5) \times 10$

$= 20.43\ \text{kN/m}^2$

$Q = q_{ns} \times$ Area of the footing

Load $= Q = 115 \times 4 = 460$ kN

$$\Delta\sigma = \frac{Q}{(B+Z)^2}$$

$$= \frac{460}{(2+1)^2} = \frac{460}{9} = 51.11\ \text{kN/m}^2$$

$$\Delta H = C_c \times H \times \frac{1}{1+e_o}\log\left(\frac{\sigma_o' + \Delta\sigma}{\sigma_o'}\right)$$

$$= 0.18 \times 2.0 \times \frac{1}{1+1.08}\log\left(\frac{20.43+51.11}{20.43}\right)$$

$= 94$ mm

02.

Sol:

$B' = B - 2lx = 1.5 - 2 \times 0.2 = 1.1$ m

$L' = L = 1.5$

Using Meyerhof's Theory

$$q_c = CN_c\, S_c d_c i_c + \gamma D N_q\, S_q\, .d_q\, i_q + 0.5\gamma B' N_\gamma S_\gamma .d_\gamma .\, i_\gamma \rightarrow 0$$

Take $i_c = i_q = i_\gamma = 1$ (vertical load)

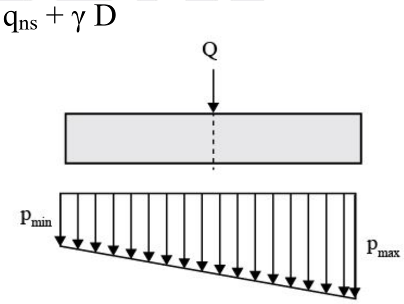
$q_u = 100 \times 5.14 \times 1.14 \times 1.27 \times 1 + 21 \times 1 \times 1 \times 1 \times 1 \times 1 = 765.16\ \text{kN/m}^2$

$q_{nu} = q_u - \gamma D$

$= 765.16 - 21 \times 1 = 744.16\ \text{kN/m}^2$

$$q_{ns} = \frac{q_{nu}}{F}$$

$q_s = q_{ns} + \gamma D$



$$= \frac{q_{nu}}{F} + \gamma D$$

$$= \left(\frac{744.16}{F} + 21 \times 1\right)$$

Taking given load 400 kN as gross load

$$p_{max} = \frac{Q}{B^2} + \frac{Q.e}{\frac{1}{6}B^3}$$

↓ Axial stress ↓ Bendingstress

$$= \frac{Q}{B^2}\left[1+\frac{6e}{B}\right]$$

$$= \frac{400}{1.5^2}\left[1+\frac{6\times 0.2}{1.5}\right] = 320 \text{ kPa}$$

For safety, $p_{max} \le q_s$

$$320 \le \frac{744.16}{F} + 21$$

$\therefore$ F = 2.49

17. Pile Foundation

01. Ans: Q_u = 134.3 kN

Sol: Given:

Diameter of bored concrete pile = 30cm

Length passes through stiff fissures = 6.50m

Depth of shrinkage & swelling =1.50m

Average undrained stress of clay = 50 kPa

below pile = 100 kPa

$\alpha = 0.3$

To find:

Ultimate load capacity = ?

$Q_u = A_b\, C\, N_c + A_s\, \alpha\, C$

$= 0.070\times100\times9+4.71\times0.3\times50$

$= 134.3$ kN

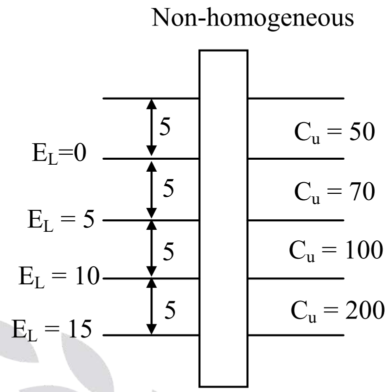
$\because A_S = \pi\, d\, l$

$= 3.14\times5\times0.3$

$= 4.71\ m^2$

02. Ans: 669 kN

Sol:



Given:

L = 20 m

ϕ = 500 mm = 0.05 m

$\alpha = 0.4$

F = 2.5

$N_c = 9$; $\phi_u = 0$

To find:

Q_{safe} = ?

$$Q_{safe} = \frac{1}{F}[A_b C N_C + A_s \alpha C]$$

At base:

$$Q_{safe} = \frac{1}{2.5}\left(\begin{array}{l}\frac{\pi}{4}\times0.5^2\times200\times9+(\pi\times0.5)\times5\times0.4\times50\\ \quad +\pi\times0.5\times5\times0.4\times70\\ \quad +\pi\times0.5\times5\times0.4\times100\\ \quad +\pi\times0.5\times5\times0.4\times200]\end{array}\right)$$

