Problem. (a) A 15m long 300mm dia pile was driven in a uniform sand ($\phi' = 40°$). The W.T. is at great depth. Average unit weight of soil is 19kN/m³. Calculate the safe load capacity of the pile with F.O.S. = 2.5

(b) Calculate the safe load capacity of the pile if W.T. is located at 2m below the G.L.

Solution ⇒ Ⓐ Tomlinson's / Berezantsev's Method.

$\frac{L}{D} = \frac{15m}{0.3m} = 50$, $N_q = 130$, → From figure.

$\delta = 0.75\phi = 0.75 \times 40° = 30°$, $K = 2$ || From table

(~~for~~ concrete pile in dense sand $\phi = 40°$)

Without Considering Critical length

$Q_u = \cancel{c}_c\; q_{pu} A_b + f_s A_s.$

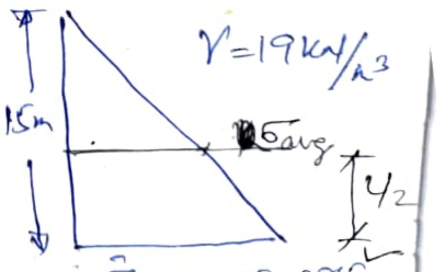
$q_{pu} = \underbrace{c N_c}_{\approx 0} + \sigma' N_q + \underbrace{\frac{1}{2}\gamma B N_\gamma}_{\approx 0} \rightarrow$ Neglected.

$c = 0$

$\Rightarrow q_{pu} = \sigma' N_q$ ✓

$= 285 \times 130$ ✓

$= 37050$ kN/m²



$\bar{\sigma} = 19 \times 15 = 285$ kN/m²

$A_b = \frac{\pi \times 0.3^2}{4} = 0.071$

$Q_{pu} = \cancel{307}\; 37050 \times 0.071 = 2631$ kN ✓

$f_s = \sigma'_{av} K \tan\delta = \frac{1}{2}(0 + 285) \times 2 \times \tan 30°$

$= 165$ kN/m²

$$Q_s = \underbrace{(\pi \times D \times L)}_{A_s} \times f_s$$

$$Q_s = \pi \times 0.3 \times 15 \times 165 = 2331.5 \text{ kN}.$$

$$Q_u = Q_{pu} + Q_f = 2631 + 2331.5 = 4962.5\text{k}$$

$$Q_{safe} = \frac{Q_u}{FOS} = \frac{4962.5}{2.5} = \underline{1985 \text{ kN}.}$$

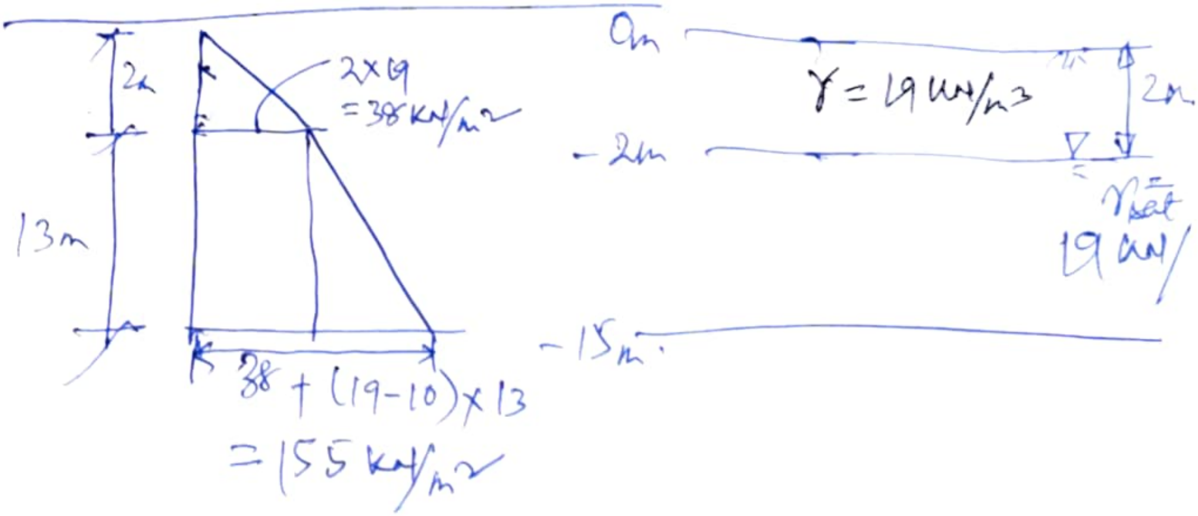
If W of pile is considered, then,

$$W = \underbrace{\left[\frac{\pi \times 0.3^2}{4} \times 15\right]}_{\text{Vol. of Conc.}} \times \overset{\gamma_{conc}}{24} = \underline{25 \text{ kN}.}$$

$$Q_u = 4962.5 - 25 \simeq 4937.5$$

$$Q_{safe} = \frac{4937.5}{2.5} = \underline{1975 \text{ kN}.}$$

(b) <u>W.T. Effect is considered.</u>



$N_q = 130$, $k = 2$, $\delta = 30^\circ$ (Remain same)

$$q_{pu} = \sigma' N_q = 155 \times 130 = \underline{20150} \text{ kN/m}^2$$

$$Q_{pu} = 20150 \times 0.071 = 1430.7 \text{ kN}$$

$$f_{s_1}\Big|_{0 \text{ to } 2m} = \sigma'_{ave}\, k \tan\delta = \frac{1}{2}(0+38) \times 2 \times \tan 30^\circ$$
$$= 22 \text{ kN/m}^2$$

$$f_{s_2}\Big|_{2 \text{ to } 15m} = \frac{1}{2}(38+155) \times 2 \times \tan 30^\circ$$
$$= 111 \text{ kN/m}^2$$

$$Q_s = f_{s_1} \times A_{s_1} + f_{s_2} \times A_{s_2}$$
$$= 22 \times \pi \times 0.3 \times 2 + 111 \times \pi \times 0.3 \times 13$$
$$= 0.3 \times \pi \left[2 \times 22 + 111 \times 13\right] = 1400.8 \text{ kN}$$

$$Q_u = Q_{pu} + Q_f$$
$$= 1430.7 + 1400.8$$
$$= 2831.5 \text{ kN}$$

$$Q_{safe} = \frac{2831.5}{2.5} = \underline{\underline{1133 \text{ kN}}}$$

④

$q_{pu} \ngtr 11000\ kN/m^2$

$f_s \ngtr 100\ kN/m^2$

] limiting values as per Tomlinson Method

But not considered here.

(ii) Considering Critical length Concept

$c = 0,\ \varphi = 40^\circ,\ N_q = 130,\ k = 2,$

$\delta = 0.75\varphi = 30^\circ,\ L = 15m\ \&$

$D = 0.3m.$

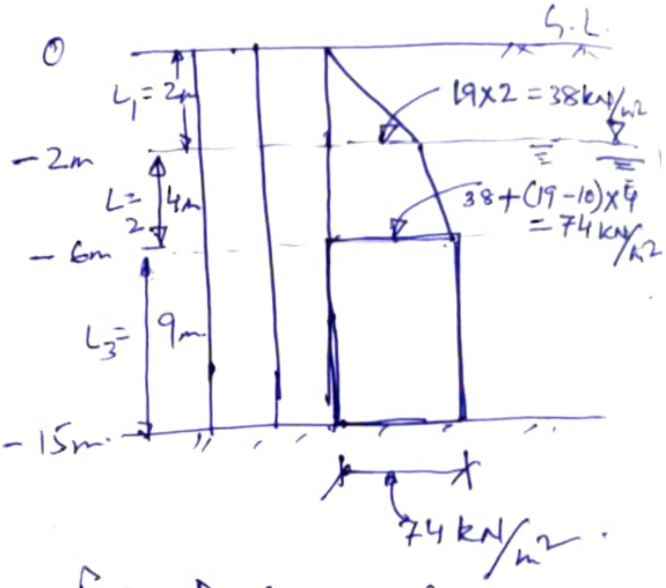
~~For~~

$$\boxed{q_{pu} = \sigma' N_q = 74 \times 130 = 9620\ kN/m^2} < 11000\ kN/m^2$$

[Vertical effective stress at base of pile / tip of pile]

