

### 4.3 Methods to determine load carrying capacity of pile:

- The ultimate Load carrying capacity of pile or ultimate Load bearing resistance of pile is the maximum load which it can be carry without failure.
- The pile transfer the load in two ways
  - 1) Through the tip in compression is called end bearing or point bearing
  - 2) By shear along the surface is called as skin friction
- All type of pile behave both end bearing and skin friction

The Load carrying capacity of pile can be determined by following method

1. Dynamic Analysis
2. Static Analysis
3. Pile load test
4. Penetration test

#### 1. Dynamic Analysis:

The load carrying capacity of a driven pile can be estimated from the resistance against penetration developed during driving operation with a hammer.

#### 2.Static Analysis:

Sum of end bearing pile/point bearing pile and friction pile

$$Q_{up} = A_s R_f + R_p A_p$$

$A_s$ =Surface area of pile

$A_p$ = Area of cross section of pile

$r_f$ =Average skin friction

$r_p$ =end/point/tip bearing of pile

#### For circular Pile:

$$A_p = \frac{\pi}{4} D^2$$

$$A_s = \pi D L$$

#### For rectangular Pile:

$$A_p = B \times D$$

$$A_s = 2(B + D)L$$

#### i) Cohesive soil:

$$r_f = \alpha \cdot C \text{ or } mc$$

$$r_p = C_p N_c, N_c = 9$$

$$r_p = 9C_p$$

$$Q_{up} = \alpha C A_s + 9C_p A_p$$

Where,  $\alpha$ =Reduction factor

$$Q_a = \frac{Q_{up}}{F}$$

$$Q_a = \frac{\alpha C A_s + 9C_p A_p}{F}$$

## ii) Cohesionless soil

$$r_f = k \tan \phi (\gamma \cdot Z + q)$$

**For circular pile:**

$$r_p = 0.3 \gamma B N_\gamma$$

**For rectangular and square pile:**

$$r_p = \frac{\gamma_B}{2} N_\gamma$$

Where,

$r_f$ =average skin friction

$\gamma$  = density of soil.

$q$ = surcharge on the ground

$\phi$  = angle of internal friction.

## Static Analysis: Problems

1.A reinforced concrete square pile of size 30x30cm and 10cm long is driven into saturated sand extending to great depth. The average effective unit weight =16KN/m<sup>3</sup>.average FS=2.5 .Find  $Q_s$

**Given data:**

square pile of size 30x30cm=0.3x0.3m

$Z$ =10cm

$\gamma$  = 16KN/m<sup>3</sup>

$F$ =2.5

**To find:**

Safe Load  $Q_s=?$

**Solution:**

Assume  $K=1.5, N_\gamma = 25, \tan\phi = 0.6$

$$Q_{up} = A_s R_f + R_p A_p$$

cohesionless soil

$$r_f = k \tan\phi (\gamma \cdot Z + q)$$

$$r_f = 1.5 \times 0.6 \times (16 \times 10 + 0) = 144$$

**For rectangular and square pile:**

$$r_p = \frac{\gamma B}{2} N_\gamma$$

$$r_p = \frac{16 \times 0.3}{2} \times 25 = 60$$

$$A_p = 0.3 \times 0.3 = 0.09 \text{ m}^2$$

$$A_s = b \times Z = 0.3 \times 10 = 3 \text{ m}^2$$

$$Q_{up} = A_s R_f + R_p A_p$$

$$Q_{up} = 0.09 \times 60 + 144 \times 3 = 437.4 \text{ KN}$$

$$Q_a = \frac{Q_{up}}{F} = \frac{437.4}{2.5} = 174.96 \text{ KN}$$

2. A pile is driven in a uniform clay of large depth .UCC=90KN/m<sup>2</sup>, 30 cm dia and 6m long, FS=3,  $\alpha=0.7$ . Determine the frictional resistance.

**Given data:**

$$UCC = 90 \text{ KN/m}^2$$

$$D = 30 \text{ cm} = 0.3 \text{ m}$$

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

$$F = 3$$

$$\alpha = 0.7$$

**To find :**

frictional resistance=?

