



IIT ROORKEE



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CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS:

Lecture 14: Pile Foundations: Group Action of Piles and Numerical

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ERD of Foundations - Modules

1. Introduction
2. Shallow Foundations
- 3. Pile Foundations**
4. Well Foundations
5. SSI for Deep Foundations



Module - 3

Pile Foundations

Module -3: Chapters

1. Piles for Static Vertical Load
2. Lateral Load on Piles
3. Dynamic Analysis of Piles
4. Design for Lateral and Dynamic Loads
5. Codal Provisions



Chapter 1: Piles for Static Vertical Loads

- Introduction
- Uses of Piles, Type of Piles, Selection of Pile Type
- Pile Load Capacity in Compression
 - Static Pile Load Formulae
 - Pile Load Test
 - Dynamic Pile Formulae
 - Correlation with Penetration Test Data
- Group Action of Piles
- Settlement of a Pile Group
- Numerical Example

Group Action of Piles

Piles are usually used in a group. This is to ensure that the structural load from a member like a column or a wall lies within the zone of the influence of the foundation. If a single driven pile is used as the foundation, one cannot be certain that the pile would be located centrally below the foundation elements because it may move laterally during driving. The resultant eccentricity of loading may result in the development of bending stresses in the pile and pile may fail structurally. Hence a minimum number of 3 piles is used under a column in a triangular pattern, even the load does not require use of 3 piles. When more than 3 piles are used they are so arranged that they are symmetrical with respect to load. Requirement of the minimum of 3 piles is not necessarily applicable to bored piles. 1 pile may be ok.



Group Action of Piles (Continued...)

Pile Cap

The load is transferred to the piles in the group through a reinforced slab on beam called the pile cap. The pile tops are connected together to the pile cap which helps the pile group act as an integral unit.

Free standing Pile group

If pile cap is standing clearly above the ground level.



Piled Foundation

If pile cap is fully resting on the soil, partially or fully buried below ground level.



Ultimate load capacity of the pile groups

The ultimate load capacity of the pile group is not necessarily equal to the sum of the individual load capacities of the piles in the groups.

$$\text{Group efficiency, } (\eta) = \frac{Q_{ug}}{nQ_u}$$

Q_{ug} = ultimate load capacity of the piles group

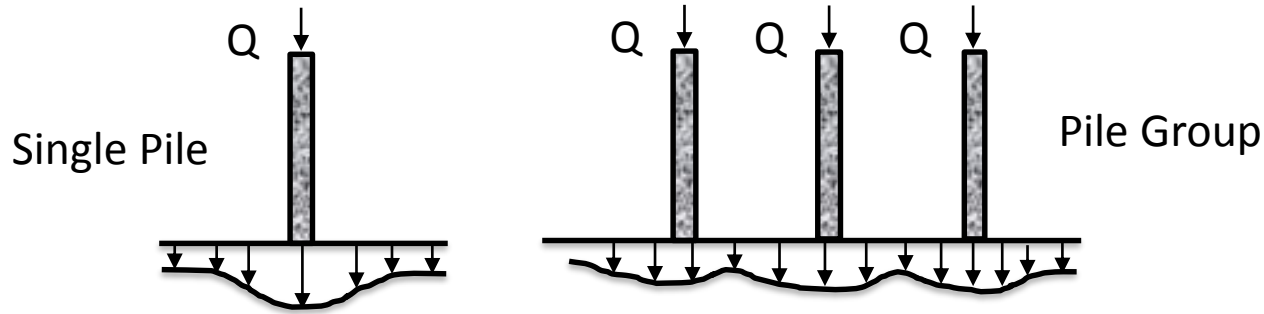
n = number of piles in the group

Q_u = load capacity of one pile

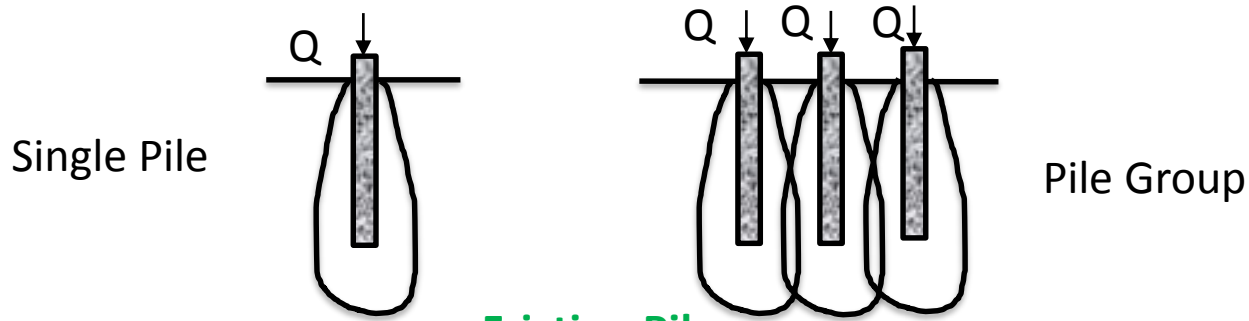
The pile group efficiency (η) depends mainly on the spacing between piles. The type of the soil in which the piles are installed and the manner of pile installation, i.e. driven, bored cast in situ etc.