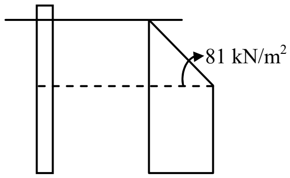
$= (353.25+1318)$

$q_u = 1672.26$

$$q_s = \frac{q_u}{F} = \frac{1672.05}{2.5} = 669 \text{ kN}$$

03. Ans: 813.41 kN

Sol:



Critical depth = 15 × diameter

= 15 × 0.3 = 4.5 m

Effective vertical pressure $\sigma_v' = 4.5\times18$

= 81 kN/m²

∴ $Q_u = A_b f_b + A_s f_s$

$$= \frac{\pi}{4}\times d^2\times\sigma_v'\times N_q + A_s.\sigma_v k\tan\delta$$

$$= \frac{\pi}{4}\times0.3^2\times81\times137 + 2\times\tan40\left(\frac{1}{2}\times81\times4.5+81\times7.5\right)$$

$$\pi\times0.3$$

= 784.40 + 1249.12

Q_u = 2033.52

∴ safe load capacity $= \frac{Q_u}{F} = \frac{2033.52}{2.5}$

= 813.40 kN

04. Ans: (Q_g = 27390.6 kN)

Sol: Given:

n = 25 L = 12 – 2 = 10 m

Dia = 0.5 m S = 1 m c/c

C = 180 kPa C_{avg} = 110 kPa

α = 0.45

$B_0 = L_0 = 4S + d$

= 4.5 m

$$Q_{gi} = n[\frac{\pi}{4}(0.5)^2\times180\times9$$
$$+\pi\times0.5\times10\times0.45\times100]$$

= 27390.76 kN

$Q_{gb} = (4.5)^2 \times 9 \times 180 + 4 \times 4.5\times 10 \times 110$

= 52605 kN

Q_g = 27390.6 kN

$\left(\begin{array}{l}\text{take minimum of two}\\ \text{i.e., } Q_{gi}\ \&\ Q_{gb}\end{array}\right)$

05. Ans: S = 2.18d

Sol: Given:

n = 16 pile group

α = 0.6

$$Q_{gi} = n\left[\frac{\pi}{4}d^2\times C\times9+\pi d\times L\times0.6C\right]$$

(neglect end bearing)

= n [πdL × 0.6 C]

Q_{gb} = 4(3S + d) × L × C

For optimum spacing

$Q_{gi} = Q_{gb}$ (η_g = 100%)

16[πdl × 0.6C] = 4(3S + d) × L × C

4πd × 0.6 = 3S + d

6.54 d = 3 S

S = 2.18 d

06. Ans. 635 kN

Sol: λ Method:

$Q_u = A_b \times C \times N_c + A_s\lambda \times \left[\sigma'_{va} + 2c\right]$

λ = constant = 0.15,

Dia = 0.4 m, $\gamma = 18\ kN/m^3$, F.O.S = 3

Depth (H) = 25 m, $N_c = 9$ for pile in clay

$\sigma'_{va} =$ Average effective vertical pressure along the pile length

$$\sigma'_{va} = \frac{0+\gamma H}{2} = \frac{0+18\times 25}{2}$$

= 225 kPa

$$Q_u = \frac{\pi}{4}\left(0.4^2\right) \times 80 \times 9 + \pi \times 0.4 \times 25 \times 0.15 \times (225 + 2 \times 80)$$

= 1904.74 kN

Safe load (or) Allowable load

$$Q_{safe} = \frac{Q_u}{F.O.S} = \frac{1904.74}{3}$$

= 635 kN

07. Ans: 68.25%; 6825 kN

Sol: Engineering News formula for Drop Hammer:

It is based on the assumption that kinetic energy delivered by the hammer during driving operation is equal to work done on the pile.

