GEOTECHNICAL ENGINEERING

Topic : Pile Foundation _ Numericals

The load Carrying capacity of Piles can be determined by following methods :

1. Static Formula
2. Dynamic Formula
3. Pile Load Test
4. Penetration Tests

Dynamic approach :

1. Modified Hiley's Formula
2. Engineering News Formula
3. Engineering News Record (ENR) Formula or Modified ENR Formula

1. Modified Hiley's Formula :

IS: 2911 (Part I) 1964 gives Following Expression to Find Ultimate Load Carrying capacity of Pile (Q_f)

$$Q_f = \frac{(\eta_h \, WH \, \eta_b)}{S + (C/2)}$$

Where, η_h - Efficiency of Hammer in Fraction

P – Weight of Pile = (A_{pile} x L_{pile} x *density*) in kN ; W – Weight of hammer ; H – Height of fall

S – Penetration per blow or Set per down or Set per blow ; C – Elastic Compression of pile

For drop Hammer, C = 2.5 cm if not given

For steam hammer, C = 0.25 cm if not given ; e – Coefficient of Restitution

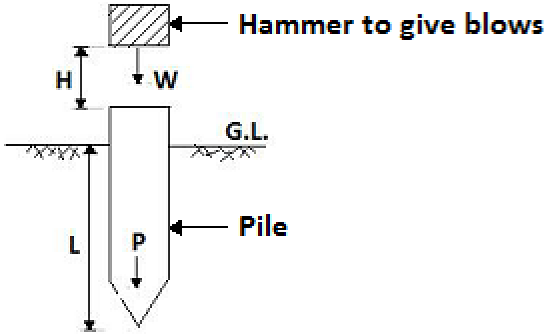
η_b – Efficiency of Hammer Blow

e = 0.25 for timber if not given and

e = 0.50 for steel material. if not given

If W > (e x P) , then $\eta_b = \frac{W + e^2 P}{W + P}$

If W < (e x P) , then $\eta_b = \left(\frac{W + e^2 P}{W + P}\right) - \left(\frac{W - e\,P}{W + P}\right)^2$



Important Notes

IS: 2911 (Part I) 1964 gives Following Expression to Find Ultimate Load Carrying capacity of Pile (Q_f)

$$Q_f = \frac{(\eta_h \, WH \, \eta_b)}{S + (C/2)}$$

- ***Note 1] If Effective Fall is directly given in the problem then, take (η_h x H) = Effective Fall in the Formula of Q_f***
- ***Note 2] If Energy is directly given in the problem then, take Energy = (W x H) in the Formula of Q_f***
- ***Note 3] Safe (Allowable) load is obtained by taking Factor of Safety as 2 to 2.5***

Problem 1 A concrete pile 40 cm x 40 cm section and 20 m long is driven by drop hammer having weight of 40 KN and falling through height of 1.2 m . The Average penetration under last 10 blows equal to 6 mm per blow. The Efficiency of hammer is 100 % . The coefficient of Restitution is 0.4. the total Elastic compression is 25 mm. Using Hiley's Formula, Determine Ultimate load on Pile ? **[RTMNU, W – 15/7 m]**

Solution :

Given : $H = 1.2$ m, $\eta_h = 100\ \% = (100/100) = 1$

$e = 0.4$, $C = 25$ mm $= 0.025$ m , $W = 40$ kN

$S = 0.006$ m for 10 Blows i.e. $(0.006/10) = 0.0006\ m/blow$

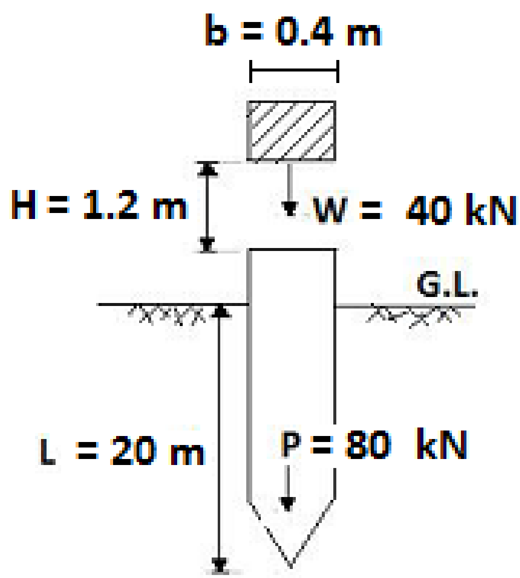
$$\text{Weight of Pile}\ (p) = (A_{pile}\ x\ L_{pile}\ x\ density)$$
$$= [(0.4\ x\ 0.4)\ x\ 20\ x\ 25] = 80\ kN$$

Here, $W > (e\ x\ P)$, $40 > (0.4\ x\ 80)$; $40 > 32$

$$\therefore\ \eta_b = \frac{W + e^2 P}{W + P} = \frac{40 + (0.4^2\ x\ 80)}{40 + 80} = 0.44$$

Ultimate Load carrying capacity of pile :

$$Q_f = \frac{(\eta_h\, W H\, \eta_b)}{S + (C/2)} = \frac{(1\ x\ 40\ x\ 1.2\ x\ 0.44)}{0.0006 + (0.025/2)} = 1612\ \text{KN}$$



Problem 2 A drop hammer Weighing 60 kN and having an effective fall of 0.8 m, drives an RCC pile weighing 35 kN. The average settlement per blow is 12 mm. the total elastic compression is 18 mm. Assuming coefficient of restitution as 0.3 and FOS of 2.5 determine of UBC and allowable load for pile ? **[SGBAU, W – 19/7 m]**

Solution :

$P = 35\ KN$, e = 0.3, C = 18 mm = 0.018 m, W = 60 kN

S = $12\ mm/blow$ = $0.012\ m/blow$; FOS = 2.5

Here, W > ($e\ x\ P$), 60 > (0.3 x 35) ; 60 > 10.5

$$\eta_b = \frac{W+e^2P}{W+P} = \frac{60 + (0.3^2\ x\ 35)}{60+35} = 0.665$$

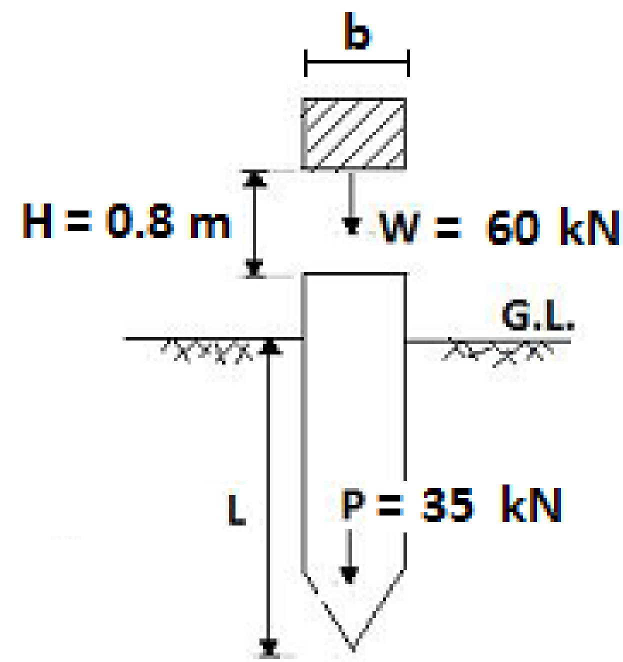
In the problem , it is clearly mentioned that Effective Fall = 0.8 m

$\therefore$ ($\eta_h\ x\ H$) = 0.8 m as per note given in the formula of Q_f

Ultimate Load carrying capacity of pile :

$$Q_f = \frac{(\eta_h W H \eta_b)}{S+(C/2)} = \frac{(0.8\ x\ 60\ x\ 0.665)}{0.012+(0.018/2)} = 1520\ \ KN$$

Safe Load (Allowable load) = (Q_f/Fos) = (1520 / 2.5) = 608 kN



Problem 3 Determine the safe load that can be carried by a pile having a gross weight of 20 kN using modified Hiley's formula. Given that The Weight of hammer = 23 kN, Height of free fall = 90 cm , Hammer efficiency = 75%. Average penetration under the last 5 blows = 10 mm , Length of pile = 20 m, Diameter of pile = 350 mm, Coefficient of restitution 0.55. ?

[SGBAU, W – 17/8 m, S – 19/ 7 m]

Solution :

Note : We have to find Allowable load which relates to the pile weight of 20 KN .

So, avoid the length and the diameter of pile and do not calculate P w.r.t. diameter again.

Given , W = 23 KN , P = 20 KN , H = 90 cm

e = 0.55 , $\eta_h = 75\ \% = (75/100) = 0.75$

S = 1 cm for 5 Blows i.e. (1/5) = 0.2 $cm/blow$

Assuming drop Hammer , C = 2.5 cm

Assuming Factor of Safety as = 2.5

Here, W > ($e \ x \ P$) , 23 > (0.55 x 20) ; 23 > 11

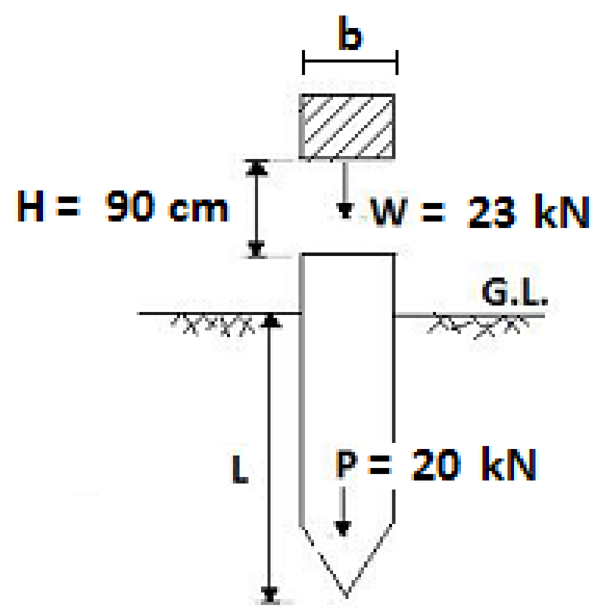
$$\eta_b = \frac{W + e^2 P}{W + P} = \frac{23 + (0.55^2 \ x \ 20)}{23 + 20} = 0.675$$

Ultimate Load carrying capacity of pile :

$$Q_f = \frac{(\eta_h \, W H \, \eta_b)}{S + (C/2)} = \frac{(0.75 \ x \ 23 \ x \ 90 \ x \ 0.675)}{0.2 + (2.5/2)}$$

$$= 722.71 \ \text{KN}$$

Safe Load (Allowable load) = (Q_f /Fos) = 290 KN



Problem 4 A Reinforced concrete pile weighing 35 KN (Inclusive of helmet and Dolly) is driven by deep hammer weighing 40 KN and having an effective fall of 0.8 m. The average set per blow is 1.4 cm . The total temporary elastic Compression is 1.8 cm. Assuming the coefficient of restitution as 0.25 and FOS as 2.0, Determine the Ultimate Bearing capacity and the Allowable load for the pile ? **[RTMNU, S – 15/ 7 m]**

Solution :

$P = 35\ KN$, e = 0.25, C = 1.8 cm , W = 40 kN

S = 1.4 $cm/blow$; FOS = 2.0

Here, W > ($e\ x\ P$) , 60 > (0.3 x 35) ; 40 > 8.75

$$\eta_b = \frac{W + e^2 P}{W + P} = \frac{40 + (0.25^2\ x\ 35)}{40 + 35} = 0.562$$

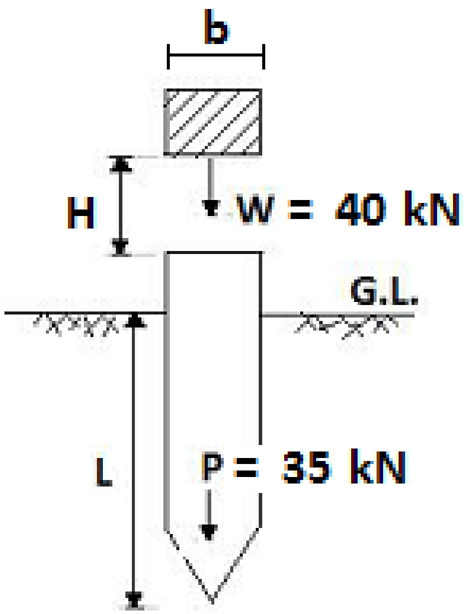
In the problem , it is clearly mentioned that Effective Fall = 0.8 m

∴ ($\eta_h\ x\ H$) = 0.8 m = 80 cm as per note given in the formula of Q_f

Ultimate Load carrying capacity (Bearing Capacity) of pile :

$$Q_f = \frac{(\eta_h W H \eta_b)}{S + (C/2)} = \frac{(80\ x\ 40\ x\ 0.562)}{1.4 + (1.8/2)} = 782\ \text{KN}$$

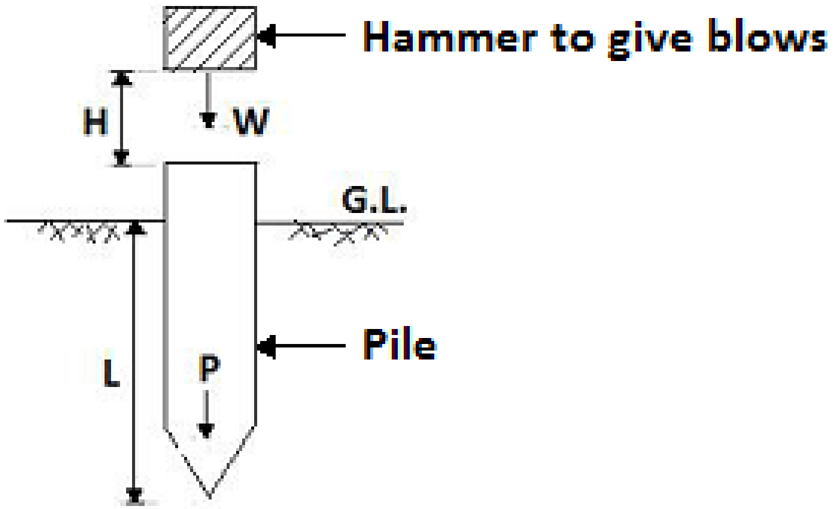
Safe Load (Allowable load) = ($Q_f\ /Fos$) = (782 / 2) = 391 kN



2. Engineering News Formula :

Following Expression is use to Find Ultimate Load carrying capacity of pile (Q_f)

$$\therefore Q_f = \frac{W\ H}{S + C}$$



Where,

W – Weight of hammer in KN ; H – Height of fall

S – Penetration per blow or Set per down or Set per blow

C – Elastic Compression of pile

For drop Hammer, C = 2.5 cm if not given

For steam hammer, C = 0.25 cm if not given

The Factor of Safety is taken as 6.00

Hence, Safe (Allowable) Load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos)$$

3. Modified Engineering News Record (ENR) Formula :

Following Expression is use to Find Ultimate Load carrying capacity of pile (Q_f)

$$\therefore\ Q_f = \frac{W\ H}{S + C}$$

For drop Hammer, Elastic Compression (C) = 2.5 cm if not Given.

For Single Acting steam Hammer, Elastic Compression (C) = 0.25 cm if not given.

The Factor of Safety is taken as 6.00

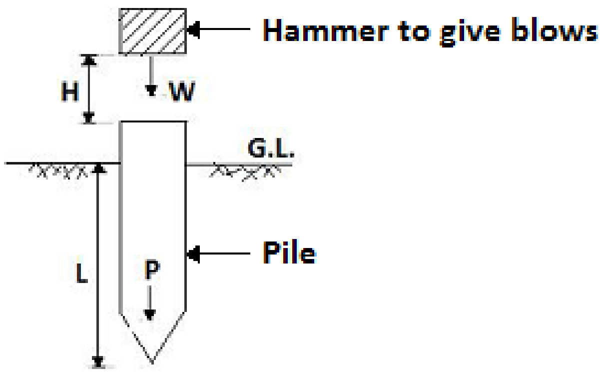
Ultimate Load Carrying capacity of Double acting steam Hammer ,

$$Q_f = \frac{(W + a\,p)\,H}{(S + C)}$$

Where, a – Effective area of piston in cm^2

P – Mean Effective steam pressure in kg/cm^2

For Double acting steam Hammer, Elastic Compression (C) = 0.25 cm if not given.



Hence, Safe (Allowable) Load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos)$$

Problem 5. A precast concrete pile was driven in sand, using a 50 kN hammer having a free fall of 1.2 m. If the penetration of pile in the last few blows of hammer was noted as 9.0 mm. Determine the load carrying capacity of pile in kN, using Engineering News formula ?