**Soln:**

$$Q_{up} = A_s R_f + R_p A_p$$

$$Q_{up} = \text{frictional resistance} + \text{end/point/tip bearing pile}$$

$$A_s R_f = \text{frictional resistance}$$

$$R_p A_p = \text{end bearing pile}$$

Given clay soil therefore it is cohesive soil

**For circular Pile:**

$$A_s = \pi D L = \pi \times 0.3 \times 6 = 5.6 m^2$$

**Cohesive soil:**

$$r_f = \alpha \cdot C \text{ or } mc$$

**UCC:**

$$C = \frac{q_u}{2} = \frac{90}{2} = 45 \text{ KN/m}^2$$

$$R_f = 0.7 \times 45 = 31.5$$

$$\text{frictional resistance} = A_s R_f = 5.6 \times 31.5 = 176.4 \text{ KN}$$

$$\text{Safe frictional resistance} = \frac{A_s R_f}{F} = \frac{176.4}{3} = 58.8 \text{ KN}$$

3. A 30cm diameter concrete pile is driven normally consolidated clay deposit 15m thick .Estimate the safe load. Take  $C_u = 70 \text{ KN/m}^2$ .

**Given data:**

Diameter  $D = 30 \text{ cm} = 0.3 \text{ m}$

Clay-cohesive

$Z = 15 \text{ m}$

$C_u = 70 \text{ KN/m}^2$ .

**To find:**

Safe load=?

**Solution:**

$$Q_{up} = A_s R_f + R_p A_p$$

**For circular Pile:**

$$A_p = \frac{\pi}{4} D^2$$

$$= \frac{\pi}{4} 0.3^2 = 0.070 m^2$$

$$A_s = \pi D L = \pi \times 0.3 \times 15 = 14.13 m^2$$

**Cohesive soil:**

Assume  $\alpha = 0.9, F = 2.5$

$$r_f = \alpha \cdot C \text{ or } mc$$

$$= 0.9 \times 70$$

$$= 63 \text{ kN/m}^2$$

$$r_p = C_p N_c, N_c = 9$$

$$r_p = 9 \times 70 = 630 \text{ kN}$$

$$Q_{up} = A_s r_f + r_p A_p$$

$$Q_{up} = 14.13 \times 63 + 630 \times 0.070$$

$$= 934.29 \text{ kN}$$

$$Q_{up} = \text{working load}$$

Where,  $\alpha$  = Reduction factor

$$Q_a = \frac{934.29}{2.5} = 373.716 \text{ kN}$$

$$Q_a \text{ or } Q_s = \text{safe load or allowable load}$$

4. A concrete pile of 45cm dia is driven through a system of layered cohesive soil. The length of the pile = 16m

1. Stiff clay = 8m,  $C_u = 30, \alpha = 0.9$

2. Medium Stiff clay = 6m,  $C_u = 50, \alpha = 0.75$

3. silt stratum = to creator depth,  $C_u = 105, \alpha = 0.5, A_s = 0.159 \text{ m}^2$ .

**Given data:**

$$D = 45 = 0.45 \text{ m}$$

Cohesive soil

$$\text{Length } L = 16 \text{ m}$$

$$A_s = 0.159 \text{ m}^2$$

**To find:**

Safe load = ?

**Solution:**

$$\text{silt stratum} = \text{to creator depth} = 16 - (8 + 6) = 2 \text{ m}$$

$$Q_{up} = A_s r_f + r_p A_p$$

$$r_f = \alpha \cdot C \text{ or } mc$$

$$= [(0.9 \times 30 \times 8) + (0.75 \times 50 \times 6) + (0.5 \times 105 \times 2)] = 357 \text{ KN/m}^2$$

$$r_p = C_p N_c, N_c = 9$$

$$r_p = 9 \times 105 = 945 \text{ KN}$$

$$A_p = \frac{\pi}{4} D^2$$

$$= \frac{\pi}{4} 0.45^2 = 0.158 \text{ m}^2$$

$$Q_{up} = 0.159 \times 357 + 945 \times 0.158 = 202.86 \text{ KN}$$

$$Q_a = \frac{202.86}{2.5} = 81.144 \text{ KN}$$

5. A group of 9 piles with 3 piles in a row is driven into soft clay extending from ground level to a great depth. The diameter and length of piles were 30 cm and 10 m respectively. The unconfined compression strength of clay is 70 kN/m<sup>2</sup>. If the piles were spaced at 90 cm centre to centre, compute the allowable load on the pile group on the basis of shear failure criteria for a factor of safety of 2.5, neglect bearing at the tip of piles, take  $m = 0.6$  for shear mobilization around each pile.