According to Engineering New's formula,

$$Q_s = \frac{W.h.\eta_h}{F(S+C)}$$

Where,

Q_S =Safe Pile capacity

W = Weight of hammer

h = height of drop

η_h = Efficiency of pile hammer

S = penetration of pile per hammer blow

C = constant

For drop hammer, C = 2.54 cm, for steam hammer C = 0.254 cm

Factor of safety = 6

Applications:

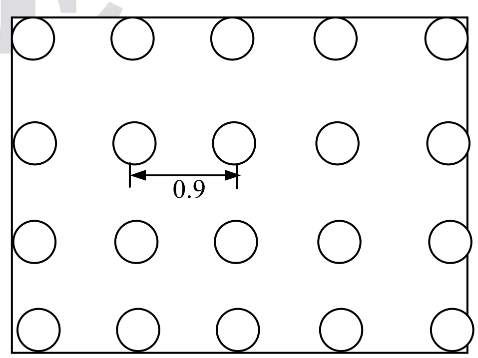
- This formula is more applicable to piles driven into cohesionless soil.
- If the pile is driven into saturated loose sand and silt, liquefaction might result, reducing the pile capacity. So it is not applicable to saturated loose sand.

4 × 5 pile group

Diameter of each pile = 0.3 m

C/C spacing = 0.9 m

capacity of a single pile = 500 kN



According to converse Labarre formula:

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$$\eta_g = 1 - \frac{\theta}{90}\left[\frac{(n-1)m + (m-1)n}{mn}\right].$$

m → no. of rows of piles = 4

n → no.of piles in each row= 5

$$\theta = \tan^{-1}\left(\frac{d}{s}\right) = 18.43$$

$$\eta_g = 1 - \frac{18.43}{90}\left[\frac{(5-1)4 + 5(4-1)}{4\times 5}\right]$$

$$= 1 - \frac{18.43}{90}\left[\frac{16+15}{20}\right]$$

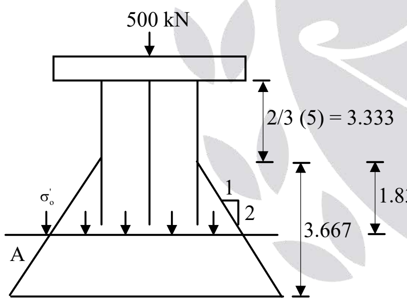
η_g = 68.25 **%**

Capacity of free standing pile group

$$= \eta_g \times Q_{gi} \times n = 0.6825 \times 500 \times 20 = 6825\ \text{kN}$$

08. Ans: 15 mm

Sol:



σ'_O at point A

= (3.333 + 1.8335) (20 – 9.81)

= 52.6466 kN/m^2

Cross-section area at A = $(1.2 + 1.8335)^2$

= 9.202 m^2

$$\Delta\sigma = \frac{500}{9.202} = 54.33\ \text{kN/m}^2$$

∴ Settlement of clay layer

$$S_f = C_c\left(\frac{H}{1+e_o}\right)\log\left(\frac{\sigma'_f}{\sigma'_o}\right)$$

$$= 0.027\left(\frac{3.667}{1+1.05}\right)\log\left(\frac{54.33+52.64}{52.64}\right)$$

= 14.8 mm ≃ 15 mm

Assignment Solutions

01. Ans: (c)

Sol: Load carring capacity q = $f_s A_s$

q = αC πDL

= 0.7 × 4 × π × 0.3 × 10

= 26.389 t

$$\text{Safe load} = \frac{q}{F} = \frac{26.389}{2.5} = 10.55\ \text{t}$$

05. Ans: (c)

Sol: $Q_g = (n.\ Q_i).\ \eta_g$

= 9 × 200 × 0.8 = 1440 kN

07. Ans: 251.8 kN

Sol: $$Q = \frac{Wh\eta_h\eta_b}{F\left(S + \frac{C}{2}\right)}$$

$$= \frac{3500\times 0.8\times 0.476}{4\left(\frac{2.54}{6} + 9\right)}$$

= 251.8 kN

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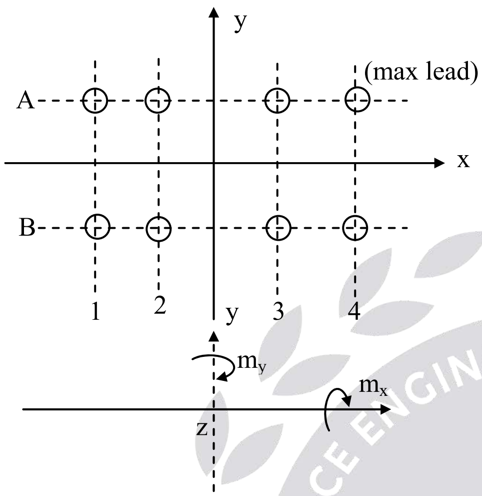
Conventional Practice Solutions

01.