[SGBAU, S – 17/7 m]

Solution :

Given : W = 50 KN , H = 1.2 m = 1200 mm ,

S = 9 $mm/blow$,

Assume Factor of Safety = 6.0

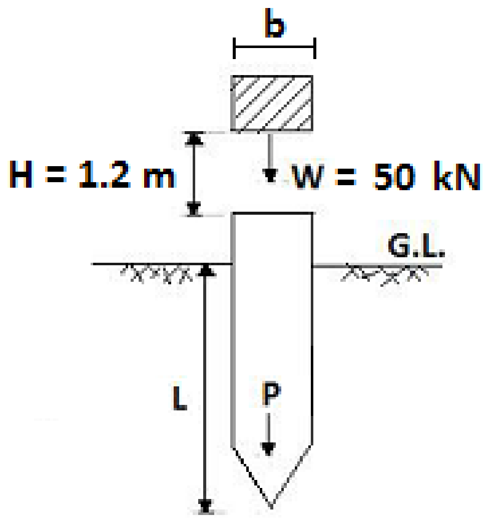
Assuming Drop Hammer , $\therefore$ C = 2.5 cm

Ultimate Load carrying capacity of pile (Q_f) is given by :

$$Q_f = \frac{WH}{S+C} = \frac{(50 \times 1200)}{9+2.5} = 5217 \text{ KN}$$

Safe (Allowable) Load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos) = (5217 / 6) = 870 \text{ KN}$$



Problem 6 A precast concrete pile was driven in sand, using 5.0 T hammer having a free Fall of 1.0 m. If the penetration of the pile in the last few blows of hammer was 8.0 mm per blow, determine the load carrying capacity of the pile in kN, using Engineering New formula. **[SGBAU, W – 14/ 8 m]**

Solution :

Given : W = 5.0 tonnes = 5000 Kg = 50,000 N = 50 KN

H = 1 m = 100 Cm,

S = 8 $mm/blow$ = 0.8 $Cm/blow$, Assume Factor of Safety = 6.0

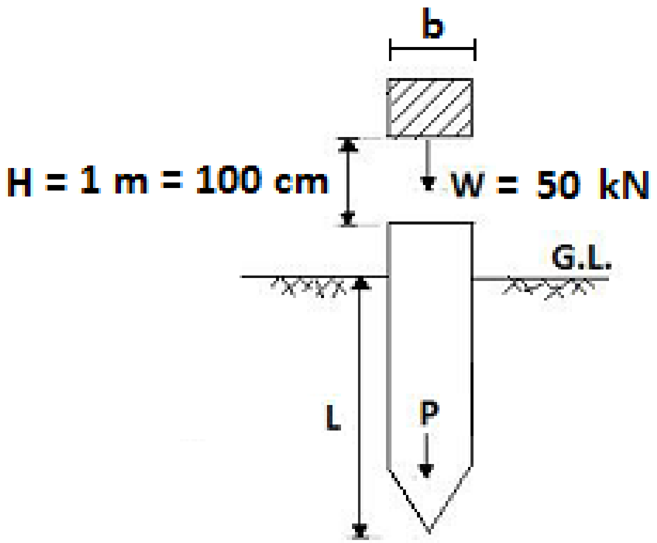
Assuming Drop Hammer, ∴ C = 2.5 cm

Ultimate Load carrying capacity of pile (Q_f) is given by :

$$Q_f = \frac{WH}{S+C} = \frac{(50 \times 100)}{0.8 + 2.5} = 1515 \text{ KN}$$

Safe (Allowable) Load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos) = (1515 / 6) = 253 \text{ KN}$$



Problem 7 A double acting steam hammer used to drive a present pile. Estimate from the following pile driving data , the ultimate load on pile using ENR formula. Weight Of Hammer = 9 KN, Stroke = 0.5 m , Effective Area of piston = 200 Cm2 , Steam Pressure at down stroke = 150 , kN/m2 . Pile Penetration For the Last 20 Blows = 15 Cm. **[SGBAU, W – 18/ 7 m]**

Solution :

Given, W = 9 KN ,

Effective Area of piston (a) = 200 Cm2 = $200 \; x \; 10^{-4} = 0.02 \; m^2$

Steam Pressure at down stroke (P) = $150 \; kN/m^2$,

Height of fall of Piston (Stroke) = H = 0.5 m.

S = 15 cm for 20 Blows i.e. $(0.15/20) = 0.0075 \; m/blow$

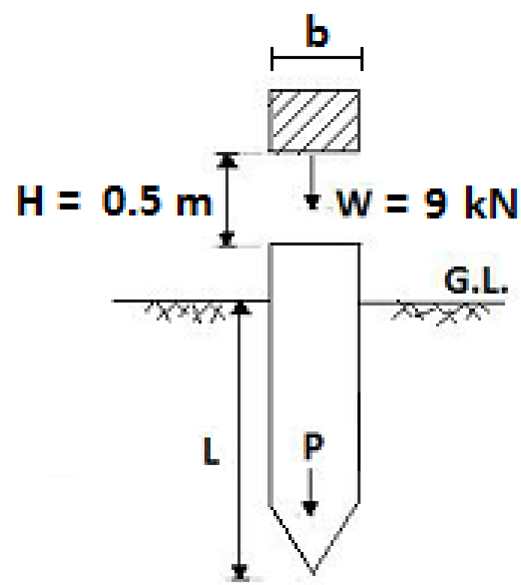
For Steam Hammer , C = 0.25 cm = 0.0025 m

Ultimate Load carrying capacity for double acting steam hammer by ENR Formula is given by,

$$Q_f = \frac{(W + a\,p)\,H}{(S + C)} = \frac{[9 + (0.02 \, x \, 150)] \, x \, 0.5}{(0.0075 + 0.0025)} = 600 \; KN$$

Safe (Allowable) Load carrying capacity of pile is given by,

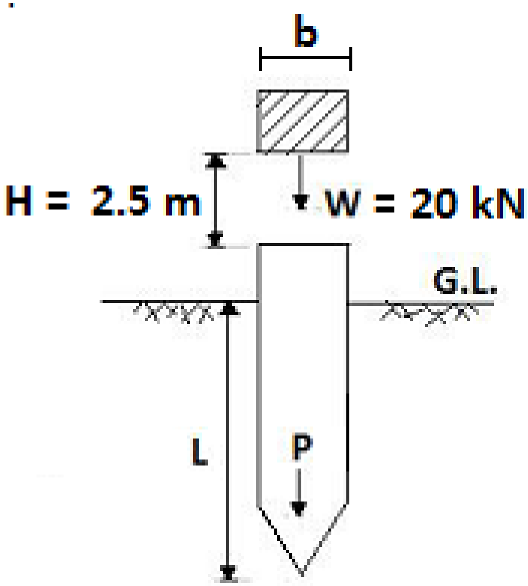
$$Q_{safe} = (Q_f / Fos) = (600 \; / \; 6) = 100 \; KN$$



Problem 8 Find the safe design load on a pile given that the weight of the drop hammer is 20 kN and penetration of pile under the last blow of the hammer is 3.5 mm. Use ENR formula. What is safe design load for same data if another piles steam hammer is used ? Height of the drop of the hammer in both cases is 2.5 m. **[SGBAU, W – 15/ 7 m]**

Solution :

Ultimate Load carrying capacity of pile (Q_f) by ENR Formula is given by :



$$Q_f = \frac{WH}{S + C}$$

Case 1]

Given, W = 20 KN ,

H = Height of fall = 2.5 m = 2500 mm , S = 3.5 $mm/blow$

For drop Hammer, Elastic Compression (C) = 2.5 cm

$$\therefore Q_f = \frac{WH}{S+C} = \frac{(20 \ x \ 2500)}{(3.5 + 2.5)} = 8333.34 \ \text{KN}$$

Safe (Allowable) Load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos) = (8333.34 / 6) = 1389 \ \text{KN}$$

Case 2]

For single acting steam Hammer , Elastic Compression (C) = 0.25 cm

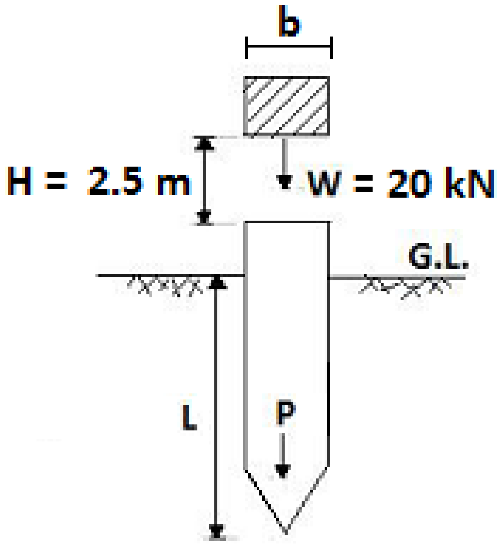
Ultimate Load Carrying capacity of single acting steam Hammer by

ENR Formula is given by ;

$$\therefore\ Q_f = \frac{WH}{S+C} = \frac{(20\ x\ 2500)}{(3.5+0.25)} = 13333.34\ \text{KN}$$

Safe (Allowable) Load or design load carrying capacity of pile is given by,

$$Q_{safe} = (Q_f / Fos) = (13333.34 / 6) = 2222.23\ \text{KN}$$



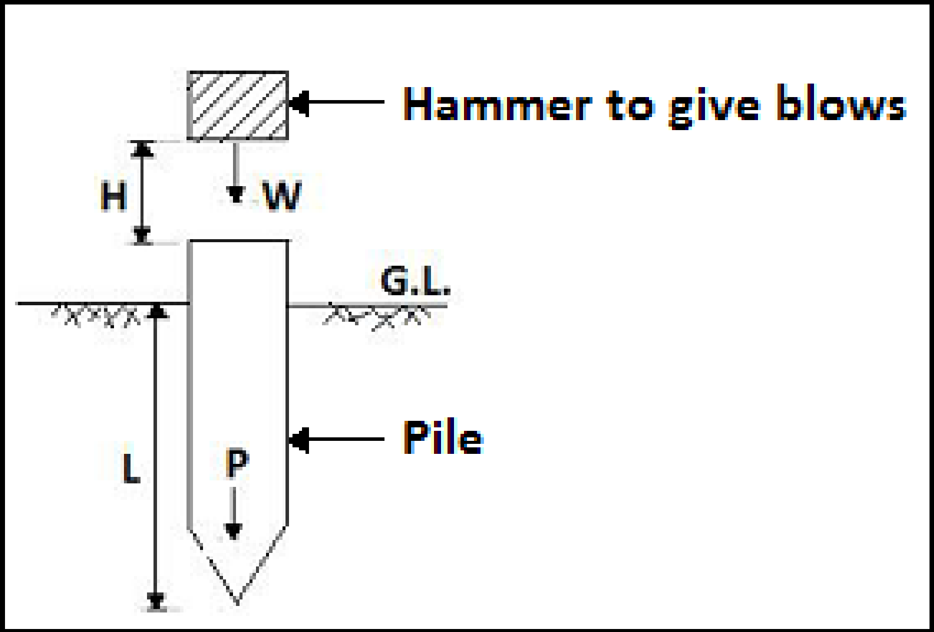


Figure : The power of group of piles

The load Carrying capacity of Piles can be determined by following methods :

1. Static Formula
2. Dynamic Formula
3. Pile Load Test
4. Penetration Tests

Static Approach

- Bored Piles
  - In Sand
  - In Clay
- Driven Piles
  - In Sand
  - In Clay

Bored Piles in Clay :

Ultimate Load Carrying capacity (Q_f) is given by :

$$Q_f = [\, Q_P + Q_S \,] = [\, C\ N_C\ A_P + \alpha\ \bar{C}\ A_S \,] = [\, 9\ C\ A_P + \alpha\ \bar{C}\ A_S \,]$$

Where, Q_P = Load Transferred through tip (point) of the pile (Bearing Resistance) = $C\ N_C\ A_P = 9\ C\ A_P$

Where, N_C = Bearing Capacity Factor = 9

C – Cohesion at base (tip) of pile in kN/m^2

$A_P =$ Cross sectional Area of the Pile ;

Q_S = Load Transferred through surface of the pile

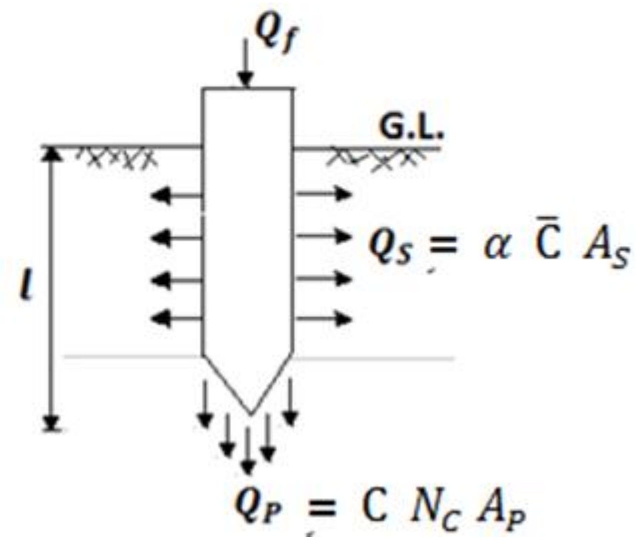
(Frictional Resistance) = $\alpha\ \bar{C}\ A_S$

n - Total Number of Piles ; l – Length of the pile.

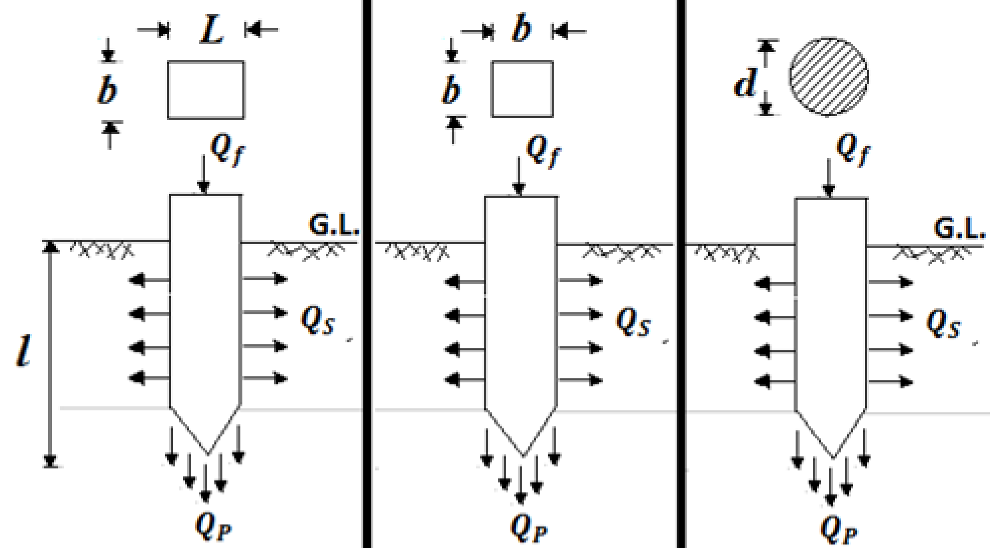
$\bar{C}$ – Cohesion along the surface of pile in kN/m^2

$\alpha = m =$ Shear Mobilizing Factor or Adhesion Factor.

