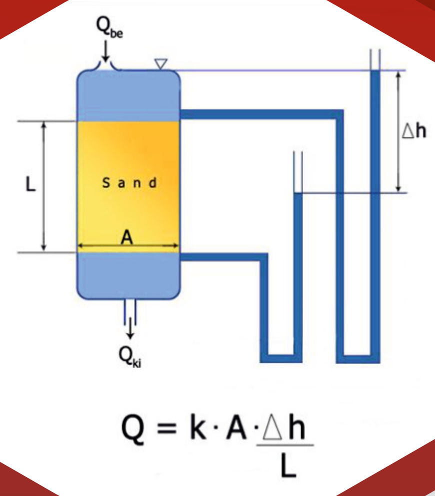
GATE | PSUs

CIVIL ENGINEERING

Geotechnical Engineering

Text Book : Theory with worked out Examples and Practice Questions



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7 Geotechnical Engineering

(Solutions for Text Book 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, $e = \frac{V_v}{V_s}$

$V_s = V_v$

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

$1.5\ V_s = V_v$

$1.5\ V_s = 1 - V_s$

$2.5\ V_s = 1$

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

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, $n = \frac{V_v}{V} = \frac{0.1}{1} = 0.1$

02. Ans: (a)

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

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

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

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

$0.5\,W_{solids_1} = W_w$

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 $= \frac{W_w}{W_s} = \frac{2-1.223}{1.223}$

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

06. Ans: (c)

Sol: $\gamma_1 = 1.66$;

$w_1 = 8\%$

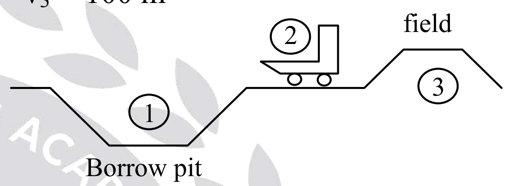
$\gamma_2 = 1.15$

$w_2 = 6\%$

$\gamma_3 = 1.82$

$w_3 = 14\%$

$v_3 = 100\ m^3$



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

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

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

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

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

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

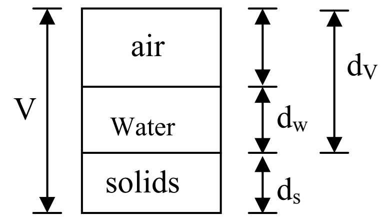
$V_1 = 104.3\ m^3$

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

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

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

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

$e \times S_r = w\,G$

$\therefore e = 0.44$ G

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

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

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

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

$\therefore G = 2.07$

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: 11.87%

Sol: To find initial porosity

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

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

$e = 0.637$

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

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

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

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:

$$\text{Water content, } w = \frac{W_w}{W_s}$$

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

$W_s = 1.3636$ 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

$V_s + V_v = V$

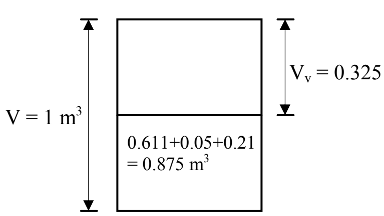
$V_v = V - V_s$

$= 1.2 - 0.875$

$= 0.325$

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

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



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: (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 =?

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

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

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

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

G = 2.90

03. 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 04, 05 & 06

04. 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 = ?

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

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

$w_s = 17.7\%$

05. Ans: (c)

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

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

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

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

$G = 2.65$

06. 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:

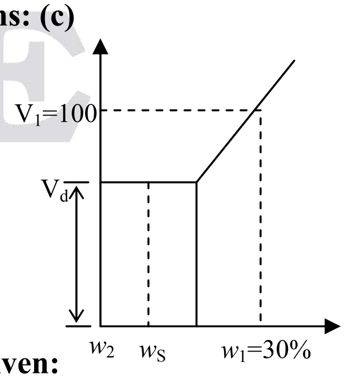
$e_2 = w_s G$

$= 0.17 \times 2.65$

$= 0.47$

07. 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

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

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

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

08. 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

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

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

$e_2 = 0.657$

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

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

$w_3 = 0.254 = 25.4\%$

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: 9%

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 $C_c = 2$

$\therefore$ 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

$\therefore$ Soil is GW-GM

03. Ans: (GM)

Sol: Fine fraction = 45%

Coarse fraction = 100 – 45 = 55%

$\therefore$ 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)

$\therefore$ % retaining on 4.75 mm sieve out of coarse fraction

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

(out of coarse fraction)

$\therefore$ 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)