$Q_{pu} = q_{pu} \times A_b$

$= 9620 \times 0.071 = 683\ kN$



for Dense sand

$\frac{L_{cr}}{D} = 20$

$\Rightarrow L_{cr} = 20 \times 0.3 = 6m.$

$Q_f = f_s \times A_s$

$$\boxed{f_s = (\sigma_{av} \times k)\tan\delta}$$

$f_{s_1}\Big|_{0\ to\ 2m} = \frac{1}{2}(0+38) \times 2 \times \tan 30^\circ$

$= \cancel{65}\ 22\ kN/m^2 \leqslant 100\ kN/m^2$

$f_{s_2}\Big|_{2\ to\ 6m} = \frac{1}{2}(38+74) \times 2 \times \tan 30^\circ = 65\ kN/m^2 < 100\ kN/m^2$

$f_{s_3}\Big|_{6\ to\ 15m} = 74 \times 2 \times \tan 30^\circ = 85.5\ kN/m^2 \leqslant 100\ kN/m^2$

[from 6 to 15m depth vertical stress is uniform i.e. $\sigma_{av} = 74\ kN/m^2$]

$$Q_f = f_{s_1} \times A_{s_1} + f_{s_2} \times A_{s_2} + f_{s_3} \times A_{s_3}$$

$$= 22 \times \underbrace{\pi \times 0.3 \times 2}_{(\text{IIDL})} + 65 \times \pi \times 0.3 \times 4 + 85.5 \times \pi \times 0.3 \times 9$$

$$= 1011 \text{ kN}$$

$$Q_u = Q_{pu} + Q_f = 683 + 1011 = 1694 \text{ kN}$$

$$Q_{safe} = \frac{Q_u}{FOS} = \frac{1694}{2.5} = \underline{\underline{678 \text{ kN}}}$$

Solution of Above Problem by

Imp.

(B) Meyerhof's Theory. (Considering critical length) must

$\phi = 40°$, $N_q = 320$

(Obtain from Meyerhof's chart)

$K = 2$, $\delta = 0.75\phi$
$= 30°$

$$q_{pu} = \sigma' N_q$$
$$= 74 \times 320$$
$$= 23680 \text{ kN/m}^2$$

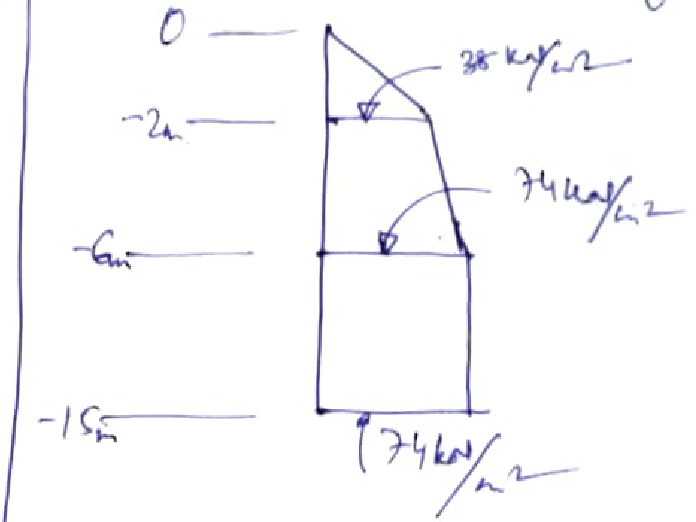
But there is limitation of above q_{pu} value.

$$q_{pu\,lim} = 50 N_q \tan\phi$$

(for dense sand)

$$= 50 \times 320 \times \tan 40°$$
$$= 13425.6 \text{ kN/m}^2$$

Pressure Distribution is same as before



But $q_{pu} \ngtr q_{pu\,limit}$

Thus, $q_{pu} = 13425.6$

$$Q_{pu} = 13425 \times 0.071$$
$$= 953 \text{ kN}$$

ⓑ Q_f = Same as calculated above based on critical depth conc

$= 1011$ kN.

$Q_u = Q_{pu} + Q_f = 953 + 1011 = 1964$ kN

$Q_{safe} = \frac{Q_u}{FOS} = \frac{1964}{2.5} = \boxed{785.6 \text{ kN}}$

ⓒ IS Code Method IS: 2911 (Part 1) : 2010

$$\boxed{Q_u = \underbrace{\underbrace{\left[A_p\left(\tfrac{1}{2}D\gamma N_\gamma + P_D N_q\right)\right]}_{q_{pu}}}_{Q_{pu}} + \underbrace{\left[\sum_{i=1}^{n} K_i P_{D_i} \tan\delta_i \, A_{si}\right]}_{Q_f}}$$

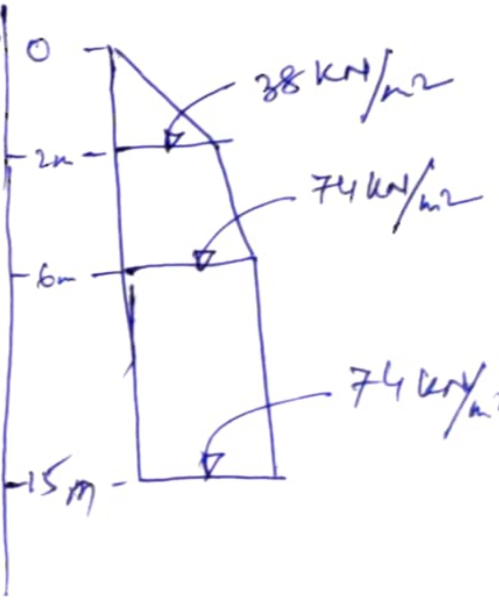
Here, $N_q = 130$, $K = 2$, $\underline{\underline{\delta = \phi}} = 40^\circ$ (Recommends)

Critical depth consideration is recommended.

$N_q = 130$, (obtained from the chart)

$K = 2$, $\delta = \phi = 40^\circ$, $\frac{L_{cr}}{D} = 20$ (for $\phi \geq 40^\circ$) $\Rightarrow \underline{\underline{L_{cr} = 6m}}$.

$N_\gamma = 109.41$ (From table)



$q_{pu} = \frac{1}{2}D\gamma N_\gamma + P_D N_q$ $P_D = \sigma'$

$= \frac{1}{2}D\gamma' N_\gamma + \sigma' N_q$

$= \left[\frac{1}{2} \times 0.3 \times (19 - 10) \times 109.41\right] + 74 \times 130$

$= 147.7 + 9620$

$= 9767.7 \text{ kN/m}^2$

$Q_{pu} = A_b \times q_{pu}$

$= 0.071 \times 9767.7 = 693.5$ kN

Calculation of fs.

$$f_{s_1}\Big|_{0\,to\,2m} = \frac{1}{2}(0+38)\times 2\times \tan 40^\circ \quad \left\{\left[\sigma'_{av} k \tan\delta\right] \,\&\, \delta=\varphi\right\}$$

$$= \frac{1}{2}\times 38\times 2\times \tan 40^\circ$$

$$= 32 \text{ kN/m}^2$$

$$f_{s_2}\Big|_{2m\,to\,6m} = \frac{1}{2}(38+74)\times 2\times \tan 40^\circ = 94 \text{ kN/m}^2$$

$$f_{s_3}\Big|_{6m\,to\,15m} = 74\times 2\times \tan 40^\circ = 124 \text{ kN/m}^2$$

$$Q_f = f_{s_1}\times A_{s_1} + f_{s_2}A_{s_2} + f_{s_3}A_{s_3}$$

$$= 32\times\pi\times D\times L_1 + 94\times\pi\times D\times L_2 + 124\times\pi\times D\times L_3$$