Take $\alpha = 1$ if not given in the problem. $A_S =$ Surface Area of the Pile



Important Notes



Rectangular Pile

$A_p = b \times L$

$A_s = (2b + 2L) \times l$

Square Pile

$A_p = b^2$

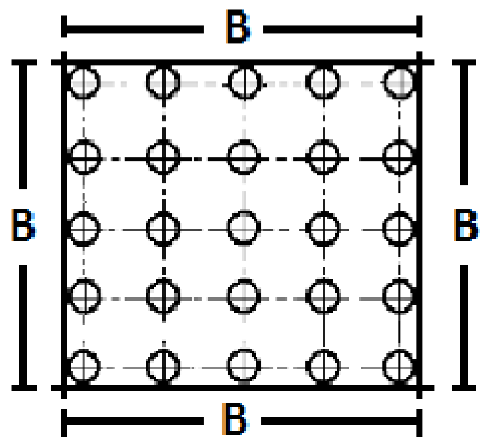
$A_s = 4 \times b \times l$

Circular Pile

$A_p = (\pi/4)\, d^2$

$A_s = \pi \times d \times l$

where, l - Length of the pile



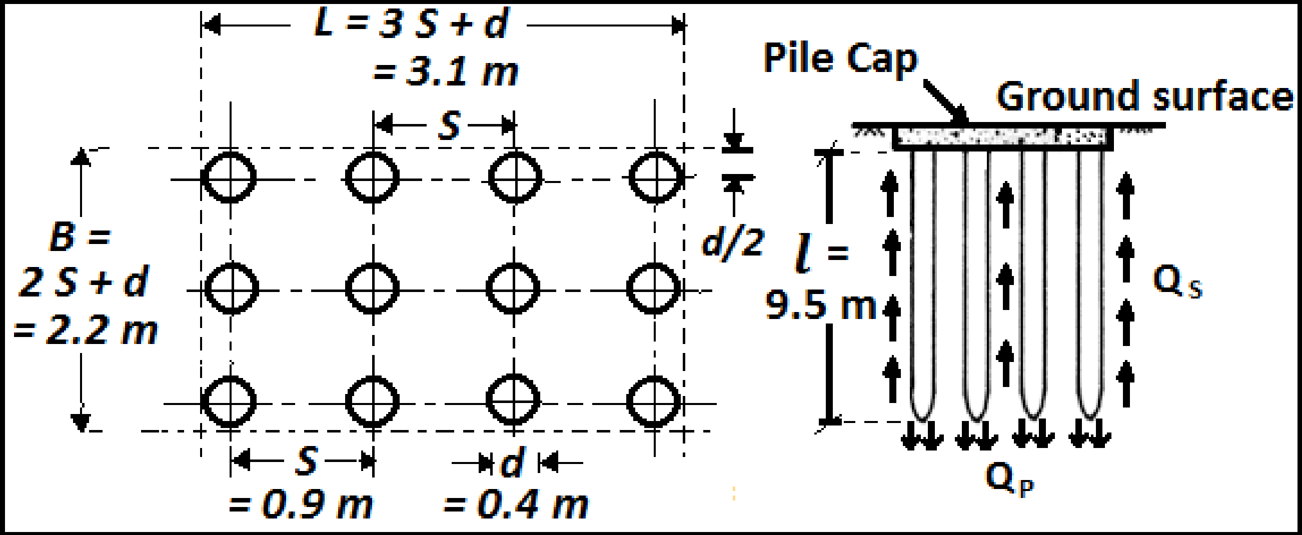
$Ap = B^2$

$As = 4\, B\, l$

Problem 4.1 A group of 12 piles was driven into soft clay. The diameter and length of piles were 400 mm & 9.5 m respectively. If unconfined compressive strength of clay is 90 kN / m2 and spacing is 900 mm C/C. what is the capacity of the group. Assume F.O.S. is 2.5 and adhesion factor 0.8. ? **[RTMNU, S – 17/ 8 m]**

Solution :

Note : 12 Number of piles can not be arranged in square pattern . so Assume that there are 3 Rows and 4 Columns. You can also assume the order as 4 rows and 3 columns as per your convenience.



Given, Diameter of Pile (d) = 400 mm = 0.4 m

Length of Pile (l) = 9.5 m

Spacing (S) = 900 mm = 0.9 m

Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.80

No. of Piles = n = 12

Unconfined Compression Strength (UCS) = 90 kN / m2

$$\therefore \text{ Cohesion } (C = \bar{C}) = (UCS/2) = (90/2) = 45 \quad kN/m^2$$

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

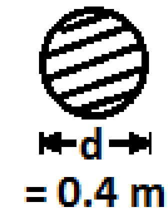
$$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$$

Bearing Resistance $(\ Q_P\ ) =\ C\ \ N_C\ A_P\ = 9\ C\ A_P = [\ 9\ x\ 45\ \ x\ \ (\pi/4)\ 0.4^2\ ] = 50.9$

Frictional Resistance $(\ Q_S\ ) =\ \alpha\ \bar{C}\ A_S\ = [\ 0.8\ x\ 45\ \ x\ \ (\ \pi\ x\ 0.4\ x\ 9.5\ )\ ] = 430$

$\therefore\ Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ] = n\,[\ C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\ ] = n\,[\ 9\ \ C\ A_P + \alpha\ \bar{C}\ A_S\ ]$

$= 12\ [50.9\ +\ 430] =\ 5772\ \ KN$



Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

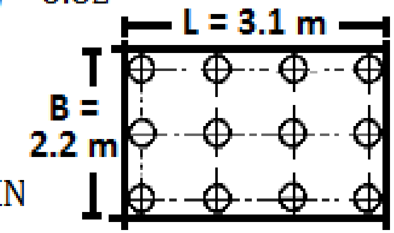
$Q_{f\ group} =\ Q_P + Q_S\ = [\ C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\ ] =\ [\ 9\ \ C\ A_P + \alpha\ \bar{C}\ A_S\ ]$

$A_P = (\ B\ x\ L\ ) = [(\ 2S + d\ )\ x\ (\ 3S + d\ )] = [(\ 2(0.9) + 0.4\ )\ x\ (\ 3(0.9) + 0.4\ )] = (\ 2.2\ x\ 3.1\ ) = 6.82$

$A_s = [2(\ 2S + d\ ) +\ 2(\ 3S + d\ )]\ x\ l$

$= [2(\ 2(0.9) + 0.4\ ) +\ 2(\ 3(0.9) + 0.4\ )]\ x\ \ 9.5\ = [(2\ x\ 2.2) + (2\ x\ 3.1)]\ x\ 9.5 = 100.7$

$Q_{f\ group} =\ [\ 9\ \ C\ A_P + \alpha\ \bar{C}\ A_S\ ] =\ [\ (9\ x\ 45\ x\ 6.82) + (\ 0.8\ x\ 45\ x\ 100.7]\ =\ 6387.3\ \ KN$



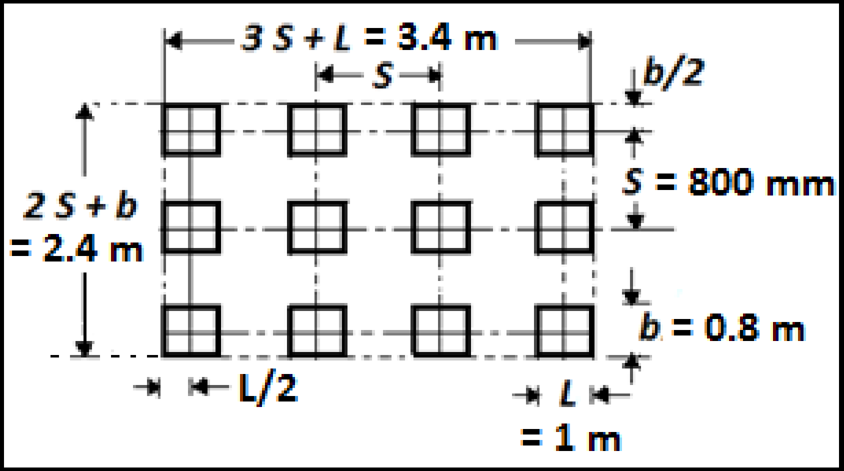
Ultimate Load Carrying capacity of group of Piles is minimum value from above two cases .

$$\therefore\ Q_{f\ group} = 5772\ \ kN$$

Problem 4.2 A group of 12 piles having rectangular C/S of 0.8 m x 1.0 m was driven into soft clay. The length of piles is 9.5 m. If unconfined compressive strength of clay is 90 kN / m2 and spacing is 800 mm C/C. what is the capacity of the group. Assume F.O.S. is 2.5 and adhesion factor 0.8. ?

Solution :

Note : 12 Number of piles can not be arranged in square pattern . so Assume that there are 3 Rows and 4 Columns. You can also assume the order as 4 rows and 3 columns as per your convenience.



Given, rectangular shape of pile having length (L) = 1 m and width (b) = 0.8 m

Length of Pile (l) = 9.5 m

Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.80 No. of Piles = n = 12

Unconfined Compression Strength (UCS) = 90 kN / m2

$$\therefore \ \text{Cohesion} \, (C = \bar{C}) = (UCS/2) = (90/2) = 45 \ \ kN/m^2$$

Case 1] When Piles acting Individually :

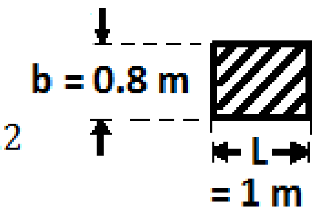
Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\,group} = n \ x \ \ Q_{f\,one} = n\,[\ Q_P + Q_S\ ]$$

$$\text{Bearing Resistance } (Q_P) = \ C\ \ N_C\, A_P \ = 9\ C\ A_P = [\,9\,x\ C\ x\ (\,L\,x\,b\,)\,] = \ [\,9\,x\,45\ \ x\ \ 1\,x\,0.8\,] = 324$$

$$\text{Frictional Resistance } (Q_S) = \ \alpha\ \bar{C}\ A_S \ = \alpha\,x\ \bar{C}\ x\ [(\,2\,L + 2\,b\,)\ \ x\ \ l\,]$$

$$= \ 0.8\,x\,45\ \ x\,\{\,[(\,2\ \ x\ \ 1\,) + (\,2\,x\,0.8\,)\,]\ \ x\ \ 9.5\,]\,\} = 1231.2$$



$$\therefore\ Q_{f\,group} = n \ x \ \ Q_{f\,one} = n\,[\ Q_P + Q_S\ ] = n\,[\,C\ N_C\,A_P \ + \ \alpha\ \bar{C}\ A_S\,] = n\,[\,9\ \ C\ A_P \ + \ \alpha\ \bar{C}\ A_S\,]$$

$$= \ 12\,[324 \ + \ 1231.2] \ = 18662 \ \ KN$$

Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

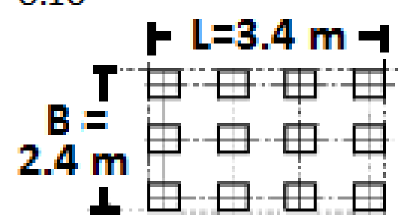
$$Q_{f\,group} = \ Q_P + \ Q_S \ \ = [\,C\ N_C\,A_P \ + \ \alpha\ \bar{C}\ A_S\,] = \ [\,9\ \ C\ A_P \ + \ \alpha\ \bar{C}\ A_S\,]$$

$$A_P = (\,B\ x\ L\,) = [(\,2S + b\,)\ x\ (\,3S + L\,)] = [(\,2(0.8) + 0.8\,)\ x\ (\,3(0.8) + 1\,)] = (\,2.4\ \ x\ \ 3.4\,) = 8.16$$

$$A_s = [\ (2\,B + 2\,L\,)\ x\ \text{ lengt of pile } (\,l\,)] = [2(\,2S + b\,) + \ 2(\,3S + L\,)]\ x\ \ l$$

$$= [2(\,2(0.8) + 0.8\,) + \ 2(\,3(0.8) + 1\,)]\ x\ \ 9.5 \ = [(2\,x\,2.4) + (2\,x\,3.4)]\ x\,9.5 = 110.2$$

$$Q_{f\,group} = \ [\,9\ \ C\ A_P \ + \ \alpha\ \bar{C}\ A_S\,] \ = \ [\,(9\,x\ \ 45\,x\ \ 8.16) + (\,0.8\,x\,45\,x\,110.2]\ = \ 7272 \ \ KN$$

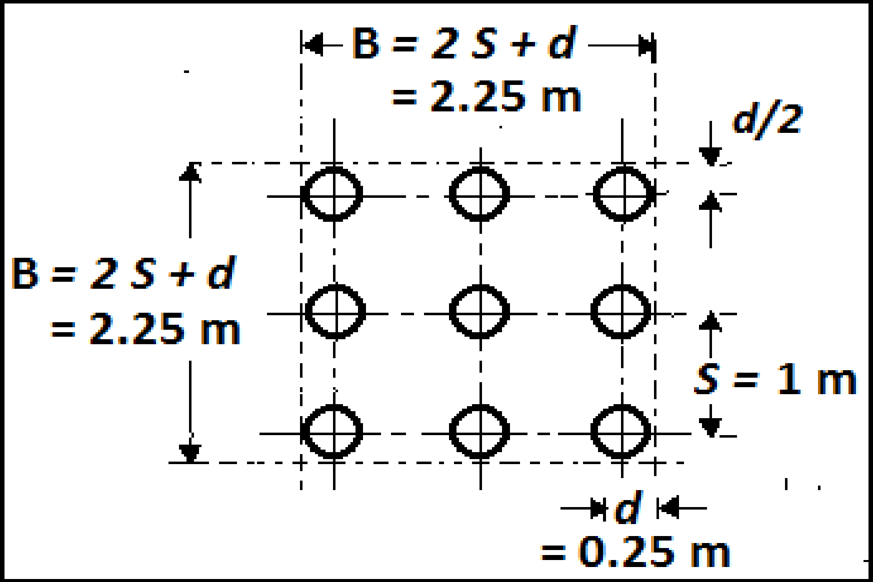


Ultimate Load Carrying capacity of group of Piles is minimum value from above two cases .

$$\therefore\ Q_{f\,group} = 7272 \ \ kN$$

Problem 4.3 A group of 9 piles arranged in a square pattern with diameter and length of each pile a 0.25 m and 10 m respectively, is used as a foundation in soft clay deposit. Taking the unconfined compressive strength of clay as 120 kN / m2 and the pile spacing as 1 m c/c, Find the load capacity of the group. Assume the bearing capacity factor Nc = 9 and adhesion factor = 0.75. A factor of safety of 2.5 may be taken. ? **[RTMNU,S–18,S–19/7m]**

Solution :



Given, Diameter of Pile (d) = 250 mm = 0.25 m

Length of Pile (l) = 10 m Spacing (S) = 1 m No. of Piles = n = 9

Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.75

Unconfined Compression Strength (UCS) = 120 kN / m2

$$\therefore \text{Cohesion} \; (C = \bar{\text{C}}) = (\text{UCS}/2) = (120/2) = 60 \quad kN/m^2$$

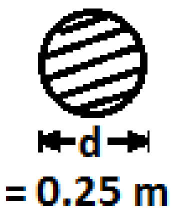
Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$$

Bearing Resistance $(\,Q_P\,) = \ C\ \ N_C\,A_P\ \ = 9\ \ C\ \ A_P = [\,9\,x\ \ 60\ \ x\ \ (\pi/4)\ \ 0.25^2\,] = \ \ 128.3$

Frictional Resistance $(\,Q_S\,) = \alpha\ \bar{C}\ \ A_S\ \ = [\,0.8\ x\ \ 60\ \ x\ (\,\pi\,x\,0.25\,x\,10\,)\,]\ =\ 377$



$$\therefore\ Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\,] = \ n\,[\,C\ N_C\,A_P\ + \ \alpha\ \bar{C}\ A_S\,] = n\,[\,9\ \ C\ \ A_P\ + \ \alpha\ \bar{C}\ A_S\,]$$

$$= \ n\,[\,9\ \ C\ \ A_P\ + \ \alpha\ \bar{C}\ A_S\,] = 9\,[128.3 + 377] = 4548\ \text{KN}$$

Case 2] Piles acting In group :

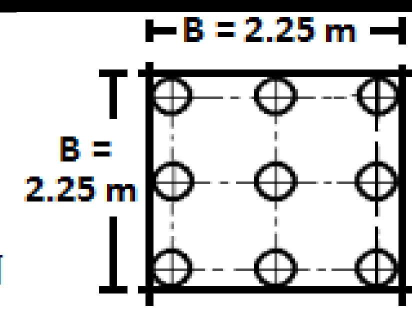
Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} \ = \ Q_P + \ Q_S \ \ = [\,C\ \ N_C\,A_P\ + \ \alpha\ \bar{C}\ A_S\,] \ = \ [\,9\ \ C\ \ A_P\ + \ \alpha\ \bar{C}\ A_S\,]$$

$$A_P = B^2 = \ (\,2S + d\,)^2 = \ [(\,2\,(\,1\,) + 0.25\,)]^2 = 5.06$$

$$A_s \ = 4\ \ B\ \ l\ \ = [\,4\,x\ \ (\,2\,(\,1\,) + 0.25\,)\,]\,x\,10 = 90$$

$$\therefore\ Q_{f\ group} \ = \ [\,9\ \ C\ \ A_P\ + \ \alpha\ \bar{C}\ A_S\,] = \ [\,(9\ x\ \ 60\ x\ \ 5.06)\ + (\,0.8\,x\,60\,x\,90)\,] = 7052\ \ \text{KN}$$



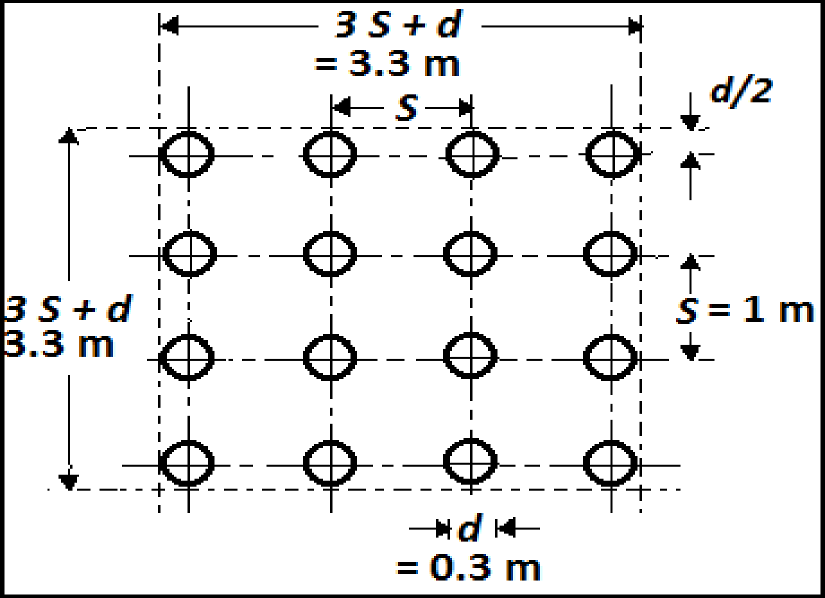
Ultimate Load Carrying capacity of group of Piles is minimum value from above two cases .