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 = 0.09×10^{-2} m/sec

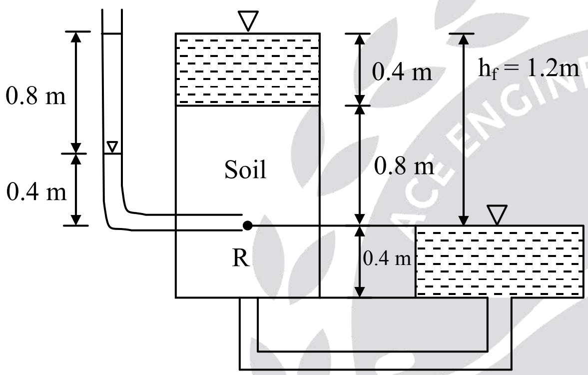
$$\frac{Q}{1m} = ki\frac{A}{1}$$

$$= \frac{0.09\times10^{-2}\times0.075\times2\times1}{1m}$$

$= 1.35 \times 10^{-4}$ m^3/sec/m

Common data for Questions.Q03 & Q04

03. Ans: (a)



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

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

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 ×1 = k

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

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

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

$Q = 1.05 \times 10^{-5}$ m^3/sec

Q = kiA

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

$k_{at\,25°C} = 1.83\times10^{-3}$ m/sec = 0.183 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%
$e = \frac{n}{n-1}$	$e_2 = \frac{0.35}{0.65} = 0.5384$
$v_1 = 0.9v_{20°C}$	$v_{20°C}$ ∴

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

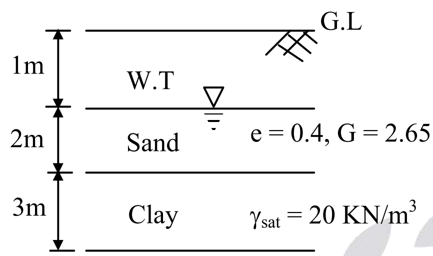
$$= \frac{0.5384^3}{1.5384}\times\frac{1.667}{0.667^3}\times0.9$$

k_2 = 0.094 cm/sec

07. Effective Stress

01. 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 =?

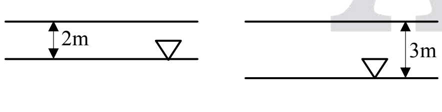
$\sigma' = \sigma - u$

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

$= 72.49\ kN/m^2$

02. Ans: (d)

Sol:



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

03. Ans: (b)

Sol: σ' at 9m depth below G.L = ?

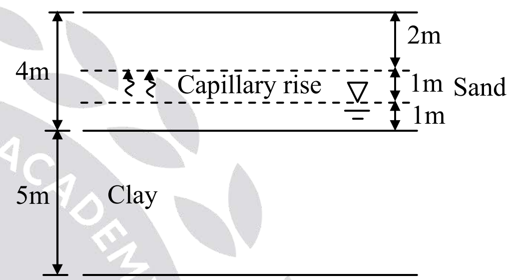
$\sigma' = \sigma - u$

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

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

04. Ans: (a)

Sol:



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

Effective stress after capillary rise at 9m = σ'

$\sigma' = \sigma - u$

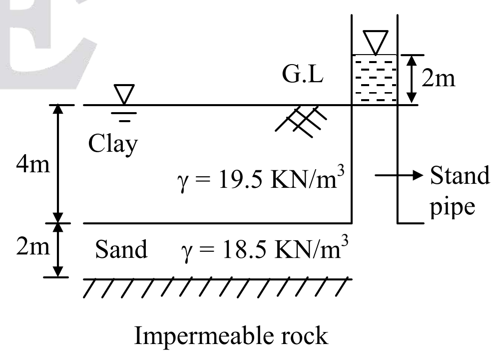
$= (2\times17)+(2\times20)+(18\times5) - 6\times9.81$

$\sigma' = 105.14$

Increase in effective stress = 105.14 – 102.14

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

Common Data for Questions Q 05 & Q 06



05. Ans: (d)

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

$\gamma_w = 10 \text{ kN/m}^2$

$\sigma' = \sigma - u$

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

$\sigma' = 35 \text{ kN/m}^2$

06. 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

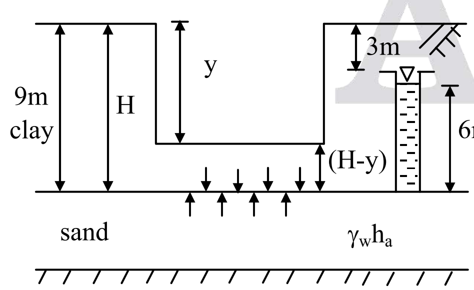
$\therefore$ Effective stress increases by 10 kN/m^2

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

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

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

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

$y = 6$ m

$\therefore$Maximum depth of trench will be excavated without failure is 6 m.