Distribution of soil during installation of the piles and overlap of the stresses between adjacent piles may cause the group efficiency becomes less than the sum of the individual capacities i.e. $\eta < 1$. Generally for smaller spacing between piles, $\eta < 1$. For larger spacing, the effect of pile interaction decreases and η approaches unity.

Ultimate load capacity of the pile groups (Continued...)



Point Bearing Piles



Friction Piles

Ultimate load capacity of the pile groups (Continued...)

In driven piles, where the soil around the piles gets densified as a loose to medium sand, η may be even more than 1. In such cases, pile group tends to behave like a block or like an equivalent single pile. Larger spacing may necessitate a bigger pile cap, which is uneconomical.

The minimum spacing of piles is recommended by different codes of practice. IS 2911 (Part I) -1979 recommends a minimum spacing of 2.5 times the diameter for point bearing piles, 3 times diameter for friction piles, 2 times in loose sand in fill deposit.

Ultimate load capacity of the pile groups (Continued...)

Failure of pile groups may be due to

- Block failure- for spacing < 2 to 3 times pile diameter.
- Individual pile failure – for larger spacing

Settlement of a pile group

The settlement in a group of pile is more than the settlement of a single pile, even when the load on the single pile and the load on each pile of the pile group are the same. This is because of the fact that the zone of the influence of a pile group is much deeper than that of a single pile.

Allowable load on a pile group

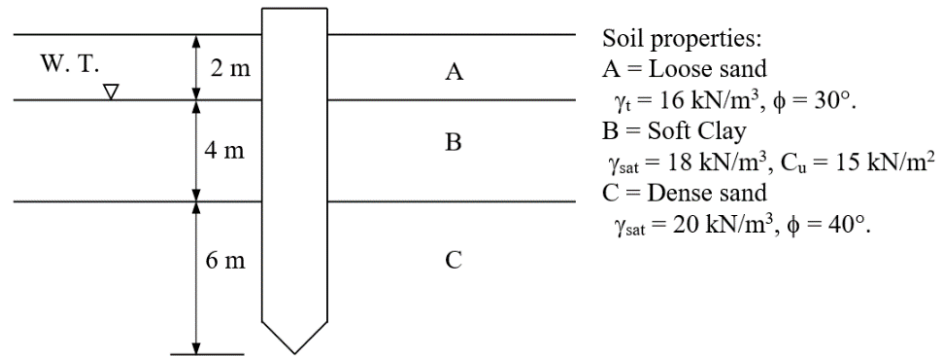
The safe pile load capacity of a pile group under vertical load is first determined on the basis of shear criterion. The settlement of the pile group under this load is then computed. The settlement should not exceed the permissible settlement. The allowable load on a pile group is the smaller of the values calculated on the basis of the shear failure criterion and the settlement criterion.

Numerical Example-1

Assuming a factor of safety equal to 3.0, determine the allowable pile load capacity of a 40 cm diameter driven concrete pile shown in Fig.

For determination of skin friction resistance in sand, values of K & δ are given in Table.

Also it shall be noted that in sand maximum unit skin friction is 100 kN/m^2 and unit point bearing resistance is limited to 11000 kN/m^2 . Further given that for clay stratum adhesion factor $\alpha = 1.0$ and for dense sand stratum bearing capacity factor $N_q = 150$.



Pile Material	δ	Value of K	
		Loose sand	Dense sand
Steel	20°	0.5	1.0
Concrete	0.75ϕ	1.0	2.0
Timber	0.67ϕ	1.5	4.0

Numerical Example-1 (Continued...)