Hence ,

$$Q_{f\ group} \ = \ \ 4548\ \ \text{kN}$$

Problem 4.4 A group of 16 piles arranged in a square pattern with diameter and length of each pile as 0.30 m and 9 m respectively, is used as foundation in soft clay deposit. Taking the unconfined compressive strength of clay as 140 kN/m2. and the pile spacing as 1 m c/c, find the load capacity of the group and its Efficiency. Assume the bearing capacity factor, Nc = 9 and adhesion factor = 0.70. A factor of safety of 2.5 may be taken ? **[RTMNU, W – 18/8 m]**

Solution :



Given, Diameter of Pile (d) = 300 mm = 0.3 m

Length of Pile (l) = 9 m

Spacing (S) = 1 m

Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.70

No. of Piles = n = 16

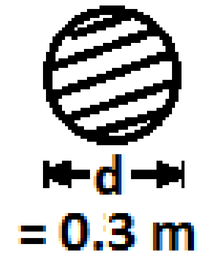
Unconfined Compression Strength (UCS) = 140 kN / m2

$\therefore$ Cohesion ($C = \bar{C}$) = $(\mathrm{UCS}/2) = (140/2) = 70 \ \ kN/m^2$

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n \times Q_{f\ one} = n\,[\,Q_P + Q_S\,]$$

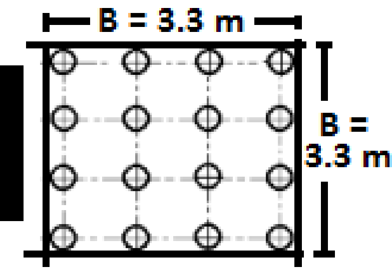


Bearing Resistance $(Q_P) = C\ N_C\ A_P = 9\ C\ A_P = [\,9 \times 70 \times (\pi/4)\ 0.3^2\,] = 44.53$

Frictional Resistance $(Q_S) = \alpha\ \bar{C}\ A_S = [\,0.7 \times 70 \times (\pi \times 0.3 \times 9)\,] = 415.632$

$$\therefore Q_{f\ group} = n \times Q_{f\ one} = n\,[\,Q_P + Q_S\,] = n\,[\,C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\,] = n\,[\,9\ C\ A_P + \alpha\ \bar{C}\ A_S\,]$$

$$= 16\,[44.53 + 415.63] = 7362.56\ \text{KN}$$



Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = Q_P + Q_S = [\,C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\,] = [\,9\ C\ A_P + \alpha\ \bar{C}\ A_S\,]$$

$A_P = B^2 = (3S + d)^2 = [(3(1) + 0.3)]^2 = 3.3^2 = 10.89$ and $A_s = 4\ B\ l = [\,4 \times 3.3 \times 9\,] = 82.8$

$$\therefore Q_{f\ group} = [\,9\ C\ A_P + \alpha\ \bar{C}\ A_S\,] = [\,(9 \times 70 \times 10.89) + (0.7 \times 70 \times 82.8]\,= 10917.9\ \text{KN}$$

Ultimate Load Carrying capacity of group of Piles is minimum value from above two cases .

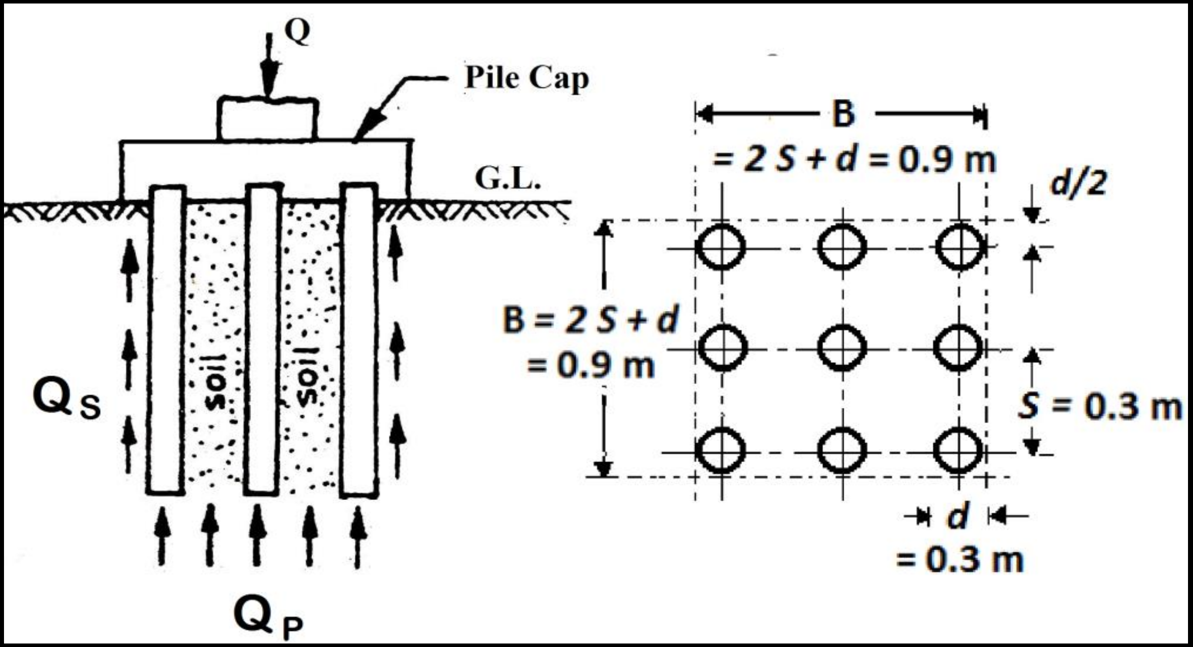
$$\therefore Q_{f\ group} = 7362.56\ \text{kN}$$

$$\text{Efficiency}\ (\eta) = \frac{\text{LCC When piles acting in Group (Case 2)}}{\text{LCC when piles acting Individualy (Case 1)}}$$

$$\therefore \eta = \left(\frac{10917.9}{7362.56}\right) = 1.482$$

Problem 4.5 A group of 9 piles with 3 piles in a row was driven in to soft clay. The diameter and length of pile were 300 mm and 9 m respectively. The UCS of clay is 70 kN/m2. The piles were spaced at 30 cm center to centre. compute the allowable load on pile group for FOS of 2.5. Neglect End bearing resistance. Take adhesion factor as 0.8 ? **[SGBAU, W – 19/7 m]**

Solution :



Given, Diameter of Pile (d) = 300 mm = 0.3 m

Length of Pile (l) = 9 m Spacing (S) = 30 cm = 0.3 m No. of Piles = n = 9

Assume Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.80

Unconfined Compression Strength (UCS) = 70 kN / m2

$\therefore$ Cohesion $(C = \bar{C}) = (UCS/2) = (70/2) = 35 \ kN/m^2$

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$

Neglecting End Bearing Resistance $(\ Q_P\ ) = \ \mathrm{C}\, N_C\, A_P \ = 9\,\mathrm{C}\,A_P$

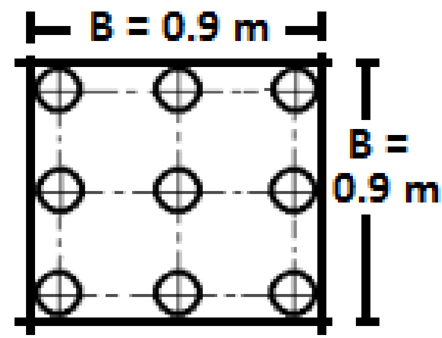
Frictional Resistance $(\ Q_S\ ) = \ \alpha\ \bar{\mathrm{C}}\ A_S \ = [\,0.8\ x\ \ 35\ \mathrm{x}\ (\,\pi\, x\, 0.3\, x\, 9\,)\,] = \ 237.50$

$\therefore\ Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\ [\,Q_S\,] = \ n\,[\ \ \alpha\ \bar{\mathrm{C}}\ A_S\,] = (\,9\,x\,237.50) = 2137.5\ \ \mathrm{KN}$

Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

$Q_{f\ group} = \ Q_P + Q_S \ \ = [\,\mathrm{C}\ N_C\ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ \ A_S\,] = \ [\,9\ \ \mathrm{C}\ \ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ \ A_S\,]$



Neglecting End Bearing Resistance $(\ Q_P\ ) = \ \mathrm{C}\, N_C\, A_P = 9\,\mathrm{C}\,A_P$

$\therefore\ Q_{f\ group} = \ Q_S\ = \ \alpha\ \bar{\mathrm{C}}\ A_S$

$A_s = 4\ \ B\ \ l\ \ = [\,4\,x\ \ (\,2\,(\,0.3\,) + 0.3\,)\,]\,x\,9 = (\,4\,x\ \ 0.9\,x\,9\,) = 32.4$

$\therefore\ Q_{f\ group} = \ Q_S\ = \ \alpha\ \bar{\mathrm{C}}\ A_S\ = (0.8\,x\ \ 35\ \ x\ \ 32.4) = 907.2$

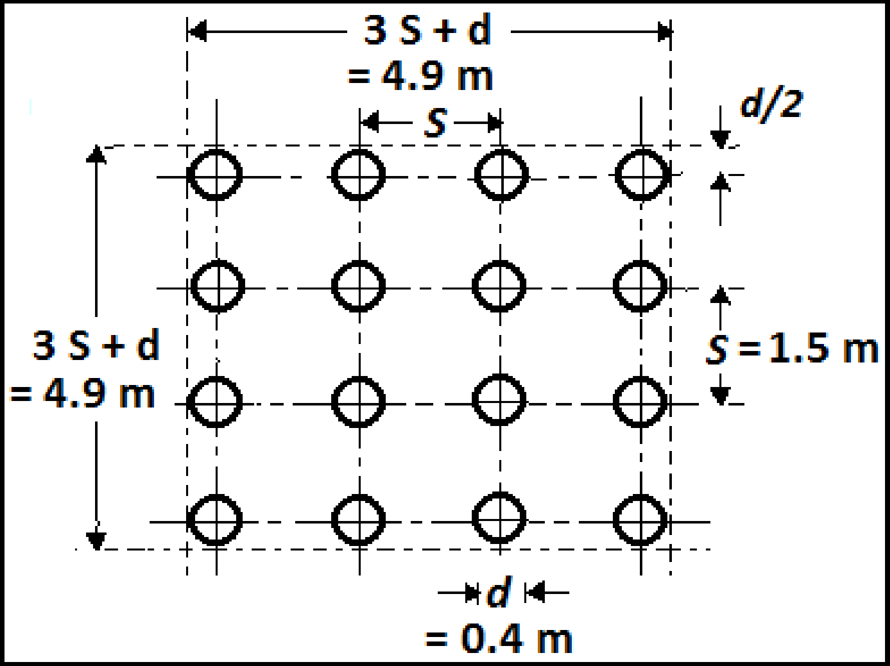
Ultimate Load Carrying capacity of group of Piles is minimum value from above two cases .

$\therefore\ Q_{f\ group} = 907.2\ \ \mathrm{kN}$

Safe Load (Allowable Load) = $Q_{f\ safe} \ = \ (\ Q_{f\ group}/fos\ ) \ = \ (\,907.2/2.5\,) = 363\ \ \mathrm{kN}$

Problem 4.6 Determine whether the failure of pile group of 16 piles of 0.4 m diameter is occurring as a block failure or when pile acts individually ? The c/c spacing of piles is 1.5 m and piles are 12 m long, Take C = 50 kN/m2, m = 0.7. Neglect the bearing resistance at the tip of pile. ? **[SGBAU, W-15, W-16/7 m]**

Solution :



Given, Diameter of Pile (d) = 0.4 m   Length of Pile (l) = 12 m   No. of Piles = n = 16

Spacing (S) = 1.5 m

Assume Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.70

Cohesion ($C = \bar{C}$) = 50 KN/m^2

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$$

Neglecting End Bearing Resistance (Q_P) = C N_C A_P = 9 C A_P

Frictional Resistance (Q_S) = $\alpha\ \bar{C}\ A_S$ = [0.7 x 50 x (π x 0.4 x 12)] = 528

$\therefore\ Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\ [\,Q_S\,] = n\ [\ \alpha\ \bar{C}\ A_S\ ] = (\,16\ x\ 528\,) = 8448$ KN

Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

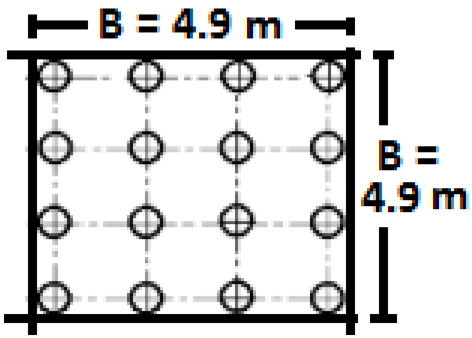
$$Q_{f\ group} = Q_P + Q_S = [\ \mathrm{C}\ N_C\ A_P + \alpha\ \bar{C}\ A_S\ ] = [\ 9\ \mathrm{C}\ A_P + \alpha\ \bar{C}\ A_S\ ]$$

Neglecting End Bearing Resistance (Q_P) = C N_C A_P = 9 C A_P

$\therefore\ Q_{f\ group} = Q_S = \alpha\ \bar{C}\ A_S$

$A_s = 4\ B\ l = [\,4\ x\ (\,3\,(\,1.5\,) + 0.4\,)\,]\ x\ 12 = (4\ x\ 4.9\ x\ 12) = 235.2$

$\therefore\ Q_{f\ group} = Q_S = \alpha\ \bar{C}\ A_S = (0.7\ x\ 50\ x\ 235.2) = 8232\ kN$



LCC in Case 2 i.e. when Piles acting in group (Block Failure) is less than LCC in Case 1 i.e. When pile acting individually .

i.e. 8232 kN < 8448 kN .