02. Ans: (c)

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

$$h_a = \frac{20\times2}{10} = 4\,\text{m}$$

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

03. Ans: 35

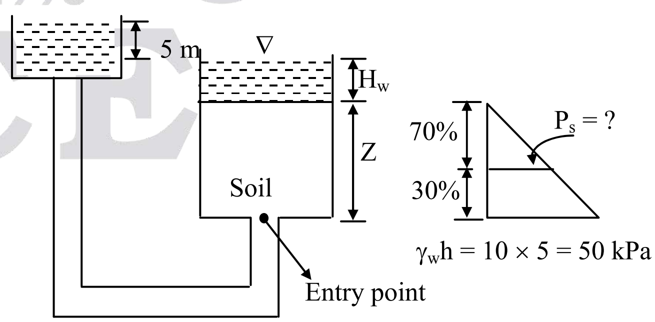
Sol: Given

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



For 100% $\rightarrow$ 50 kPa

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

04. Ans: 1.91 m

Sol:

Depth of soil layer = 1200 mm

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

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

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

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

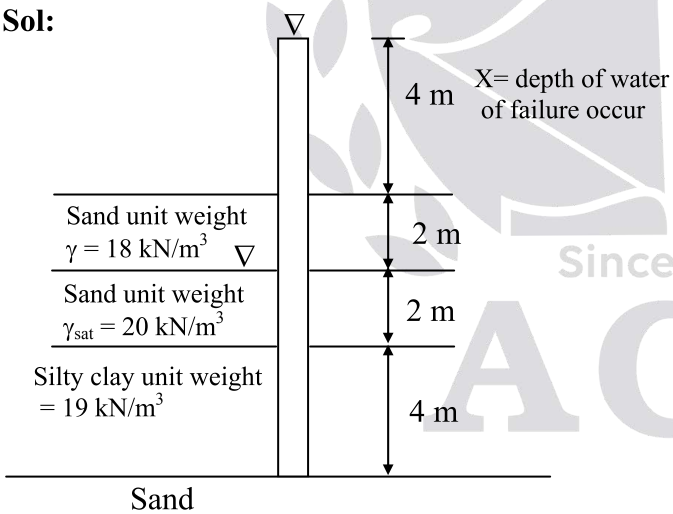
$$z = 3.1168 \text{ m}$$

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/m³

Sol:

$$V_s = \frac{V}{n}$$

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

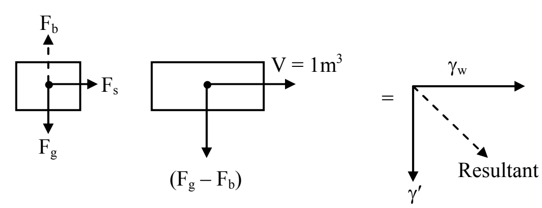
$V = k.i$

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

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

$h_B = 2.2$ m

$i = 0.2$



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

07. Ans: (d)

Sol:

Total stress at point A

= 0.7 × 9.81 + 20.6 × 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

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

= 27.467 – 9.81 × 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 × 0.75

= 7.3575 kN/m^3

09. Seepage Analysis

01. Ans: 0.0086

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

Q = ki

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

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

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

= 0.0086 m^3/day

02. 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

03. 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 $= \frac{3.4}{6} = 0.566\,\text{m}$

∴ 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

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

$N_f = 1, \quad N_d = 6$

$$q = 4\times10^{-3}\times10^{-2}\times3.4\times\frac{1}{6}$$

$$= 2.266\times10^{-5}\ \text{m}^3/\text{sec/m}$$

04. Ans: (a)

Sol:

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

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

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

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

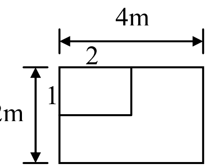
$$i_{exit} = \frac{0.525}{1.65} = 0.3181$$

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

10. Stress Distribution

01. Ans: (b)

Sol:



At centre:

$\sigma_Z = I\,q$

$Z = 5$ m

To Calculate I:

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

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

m = 0.4n = 0.2

From Table, I = 0.0328

$$\left.\begin{aligned}\sigma_Z &= 0.0328\times8\\ &= 0.2624\end{aligned}\right\}\text{At corner of } 1\times2 \text{ rectangle}$$

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

At corner:

From given table, I = 0.0931

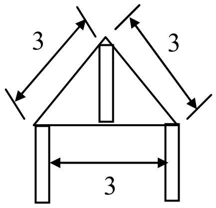
$$m = \frac{4}{5} = 0.8$$

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

σ_Z = 0.0931 × 8 = 0.744 t/m^2

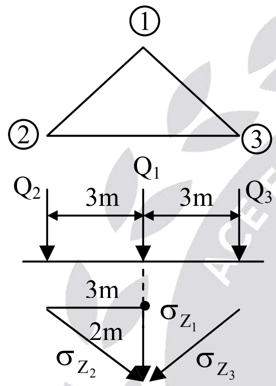
02. Ans: (d)

Sol:



Total load = 200t

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



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

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

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

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

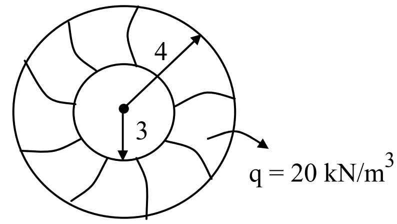
$\sigma_{Z_2} = 0.417\ t/m^2 = \sigma_{Z_3}$

$\sigma_Z = 7.95 + 0.417 + 0.417$

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

03. Ans: (c)

Sol:



σ_Z at centre =?