**Given Data:**

$n = 9$  piles with 3 piles in a row.  $S = 90 \text{ cm} = 0.9 \text{ m c/c}$

$D = 30 \text{ cm} = 0.3 \text{ m}$   $L = 10 \text{ m}$

$q_u = 70 \text{ kN/m}^2$

$$c = \frac{q_u}{2} = \frac{70}{2} = 35 \text{ KN/m}^2$$

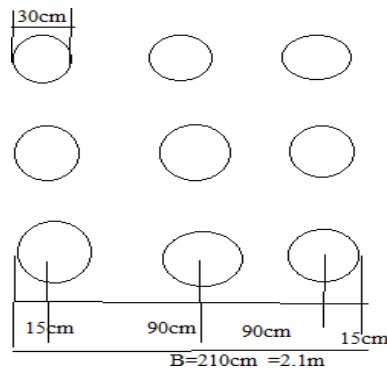
F.S. = 2.5,  $m = 0.6$

**To Find:**

$Q_a = ?$

**Solution:**

**Ultimate load on pile based on individual action::**



Size of pile group = BXB

$$= 2.1\text{m} \times 2.1\text{m}$$

$$Q_{up} = A_s r_f + A_p r_p$$

$A_s r_f$  = Friction pile

$A_p r_p$  = end/point/tip bearing

In question neglect bearing at the tip of piles, therefore

$$Q_{up} = A_s r_f$$

$$A_s = \pi d L = \pi \times 0.3 \times 10 = 9.42\text{m}^2$$

$$r_f = \alpha C = mc = 0.6 \times 35 = 21$$

$$= 9.42 \times 21 = 197.82 \text{ kN}$$

$$Q_{un} = n \times Q_{ug} = 9 \times 197.82 = 1780.38 \text{ kN}$$

**Ultimate load on pile based on group action:**

$$Q_{up} = A_s r_f$$

$$A_s = 4BL = 4 \times 2.1 \times 10 = 84\text{m}^2$$

$$Q_{up} = 84 \times 21 = 1764 \text{ kN}$$

Ultimate load on pile = least = 1780.3 kN

When the pile acting individually,

$$\text{Safe load on pile} = \frac{1780.3}{2.5} = 712.5 \text{ kN}$$

6. A group of 16 friction piles is to support a column load of 4000kN. The piles will be driven in four rows with four numbers in each column. The piles are 35 cm diameter and the c/c spacing is 1m both ways. What set value must be attained by the piles when driven by a single acting 22.5kN steam hammer with 90cm stroke so that the pile group can carry the column load? Assuming L= 10m