Hence the Foundation will fail by Piles acting in Group and the load at failure would be 8232 kN

Problem 4.7 A square group of a piles, 300 mm diameter is arranged with a pile spacing of 3d, where d is the diameter of pile. The length of the pile is 9.0 m. Unit cohesion of clay is 75 kN/m2. Neglecting bearing at the tip of pile, determine the group capacity. Assume adhesion factor as 0.75 ? **[SGBAU, S – 19/6 m]**

Solution :

Given, Diameter of Pile (d) = 300 mm = 0.3 m

Length of Pile (l) = 9 m

Number of piles in the group = n

Spacing (S) = 3 d = (3 x 0.3) = 0.9 m = 900 mm

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.75

Cohesion ($C = \bar{C}$) = 75 kN/m^2

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n \ x \ \ Q_{f\ one} = n\,[\ Q_P + Q_S\,] = n\,[\,C\ N_C\ A_P\ + \alpha\ \bar{C}\ A_S\,] = n\,[\,9\ C\ A_P\ + \alpha\ \bar{C}\ A_S\,]$$

Neglecting End Bearing Resistance or Resistance at base or at tip (point) of the pile (Q_P) = $C\ N_C\ A_P = 9\ C\ A_P$

Where, A_P = Cross sectional area of pile = $(\pi/4)\ d^2$

and Frictional Resistance or resistance along surface of the pile $(Q_S) = \alpha\ \bar{C}\ A_S$

Where, A_S = Surface area of pile = $(\pi\ x\ d\ x\ l)$

∴ Frictional Resistance (Q_S) = $\alpha\ \bar{C}\ A_S = [\,0.75\ x\ 75\ x\ (\pi\ x\ 0.3\ x\ 9)\,] = 477.12$

∴ $Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\ [\,Q_S\,] = n\,[\,\alpha\ \bar{C}\ A_S\,] = 477.12\ n$

So, The Ultimate Load Carrying capacity of group of Piles (Group Capacity) is found in terms of number of piles (n)

i.e. ∴ $Q_{f\ group} = 477.12\ n$

Design Approach

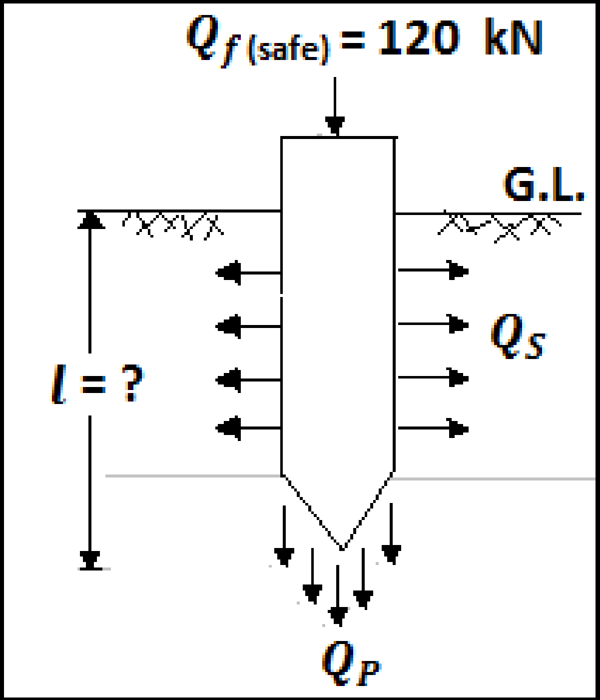
Important Note

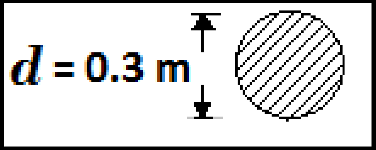
While solving Design based Numerical i.e. to find length of Pile *l* (also called as depth of penetration) , dimensions of pile such as diameter (d), width (b) , length (l) , Spacing in between piles (S) , Width of group of piles (B) and number of piles (n) etc : -

Always neglect End Bearing Resistance $(Q_P) = [C \ N_C \ A_P] = [9 \ \ C \ \ A_P]$ *in both cases*

Problem 4.8 concrete pile of diameter 30 cm is to be constructed in a cohesive soil of stiff consistency with unconfined compressive strength of 160 kN /m2. Determine the length of the pile (depth of penetration) to carry the safe load of 120 kN with factor of safety of 2. Assume the adhesion factor = 0.6 ? **[RTMNU, W -18/7m]**

Solution :





Given, Diameter of Pile (d) = 30 cm = 0.3 m

Length of Pile (l) = ?

Factor of Safety (FOS) = 2

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.60

No. of Piles = n = 1

Unconfined Compression Strength (UCS) = 160 kN / m2

$\therefore$ Cohesion ($C = \bar{C}$) = (UCS/2) = (160/2) = 80 kN/m^2

Safe Load (Allowable load) = 120 KN

Ultimate Load (Q_f) = Safe load x FOS

$= (120 \ x \ 2) = 240 \ kN$

Ultimate Load Carrying capacity of single Pile is given by :

$Q_f = [\ Q_P + Q_S\ ] = [\ C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\ ] = [\ 9\ C\ A_P + \alpha\ \bar{C}\ A_S\ ]$

Neglecting End Bearing Resistance or Resistance at base or at tip (point) of the pile (Q_P) = $C\ N_C\ A_P = 9\ C\ A_P$

Where, A_P = Cross sectional area of pile = $(\pi/4)\ d^2$

and Frictional Resistance or resistance along surface of the pile (Q_S) = $\alpha\ \bar{C}\ A_S$

Where, A_S = Surface area of pile = $(\pi\ x\ d\ x\ l)$

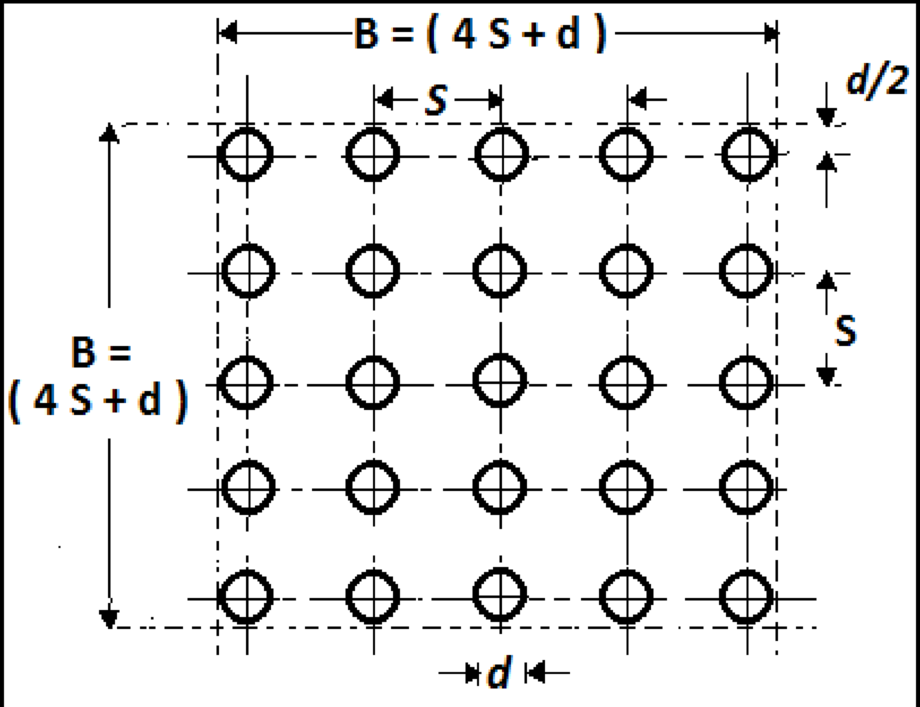
$\therefore\ Q_f = [\ Q_S\ ] = [\ \alpha\ \bar{C}\ A_S\ ]$ ……………………………..by neglecting Q_P

$\therefore\ 240 = [\ 0.6\ x\ 80\ x\ (\pi\ x\ 0.3\ x\ l\ )\ ]$

$\therefore$ Depth of penetration or Length of Pile (l) = 5.3 m

Problem 4.9 A 25 pile group has to be arranged in the form of square in soft clay with uniform spacing. Neglect end bearing resistances, Determine the optimum value of spacing of the piles in terms of pile diameter. Assuming a shear mobilization factor of 0.70 . ? **[SGBAU, S -15/7 m]**

Solution :



Let the Diameter of Pile = d and Length of Pile = l

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.70

No. of Piles = n = 25

Let the Spacing in between the piles = S = ?

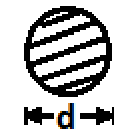
Hence, the width of square group of 25 piles = B = (4 S + d)

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$$

$$\therefore\ \ Q_{f\ group} = n\,[\,\mathrm{C}\ N_C\ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ \ A_S\,] = n\,[\,9\ \mathrm{C}\ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ A_S\,]$$



Neglecting End Bearing Resistance $(\ Q_P\ )\ =\ \mathrm{C}\ \ N_C\ \ A_P\ =\ 9\ \ \mathrm{C}\ \ A_P$

$$\therefore\ Q_{f\ group} = n\ \ (\ Q_S\ )\ =\ n\,[\ \alpha\ \bar{\mathrm{C}}\ A_S\ ]\ =\ 25\,[\,0.7\ \ x\ \ \bar{\mathrm{C}}\ \ \mathrm{x}\ (\,\pi\, d\ \ l\,)] = 55\ \ \bar{\mathrm{C}}\ \ d\ \ l \ldots\ldots\ldots\ldots\ldots\ldots\ \text{Eqn}\ (i)$$

Case 2] Piles acting In group :

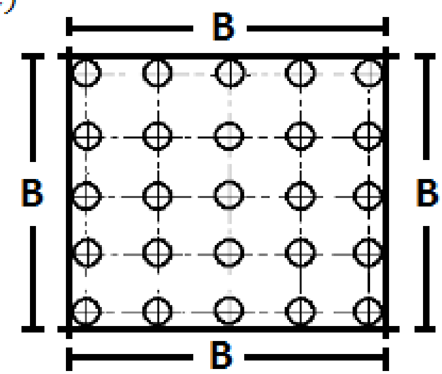
Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = \ Q_P + \ Q_S\ \ = [\,\mathrm{C}\ \ N_C\ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ \ A_S\,] = [\ 9\ \ \mathrm{C}\ \ A_P\ +\ \alpha\ \bar{\mathrm{C}}\ A_S\,]$$

Neglecting End Bearing Resistance $(\ Q_P\ )\ = \mathrm{C}\ N_C\ A_P\ \ = 9\ \mathrm{C}\ A_P$

$$\therefore\ \ Q_{f\ group} =\ \ Q_S\ =\ \alpha\ \ \bar{\mathrm{C}}\ \ A_S$$

$$= [\,0.7\ x\ \ \bar{\mathrm{C}}\ \ x\ \ (\ 4\ \ B\ \ l\ )\,] = 0.7\,\bar{\mathrm{C}}\ \ [\,4\ (4\,s + d\,)\,]\ x\ \ l\ \ \ldots\ldots\ldots\ldots\ldots\ldots\ \text{Eqn}\ (ii)$$



Equating Equation (i) and (ii)

$$55\ \ \bar{\mathrm{C}}\ \ d\ \ l\ =\ 0.7\,\bar{\mathrm{C}}\ \ [\,4\,(4\,s + d\,)\,]\ x\ \ l\ \ ; \qquad \therefore\ \ (\,55/0.7)\ d\ =\ \ 4\ (\,4\ s\ +\ d\,)$$

$$\therefore\ 78.57\ \ d\ \ = 16\ s\ +\ 4\ \ d$$

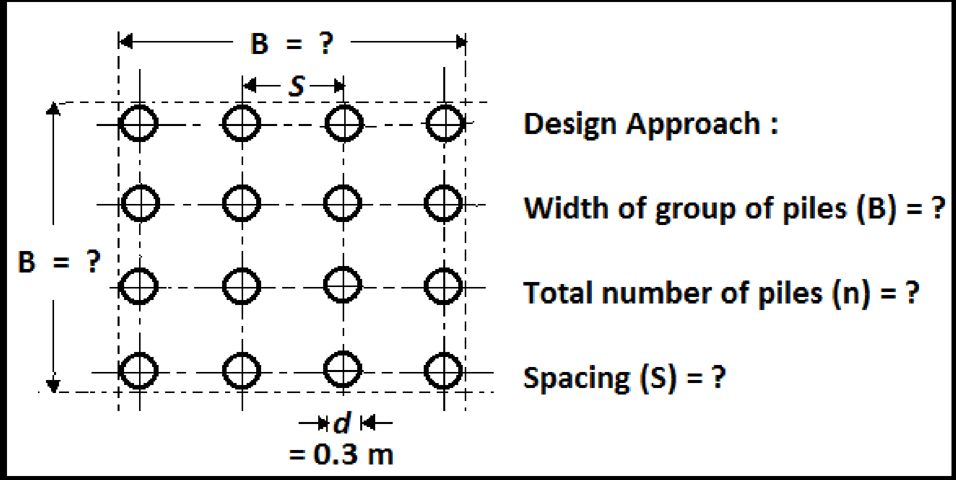
$$\therefore\ 74.57\ \ d\ \ = 16\ s$$

$$\therefore\ \ \text{Spacing}\ (\ \mathrm{S}\ )\ =\ \ 4.66\ \ d$$

Hence, the Spacing (S) is equal to 4.66 times the diameter of the pile.

Problem 5.0 Design a square pile group to carry 600 KN load in clay with an unconfined compressive strength of 80 KN/M2. The piles are 30 cm diameter and 9 m long. take Adhesion factor 0.6 . use F.S. = 03 ? **[SGBAU, S -17/7 m , S-18/ 8 m]**

Solution : Let us assume the figure for understanding the design approach :



Let the Diameter of Pile = d = 30 cm = 0.3 m and Length of Pile = l = 9 m

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.60

Factor of safety (FOS) = 3.0 No. of Piles = n = ?

Let the Spacing in between the piles = S = ?

Let the width of square group of piles = B = ?

Unconfined Compression Strength (UCS) = 80 kN / m2

Cohesion ($C = \bar{C}$) = (UCS/2) = (80/2) = 40 kN/m^2

Safe Load (Allowable load) $Q_{f\ safe}$ = 600 KN

∴ Ultimate Load ($Q_{f\ group}$) = Safe load x FOS = (600 x 3) = 1800 kN

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n \ x \ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ]$$

$\therefore\ Q_{f\ group} = n\,[\mathrm{C}\ N_C\ A_P + \alpha\ \bar{\mathrm{C}}\ A_S\,] = n\,[\,9\ \mathrm{C}\ A_P + \alpha\ \bar{\mathrm{C}}\ A_S\,]$

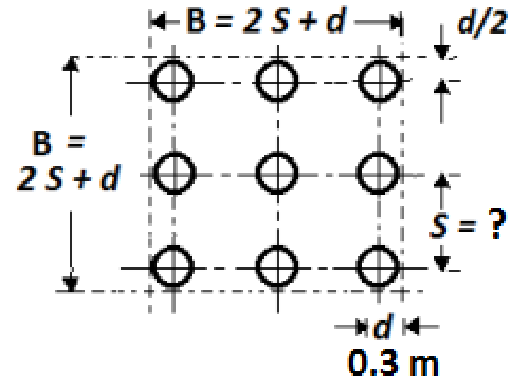
Neglecting End Bearing Resistance $(\,Q_P\,) = \mathrm{C}\ N_C\ A_P = 9\ \mathrm{C}\ A_P$

Frictional Resistance $(\,Q_S\,) = \alpha\ \bar{\mathrm{C}}\ A_S = [\,0.6\ x\ \ 40\ \mathrm{x}\ (\,\pi\ x\ 0.3\ x\ 9\,)\,] = 203.57$

$\therefore\ Q_{f\ group} = n\ [\,Q_S\,]$

$\therefore\ \ 1800 = n\ [\ \alpha\ \bar{\mathrm{C}}\ A_S\,] = 203.57\ n$

$\therefore$ Number of Piles in group (n) = 9 $No.$



Case 2] Piles acting In group :

Ultimate Load Carrying capacity of group of Piles is given by :

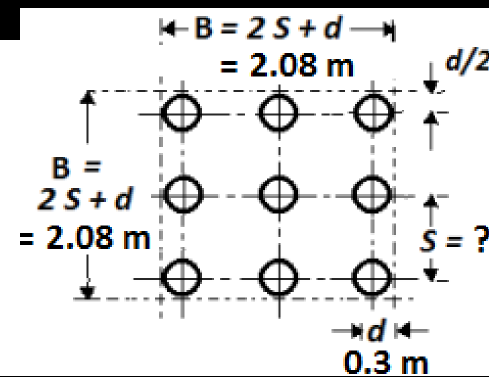
$Q_{f\ group} = Q_P + Q_S = [\,\mathrm{C}\ N_C\ A_P + \alpha\ \bar{\mathrm{C}}\ A_S\,] = [\,9\ \mathrm{C}\ A_P + \alpha\ \bar{\mathrm{C}}\ A_S\,]$

Neglecting End Bearing Resistance $(\,Q_P\,) = \mathrm{C}\,N_C\ A_P = 9\,\mathrm{C}\,A_P$

$\therefore\ Q_{f\ group} = Q_S = \alpha\ \bar{\mathrm{C}}\ A_S = (\ 0.6\ x\ 40\ x\ 4\ B\ l\ )$

$\therefore\ \ 1800 = [\,(\ 0.6\ x\ 40\,)\ x\ (\ 4\ x\ B\ x\ 9\ )$

$\therefore$ B = width of square group of piles = 2.08 m



$\therefore$ From Figure , we have width of square group of 9 piles = B = (2 S + d) = 2.08 m

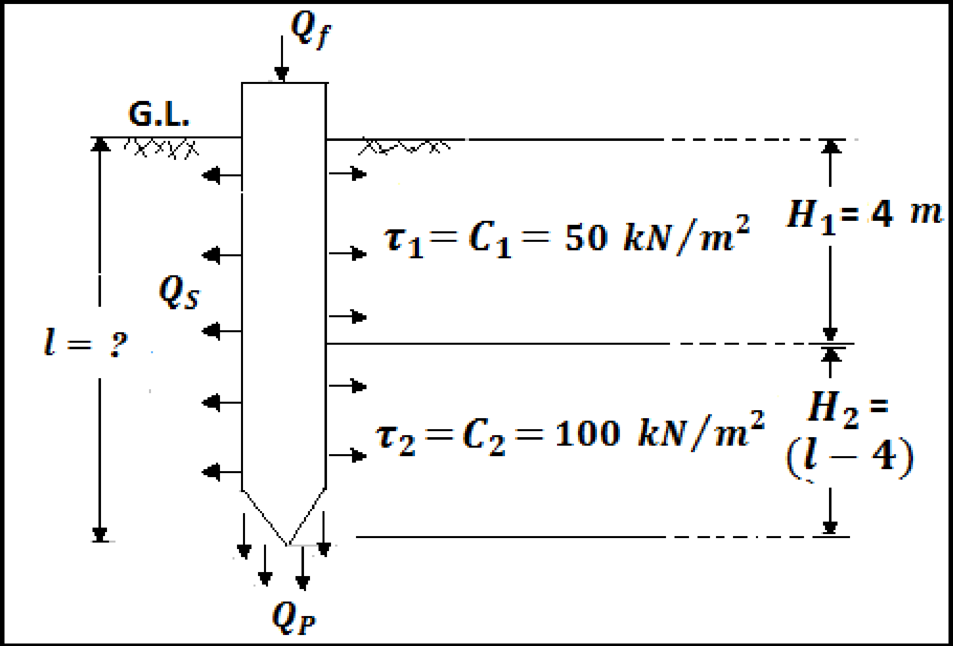
$\therefore$ (2 S + 0.3) = 2.08 m

$\therefore$ Spacing (S) = 0.89 m $\approx$ 0.9 m = 900 mm

Problem 5.1 In a two layered cohesive soil bored piles of diameter 350 mm are installed. The top layer has a thickness of 4 m and the bottom layer is of considerable depth. The shear strength of the top layer is 50 kN / m2 & that of bottom 100 kN / m2 . Determine the depth of penetration required to carry safe load of 500 KN allowing FS 2.5. Assume α = 0.5 ?