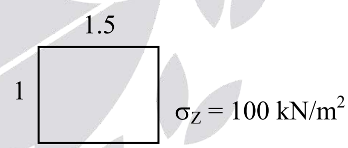
Z = 10 m

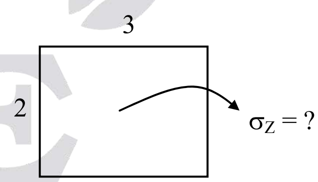
$$\sigma_Z = 20\left[1-\left(\frac{1}{1+\left(\frac{4}{10}\right)^2}\right)^{3/2}\right] - 20\left[1-\left(\frac{1}{1+\left(\frac{3}{10}\right)^2}\right)^{3/2}\right]$$

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

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

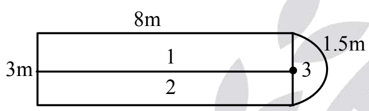
$$\sigma = q\left[1-\left(\frac{1}{1+(r/z)^2}\right)^{3/2}\right]$$

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

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

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

$$= 200\left[1-\left(\frac{1}{1+\left(\frac{1.5}{3}\right)^2}\right)^{3/2}\right] = 56.89 \text{ KPa}$$

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

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

$C_v = 6 \times 10^{-3}$ cm²/s

S_f =?, t_{90} = ?

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

$$= \frac{6\times10^{-3}\times 2\times 365\times 24\times 60\times 60}{800^2} = 0.5913$$

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%

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

$$\Rightarrow 81.16 = \frac{120}{s_f} \times 100$$

s_f = 147.86 mm

(b)

$$T_v = 1.781 - 0.953\log_{10}(100 - 90\%)$$
$$= 0.848$$
$$T_v = \frac{C_v t}{d^2} \Rightarrow 0.848 = \frac{6\times10^{-3}\times t}{120^2}$$
$$\Rightarrow t = 2.86 \text{ years}$$

02. Ans: (a)

Sol: $\Delta H_1 = 1$ cm,

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

$\Delta H_2 = ?$

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

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

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

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

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

$\Delta H = 80$ mm ; $t_1 = 4$ yrs

= 60% (less than)

$t_2 = 9$ yrs

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

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

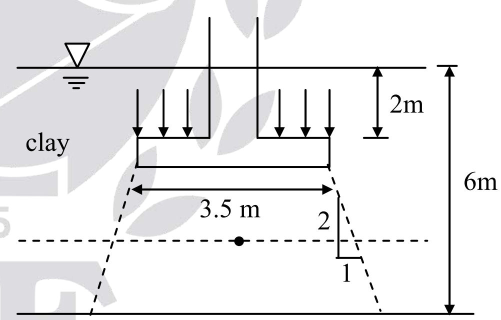
$$\Rightarrow t \propto U^2 \Rightarrow t \propto s^2$$

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

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

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

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

$t_1 = 15$ 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: $d_1 = \frac{20}{2} = 10$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,

$S_f = 360$

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

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

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

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

$\sigma' = 146$ kPa

13. Ans: 422.7 mm

Sol:

Preliminary analysis	**Detailed investigation**
H_1	$H_2 = 1.2H_1$
$\Delta\sigma'_1 = 24$KPa	$\Delta\sigma'_2 = \Delta\sigma' + 1\times\gamma_w$ = 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

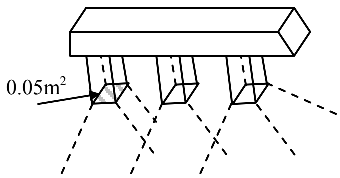
$\dfrac{s_{f_1}}{s_{f_2}} = \dfrac{H_1\Delta\sigma'}{H_2\Delta\sigma'}$

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

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

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

13. Shear Strength

01. Ans: (a)

Sol: Direct stress, σ_1 = 5 Kg/cm^2

All round stress, σ_3 = 3.2 Kg/cm^2

Shear on failure plane, τ_f = 0.9

ϕ = ?

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

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

Another method:

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

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

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

$$1 = \cos\phi$$

$$\phi = 0$$

Common data for Questions 02 & 03

02 & 03 Ans: (c) & (b)

Sol: Given:

Unconfined compressive test (ϕ = 0)

q_u = 1.2 kg/cm^2

α_f = 50

Cohesion of soil =?