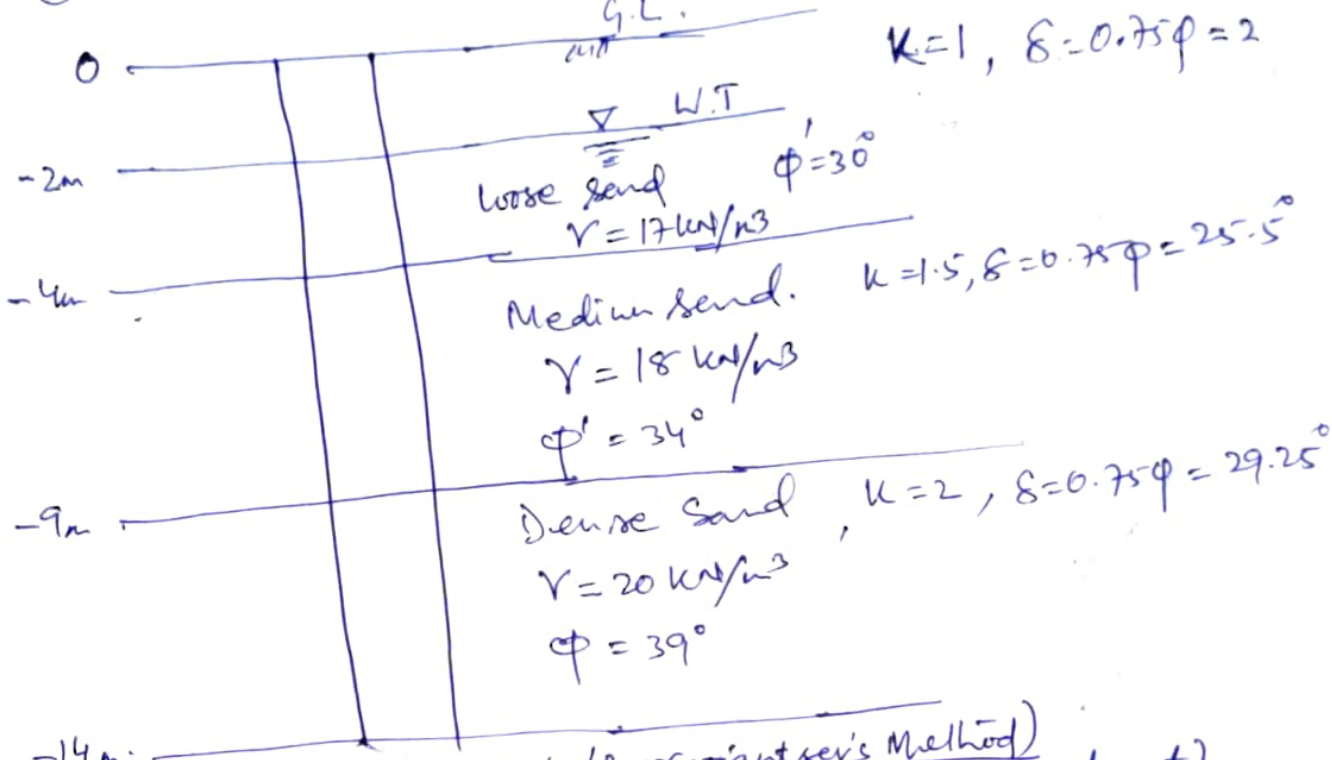
$$= \pi\times 0.3\left[2\times 32 + 4\times 94 + 9\times 124\right] = 1465.7 \text{ kN}$$

$$Q_u = Q_{pu} + Q_f = 693.5 + 1465.7 = 2159.2 \text{ kN}$$

$$Q_{safe} = \frac{Q_u}{FOS} = \frac{2159.2}{2.5} = \underline{863.68 \text{ kN}}$$

⑧ Layered Soil.

Problem ② (Without considering critical length)

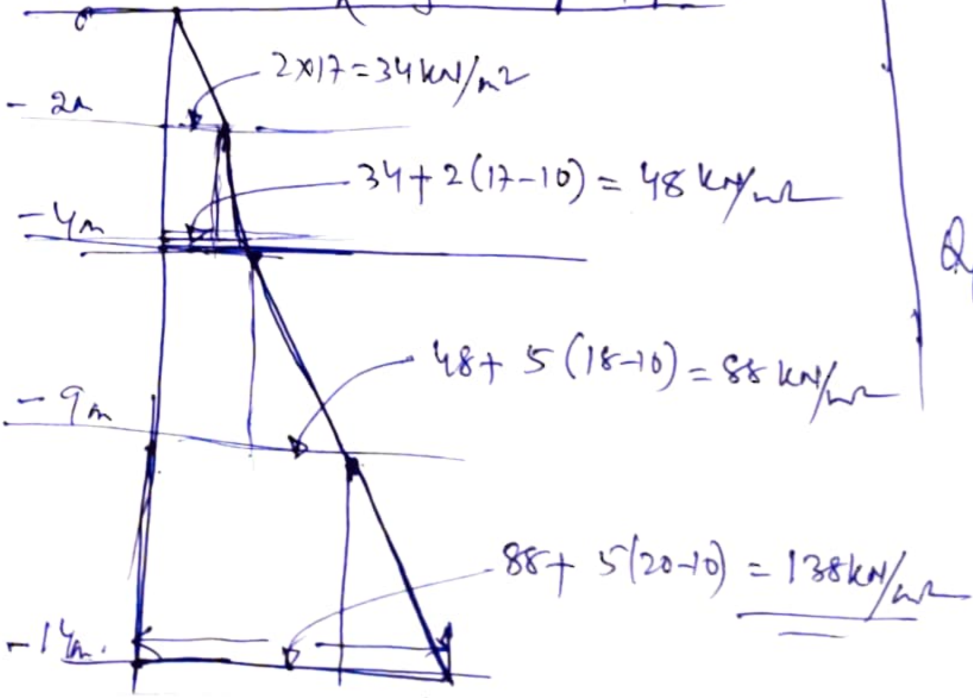


Method-1 (Tomlinson's / Berezantsev's Method)

$$\frac{L}{D} = \frac{14}{0.35} = 40 \Rightarrow N_q = \underline{\underline{132}} \text{ (from chart)}$$

$$\sigma'_{\text{base of pile}} = 2\times17 + 2(17-10) + 5(18-10) + 5(20-10) = 138 \text{ kN/m}^2$$

σ_v' Distribution Diagram along the length of pile.



(Effective vertical stress at base of pile)

$$q_{pu} = \sigma' N_q$$

$$= 138 \times 132$$

$$= 18216 \text{ kN/m}^2$$

$$Q_{pu} = \frac{\pi \times 0.35^2}{4} \times 18216$$

$$= 1752 \text{ kN}$$

$$f_{s_1}\Big|_{0\text{ to }2m} = \frac{1}{2}(0+34)\times 1\times \tan 22.5^\circ = 7\ \text{kN/m}^2$$

$$f_{s_2}\Big|_{2\text{ to }4m} = \frac{1}{2}(34+48)\times 1\times \tan 22.5^\circ = 17\ \text{kN/m}^2$$

$$f_{s_3}\Big|_{4\text{ to }9m} = \frac{1}{2}(48+88)\times 1.5\times \tan 25.5^\circ = 48.7\ \text{kN/m}^2$$

$$f_{s_4}\Big|_{9\text{ to }15m} = \frac{1}{2}(88+138)\times 2\times \tan 29.25^\circ = 126.6\ \text{kN/m}^2$$

$$Q_f = A_{s_1}\times f_{s_1} + A_{s_2}\times f_{s_2} + A_{s_3} f_{s_3} + A_{s_4} f_{s_4}$$

$$= \pi D\,(L_1\times f_{s_1} + L_2 f_{s_2} + L_3 f_{s_3} + L_4\times f_{s_4})$$

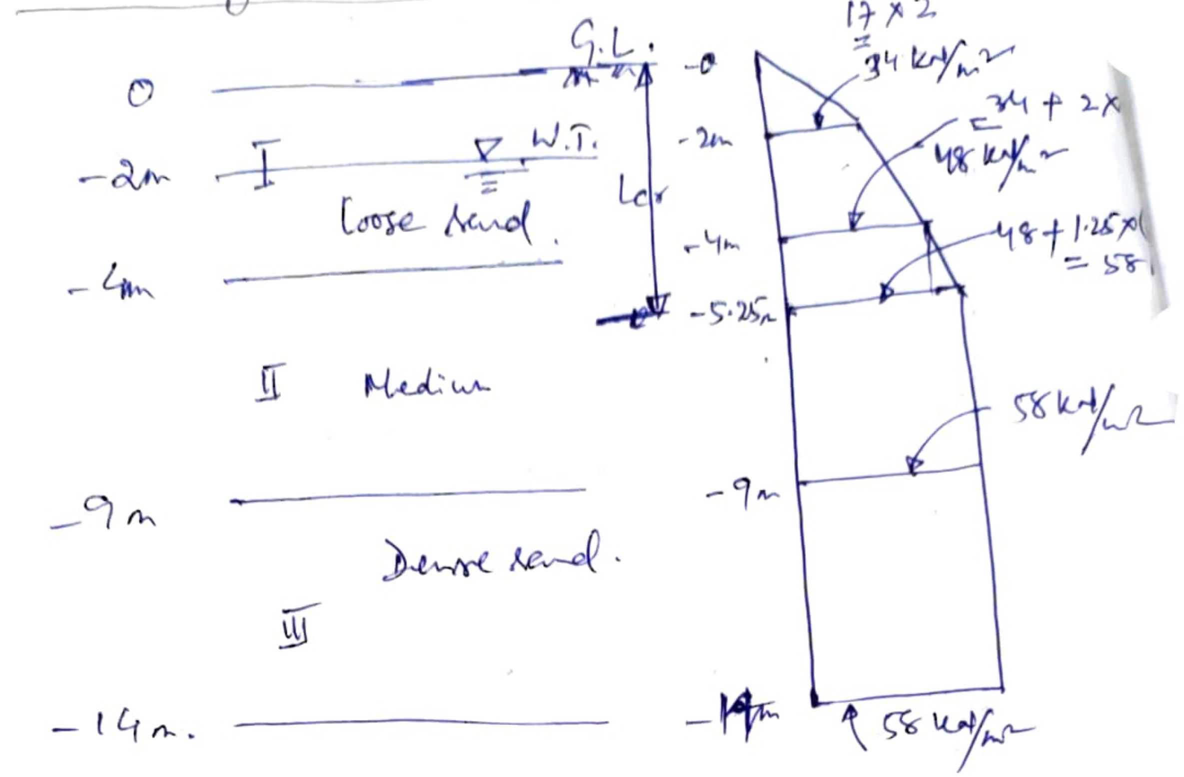
$$= \pi\times 0.3\,(2\times 7 + 2\times 17 + 5\times 48.7 + 5\times 126.6)$$