[RTMNU, S-17, S-10,/8 m]

Solution :



Given, Diameter of Pile (d) = 350 mm = 0.35 m

Depth of penetration or Length of Pile (*l*) = ?

Factor of Safety (FOS) = 2.5

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.75

Since the soil is purely cohesive hence shear strength (τ) is due to Cohesion (C) ; $\therefore\ \tau = C =$ Cohesion

For Top Layer, Shear strength (τ_1) = Cohesion $(C_1) = 50\ kN/m^2$

For Bottom Layer, Shear strength (τ_2) = Cohesion $(C_2) = 100\ kN/m^2$

Safe load (Allowable load) $Q_{f\ safe} = 500\ kN$

$$\text{Ultimate Load } (Q_f) = \text{Safe load } x \text{ FOS}$$
$$= (500 \; x \; 2.5) = 1250 \; kN$$

Ultimate Load Carrying capacity of single Pile is given by :

$$Q_f = [\,Q_P + Q_S\,] = [\,C \; N_C \; A_P + \alpha \; \bar{C} \; A_S\,] = [\,9 \; C \; A_P + \alpha \; \bar{C} \; A_S\,]$$

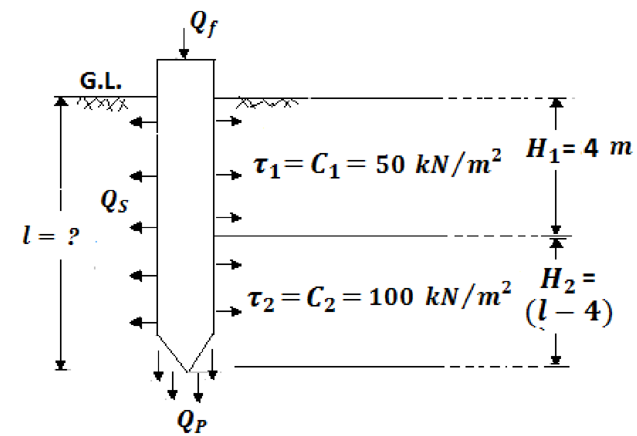
Neglecting End Bearing Resistance $(Q_P) = C \; N_C \; A_P = 9 \, C \; A_P$

Frictional Resistance $(Q_S) = \alpha \; \bar{C} \; A_S = \alpha \; \bar{C} \; (\pi \, x \, d \, x \, l)$

Where, $\bar{C}$ = Cohesion along Surface of the pile $= [(C_1 \; x \; H_1) + (C_2 \; x \; H_2)] \,/\, l$

$$\therefore \; \bar{C} = [(50 \; x \; 4) + [100 \; x \; (l - 4)] \,/\, l$$

$$\therefore \; Q_f = [\,Q_S\,] = [\,\alpha \; \bar{C} \; A_S\,] \ldots\ldots\ldots\ldots\ldots \; neglecting \; (Q_P)$$



$$\therefore 1250 = 0.5 \, x \left\{ \frac{[(50 \; x \; 4) + [100 \; x \; (l - 4)]}{l} \right\} x \; (\pi \, x \, 0.35 \, x \, l)$$

$$1250 = (0.55 \, x \, l) \, x \left\{ \frac{[\,200 + (100 \, x \, l) - 400}{l} \right\}$$

$$1250 = 0.55 \, x \, [\,(200 + 100 \; l - 400)$$

$$1250 = .(110 + 55 \; l - 220) \; ; \qquad 1360 = (55 \, x \, l)$$

$\therefore$ Total Length of the pile or Depth of penetration $(l) = 24.72 \; m$

Alternative method :

Ultimate Load (Q_f) = $\left(Q_{f\ safe}\ x\ fos \right)$ = (500 x 2.5) = 1250 kN

Also we know that, Ultimate Load Carrying capacity of Single Pile (Q_f)

$$Q_f = [\ Q_P + Q_S\ ] = [\ C\ N_C\ A_P + \alpha\ \bar{C}\ A_S\ ] = [\ 9\ C\ A_P + \alpha\ \bar{C}\ A_S\ ]$$

Neglecting End Bearing Resistance (Q_P) = $C\ N_C\ A_P = 9\ C\ A_P$

Frictional Resistance (Q_S) = $\alpha\ \bar{C}\ A_S$

$$\therefore\ Q_f = [\ Q_S\ ] = [\ \alpha\ \bar{C}\ A_S\ ]$$

For top Layer, Cohesion along Surface of the pile ($\bar{C}_1$) = 50 kN/m^2

For bottom Layer, Cohesion along Surface of the pile ($\bar{C}_2$) = 100 kN/m^2

$$Q_f = [\ \alpha\ \bar{C}\ A_S\ ]_{Top\ layer} + [\ \alpha\ \bar{C}\ A_S\ ]_{bottom\ layer}$$

$$Q_f = \alpha\ \bar{C}\ (\pi\ d\ H_1) + \alpha\ \bar{C}\ (\pi\ d\ H_2)$$

$$Q_f = [\,0.5\ x\ 50\ x\ (\pi\ x\ 0.35\ x\ 4)\,] + [\,0.5\ x\ 100\ x\ (\pi\ x\ 0.35\ x\ H_2)\,]$$

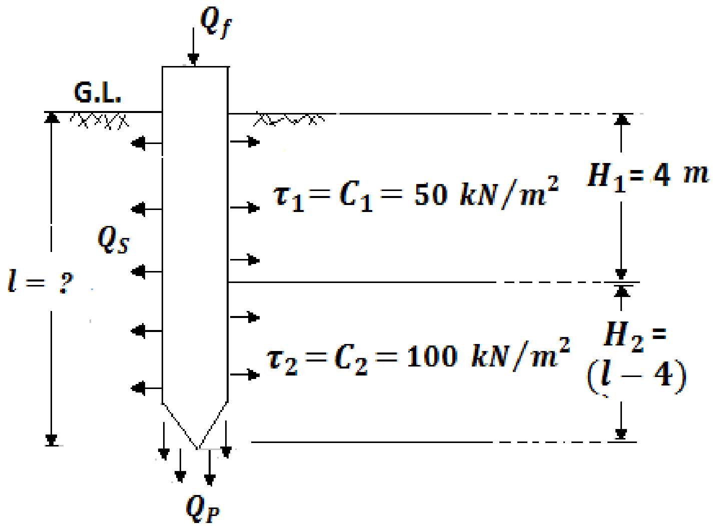
$$1250 = [\,0.5\ x\ 50\ x\ (\pi\ x\ 0.35\ x\ 4)\,] + [\,0.5\ x\ 100\ x\ (\pi\ x\ 0.35\ x\ H_2)\,]$$

$$1250 = 109.95 + (\ 55\ x\ H_2\ )$$

$\therefore$ Thickness of the Bottom layer (H_2) = 20.72 m

Hence, Total Length of the pile or Depth of penetration (l) is given by

$$l = (H_1 + H_2) = (4 + 20.72) = 24.72\ m$$



Problem 5.2 A 200 mm diameter , 8 m long piles are used in foundation on uniform deposit of medium clay having qu = 100 kN/m2. The spacing in between piles is 500 mm . there are q Piles in square pattern. Calculate pile load capacity of group . Assume adhesion factor as 0.9 ? **[RTMNU, S-7/7 m]**

Solution :

Given, Diameter of Pile (d) = 200 mm = 0.2 m

Length of Pile (*l*) = 8 m

Number of piles in the group = n = q

Spacing (S) = 500 mm = 0.5 m

Adhesion factor (Shear Mobilizing Factor) = α = m = 0.9

Unconfined Compression Strength (UCS) = qu = 100 kN/m2

Cohesion ($C = \bar{\text{C}}$) = $(q_u/2) = (100/2) = 50 \quad kN/m^2$

Case 1] When Piles acting Individually :

Ultimate Load Carrying capacity of group of Piles is given by :

$$Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\,[\ Q_P + Q_S\ ] = n\,[\ \text{C}\ N_C\ A_P + \alpha\ \bar{\text{C}}\ A_S\ ] = n\,[\ 9\ \ \text{C}\ A_P + \alpha\ \bar{\text{C}}\ A_S\ ]$$

Neglecting End Bearing Resistance or resistance at base or tip (point) of the pile (Q_P) = $\text{C}\ N_C\ A_P = 9\ \ \text{C}\ A_P$

Frictional Resistance or resistance developed along the surface of the pile (Q_S)

$$Q_S = \alpha\ \bar{\text{C}}\ A_S = [\,0.9\ x\ 50\ \text{x}\ (\pi\ x\ 0.2\,x\ 8\,)\,] = 226.19$$

$$\therefore\ Q_{f\ group} = n\ x\ \ Q_{f\ one} = n\ [\,Q_S\,] = q\ [\ \alpha\ \bar{\text{C}}\ A_S\,] = 226.19\ \ q \ \ldots\ldots\ldots\ldots\ldots\ldots\ (n = q)$$

So, The Ultimate Load Carrying capacity of group of Piles (Group Capacity) is found in terms of number of piles ($n = q$)

i.e. $\therefore\ Q_{f\ group} = 226.19\ \ q$

The load Carrying capacity of Piles can be determined by following methods :

1. Static Formula
2. Dynamic Formula
3. Pile Load Test
4. Penetration Tests

Static Approach

- Bored Piles
  - In Sand
  - In Clay
- Driven Piles
  - In Sand
  - In Clay

Driven Piles in sand :

Ultimate Load Carrying capacity of driven piles in Sand (Q_f) :

$$Q_f = [\,Q_P + Q_S\,] = (\,q_p\,A_P + f_S\,A_S\,)$$

Q_P = Load Transferred through tip (point) of the pile (Bearing Resistance):

$$Q_P = (\,q_p\,A_P\,) = [\,(\,\bar{\sigma}\,N_q)\,x\,A_P\,]$$

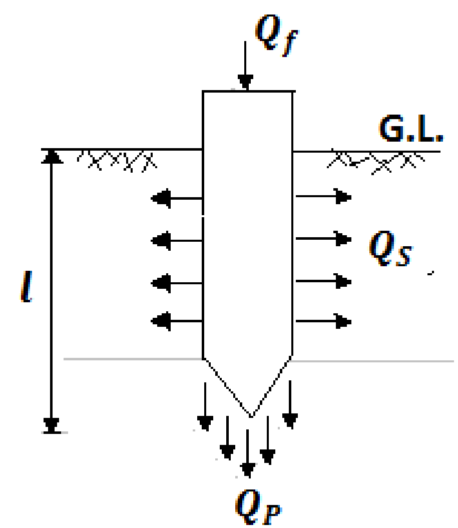
Where , q_p – Bearing capacity of pile in $kN/m^2 = (\,\bar{\sigma}\,N_q)$

Q_S = Load Transferred through surface of the pile (Frictional Resistance):

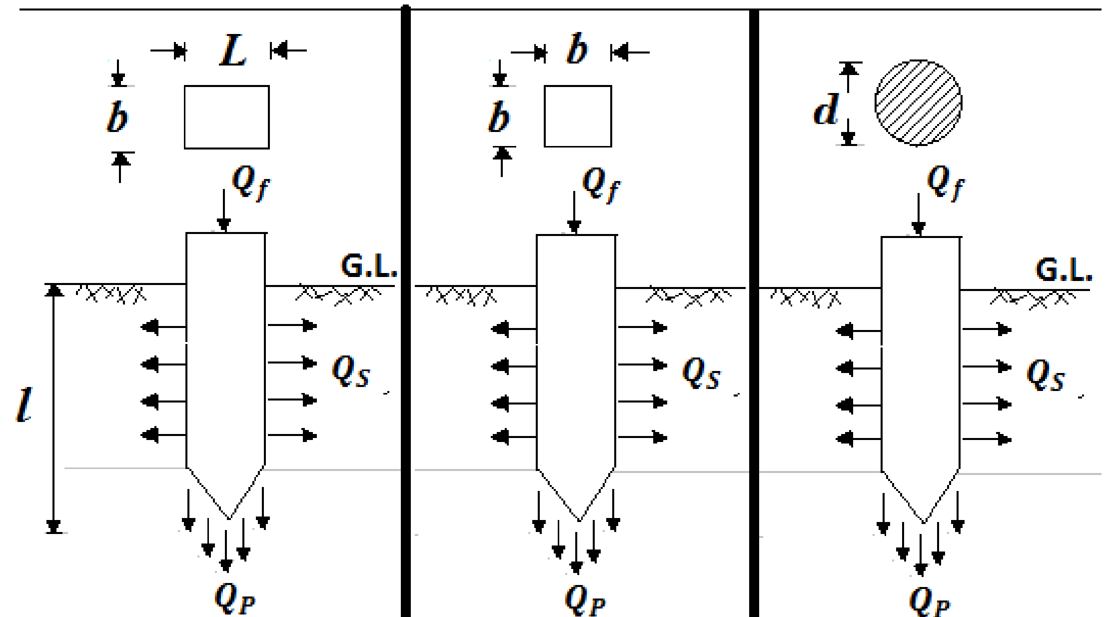
$$Q_S = f_S\,A_S$$

Where , f_S = Negative skin friction = $\overline{\sigma_{avg}}\,k\,\tan\delta$

A_P = Cross sectional Area of the Pile ; A_S = Surface Area of the Pile



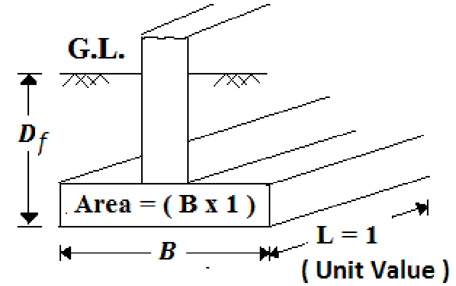
Important Note



Rectangular Pile	Square Pile	Circular Pile
$A_p = b \times L$	$A_p = b^2$	$A_p = (\pi/4)\, d^2$
$A_s = (2b + 2L) \times l$	$A_s = 4 \times b \times l$	$A_s = \pi \times d \times l$

where, l - Length of the pile

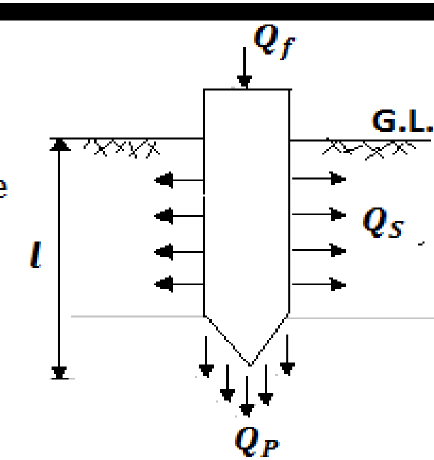
Determination of Bearing capacity of the pile (q_p) :



The Tarzaghi's equation for bearing capacity (q_p) of Strip Footing is as follows :

$$q_p = [\, C\, N_C + \bar{\sigma}\; N_q + 0.5\, \gamma\, B\, N_r \,] = [\, C\, N_C + (\gamma\; D_f\,)\, N_q + 0.5\, \gamma\, B\, N_r \,]$$

Where, B - Width of strip footing and D_f − depth of foundation



in case of driven piles, the above equation can be write as

$$q_p = [\, C\, N_C + \bar{\sigma}\; N_q + 0.5\, \gamma\, b\, N_r \,] = [\, C\, N_C + (\gamma\; l\,)\, N_q + 0.5\, \gamma\, b\, N_r \,]$$

Where, $\bar{\sigma} = \bar{\sigma}_v$ = Vertical stress developed due to soil or also called as surcharge pressure

= Unit weight (γ) x Depth (length of the pile) (l)

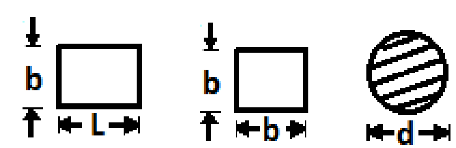
b − Width of pile ; N_C , N_q , N_r − Tarzaghi's Bearing Capacity Factors

C − Cohesion at the base or point (tip) of the pile in kN/m2

We know that For Cohesion less soil or Sandy soil, Cohesion (C) = 0

Again , in case of driven piles, width of the pile (b) is very small compared to depth (Length) l

Hence neglecting Width (b) factor also



$$\therefore\; q_p = (\bar{\sigma}\; N_q) = (\gamma\; l\; N_q\,)$$

$\therefore$ Bearing resistance $(Q_P) = (q_p\; A_P) = [\,(\bar{\sigma}\; N_q)\; x\; A_P\,] = [(\gamma\; l\; N_q\,)\; x\,(\pi/4\,)d^2]$ ……….for Circular s/c pile

$\therefore$ Bearing resistance $(Q_P) = (q_p\; A_P) = [\,(\bar{\sigma}\; N_q)\; x\; A_P\,] = [(\gamma\; l\; N_q\,)\; x\; (b\; x\; L)]$ ……….for rectangular s/c pile

$\therefore$ Bearing resistance $(Q_P) = (q_p\; A_P) = [\,(\bar{\sigma}\; N_q)\; x\; A_P\,] = [(\gamma\; l\; N_q\,)\; x\, b^{\,2}]$ ……….for square s/c pile

Critical Depth Factor (L c) :

In case of driven piles vertical pressure gives greater value with increase of depth , this increase in pressure can be seen up to some depth. after this, the effective pressure remains constant . This limiting value of depth is called critical depth (Lc) as shown in figure.