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

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

$\because\ \alpha_f = 50$

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

$5 \times 2 = \phi$

$\phi = 10°$

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

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

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

$C_u = 0.5\ kg/cm^2$

04. 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'

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

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

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

$\phi = 22^o$

05. 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

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

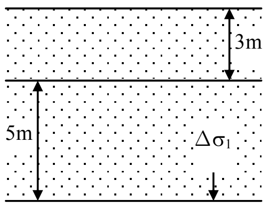
$\Delta u_d = AB\ \Delta\sigma_d$

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

$\Rightarrow A = -0.228$

06. 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

14. Earth Pressure

01. Ans: 316.7 kN

Sol: Given:

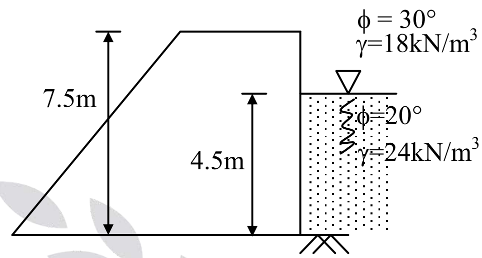


Fig. (1)

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

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

$\therefore$ at 3 m below, $\sigma_v = 18 \times 3 = 54$ kN/m^2

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

$\therefore$ 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

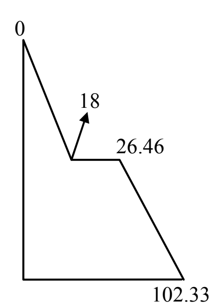
$$P_{a_2} = 0.49(117) + 10 \times 4.5$$

$= 102.33$ kN/m^2

Total active thrust

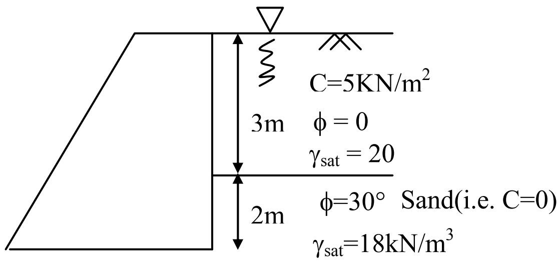
$$= \frac{1}{2} \times 18 \times 3 + \left(\frac{26.46 + 102.33}{2}\right)4.5$$

$= 316.77$ 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 $\sigma'_v = 0$

$\sigma_h = K_a(0)$

$\sigma_h = 0$

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

b) **At 3 m depth:**

a) **Just above:**

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

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

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

$= 50$ 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:**

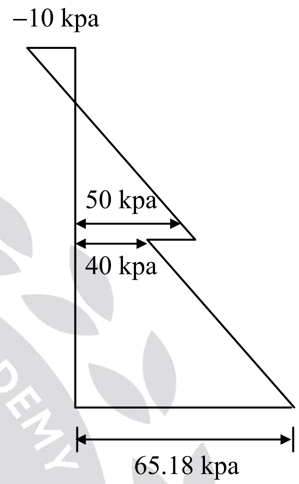
$\sigma'_v = 3\gamma' + 2\gamma'$

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

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

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

$= 65.18$ kPa



To compute force:

$F = P_a \times A$

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

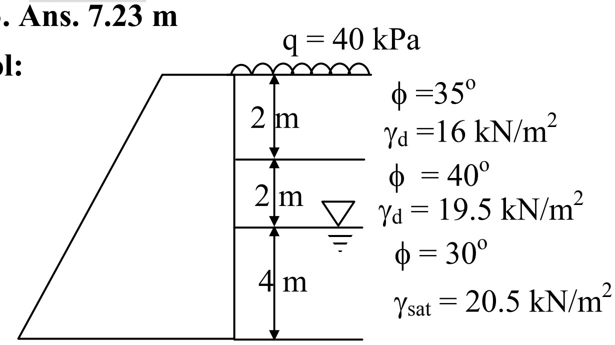
$F = P_a$ = area of +ve portion of diagram

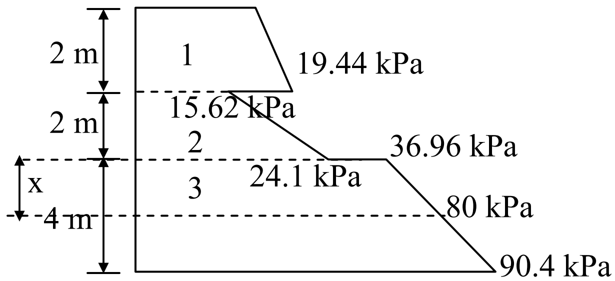
$= \left(\frac{1}{2} \times 50 \times 2.5\right) + \frac{1}{2}(40 + 65.4) \times 2$

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

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

$= 111 + 10.69\ x$ (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

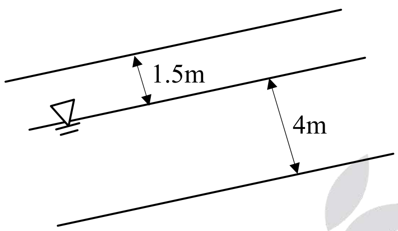
From top $= 2 + 2 + x = 7.23$ m

14. Stability of Slopes

01.