$$= 1016\ \text{kN}$$

$$Q_u = Q_{pu} + Q_f = 1752 + 1016 = 2768\ \text{kN}$$

$$Q_{safe} = \frac{2768}{2.5} = \boxed{1107\ \text{kN}}$$

Considering Critical length Concept



As the layer I & II are loose to medium dense sand

we have, $\frac{L_{cr}}{D} = 15$, $L_{cr} = 15 \times 0.35 = 5.25m.$

Point load resistance / End bearing resistance

$$q_{pu} = \sigma' \times N_q = 58 \times 132 = 7656 \text{ kN/m}^2$$

$$Q_{pu} = q_{pu} \times A_b = 7656 \times \frac{\pi}{4} \times 0.35^2 = 736 \text{ kN}$$

Skin friction Resistance

$$f_s = \sigma'_{ave} \times k \times \tan\delta$$

$$f_{s1}\Big|_{0 \text{ to } 2m} = \frac{1}{2}(0+34) \times 1 \times \tan 22.5^\circ$$
$$= 7.04 \text{ kN/m}^2$$

$$f_{s2}\Big|_{2 \text{ to } 4m} = \frac{1}{2}(34+48) \times 1 \times \tan 22.5^\circ = 17 \text{ kN/m}^2$$

$$f_{s3}\Big|_{4 \text{ to } 5.25m} = \frac{1}{2}(48+58) \times 1.5 \times \tan 25.5^\circ = 53 \times 1.5 \times 0.48$$
$$= 38.16 \text{ kN/m}^2$$

$$f_{s_4}\Big|_{5.25-9m} = 58 \times 1.5 \times \tan 25.5^\circ = 58 \times 1.5 \times 0.48$$
$$= 41.76 \text{ kN/m}^2$$

$$f_{s}\Big|_{9m-14m} = 58 \times 2 \times \tan 29.25^\circ = 58 \times 2 \times 0.56 = 64.96 \text{ kN/m}^2$$

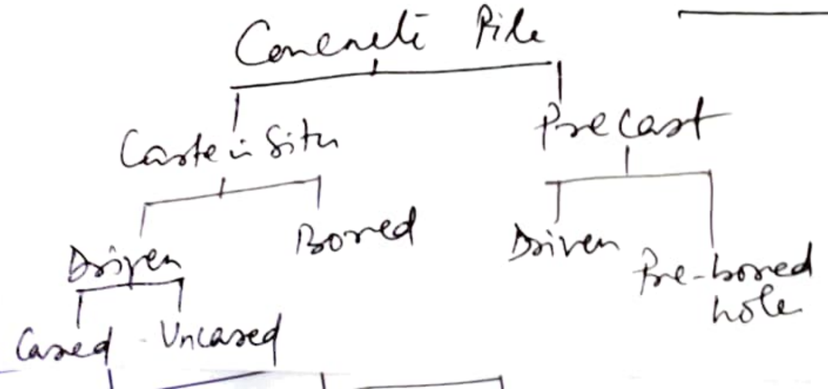
$$Q_f = Q_{f_1} + Q_{f_2} + Q_{f_3} + Q_{f_4} + Q_{f_5}$$
$$= f_{s_1} \times A_{s_1} + f_{s_2} \times A_{s_2} + f_{s_3} \times A_{s_3} + f_{s_4} \times A_{s_4} + f_{s_5} A_{s_5}$$
$$= 7.04 \times \underline{\pi \times 0.35} \times 2 + 17 \times \underline{\pi \times 0.35} \times 2 + 38.16 \times \underline{\pi \times 0.35} \times 1.25$$
$$+ 41.76 \times \underline{\pi \times 0.35} \times (9 - 5.25) + 64.96 \times \underline{\pi \times 0.35} \times 5$$
$$= \pi \times 0.35 \left[2 \times 7.04 + 17 \times 2 + 38.16 \times 1.25 + 41.76 \times 3.75 + 64.96 \times 5 \right] =$$
$$= 638 \text{ kN}$$

$$Q_u = 1752 + 638 = 1374 \text{ kN} \qquad Q_u = Q_{pu} + Q_f.$$

$$Q_{safe} = \frac{1374}{2.5} = 549.6 \text{ kN}$$

Ans.

__Assignment__ — Solve the above problem using IS Code method. IS 2911 (Part 1/Sec 1) : 2010



Problem. A 15m long pile with diameter 400mm was driven in a homogeneous clay with unconfined compressive strength of 100 kPa. Calculate the ultimate load carrying capacity of the pile. $\left[Q = q_{pu} A_b + f_s A_s \right]$

Solution :- $C_u = \frac{q_u}{2} = \frac{100}{2} = 50 \text{ kPa}$.

From the table, soil consistency is Medium.

From chart & table } $\alpha = 0.7$ = adhesion factor

Pile must go at least 5D inside bearing strata

$$\boxed{Q_u = A_b \times \overbrace{(C_{ub} N_c)}^{q_{pu}} + A_s \overbrace{(\alpha C_u)}^{f_s}}$$

$N_c = 9$ for deep pile from Skempton's Recommendation.

$$Q_u = \frac{\pi \times 0.4^2}{4} \times 50 \times 9 + \pi \times 0.4 \times 15 \times 0.7 \times 50$$

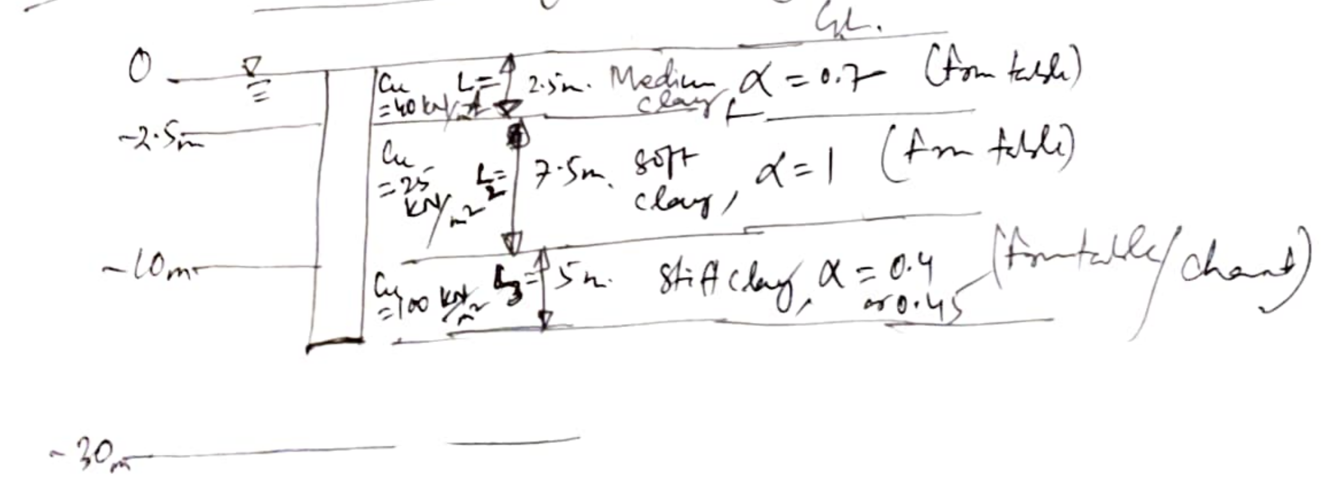
$$= 56.52 + 659.4 = 716 \text{ kN} ✓$$

$$Q_a = Q_{safe} = \frac{Q_u}{2.5} = \frac{716}{2.5} = 286.4 \text{ kN}$$ (Ans).

C_{ub} = undrained cohesion at base of pile

C_u = undrained cohesion in embedded length of pile.