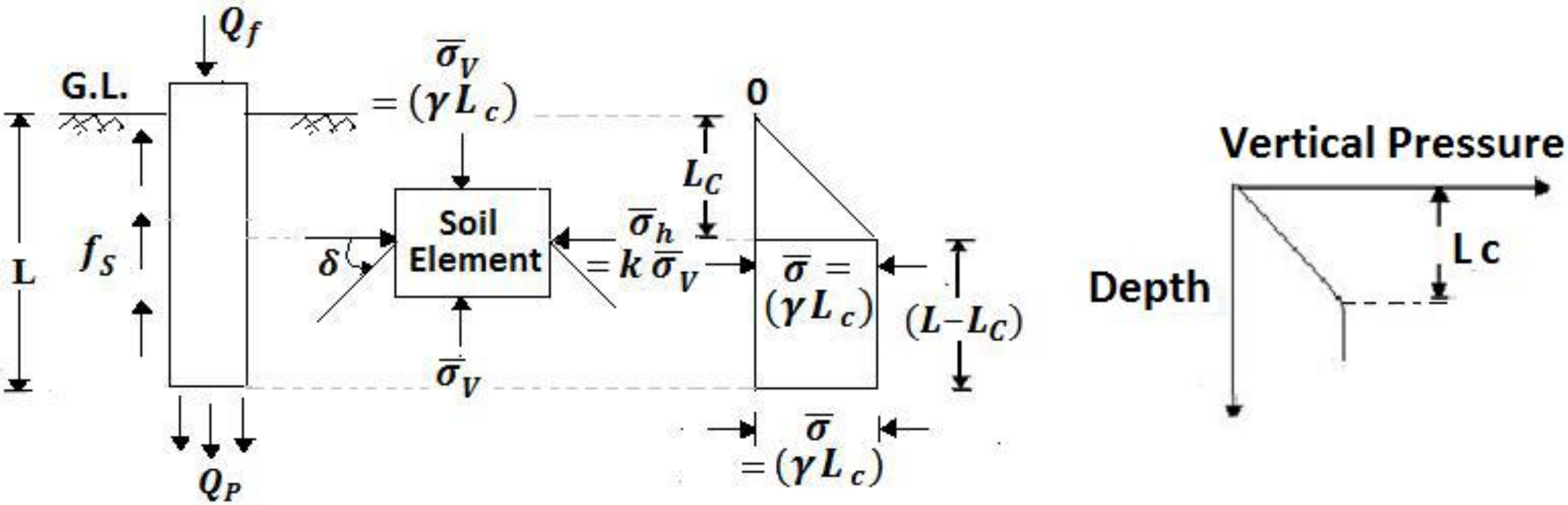


Figure : Stresss Distribution

Bearing capacity (q_p) of the pile if the critical depth exists is given by,

$$\therefore\ q_p = (\bar{\sigma}\ N_q) = (\gamma\ L_C\, N_q)$$

For Loose sand, $L_C = 10\ \text{B}$

For Dense sand, $L_C = 20\ \text{B}$ where, B – width of pile. γ – Unit weight of the soil in KN/m2

N_q – Bearing capacity factor

Determination of Unit Skin Friction (Fs) :

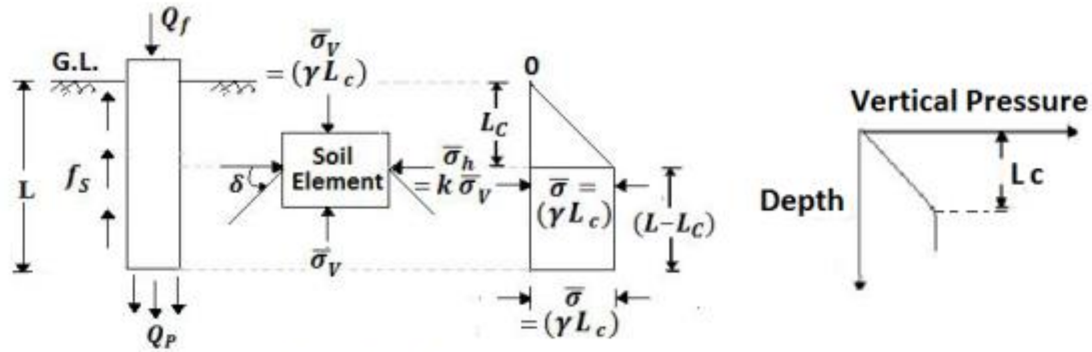


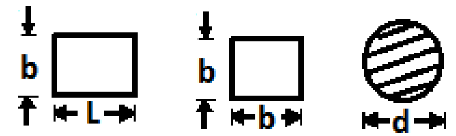
Figure : Stresss Distribution

Frictional resistance or resistance along the surface of the pile $(Q_S) = (f_S \;\; A_S)$

$f_S =$ Unit skin friction (negative skin friction) $= \overline{\sigma_{avg}} \; k \; \tan \delta$

$$f_{S\,1} \; [(\text{depth of } 0 \; to \; L_C)] = \left[\frac{1}{2} (0 + \gamma \; L_C) \right] \; x \;\; k \;\; \tan \delta$$

$f_{S\,2}$ [(depth of L_C to L)] $= [\, (\gamma \; L_C)\,] \; x \;\; k \;\; \tan \delta$ as the stress is linear.



Where, $k -$ Lateral Earth Pressure Coefficient = 0.5 (if not given) ;

$\delta -$ Angle of friction between pile and soil (wall friction angle)

$\therefore$ Frictional Resistance $(Q_S) = \; f_S \;\; A_S = [\, (f_{S1} \;\; x \;\; A_{S1} \;)_{(\text{depth of } 0 \; to \, L_C)} + \; (f_{S2} \;\; x \;\; A_{S2} \;)_{(\text{depth of } L_C \; to \; L)} \,]$

$A_S =$ Surface area of the pile

$A_{S\,1} \; (0 \;\; \text{to} \; L_C) = (\pi \; x \;\; d \; x \; L_C)$ and $A_{S\,2} \; [(L_C \;\; to \;\; L)] = [\, (\pi \; x \;\; d \; x \, (L - L_C))]$ …………………..for circular s/c pile

$A_{S\,1} \; (0 \;\; \text{to} \; L_C) = (4 \; x \; b \; x \; L_C)$ and $A_{S\,2} \; [(L_C \;\; to \;\; L)] = [\, (4 \; x \; b \;\; x \, (L - L_C))]$ …………………..for square s/c pile

$A_{S\,1} \; (0 \;\; \text{to} \; L_C) = (2b + 2\,L\,) \; x \; L_C$ and $A_{S\,2} \; [(L_C \;\; to \;\; L)] = [\, ((2b + 2\,L\,) \;\; x \, (L - L_C))]$.for rectangular s/c pile

Problem 5.3 A 12.0 m long 300 mm diameter concrete pile is driven in a uniform deposit of sand having Ø = 40 degree. The average dry unit weight of sand 18 KN/m3. Using Nq = 137 and factor of safety of 2.5. Assume the critical length of pile as 15 times the diameter. take k for dense = 2.0. calculate the safe load carrying capacity of pile for following Conditions

i) The water table is very much down and is not likely to rise in future. i.e. The water table is at greater depth . **[SGBAU, W – 14/ 7 m]**

ii) The water table is located at depth of 2 m from ground surface.

Solution :

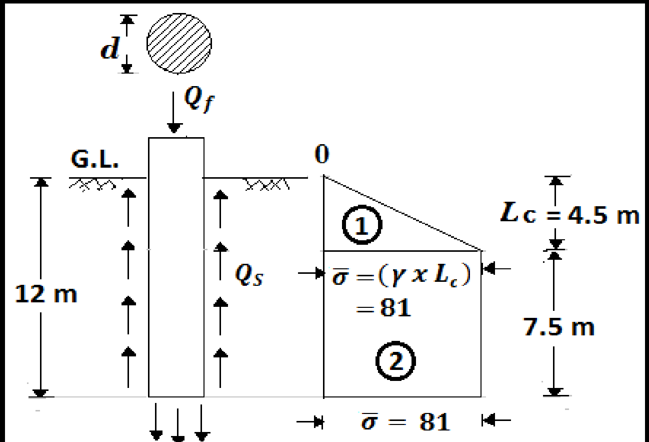


Figure : Stresss Distribution

Given, Diameter of Pile (d) = 300 mm = 0.3 m Length of Pile (*l*) = 12 m

Angle of shearing resistance or internal friction = Ø = 40 degree. No. of Piles = n = 1

Lateral earth pressure coefficient = k = 2.0 ; factor of safety (fos) = 2.5

Bearing capacity factor = Nq = 137 unit weight of sand = ϒ = 18 KN/m3

Assume , Angle of friction between pile and soil or wall friction angle = δ = Ø = 40 degree.

The critical length of pile (L c) = 15 d = 15 x 0.3 = 4.5 m

Case 1] The water table is at greater depth or water table does not exist within depth of 12 m

Ultimate Load Carrying capacity of Single Pile is given by :

$$Q_f = Q_p + Q_s$$

Q_P = Load Transferred through tip (point) of the pile (Bearing Resistance)

$Q_P = \bar{\sigma}\ N_q\ A_P = \{ [\bar{\sigma}$ at base (tip) of pile $]\ x\ N_q\ x\ (\pi/4)\, d^2 \}$

$= [\,81\ x\ 137\ x\ (\pi/4)\, 0.3^2] = 784.40$

Q_S = Load Transferred through surface of the pile (Frictional Resistance)

$Q_S = f_S\ A_S$

Where, f_S = Negative skin friction = $\overline{\sigma_{avg}}\ k\ \tan\delta$

$f_{S\,1}\ (0$ to $4.5\,m) = 1/2\,(0 + 81)\ x\ 2\ x\ \tan 40^0 = 90.50\ \ kN/m^2$

$f_{S\,2}\ (4.5$ to $12\,m) = 1/2(81 + 81)\ x\ 2\ x\ \tan 40^0 = 181\ \ kN/m^2$

A_S = Surface area of the pile = $\pi\ d\ l$ ……… for circular section pile

$A_{S\,1}\ (0$ to $4.5\,m) = (\pi\ x\ 0.3\ x\ 4.5) = 4.24\ \ m^2$

$A_{S\,2}\ (4.5$ to $12\,m) = (\pi\ x\ 0.3\ x\ 7.5) = 7.068\ \ m^2$

$\therefore\ Q_S = [\ (f_{S\,1}\ x\ A_{S\,1}) + (f_{S\,2}\ x\ A_{S\,2})\,]$

$Q_S = [(90.50\ x\ 4.24) + (181\ x\ 7.068) = 1663.028\ \ kN/m^2$

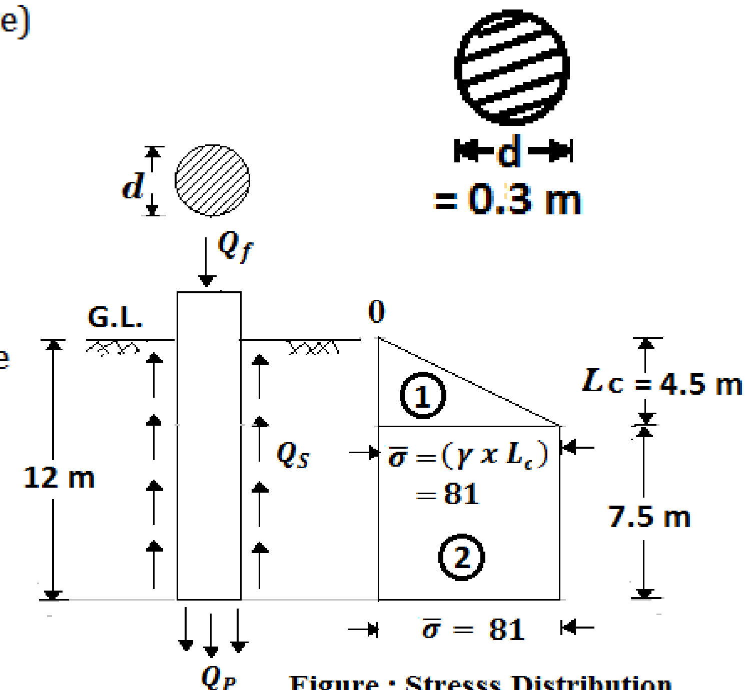


Figure : Stresss Distribution

Ultimate Load Carrying capacity of Pile (Q_f) :

$Q_f = (Q_P + Q_S) = (784.40 + 1663.028) = 2447.43\ \ kN$

Safe Load (Allowable Load) = $Q_{f\,safe} = (Q_f\ /\ fos) = (2447.43\ /2.5) = 979\ \ kN$

Case 2] The water table is located at depth of 2 m from ground surface.