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

$i = 28°$, $\gamma_w = 9.8$ kN/m^3



Against translational failure,

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

$$= \frac{0 + (r1.5 + (4-1.5)r')\tan\phi\cos^2 i}{(r1.5 + (4.15)r')\cos i\sin i}$$

$$= \frac{(19\times1.5 + 2.5\times(19-9.8))\tan 35\cos^2 28}{(19\times1.5 + 2.5\times19)\cos 28\sin 28}$$

= 0.89

02. Ans: 4.77

Sol:

Infinite slope, seepage parallel to slope

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

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

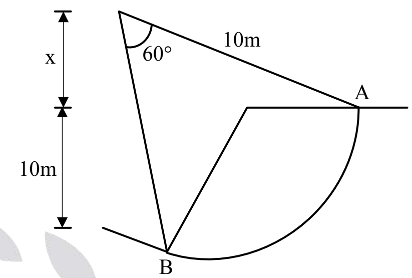
$H_c = 4.77$

03. Ans: 1.184, 2.66

Sol:

C = 50 kN/m^2

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



$N = \sigma' l.1$

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

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

$$F = \frac{C.\hat{L} + \Sigma N\tan\phi}{\Sigma T} = \frac{C.\hat{L} + N\tan\phi}{T}$$

$$F = \frac{50\times10.47 + 255(10.47)\tan 10}{840}$$

= 1.1836

w.r. to height

$$H_C = \frac{4C}{\gamma\sqrt{k_a}}$$

$$= \frac{4C}{\gamma}\tan\left[45 + \frac{\phi}{2}\right] = \frac{4\times50}{18}\tan 50 = 13.24\,m$$

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_ϕ = 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

$$F_S = \frac{\tan\phi}{\tan\phi_m} \Rightarrow 1.5 = \frac{\tan 15^\circ}{\tan\phi_m}$$

$$\tan\phi_m = \frac{\tan 15^\circ}{1.5}$$

ϕ_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 ; ϕ = 15°

γ_{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_ϕ = 2.89

Sol: Given:

Embankment is to be made of a soil

Shear parameters of soil:

C' = 30 KN/m^2 ; ϕ' = 15°

To find F_ϕ if $F_C = 1$

$$S_m = \frac{C'}{F_C} + \frac{\sigma' \tan\phi}{F_\phi} \;;\; (\phi' = 15')$$

$$39.25 = \frac{30}{1} + \frac{100 \times \tan 15}{F_\phi}$$

$$F_\phi = 2.89$$

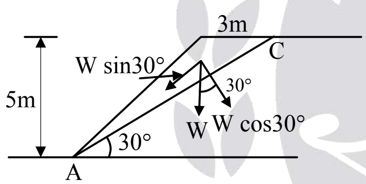
To find F_C if $F_\phi = 1$

$$S_m = \frac{C'}{F_C} + \frac{\sigma' \tan\phi'}{F_\phi}$$

$$39.25 = \frac{30}{F_C} + \frac{26.79}{1} \Rightarrow F_C = 2.40$$

07.

Sol:



Area of wedge:

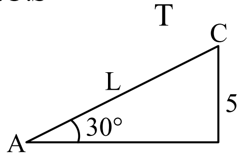
$$a = \frac{1}{2} \times b \times H = \frac{1}{2} \times 3 \times 5 = 7.5\,m^2$$

$W = a \times 1 \times \gamma$

$N = w \cos 30°$

$T = w \sin 30°$

$$F.O.S = \frac{C.L + N \tan\phi}{T}$$



$$\sin 30° = \frac{5}{L};\; L = \frac{5}{\sin 30°} = 10$$

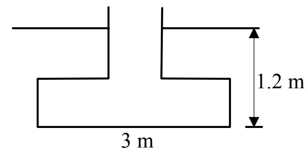
$\therefore$ F = 4.63

16. Bearing Capacity of Soil

01. Ans: 2.54, 2.03

Sol:

(a)



Net ultimate bearing capacity

$q_{nu} = CN_c + (N_q - 1)\,\gamma_D + 0.4\,\gamma B N_\gamma$

$C = 0,\ N_q = 22,\ N_\gamma = 20$

$q_{nu} = 21 \times 17 \times 1.2 + 0.4 \times 17 \times 3 \times 20$

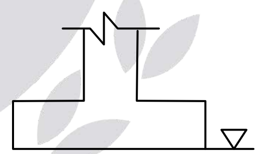
$= 836.4$ KPa

Safe bearing capacity $q_s = \dfrac{q_{nu}}{F} + \gamma_D$

$$350 = \frac{836.4}{F} + 17 \times 1.2$$

F = 2.54

(b)