Problem. Pile in clay in layered soil.



$$Q_{pu} = A_b \times q_{pu} \underset{\wedge}{\overset{= A_b C_{ub} N_c}{=}} \frac{\pi \times 0.4^2}{4} \times 100 \times 9 = 113 \text{ kN/m}^2$$

$$Q_f = \sum_{i=1}^{m} A_{si} \alpha_i C_{ui}$$

$$= \pi \times 0.4 \left[2.5 \times 0.7 \times 40 + 7.5 \times 1 \times 25 + 5 \times 0.45 \times 100\right]$$

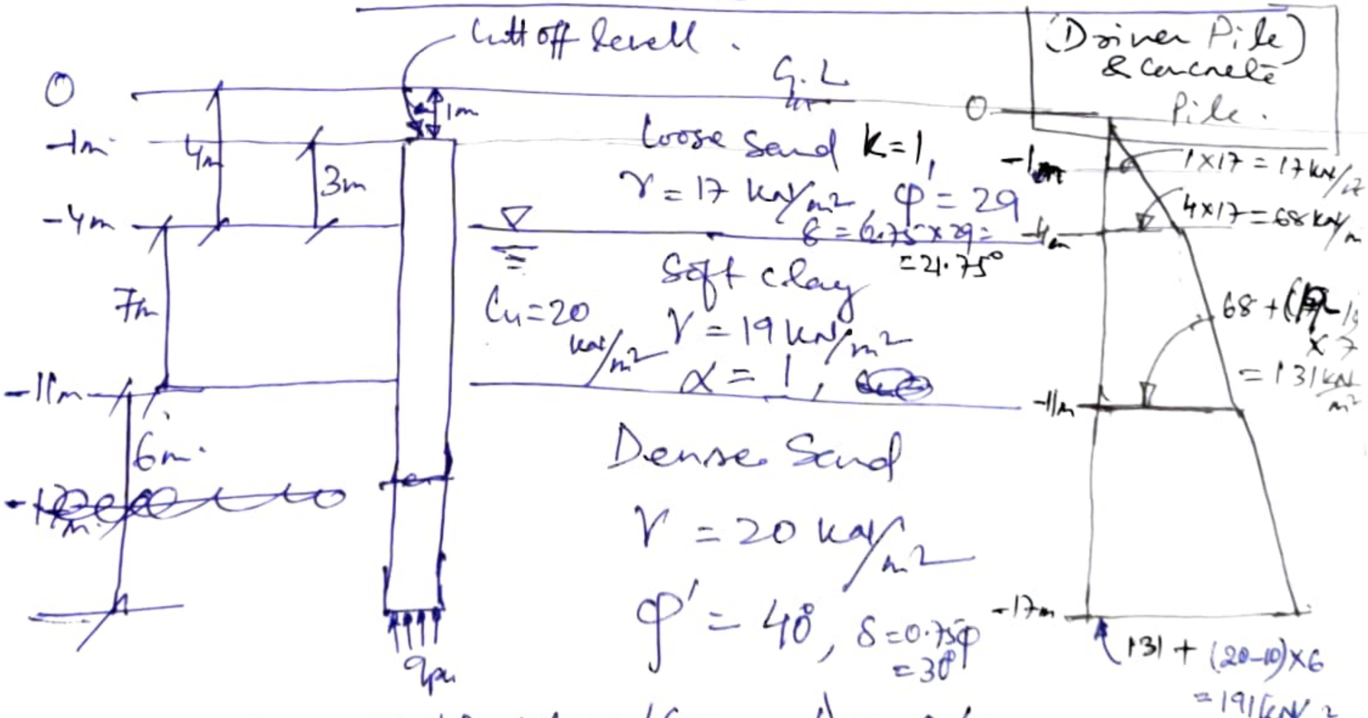
$$= 606 \text{ kN.}$$

$$Q_u = Q_{pu} + Q_f = 113 + 606 = 719 \text{ kN.}$$

$$Q_a = Q_{safe} = \frac{719}{2.5} = 287.6 \text{ kN.}$$

Problem.

Pile in Sandy-clay a layered Soil



$$L = 3 + 7 + 6 = 16m, \quad D = 0.4m.$$

Tomlinson's ~~Solution~~ Method (Considering full effective overburden stress)

$$Q_{pu} = q_{pu} \times A_b = (\sigma'_b N_q) \times A_b$$

$$= 191 \times 132 \times \frac{\pi}{4} \times 0.4^2 = 3167 \text{ kN}$$

$$\frac{L}{D} = \frac{16}{0.4} = 40, \quad N_q = 132$$

for $\phi' = 40$

Q_f = Skin friction Resistance

$$f_{s1}\Big|_{1\,to\,4m} = \frac{1}{2}(17+68)\times 1\times \tan 21.75^\circ = 17\ kN/m^2$$

$$\left\{ f_s = \sigma'_{ave}\, k \tan\delta \right\}$$

$$f_{s2}\Big|_{4\,to\,11m} = \alpha C_u \quad \text{(clay layer)}$$

$$= 1\times 20 = 20\ kN/m^2$$

$$f_{s3}\Big|_{11\,to\,17m} = \frac{1}{2}(131+191)\times 2\times \tan 30^\circ = 186\ kN/m^2$$

$$Q_f = \pi\times 0.4\left[(4-1)\times 17 + (11-4)\times 20 + (17-11)\times 186\right] = 1642\ kN$$

$$Q_u = Q_{pu} + Q_f = 3167 + 1642 = 4809\ kN$$

$$Q_{safe} = Q_a = \frac{4809}{2.5} = \underline{1924\ kN}$$

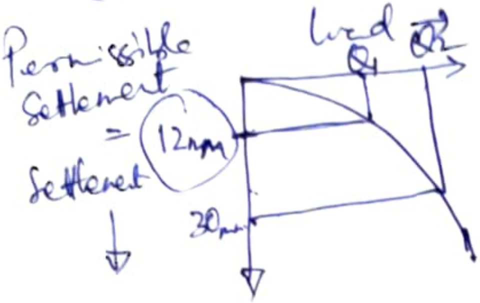
(Ans)

Piles in Cohesive Soil (IS : 2911 (Part 1) : 2010)

$$Q_u = A_p N_c C_p + \sum_{i=1}^{n} \alpha_i C_i A_{si}$$

continuation of Pile Load Test

The allowable load on a single pile shall be lesser of the following as per IS.



1) $Q_{allowable_1} = \frac{2}{3} Q_1$

2) $Q_{allowable_2} = \frac{1}{2} Q_2$

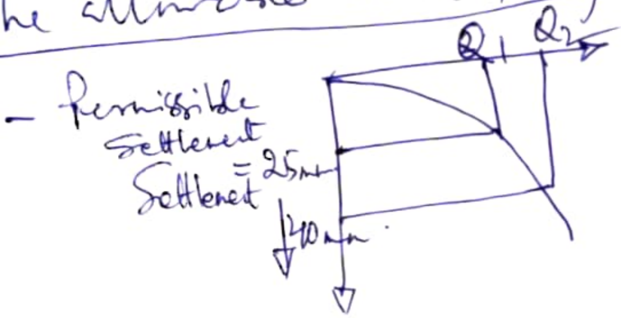
$Q_{allowable}$ is minimum of Q_{all_1} & Q_{all_2}

Settlement = 10% of pile Diameter

7.5% of bulb in case of underreamed piles.

If the D = 300mm; Settlement = 30mm

The allowable load of group piles.



1) $Q_{allowable_1} = Q_1$

2) $Q_{allowable_2} = \frac{2}{3} Q_2$

Min^m of the above two.

Problem.

	Settlement	load	Qallowable
①	12mm	$Q_1 = 230$ kN	$\frac{2}{3} \times 230 = 153$ kN
2)	10% pile Dia. = 30mm	$Q_2 = 410$ kN	$\frac{1}{2} \times 410 = 205$ kN

Min^m of two

Pile load Test.