Sol:



$M_y = \sum M_1 = 360$ kN.m

$M_x = \sum M_2 = 140$ kN.m

At any pile, the load induced,

$$P = \frac{\sum V}{N} \pm \frac{M_x . y}{\sum y^2} \pm \frac{M_y . x}{\sum x^2}$$

$\sum y^2 = 8 \times 0.3^2 = 0.72\ m^2$

$\sum x^2 = 4\times 0.675^2 + 4\times 0.225^2$

$= 1.8225 + 0.2025$

$\sum x^2 = 2.025\ m^2$

Load on pile member : A1, A2, A3, A4

$$P_{A_1} = \frac{800}{8} + \frac{140}{0.72}\times 0.3 - \frac{360}{2.025}\times 0.675$$

$P_{A_1} = 38.33\,kN$

$$P_{A_2} = \frac{800}{8} + \frac{140}{0.72}\times 0.3 - \frac{360}{2.025}\times 0.225$$

$P_{A2} = 118.33$ kN

$$P_{A_3} = \frac{800}{8} + \frac{140}{0.72}\times 0.3 + \frac{360}{2.025}\times 0.225$$

$P_{A_3} = 198.33$ kN

$$P_{A_4} = \frac{800}{8} + \frac{140}{0.72}\times 0.3 + \frac{360}{2.025}\times 0.675$$

$P_{A4} = 278.33$ kN

Load on pile B_1:

$$P_{B_1} = \frac{800}{8} - \frac{140}{0.72}\times 0.3 - \frac{360}{2.025}\times 0.675$$

$P_{B_1} = -78.33\,kN(\text{tensile})$

Load on pile B_2:

$$P_{B_2} = \frac{800}{8} - \frac{140}{0.72}\times 0.3 - \frac{360}{2.025}\times 0.225$$

$P_{B_2} = 1.67$ kN

Load on pile B_3:

$$P_{B_3} = \frac{800}{8} - \frac{140}{0.72}\times 0.3 + \frac{360}{2.025}\times 0.225$$

$P_{B_3} = 81.67\,kN$

Load on pile B_4:

$$P_{B4} = \frac{800}{8} - \frac{140}{0.72}\times 0.3 + \frac{360}{2.025}\times 0.2675$$

$P_{B4} = 161.67$ kN

02.

Sol: Given safe load = 200 kN

Design load = safe load × FOS

= 200 × 4

= 800 kN

Design load = Frictional resistance + Bearing

⇒ 800 = FR + 0.2 × 800

⇒ FR = 640 kN

∴ Frictional resistance = $\pi D L S_f$ = 640 kN

$$\Rightarrow L = \frac{640}{\pi D S_f} = \frac{640}{\pi \times 0.3 \times 50}$$

⇒ L = 13.6 m

03.

Sol: Given pile weight, P = 30 kN

Coefficient of restitution, e = 0.25

Weight of drop hammer, w = 40 kN

Height of drop = 0.8 m = 80 cm

Total temporary elastic compression,

c = 1.8 cm

Average set per blow, S = 1.4 cm

P.e = 30 × 0.25 = 7.5 < 40

⇒ w > Pe

$$\therefore \text{Efficiency of blow, } \eta_b = \frac{w + P.e^2}{w + P}$$

$$= \frac{40 + 30 \times 0.25^2}{40 + 30}$$

= 0.598

Assuming efficiency of hammer, $\eta_h = 1$

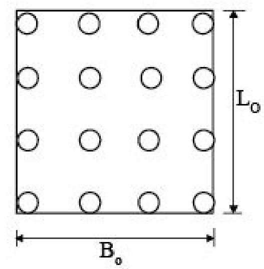
For ultimate bearing capacity, F.O.S = 1

$$Q_s = \frac{wh\eta_h\eta_b}{F\left(S + \frac{C}{2}\right)}$$

$$= \frac{40 \times 80 \times 1 \times 0.598}{1 \times \left(1.4 + \frac{1.8}{2}\right)} = 832 \text{ kN}$$

04.