Solution

Ultimate pile load capacity,

$$Q_u = Q_f + Q_{pu}$$

(a) Skin Friction Capacity, Q_f

This is determined layer by layer

(i) Loose sand Stratum

For concrete pile, $\delta = 0.75\phi = 0.75 \times 30 = 22.5^\circ$ and $K = 1$ for loose sand

For first stratum $L/D = 2/0.4 = 5 < 15$

Therefore, $\bar{\sigma}$ increase linearly with depth.

$$\overline{\sigma_{av}} = \frac{1}{2} \gamma_t * L = \frac{1}{2} 16 * 2 = 16 \text{ kN/m}^2$$

$$\begin{aligned} \text{Unit skin friction resistance } (f_s)_{av} &= \overline{\sigma_{av}} * K * \tan\delta = 16 * 1 * \tan 22.5 \\ &= 6.627 \text{ kN/m}^2 < 100 \text{ kN/m}^2 \text{ (o.k.)} \end{aligned}$$

Numerical Example-1 (Continued...)

skin friction resistance $(Q_f)_1 = (f_s)_{av} A_s = 6.627 * \pi * 0.4 * 2 = 16.66 \text{ kN}$

(ii) Soft Soil Stratum

Given for $c_u = 15 \text{ kN/m}^2$ $\alpha = 1.0$

skin friction resistance $(Q_f)_2 = \alpha c_u A_s = 1.0 * 15 * \pi * 0.4 * 4 = 75.40 \text{ kN}$

(iii) Loose sand Stratum

Due to the arching effect, depth of clay stratum is not required to consider in determining critical length of pile therefore

For first stratum $L/D = 6/0.4 = 15 < 20$ (for dense sand)

Therefore, $\bar{\sigma}$ increases linearly with depth.

$\bar{\sigma}$ at the top of sand stratum

$$\bar{\sigma} = 16 * 2 + (18 - 9.81) * 4 = 64.76 \text{ kN/m}^2$$

Numerical Example-1 (Continued...)

$\bar{\sigma}$ at the tip of the pile

$$\bar{\sigma} = 64.76 + (20 - 9.81) \times 6 = 125.9 \text{ kN/m}^2$$

$$\overline{\sigma}_{av} = \frac{64.76 + 125.9}{2} = 95.33 \text{ kN/m}^2$$

From given water table (for dense sand)

$$\delta = 0.75\phi = 0.75 \times 40 = 30^\circ \text{ and } K = 2$$

$$\begin{aligned}(f_s)_{av} &= \overline{\sigma}_{av} * K * \tan\delta = 95.33 * 2 * \tan 30 \\ &= 110.07 \text{ kN/m}^2 > 100 \text{ kN/m}^2\end{aligned}$$

Therefore, $(f_s)_{av} = 100 \text{ kN/m}^2$ will be used.

$$\text{skin friction resistance } (Q_f)_3 = (f_s)_{av} A_s = 100 * \pi * 0.4 * 6 = 754 \text{ kN}$$

$$\begin{aligned}\text{Total skin friction capacity } Q_f &= (Q_f)_1 + (Q_f)_2 + (Q_f)_3 \\ &= 16.67 + 75.4 + 754 = 846.07 \text{ kN}\end{aligned}$$

Numerical Example-1 (Continued...)

(b) Point Load Capacity, Q_{pu}

$\bar{\sigma}$ at the tip of the pile = 125.9 kN/m² and $N_q = 150$ (given)

$$q_{pu} = \bar{\sigma} N_q = 125.9 * 150 = 18885 \text{ kN/m}^2 > 11,000 \text{ kN/m}^2$$

Hence $q_{pu} = 11,000 \text{ kN/m}^2$ will be used

$$\begin{aligned} \text{Ultimate point bearing resistance, } Q_{pu} &= q_{pu} A_b = 11,000 * \frac{\pi}{4} * 0.4^2 \\ &= 1382.3 \text{ kN} \end{aligned}$$

(c) Allowable Pile Load Capacity, Q_a

$$\begin{aligned} \text{Ultimate pile load capacity, } Q_u &= Q_f + Q_{pu} \\ &= 1382.3 + 846.07 \text{ kN} \\ &= 2228.37 \text{ kN} \end{aligned}$$

$$\text{Allowable pile load capacity, } Q_a = \frac{Q_u}{FS} = \frac{2228.37}{3} = 742.79 \text{ kN}$$

References

1. **Prakash S. (1981), "Soil Dynamics", McGraw-Hill Company, New York**
2. **Ranjan G. and Rao A.S.R. (2004), "Basic and Applied Soil Mechanics", New Age Int. Ltd., New Delhi.**

Thank You