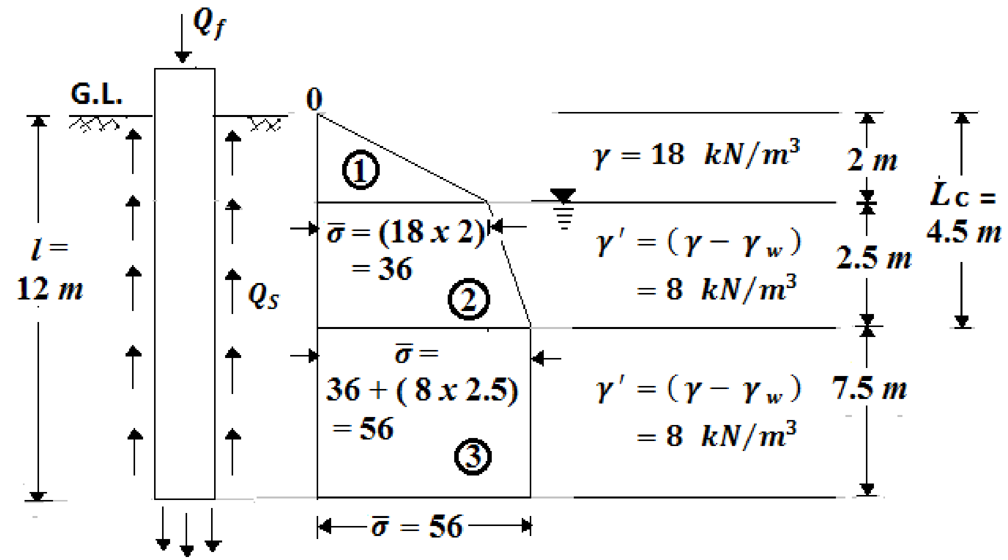


Figure : Stresss Distribution

Dry Unit weight of sand $(\gamma_d) = 18 \quad kN/m^3$

Submerged unit weight $(\gamma') = (\gamma - \gamma_w) = (18 - 10) = 8 \quad kN/m^3$

Where, $\gamma_w -$ Unit weight of water $= 9.81 \approx 10 \quad kN/m^3$

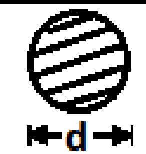
Ultimate Load Carrying capacity of Single Pile is given by :

$$Q_f = Q_p + Q_s$$

Q_P = Load Transferred through tip (point) of the pile (Bearing Resistance)

$$Q_P = \bar{\sigma} \, N_q \, A_P = \{ [\, \bar{\sigma} \text{ at base (tip) of pile} \,] \ x \ N_q \ x \ (\pi/4) \, d^2 \}$$

$$= [\, 56 \ x \ 137 \ x \ (\pi/4) \ 0.3^{\,2}] = 542.41 \quad kN/m^2$$



Q_S = Load Transferred through surface of the pile (Frictional Resistance)

$Q_S = f_S \; A_S$

Where, f_S = Negative skin friction $= \overline{\sigma_{avg}} \; k \; \tan\delta$

f_{S1} (0 to 2 m) $= 1/2\,(0 + 36)\; x\; 2\; x\; \tan 40^0 = 40.22$

f_{S2} (2 to 4.5 m) $= 1/2\,(36 + 56)\; x\; 2\; x\; \tan 40^0 = 102.78$

f_{S3} (4.5 to 12 m) $= 1/2(56 + 56)\; x\; 2\; x\; \tan 40^0 = 125.13\; kN/m^2$

A_S = Surface area of the pile $= \pi\; d\; l$ ……………. for circular section pile

A_{S1} (0 to 2 m) $= (\pi\; x\; 0.3\; x\; 2) = 1.885\; m^2$

A_{S2} (2 to 4.5 m) $= (\pi\; x\; 0.3\; x\; 2.5) = 2.356\; m^2$

A_{S3} (4.5 to 12 m) $= (\pi\; x\; 0.3\; x\; 7.5) = 7.068\; m^2$

$\therefore\; Q_S = [\,(f_{S1}\; x\; A_{S1}) + (f_{S2}\; x\; A_{S2}) + (f_{S3}\; x\; A_{S3})\,]$

$Q_S = [(40.22\; x\; 1.855) + (102.78\; x\; 2.356) + (125.13\; x\; 7.068)$

$= 1201.176\; kN/m^2$

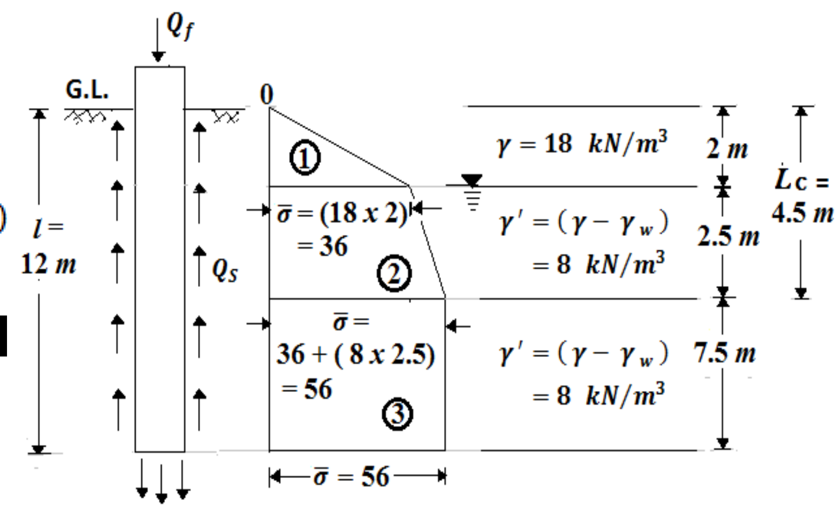


Figure : Stresss Distribution

$\therefore$ Ultimate Load Carrying capacity of Pile (Q_f):

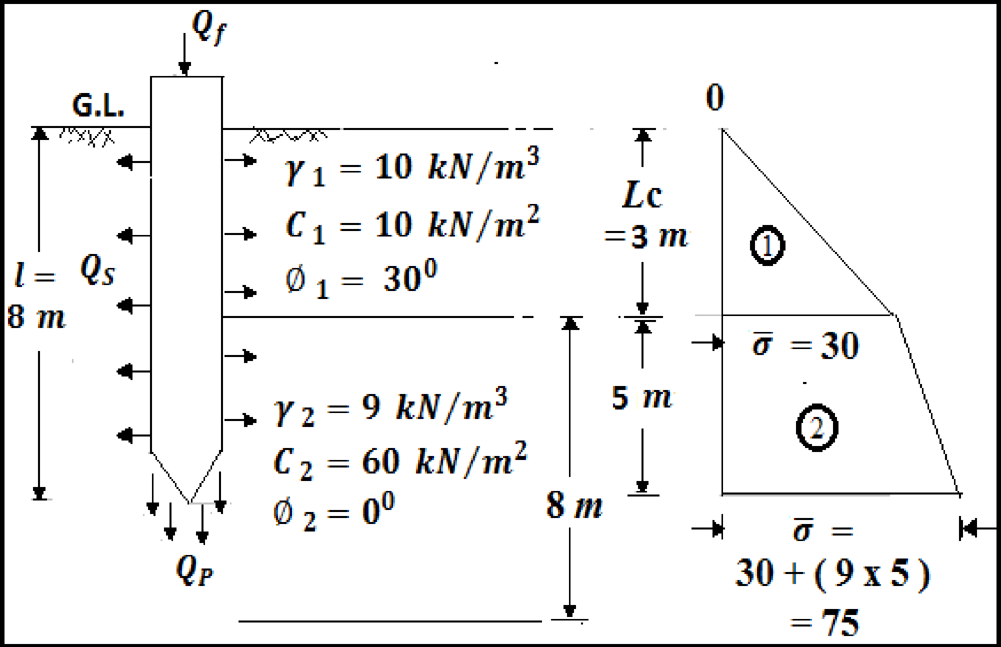
$Q_f = (Q_P + Q_S) = (542.41 + 1201.176) = 1743.58\; kN$

Safe Load (Allowable Load):

$Q_{f\,safe} = (Q_f\,/\,fos) = (1743.58\,/2.5) = 697.43\; kN$

Problem 5.4 A pile 300 mm diameter 8 m long is cast in situ in a soil consisting Of two layers:
1st, 3 m thick - ϒ = 10 kN/m3, C = 10 kN/m2 Ø = 30 degree
2 nd, 8 m thick - ϒ = 9 kN/m3, C = 60 kN/m2 Ø = 0 degree
Determine its static capacity if F.S. = 2.0, K = 0.5 , and δ = Ø ? **[SGBAU, W – 16/7 m]**

Solution :



Given, Diameter of Pile (d) = 300 mm = 0.3 m

Length of Pile (*l*) = 8 m

No. of Piles = n = 1

factor of safety (fOS) = 2.0

Lateral earth pressure coefficient = k = 0.5

Bearing capacity factor = Nc = 9

Angle of friction between pile and soil or wall friction angle = δ = Ø (given)

Assume Adhesion factor (Shear Mobilizing Factor) = α = m = 0.60

As we know that for cohesion less or Granular soil (Sandy soil): $C = 0$ and $\emptyset > 0^0$

For Cohesive soil (Clay) : $C > 0$ and $\emptyset = 0^0$

Where, $\emptyset$ – Angle of Shearing Resistance or internal friction and C – Cohesion of soil in kN/m^2

The soil in the top layer is cohesion less or granular or sandy soil because $C_1 = 10 \ kN/m^2 \approx 0$ and $\emptyset_1 > 0^0$

and the soil in Bottom layer is said to be Cohesive soil (stiff clay) because $C_2 = 60 \ kN/m^2 > 0$ and $\emptyset_2 = 0^0$

As we have already discussed, Critical Depth for loose sand is given by, $L_C = (10\,d) = (10 \ x \ 0.3) = 3\,m$

Ultimate Load Carrying capacity of Single Pile is given by :

$Q_f = Q_p + Q_s$

Q_P = Load Transferred through tip (point) of the pile (Bearing Resistance):

$Q_P = [\ \bar{\sigma} + C\,N_C\ ]\,A_P$

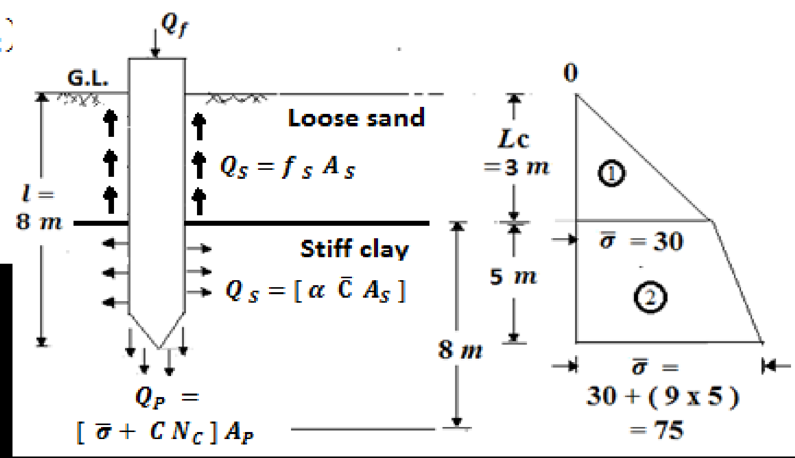
Where , A_P = cross sectional area of pile = $(\pi/4)\ d^2$...... Circular c/s pile

Cohesion at tip (base) of pile (C) = Cohesion of Bottom layer (C_2)

$\therefore\ C = (C_2) = 60\ kN/m^2$

$\therefore\ Q_P = [\,(\ \bar{\sigma}$ at base (tip) of pile) + $(C\ x\ N_C)\,]\ x\ (\pi/4)\,d^2$

$Q_P = [\,75 + (60\,x\,9)\,]\ (\pi/4)\ 0.3^2 = 43.47\ \ kN/m^2$



How to determine the frictional resistance (Q s) :

Layer I or Top layer having loose sand of depth (0 to 3 m) :

Q_S = Load Transferred through surface of the pile (Frictional Resistance) :

$Q_S = f_S \; A_S$

Where , f_S = Negative skin friction = $\overline{\sigma_{avg}} \; k \; \tan \delta$

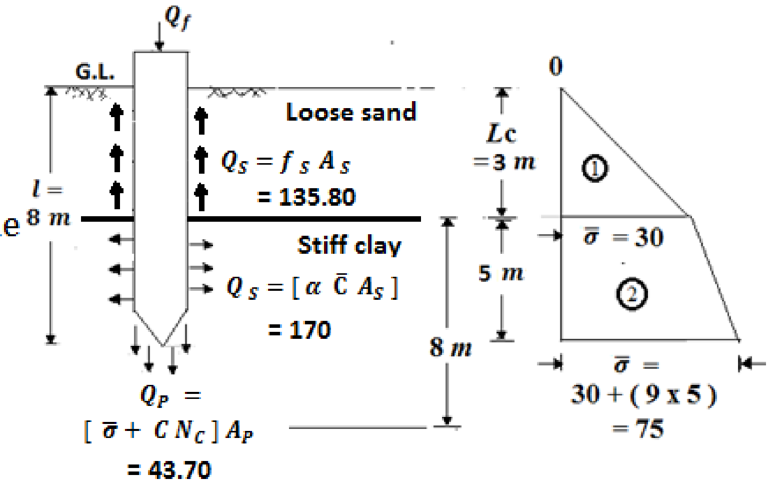
$f_{S\,1}$ (0 to 3 m) = $1/2\,(0 + 30)\; x\; 0.5\; x\; \tan\, 30^0 = 48.04$

A_S = Surface area of the pile = $\pi \; d \; l$ ... . for circular section pile

$A_{S\,1}$ (0 to 3 m) = $(\pi \; x \; 0.3 \; x \; 3) = 2.827 \; m^2$

∴ Frictional Resistance for top layer ($Q_{S\,1}$) is given by,

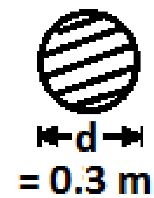
$Q_{S\,1} = [\,(f_{S\,1}\; x\; A_{S\,1})\,] = (48.04\; x\; 2.827) = 135.80 \;\; kN/m^2$



Layer II or Bottom layer having stiff clay of depth (3 to 8 m) :

The Frictional Resistance for bottom layer ($Q_{S\,2}$) is given by,

$Q_{S\,2} = [\,\alpha\; \bar{C}\; A_S\,] = [\,0.6\; x\; 60\; x\; (\pi\; x\; 0.3\; x\; 5)\,] = 170 \;\; kN/m^2$



∴ Total frictional Resistance along the surface (length) of the pile (Q_S) :

∴ $Q_S = (\,Q_{S\,1} + Q_{S\,2}\,) = (\,135.80 + 170\,) = 305.8$

Ultimate Load Carrying capacity of Single Pile is given by :

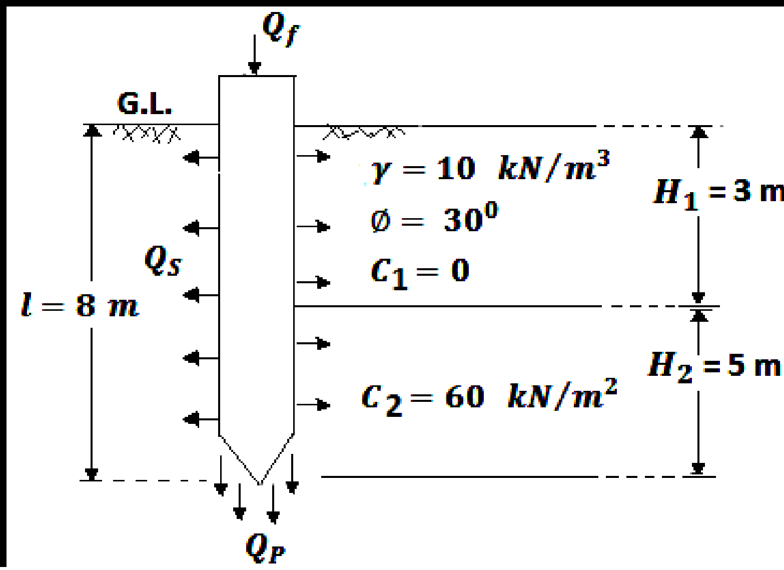
∴ $Q_f = [\,Q_P + Q_S\,] = (\,43.47 + 305.8\,) = 349.27 \; kN$

Static Capacity or Safe Load (Allowable Load) is given by:

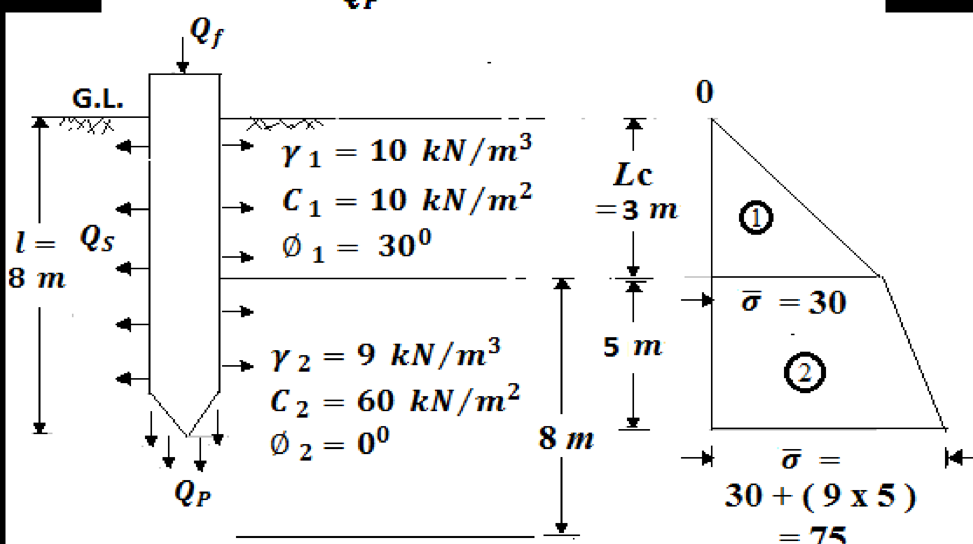
$Q_{f\,safe} = (\,Q_f \,/\, fos\,) = (\,349.27\,/2\,) = 174.63 \;\; kN$

Problem 5.5 Determine safe load carrying capacity of 400 mm diameter and 8 m long pile passing through two layer soil strata. The upper layer is 3 m thick cohesion-less having unit weight of 10 kN/m3 while lower layer is cohesive soil having unit cohesion as 60 kN/m2. take K = 0.5 and FOS = 02. **[SGBAU, S – 18/8 m]**

Solution :



This Problem



Previous Problem


DOUBT
KILLS
MORE
DREAMS
THAN
FAILURE
EVER
WILL.
- Suzy Kassem
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