$\boxed{Q_a = 153 \text{ kN}}$

Continuous test

Can't be det. Q_{pu} & Q_f

⑯

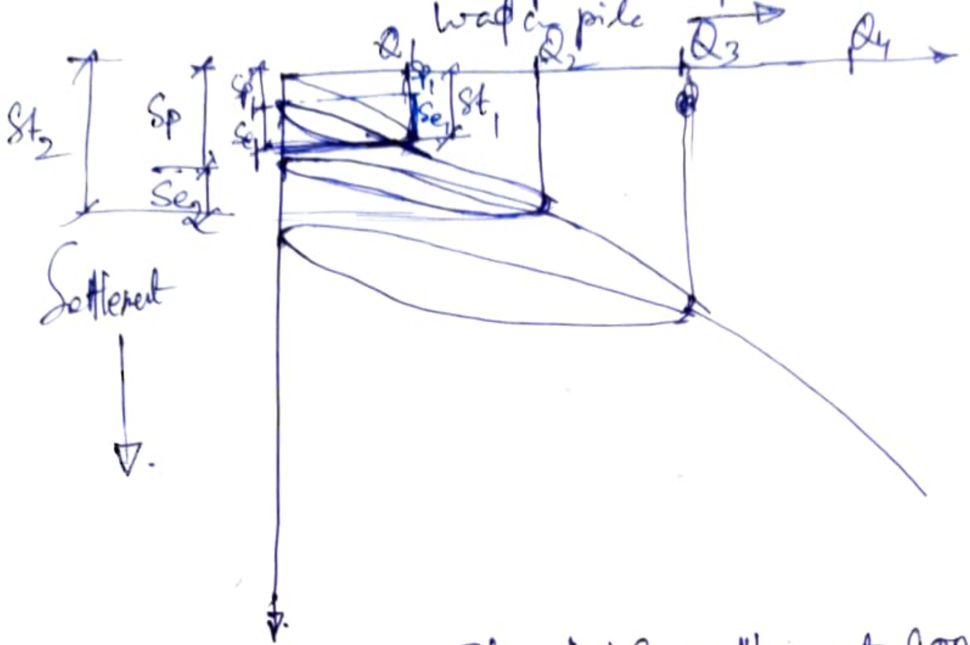
Cyclic Pile load test.

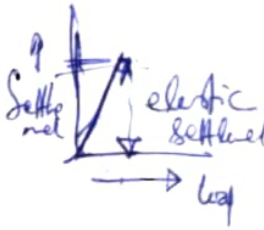
- Limited to initial test only

↓

$\boxed{\text{on Test pile only.}}$

- To find Q_{pu} & Q_f separately.





S_{t_2} = total settlement corresponding to load Q_2

S_p = permanent deformation
= Plastic settlement

S_e = elastic settlement = recoverable deformation

Total settlement $= S_t = S_e + S_p$ —— ①

$S_t = \Delta l + S_b$

Δl = compression of the pile material.

S_b = " " soil at the pile base.

$S_b = \bar{S}_e + \bar{S}_p$ — plastic compression of soil at base.

↓ elastic compression of soil at base

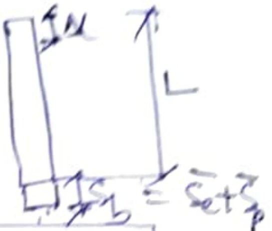
$S_t = \Delta l + \bar{S}_e + \bar{S}_p$ —— ②

Deformation of pile material never reaches plastic zone. as it is very rigid.

$S_e + S_p = \underline{\Delta l + \bar{S}_e + \bar{S}_p}$

$\bar{S}_e = \underbrace{(S_p - \bar{S}_p)}_{0} + S_e \cancel{+} - \Delta l$.

Plastic settlement of pile is neglected.
$S_p = \bar{S}_p$



$\boxed{S_t = \Delta l + S_b}$

$\bar{S}_e = S_e - \Delta l$.

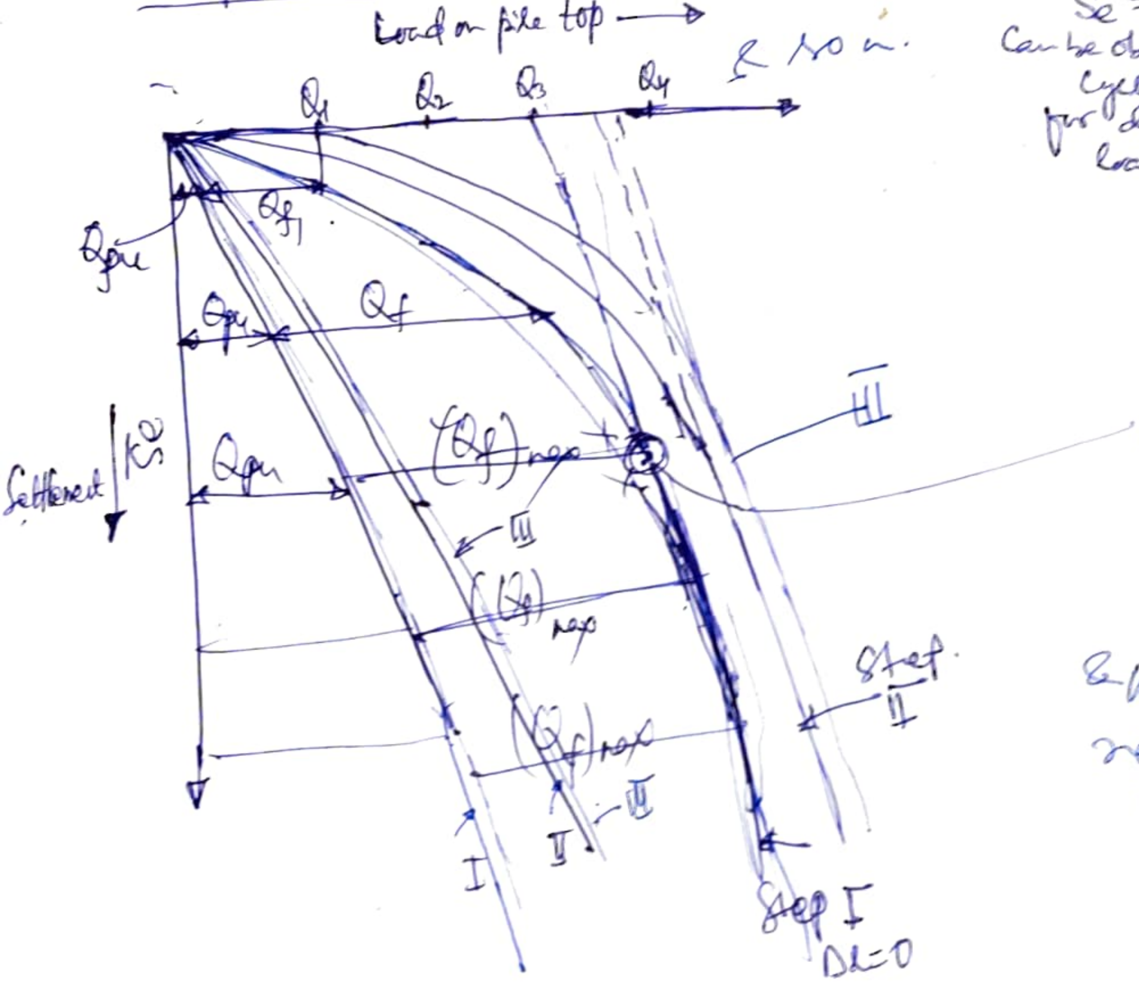
Can be determined from the plot

$$\Delta l = \frac{(Q - Q_f/2)L}{AE}$$

Q = load on the pile; Q_f = friction load.

Step – I   First Trial → Assume $\Delta l = 0$

$\bar{S}_e = S_e$. Can be obtained from the cyclic load plot for different loads Q_1, Q_2 . . . .



Friction is fully mobilised first then tip resistance is mobilised

⑱ **Step-II** Take Q_{f_n} $(Q_{f_1}, Q_{f_2}, \ldots)$ from the curve.

for any Q $(Q_1, Q_2, \ldots$ etc)

Then get corresponding $\Delta l_1 = \frac{(Q_1 - Q_{f_1}/2)L}{AE}$.

$$\bar{S}_{e_1} = S_{e_1} - \Delta l_1$$

$\downarrow$ from cyclic load test.

$$\bar{S}_{e_2} = S_{e_2} - \Delta l_2 \quad \text{\& so on.}$$

Then plot it $\bar{S}_e$ v Q(load).

Step-III. Take new Q_f $(Q_{f_1}, Q_{f_2}, \ldots)$

for Q. $(Q_1, Q_2, \ldots$ etc).

get values of $\Delta l_1, \Delta l_2, \ldots$

Continue this process till the two consecutive curves overlap. Then you will get correct value of Q_f & Q_{pu} for the plot.

$$(Q_f)_a = \frac{Q_f}{2.5} \qquad (Q_{pu})_a = \frac{Q_{pu}}{2.5}$$

ENR. Dynamic Pile formula.

Problem ① A 250 mm dia pile was driven with a drop hammer of weight 2200 kg & having a free fall of 1.5m. The total penetration of the pile was recorded in last 5 blows 30 mm. Determine the safe pile load using ENR.

