



IIT ROORKEE



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CERTIFICATION COURSE

EARTHQUAKE RESISTANT DESIGN OF FOUNDATIONS:

Lecture 13: Pile Foundations subjected to Static Vertical Load

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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

Pile Foundations: Introduction

A shallow foundation is usually provided when the soil at a shallow depth has adequate capacity to support the load of the superstructure.

When the soil at shallow depth is poor, in order to transmit the load safely, the depth of foundation has to be increased till a suitable stratum is met. Such foundation are called deep foundation- Piles, Piers and Wells are example of deep foundation.

Uses of Piles

- Piles are Small diameter shafts, usually used in group
 - i. End Bearing or Point Bearing Piles
 - ii. Friction Piles or Floating Piles --- through soft soil
 - iii. Laterally Loaded Piles
 - iv. Pile driven at angles --- Battered Piles
 - v. Compaction Piles --- Compacting loose sand deposits
 - vi. Tension Piles --- used to resist uplift loads and are thus in tension
 - vii. Anchorage against horizontal pull --- Anchor Piles

Types of Piles

Material of Construction: Timber, Steel, Concrete, Composite

Cross Section: Circular, Square, Hexagonal, I/H section

Method of load transfer: Bearing, Friction etc.

Method of Forming: Precast, Pre-stressed Cast in situ

Method of Installation: Driven, Bored

Selection of Pile Type

The selection of the type of pile, depends on the several factors

- i. The type of structure and load it carries.
- ii. The location of site
- iii. Soil condition and position of water table
- iv. Required pile length and structural capabilities of the pile
- v. Durability
- vi. Economy

Pile Load Capacity in Compression

General **Requirements for Satisfactory Performance** are the same as for other type of foundations i.e.

- i. Adequate safety factors against Shear Failure
- ii. Settlement shall be within Permissible Limit

The **load capacity** of the pile can be estimated by several methods as:

- a) Static Pile Load Formulae
- b) Pile Load Test
- c) Dynamic Pile Formulae
- d) Correlation with Penetration Test Data

Static Pile Load Formulae

When a compression load Q is applied at the top of pile, the pile will tends to move vertically downward relative to the surrounding soil. This will cause shear stress to develop between the soil and surface of the shaft and load is distributed as friction load along a certain length of the pile from top. As the load increases friction load increases

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

Q_f = ultimate skin friction resistance of the pile

Q_{pu} = ultimate point load (till the soil at the base fails by punching shear)

If $Q_{pu} \gg Q_f \rightarrow$ Point bearing pile

If $Q_{pu} \ll Q_f \rightarrow$ Friction pile

Static Pile Load Formulae (Continued...)

The general equation for unit point bearing resistance q_{pu} for a $c-\phi$ soil may be written as

$$q_{pu} = cN_c + \bar{\sigma}N_q + \frac{1}{2}\gamma BN_\gamma$$

Where $\bar{\sigma} = \gamma L$, L = length of pile. In deep foundation the term $\frac{1}{2}\gamma BN_\gamma$ is quite small as compared to $\bar{\sigma}N_q$ and is usually neglected

Therefore,
$$q_{pu} = cN_c + \bar{\sigma}N_q$$

For a granular soil, $q_{pu} = \bar{\sigma}N_q$ }

For clay soil, $q_{pu} = cN_c$ } N_c and N_q are function of ϕ

$\bar{\sigma}$ increase linearly and thus become constant at a critical depth (=15D for loose sand and =20D for dense sand)

Static Pile Load Formulae (Continued...)

Ultimate point bearing resistance , $Q_{pu} = q_{pu}A_b$

Ultimate skin friction resistance , $Q_f = (f_s)_{av}A_s$

$(f_s)_{av}$ = Average unit skin friction resistance

$(f_s)_{av} = K \bar{\sigma}_{av} \tan \delta$ **for sand**

$\bar{\sigma}_{av}$ = Average Overburden pressure = γL

K = Lateral earth pressure coefficient

δ = angle of friction between pile and soil

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

Static Pile Load Formulae (Continued...)