Sol:



$B_o = L_o = 3s + D = 3 \times 75 + 25 = 250$ cm

= 2.5 m

$$C = \frac{1}{2} \times 36 = 18 \text{ kPa}$$

(i) Negative skin friction based on individual pile failure mode

$F_{ngi} = h.\ F_n$

$= 16 \times \pi\ D L_c\ \alpha C$

$= 16 \times \pi \times 0.25 \times 3 \times 1 \times 18$

= 678.58 kN

(ii) Negative skin friction based on block failure mode

$F_{ngb} = p_g.\ L_c\ .C + A_g\ .\ L_c\ .\ \gamma$

$= 4B_o\ L_c.\ C + B_o^2 \times L_c.\ \gamma$

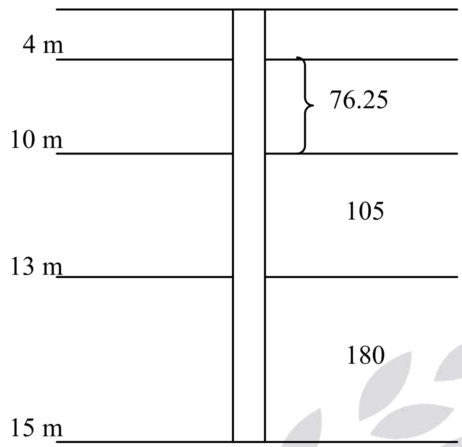
$= 4 \times 2.5 \times 3 \times 18 + 2.5^2 \times 3 \times 15$

= 821.25 kN

∴ Negative skin friction = higher of Fngi & Fngb = 821.25 kN

05.

Sol:



Avg. 'C' from 4 to 10 m $= \dfrac{60+74+81+90}{4}$

$= 76.25$ kN/m^2

If $\phi_u = 0$, $S_u = C_u$

Ultimate load capacity based on end bearing and the skin friction from 4 to 15 m

$Q_u = A_p\, C_p\, N_c + \Sigma A_s\, \alpha C$

$$= \frac{\pi}{4}\times 0.5^2 \times 180\times 9 + \pi\times 0.5\times 6\times 0.45\times 76.25$$

$$+\, \pi\times 0.5\times 3\times 0.45\times 105 + \pi\times 0.5\times 2\times 0.45\times 180$$

= 1118 kN

Negative skin friction for 4 m depth

$F_n = \pi.D.L_c.\ \alpha\ C$

$= \pi \times 0.5 \times 4 \times 0.45 \times 40$

= 113.09 kN

$$Q_{safe} = \frac{Q_u}{F} - F_n$$

$$= \frac{1118}{2.5} - 113.09$$

= 334.11 kN

18. Soil Exploration

02. Ans: (c)

Sol: $N = 6 + 6 + 8 + 7 = 27$

$N' = C_N N = 1 \times 27 = 27$

$$N'' = 15 + \left(\frac{N'-15}{2}\right) = 21$$

03. Ans: 14

Sol: Corrected value $N' = C_N N$

C_N=correction factor for over burden pressure

$$C_N = 0.77\log_{10}\left(\frac{1905}{\sigma_o'}\right)$$

$$\sigma_o' = 2\times 18 + (18-9.81)\times 3$$

$= 60.57$ kN/m^2

$$C_N = 0.77\log_{10}\left(\frac{1905}{60.57}\right) = 1.153$$

$N' = 1.153 \times 12 = 13.8 \simeq 14$

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19. Sheet Piles

01. Ans: 98.7 kN

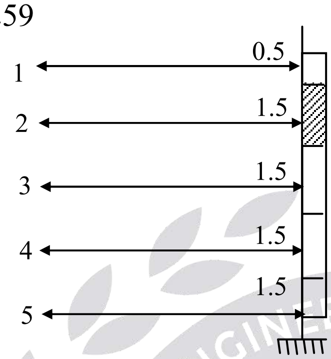
Sol: $k_a = \dfrac{1-\sin\phi}{1+\sin\phi} = 0.259$

$\gamma = 20\ \text{kN/m}^3$

$H = 6.5\ \text{m}$

$\phi = 36°$

$C = 0$



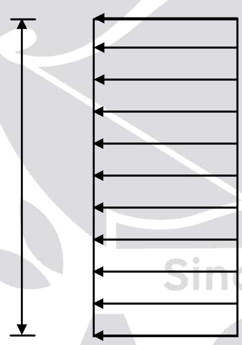
$P' = 0.65\ K_a H\gamma$

$P' = 21.93\ \text{kN/m}^2$

Total pressure acting P = 21.93 kN/m^2 × Height × Width

$P = 21.93 \times 6.5 \times 3$

$P = 427.7\ \text{kN}$



$P' = 0.65\ K_a H\gamma$

The average load taken by the strut

$$= \frac{427.7}{5} = 85.55\ \text{kN}$$

But in the problem they asked maximum load taken by the strut

struts (1) (2) (3) (4) are taken maximum loads, (5) struts are taken minimum load.

Strut (2) taken load = 1.5×3×P′

= 1.5×3×21.93 kN

= 98.68 kN