Soln.

$$Q_a = Q_{safe} = \frac{WH}{F(S+C)} = \boxed{\frac{WH}{F(S+2.5)}} \rightarrow \text{for drop hammer}$$

$W = 2200\,kg$, $H = 1.5\,m = 1.5 \times 10^2\,cm$.

S = averge blow $= \frac{30\,mm}{5} = 6\,mm = 0.6\,cm/blow$

$$Q_a = \frac{2200 \times 1.5 \times 10^2}{6\,(0.6+2.5)} = 17742\,kg$$

$$Q_a = \frac{17742 \times 9.81}{1000} = \underline{174\,kN}$$

Prob.② Modified Hiley Formula : A 400mm dia & 12m long pile was driven by double acting hammer (total mass of 2200 kg & height of fall 1.5m). The driving was done with 2.5cm cushion only. The average * penetration in last five blows was 3 mm/blow. Determine the safe pile load. Unit weight of conc. is 24 kN/m³

Soln.

$$W = \frac{2200 \times 9.81}{1000} = 21.6\,kN = \underline{2.16\,t}$$

(weight of hammer)

$$P = \frac{\pi}{4} \times 0.4^2 \times 12 \times 24 = 36.2\,kN = \underline{3.62\,t}.$$

(wt. of pile)

for double acting hammer $e = \underline{0.5}$

$P \times e = 3.62 \times 0.5 = 1.81\,t$, So $W > Pe$.

$$\eta = \frac{W + Pe^2}{W + P} = \frac{2.16 + 3.62 \times 0.5^2}{2.16 + 3.62} = \underline{0.53}$$

$$\eta_h = \underline{0.85}$$

C_1 (2.5 cm cushion is used)

$$= 1.77 \times \frac{Q_u}{A}, \quad C_2 = 0.675\,\frac{Q_u L}{A}, \quad C_3 =$$

L = length of pile, A = c/s of pile

$$C = C_1 + C_2 + C_3 = (1.77 + 0.675L + 3.55)\,\frac{Q_u}{A}$$

$$= (1.77 + 0.675 \times 12 \times 3.55) \times \frac{Q_u}{A}$$

$$A = \frac{\pi}{4} \times 0.4^2$$

$$\Rightarrow C = 0.0107\,Q_u \text{ ton}$$

$$\Rightarrow \frac{C}{2} = 0.00534\,Q_u$$

$$Q_u = \frac{W h\,\eta\,\eta_h}{S + \frac{C}{2}} = \frac{2.16 \times 1.5 \times 10^2 \times 0.85 \times 0.53}{0.3 + 0.00534\,Q_u}$$

$$\Rightarrow Q_u^2 + 56.2\,Q_u - 273.3 \times 10^2 = 0$$

$$Q_u = \frac{-56.2 \pm \sqrt{56.2^2 - 1 \times (-273.3 \times 10^2)}}{2 \times 1}$$

$$= 139.6\,t = 1396 \text{ kN}$$

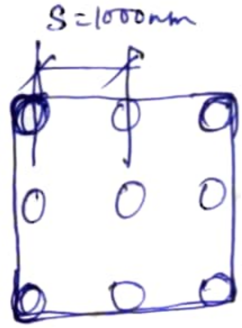
$$Q = \frac{Q_u}{2.5} = \frac{1396}{2.5} = 558.4 \text{ kN.}$$

(Ans)

Design of a Pile group.

Design a pile group considering RCC piles for a column of size 650mm×650mm carrying a load of 1570kN (total). The exploration data reveal that sub soil consists of deposit of clay extending to a greater depth. The other data of the deposit are: $C_c = 0.1$

Solution :- **First trial.**



Assume 9 no. of piles, L = 15m,

$C_u = \frac{q_u}{2} = \frac{70}{2} = 35\ kN/m^2$ | D = 400mm, S = 2D (As per (minm spacing) IS code for clay soil)

$S = 2 \times D = 2 \times 400\ mm = 800\ mm$ (Minm spacing)

Let provide S = 1000mm.

$B = 2S + D$
$= 2 \times 1000 + 400$
$= 2400\ mm$
$= 2.4\ m.$

$\alpha = 0.7$ from table.

$L' = B = 2.4\ m.$

Bearing Capacity check.

1) Single pile failure / Single pile capacity.

$$Q_u = C_u N_c A_b + (\alpha C_u) A_s = 35 \times 9 \times \frac{\pi}{4} \times (0.4)^2 + 0.7 \times 35 \times \pi \times 0.4 \times 15$$

$$= 501.6\ kN.$$

$$Q_{ug} = n Q_{us} = 9 \times 501.6 = 4514\ kN$$

2) Group or Block failure / Group pile capacity $\alpha = 1$

$$Q_u = C_u N_c A_b + C_u \boxed{A_s} \text{ — } \boxed{P_b \times L}$$

②

$(A_b = B^2 = 2.4^2)$

$$Q_{ug} = 35 \times 9 \times (2.4)^2 + \underset{\alpha}{\textcircled{1}} \times 35 \times \underline{[5 \times 2(2.4+2.4)]}$$

$$= 1814 + 5040 = 6854 \text{ kN}$$

$\therefore$ $Q_{ug} = 4514$ kN. (min^m of Above two)

$$Q_{ug\,safe} = \frac{4514}{2.5} = 1804 \text{ kN} > 1520 \text{ kN}$$

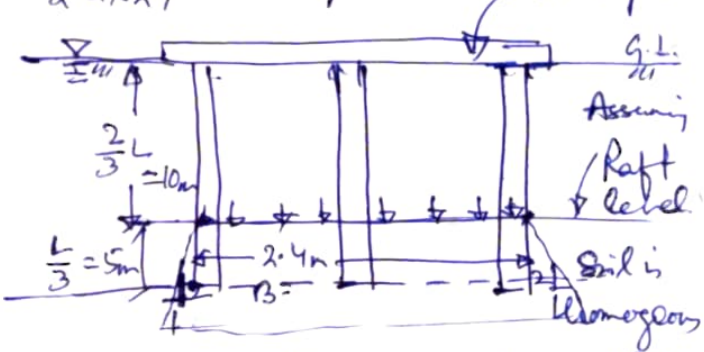
hence safe.

Settlement Criterion check.

$$q_n = \frac{1520}{2.4 \times 2.4} = 260 \text{ kN/m}^2$$

1) Immediati Settlement.

$$S_i = \cancel{S_i} = \frac{q_n B (1-\mu^2)}{E} I_f$$



$I_f = 1.12$ for $\frac{L}{B} = 1$ (for square footing) from table

$\mu = 0.5$

If nothing is given, then
$E = \underline{750\, C_u}$
$= 750 \times 35$
$= 26250$ kN/m²

$\gamma_{sat} = 20$ kN/m³

Influence zone below the raft.
$= 2B = 2 \times 2.4$
$= 4.8$m.

$L = 15$m
$C_c = 0.1$
$e_0 = 0.9$

$\boxed{L = B = 2.4m.}$

Dimension of raft

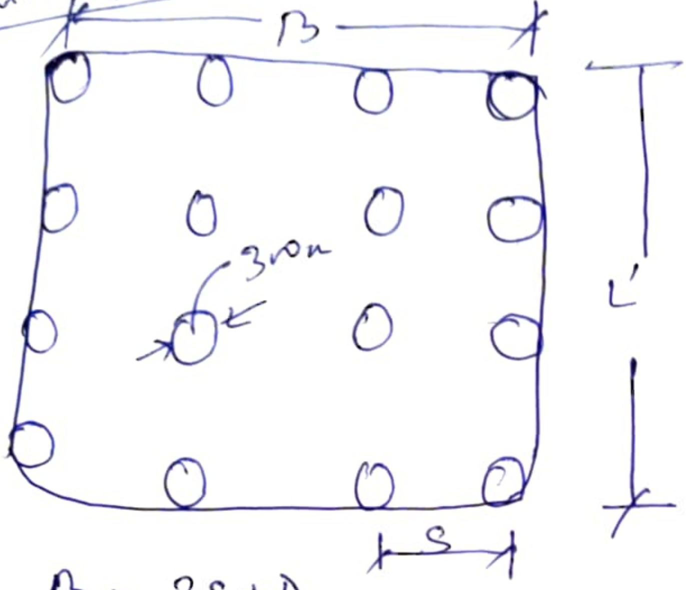
$$S_i = \frac{260 \times 2.4}{26250}(1-0.5^2) \times 1.12$$

$= 20$mm.

roblem. ✓ Group Pile.

Determine the spacing of 16 piles with dia. 300mm such that the efficiency of pile group is 1. The piles were constructed in uniform clay soil with $q_u = 50 kPa$.