Limiting Condition

- $(f_s)_{av} \nlessgtr 100 \text{ kN/m}^2$ for sandy soil
- For loose sand $\bar{\sigma}$ = increase upto 15D
- For dense sand $\bar{\sigma}$ = increase upto 20D

$$f_s = \alpha c_u, \text{ for clay}$$

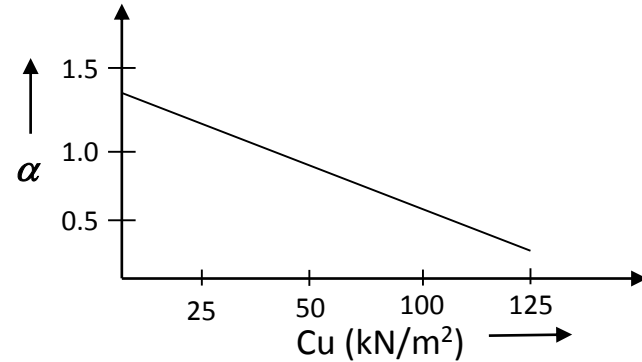
α = adhesion factor

$$q_{pu} = cN_c + \bar{\sigma}N_q, \nlessgtr 11,000 \text{ kN/m}^2 \text{ in normal silica sand}$$
$$\nlessgtr 5,000 \text{ kN/m}^2 \text{ in calcareous sand}$$

$$Q_u = q_{pu}A_b + (f_s)_{av}A_s$$

$$\text{For pure clay, } Q_u = c_u N_c A_b + \alpha c_u A_s$$

$$\text{For pure sand, } Q_u = \gamma L N_q A_b + (f_s)_{av} A_s$$



Pile Load Test (in situ test)

Direct method for determining the allowable load on piles.

Three types of test

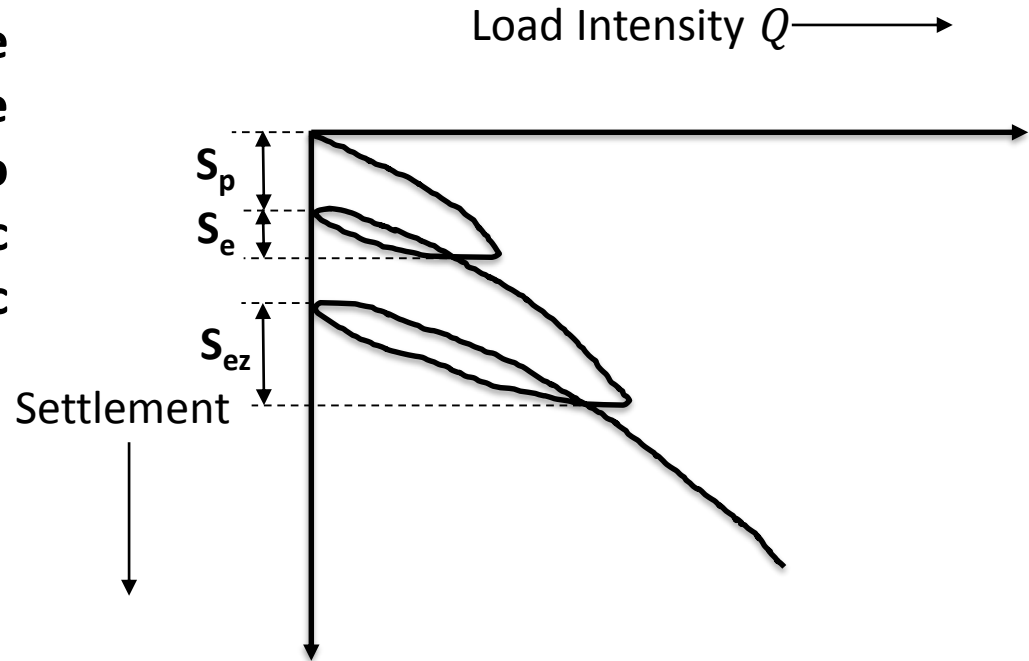
- (i) Vertical load test (compression)--- Load settlement curve
- (ii) Lateral Load test
- (iii) Pull out test

Two categories of tests are (a) Initial test (b) Routine test. Initial test are carried out on test pile to estimate the allowable load/ predict the settlement at a working load. Routine test is carried out as a check on working piles and to access the displacement corresponding to the working load.