$q_{nu} = (N_q - 1)\gamma D + 0.4\,\gamma' B N_\gamma$

$= 21 \times 17 \times 1.2 + 0.4\,(20 - 9.81)\,3 \times 20$

$= 672.96$

Safe bearing capacity

$$q_s = \frac{q_{nu}}{F} + \gamma D$$

$$350 = \frac{672.96}{F} + 17 \times 1.2$$

F = 2.04

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:

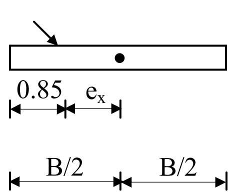
Sol: q_n =?

Q = P cos 30

$B' = B - 2e_x = 1.7$ m

$L' = L - 2e_y = 2$ m

$A' = B'L' = 3.4\ m^2$



$$e_x = \frac{B}{2} - 0.85 = 1 - 0.85 = 0.15\ m$$

$e_y = 0$

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

$$q_{ns} = \frac{q_{nu}}{F} = \frac{390.78}{3} = 130.26\,kPa$$

Net sate load

$Q_{na} = A'q_{ns} = 3.4 \times 130.26 = 442.88$ kN

04. Ans:

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

$$q_g = \frac{Q_s}{A} = \frac{2060.1}{1.5^2}\ kN/m^2$$

= 915.6 kPa

$$q_s = \frac{q_n - \gamma D_f}{F} + \gamma D_f$$

$$q_s = \frac{1.3N_c + \gamma D_f (N_q - 1) + 0.4\gamma B N_r}{F} + \gamma D_f$$

$915.6 = q_s$

$$= \frac{0 + 20.6 \times D_f \times (22-1) + 0.4 \times 20.60 \times 2.5 \times 20}{3} + 20.6 \times 17$$

equate $q_g = q_s$

$D_f = 5.01$ m

05. Ans: 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; γ_{clay} = 19 kN/m^3

For safety $q_n \le q_{na}$

Where, q_{na} →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

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 = ?

$Q_u = A_b\, C\, N_c + A_s\, \alpha\, C$

$= 0.070\times100\times9+4.71\times0.3\times50$

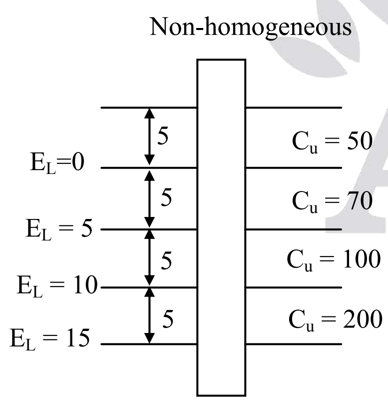
$= 134.3$ kN

$\because A_S = \pi\, d\, l$

$= 3.14\times5\times0.3 = 4.71\ m^2$

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:

$$Q_{safe} = \frac{1}{2.5}\left(\begin{array}{l}\frac{\pi}{4}\times0.5^2\times200\times9+(\pi\times0.5)\times5\times0.4\times50\\ +\pi\times0.5\times5\times0.4\times70\\ +\pi\times0.5\times5\times0.4\times100\\ +\pi\times0.5\times5\times0.4\times200]\end{array}\right)$$

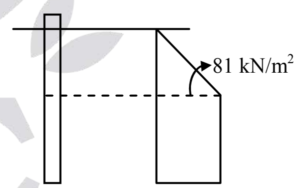
$= (353.25+1318)$

$q_u = 1672.26$

$$q_s = \frac{q_u}{F} = \frac{1672.05}{2.5} = 669\ \text{kN}$$

03. Ans: 813.41 kN

Sol:



Critical depth = 15 × diameter

= 15 × 0.3 = 4.5 m

Effective vertical pressure $\sigma_v' = 4.5\times18$

$= 81\ kN/m^2$

$\therefore\ Q_u = A_b f_b + A_s f_s$

$$= \frac{\pi}{4}\times d^2\times\sigma_v'\times N_q + A_s.\sigma_v k\tan\delta$$

$$= \frac{\pi}{4}\times 0.3^2 \times 81\times 137 + 2\times \tan 40\left(\frac{1}{2}\times 81\times 4.5 + 81\times 7.5\right)$$

$\pi \times 0.3$

= 784.40 + 1249.12

Q_u = 2033.52

$\therefore$ 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

$$Q_{gi} = n[\frac{\pi}{4}(0.5)^2 \times 180 \times 9 + \pi \times 0.5 \times 10 \times 0.45 \times 100]$$

= 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

$$\begin{pmatrix}\text{take minimum of two}\\ \text{i.e., } Q_{gi}\ \&\ Q_{gb}\end{pmatrix}$$