Solution :-



$q_u = 50 kN/m^2$

$C_u = \frac{50}{2} = 25 kN/m^2$

$\eta_g = 1$

$\eta_g = \frac{Q_{ug}}{n Q_{us}}$

Neglect the tip resistance of pile group. (Floating pile not resting on hard strata)

$B = 3S + D$

$L' = 3S + D$

1) Block failure

$$Q_{ug} = \underbrace{C_u N_c A_b} + C_u A_s$$
$$= 0 + C_u A_s = C_u 2(B + L') \times L$$
$$= 25 \times 2(3S + D + 3S + D) \times L$$
$$= 25 \times 2 \times 2(3S + D) \times L = 100(3 \times S + 300) \times L$$

2) Single pile failure

$Q_{us} = \alpha C_u A_s$

$\alpha = 0.95$ from chart

$$Q_{us} = \alpha C_u \times A_s$$
$$= 0.95 \times 25 \times \pi \times D \times L$$
$$= 0.95 \times 25 \times \pi \times 300 \times L$$

②

$$\eta_g = \frac{\cancel{100}\, Q_{ug}}{\eta\, Q_{us}} = \frac{100(3S+300)L}{16\times0.95\times25\times\pi\times}$$

As, $\eta_g = 1$ $\Rightarrow$ $100(3S+300)L = 16\times0.95\times25\times\pi\times3$

$\Rightarrow$ $\underline{S = 1094\,mm.}$ $\approx 3.65D$. hence ok.

As per IS code $S_{min} = 2.5D$

or $\underline{\underline{3D}}$ (max^m. requirement)

Applyis connections.

1st Connection is rigidity Connection = 0.8

Depth Correction = 0.57 (from chart)

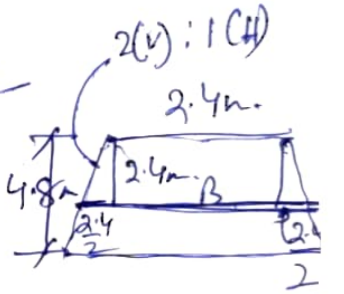
$\frac{\sqrt{LB}}{D_f}$, D_f = 10m = Depth of raft

$= \frac{\sqrt{2.4 \times 2.4}}{\sqrt{10}} = 0.24$, $\frac{L}{B} = 1$.

S_i (connected) = 20 × 0.8 × 0.57 = 9.12 mm.

ii) Consolidation Settlement

$\bar{P}_0 = \overset{\boxed{Z\gamma_{sub}}}{(10 + 2.4) \times (20 - 10)} = 124$ kN/m²



$\Delta P = \frac{260 \times 2.4 \times 2.4}{(\underline{2.4 + 2.4})(2.4 + 2.4)}$

B   L

$S_c =$

= 65 kN/m²

$S_c = \frac{0.1}{1 + 0.9} (4.8) \log_{10} \frac{124 + 65}{124} = 46.2$ mm.

Connection.

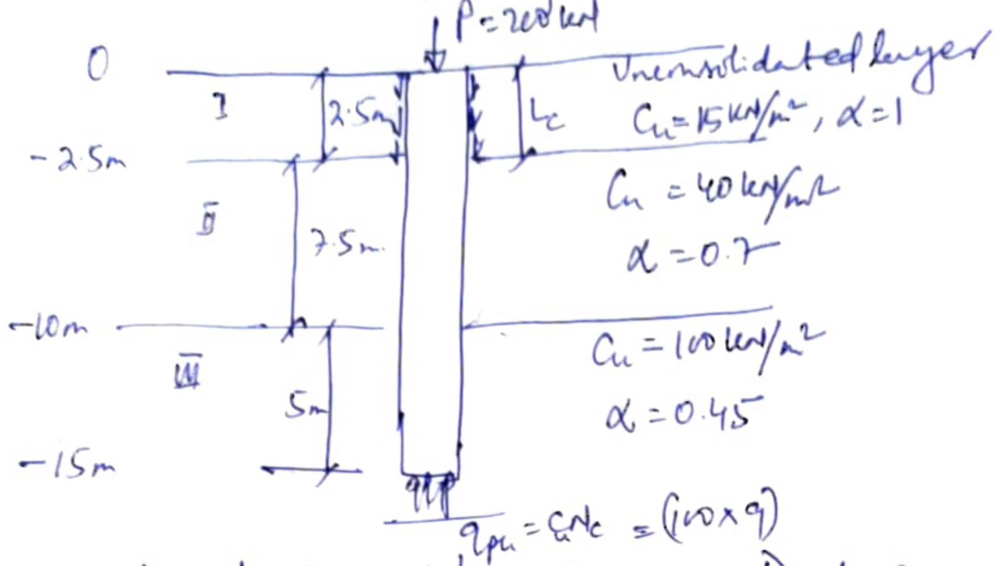
1) Rigidity connection factor = 0.8
2) Depth connection factor = 0.57
3) Pore water connection factor = 0.7
(Normally consolidated clay)

$(S_c)_{\text{connected}}$ = 46.2 × 0.8 × 0.57 × 0.7 = 15 mm.

Total settlement, $S_{(\text{connected})}$ = 9.12 + 15 = 24.12 mm < 40 safe.

Problem on negative skin friction

Working load on the pile = 200 kN (P)



L = length of pile = 15m. , D = 400mm = 0.4m.

$$Q_{pu} = C_u N_c \times A_b$$

$$= (100\times9)\times\frac{\pi}{4}\times0.4^2 = \underline{113 kN}$$

$$Q_f = \sum f_s A_s = \underbrace{(\alpha_2 C_{u_2})}_{f_{s_2}} A_{s_2} + \underbrace{(\alpha_3 C_{u_3})}_{f_{s_3}} A_{s_3}$$

layer-I

Compressible layer (layer II)

doesn't contribute any skin friction

$$\Rightarrow Q_f = 0.7\times40\times\pi\times0.4\times7.5 + 0.45\times100\times\pi\times0.4\times5 = \underline{546.4 kN}$$

For layer-I

Negative skin friction, $F_n = f_s A_s = (\alpha C_u)\times\pi\times d\times L_c$

$$= 1\times15\times\pi\times0.4\times2.5$$

$$= 47.1 kN$$

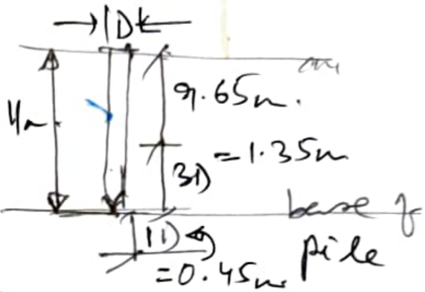
$$F.O.S. = \frac{Q_{pu}+Q_f}{P+F_n} = \frac{113+546.4}{200+47.1} = 2.7 > 2.5$$

hence ok.

Problem using SCPT data for Pile load capacity

Problem. Determine the allowable load carrying capacity of a 11m long & 450mm dia. driven pile constructed in the sand with cone resistance (SCPT) profile as shown in the figure. (Provided)

Method - I



$$q_{pu} = q_c$$

$L = 11m$, $D = 450mm$.

at depth 11.45m, $q_c = 20\times10^3$ kN/m²

at depth ~~10.5m~~ 11.0m, $q_c = 10\times10^3$ kN/m²

at 10.5m, $q_c = 500$ kN/m²

at 9.65m, $q_c = 520$ kN/m²

$(q_c)_{average}$ = weighted average of q_c

$$= \left[\frac{(20\times10^3 + 10\times10^3)}{2}\times0.45 + \frac{(10\times10^3+520)}{2}\times(11-10.5) + \left(\frac{520+500}{2}\right)(10.5-9.65)\right] \Big/ (1.35+0.45)$$

$= 6507$ kN/m²

$q_{pu} = q_c = 6507$ kN/m²

$$Q_u = q_{pu}\times A_b = 6507\times\frac{\pi}{4}\times0.45^2 = 1034.4\text{ kN}$$

$q_{c\,(average)}$ from 0 - 11m $= 3642$ kN/m² $= 36.42$ kg/

② for. Q_f Calculation.

$$q_{c(\text{average})}\Big|_{0\text{ to }11m} = 3642\ kN/m^2 = 36.42$$

$$f_s = \frac{q_{c(avg)}}{2} = \frac{36.42}{2} = 18.21\ kN/m^2 < 100k$$

hence ok.

$$Q_f = \pi(0.45)\times 11 \times 18.21 = 283\ kN$$

$$Q_u = 1034.4 + 283 = 1317.4\ kN.$$

$$Q_{safe} = \frac{1317.4}{2.5} = \boxed{527\ kN}$$

Ans