Pile Load Test (Continued...)

The total settlement S of the a pile obtained from a pile load test comprises of two component, namely elastic settlement S_e and Plastic Settlement S_p

$$S = S_e + S_p$$



Load settlement Curve

Dynamic Pile Formulae

Dynamic pile formulae are useful in estimating pile capacity. These are based on the laws governing the impact of elastic bodies.

Hammer used in pile deriving:

- i. Drop hammer: The hammer is lifted up and dropped freely
- ii. Steam Hammer: (a) Single acting– steam/air pressure is used to lift the ram upto the required height. Then ram drop under the gravity which transmits the energy to the pile through the cap block.
(b) Double acting– steam is used both way to lift and to add gravity in dropping
- iii. Diesel hammer: Lighter and High mobility

Engineering News Formulae

The dynamic resistance of soil Q_u is assumed to be ultimate pile load capacity. Equating the energy input and work done

$$Q_a = \frac{WH}{F(S + C)}$$

Where, Q_a = Allowable load

W = Weight of Hammer falling through a height of H

S = Real set per blows

C = Empirical factor, allowable reduction in the theoretical set due to energy loss

F = Factor of safety (Usually taken as 6)

Engineering News Formulae (Continued...)

1. Drop hammers:

$$Q_a = \frac{WH}{6(S+2.5)}$$

2. Single acting steam Hammer:

$$Q_a = \frac{WH}{6(S+0.25)}$$

Where, Q_a and W are in *kgf*, S , H and C are in *cm*

Modified Hiley Formula

Considered to be superior to the Engineering News formula, as it takes into account various energy losses during driving in a more realistic manner. Equating the available energy with useful work done and losses

$$R = \frac{Wh\eta}{(S+\frac{C}{2})} = \frac{Wh\eta}{(S+\frac{1}{2}(C_1+C_2+C_3))}$$

Where, R = Ultimate driving resistance in tonnes. The safe load is estimated by dividing the ultimate driving resistance by a F.S. of 2.5

W = Weight of hammer in tones

h = effective fall of hammer (in cm)

η = Efficiency of the blow that represents the ratio of energy after impact to the string energy of the ram.

Modified Hiley Formula (Continued...)

S = The final set of penetration per blows in cm

C = Total elastic compression = $C_1 + C_2 + C_3$

C_1 = Temporary elastic compression of dolly and packing

C_2 = Temporary elastic compression of pile

C_3 = Temporary elastic compression of soil

When $W > Pe$ and pile is driven into penetrable ground

$$\eta = \frac{W + Pe^2}{W + P}$$

When $W < Pe$ and pile is driven into penetrable ground

$$\eta = \frac{W + Pe^2}{W + P} - \left(\frac{W - Pe}{W + P} \right)^2$$

Where, **P** = Weight of pile, anvil and followers

e = coefficient of restitution of the material under impact.

Usefulness of Dynamic Formulae for Pile capacity

Because of the uncertainty about the relationship between the static load and dynamic load resistance, the pile deriving formulae have very limited utility. These are based on the assumption of impact of two free elastic bodies. Pile is not a free body. These formulas are useful for coarse sand but are not so in the case of cohesive soil deposits.

In saturated uniform sand deposits, vibration during driving are likely to cause liquefaction.

The dynamic formulae fails to provide information about the settlement under the load.

Correlations with penetration test data

Static cone penetration data (CPT) and standard Penetration test (SPT) are often used to determine the pile load capacity. CPT gives the variation of resistance value at tip of the cone a_c and the skin friction resistance q_c on the sleeve with depth. SPT yields the N values of the subsoil strata at regular intervals of depth.

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