05. Ans: S = 2.18d

Sol:

Given:

n = 16 pile group

α = 0.6

$$Q_{gi} = n\left[\frac{\pi}{4}d^2 \times C \times 9 + \pi d \times L \times 0.6C\right]$$

(neglect end bearing)

$= n\,[\pi dL \times 0.6\,C]$

$Q_{gb} = 4(3S + d) \times L \times C$

For optimum spacing

$Q_{gi} = Q_{gb}$ (η_g = 100%)

$16[\pi dl \times 0.6C] = 4(3S + d) \times L \times C$

$4\pi d \times 0.6 = 3S + d$

6.54 d = 3 S

S = 2.18 d

06. Ans. 635 kN

Sol: λ Method:

$Q_u = A_b \times C \times N_c + A_s\lambda \times [\sigma'_{va} + 2c]$

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

σ'_{va} = Average effective vertical pressure along the pile length

$$\sigma'_{va} = \frac{0 + \gamma H}{2} = \frac{0 + 18 \times 25}{2}$$

= 225 kPa

$$Q_u = \frac{\pi}{4}\left(0.4^2\right) \times 80 \times 9 + \pi \times 0.4 \times 25 \times 0.15$$

$$\times (225 + 2 \times 80)$$

$$= 1904.74 \text{ kN}$$

Safe load (or) Allowable load

$$Q_{safe} = \frac{Q_u}{F.O.S} = \frac{1904.74}{3}$$

$$= 635 \text{ kN}$$

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:

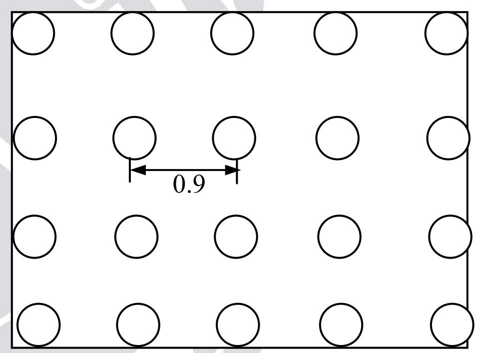
- This formula is more applicable to piles driven into cohesionless soil.
- If the pile is driven into saturated loose sand and silt, liquefaction might result, reducing the pile capacity. So it is not applicable to saturated loose sand.

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:

$$\eta_g = 1 - \frac{\theta}{90}\left[\frac{(n-1)m + (m-1)n}{mn}\right].$$

m → no. of rows of piles = 4

n → no.of piles in each row= 5

$$\theta = \tan^{-1}\left(\frac{d}{s}\right) = 18.43$$

$$\eta_g = 1 - \frac{18.43}{90}\left[\frac{(5-1)4 + 5(4-1)}{4\times 5}\right]$$

$$= 1 - \frac{18.43}{90}\left[\frac{16+15}{20}\right]$$

$\eta_g = 68.25$ **%**

Capacity of free standing pile group

$= \eta_g \times Q_{gi} \times n = 0.6825 \times 500 \times 20 = 6825\ \text{kN}$

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

$$C_N = 0.77 \log_{10}\left(\frac{1905}{\sigma_o'}\right)$$

$$\sigma_o' = 2 \times 18 + (18 - 9.81) \times 3$$

$= 60.57\ \text{kN/m}^2$

$$C_N = 0.77 \log_{10}\left(\frac{1905}{60.57}\right) = 1.153$$

$N' = 1.153 \times 12 = 13.8 \simeq 14$

19. Sheet Piles

01. Ans: 98.7 kN

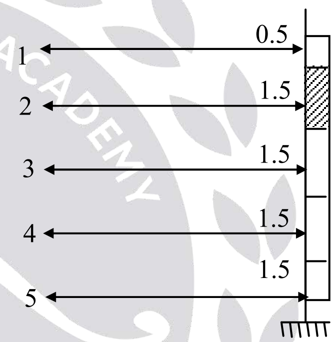
Sol: $k_a = \dfrac{1 - \sin\phi}{1 + \sin\phi} = 0.259$

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

H = 6.5 m

$\phi = 36°$

C = 0



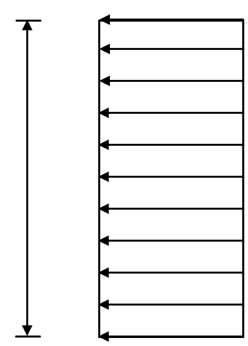
$P' = 0.65\ K_a H\gamma$

$P' = 21.93\ \text{kN/m}^2$

Total pressure acting P = 21.93 kN/m^2 × Height × Width

$P = 21.93 \times 6.5 \times 3$

P = 427.7 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 = $1.5 \times 3 \times P'$

$= 1.5 \times 3 \times 21.93$ kN

$= 98.68$ kN