**Solution:**

**Case1)i)Load carried by group action**

$$Q_{up} = A_s r_f + A_p r_p$$

$$A_s = 4BL$$

$$= 4 \times 3.35 \times 10$$

$$= 134 m^2$$

$$Q_{up} = 84 \times 21 = 1764 \text{ KN}$$

$$A_p = B^2 = 3.35^2 = 11.22 m^2$$

$$r_p = C N_c = 9C$$

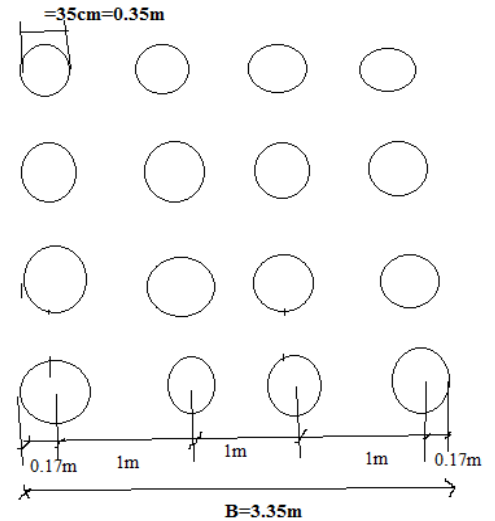
$$r_f = \alpha C = mc = 0.7 \times C$$

In group load is 4000KN

$$Q_{ug} = A_s r_f + A_p r_p$$

$$4000 = 134 \times 0.7 C + 11.22 \times 9C$$

$$C = 22 \text{ KN/m}^2$$


**ii)Load carried by individual action:**

$$Q_{up} = A_s r_f + A_p r_p$$

$$A_p = \frac{\pi d^2}{4} = \frac{\pi \times (0.35)^2}{4} = 0.096 m^2$$

$$r_p = C N_c = 22 \times 9 = 198 \text{ KN/m}^2$$

$$r_f = \alpha C = mc = 0.7 \times 22 = 15.4 \text{ KN/m}^2$$

$$A_s = \pi d L = \pi \times 0.35 \times 10 = 10.99 m^2$$

$$Q_{up} = 10.99 \times 15.4 + 0.096 \times 198 = 188.254 \text{ KN}$$

$$Q_{un} = n \times Q_{up}$$

$$= 16 \times 188.25$$

$$= 3012.064$$

Individual pile fails first.

**Caseii)Engineering news formula**

$$Q_u = WH/6(S+C) \text{ for stream hammer } C=0.254$$

$$2628 = [22.5 \times 0.9 \times 100] / [6(S + 0.254)]$$

$$2628 = 20.25 / [6S + 1.524]$$

$$2628(6S + 1.524) = 20.25 \times 100 \text{ (neglect the sign)}$$

$$6S + 1.524 = 0.77$$

$$6S = 0.752$$

$$S = 0.125 \text{ cm}$$

$$S = 1.25 \text{ mm}$$

7. Design a friction pile group to carry a load of 3000 kN including the weight of the pile cap at a site where the soil is uniform clay to a depth of 20 m underlain by rock. Average unconfined compressive strength of the clay is  $70 \text{ kN/m}^2$ . The clay may be assumed to be of normal sensitivity and normally loaded, with liquid limit of 60%. A factor safety of 3 is required against shear failure.

**Given**

$$Q_{ug} = 3000 \text{ kN}$$

$$C = q_u/2 = 70/2 = 35 \text{ kN/m}^2$$

$$\text{Permission } C = \frac{c}{F}$$

$$\text{Permission } C = 35/3 \text{ kN/m}^2$$

Assume, Let the length of pile = 10 m

Diameter of the pile = 0.5 m

Spacing of pile =  $3d = 3 \times 0.5 = 1.5 \text{ m} = 150 \text{ cm}$

Let the no. Of piles = n

$$Q_{up} = C \pi d L$$

$$Q_{ug} = n Q_{up}$$

$$Q_{ug} = n \times 35/3 \times \pi \times 0.5 \times 10$$

$$n = 16.37$$

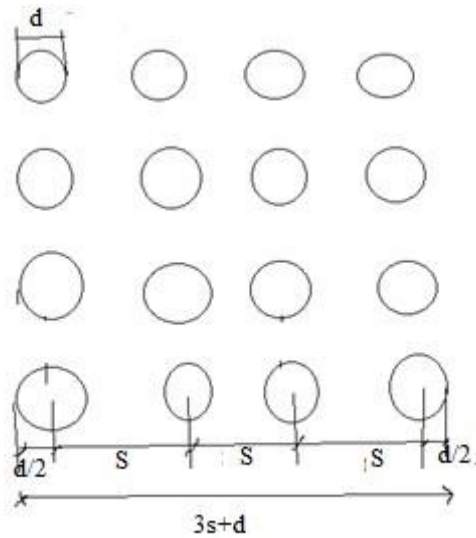
For square arrangement keep n = 16

The modified length L will then have to increase by the ratio  $16.37/16$

$$L = 10 \times 16.37/16$$

$$L = 10.23 \text{ m} \approx 11 \text{ m}$$

Check for group action



$$B = 3s + d = 3 \times 150 + 50 = 500 \text{ cm} = 5 \text{ m}$$

Load taken by group action

$$\begin{aligned} &= 4 \text{ BL} \times C + A \text{ P. C } N_c \\ &= 4 \times 5 \times 11 \times (35/3) + [(5 \times 5) \times (39/3) \times 9] \\ &= 2566.7 + 2625 \end{aligned}$$

$$Q_{ug} = 5191.7 \text{ kN} > 3000 \text{ kN}$$

Hence safe,