Module 5 : Design of Deep Foundations

Lecture 25 : Pile Groups [Section 25.1 : Different types of pile groups]

Objectives

In this section you will learn the following

- Different types of pile groups

Different types of pile groups

The different types of pile groups are shown below:

Fig.5.41 Different Pile groups

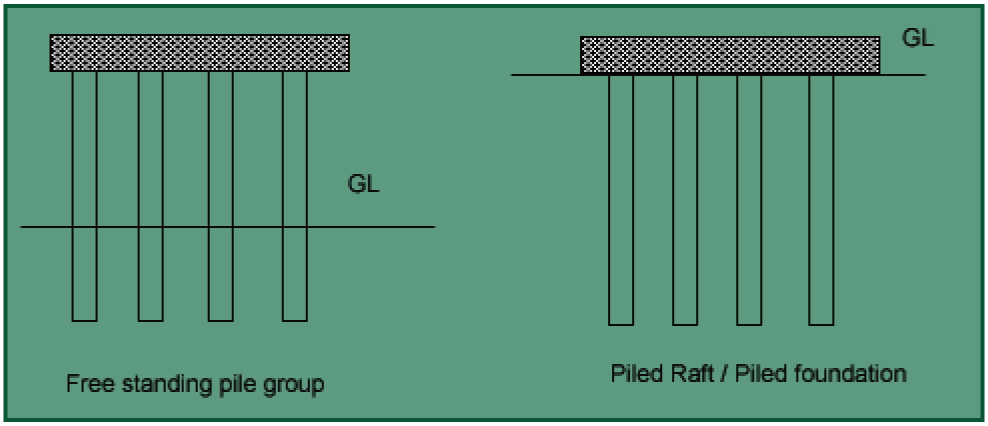


Fig. 5.42 Pile Groups

Usually the GL and the base of the piled foundation are made flush with one another. As a result the Pile foundation has a higher load bearing capacity and lesser settlement. This is because the pile in piled raft foundation are in contact with more soil than the free standing pile group.

Recap

In this section you have learnt the following.

- Different types of pile groups

Module 5 : Design of Deep Foundations

Lecture 25 : Pile Groups [Section 25.2 : Group Deficiency Factor (η) ; Block Failure Criteria]

Objectives

In this section you will learn the following

- Group Deficiency Factor
- Block Failure Criteria

GROUP DEFICIENCY FACTOR (η)

For bearing capacity,
η = (Ultimate load capacity of group) / Sum of ultimate load capacity of individual piles)

$\eta = P_{ug} / nP_u$

The aim of the designer is to make η =100% or 1.0
However for sandy soils, η **> 1.0**

This is because, the soils gets densified due to driving of piles in sandy soil and hence soil strength properties increase. Therefore while starting a design we start with

$P_{ug} = nP_u$. Since P_u remains same, therefore calculate nP_u based on the no. of piles to be used. Compare with P_{ug} In design take whichever value is minimum.

Alternatively, P_{ug} is expressed as function of spacing of piles (s) and equated with nP_u .

Calculate 's' for η =1.0. Usually, 's' is taken as 3d to 8d depending on the soil and pile parameters. Lower the value of s, higher is the lower is the efficiency.

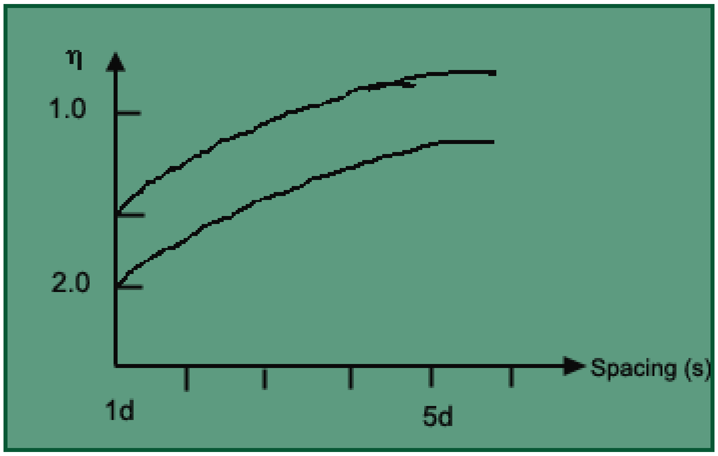
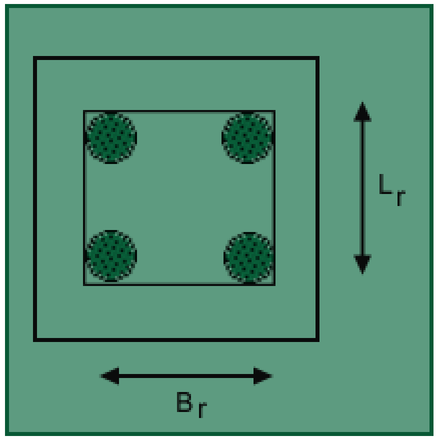


Fig. 5.43 Variation of efficiency of pile group with spacing of piles

Block Failure Criteria

In this case it is assumed that the pile group fails as a block.



$$P_{ug} = B_{r}.L_{r}.cN_c + (B_{r} + L_{r})L_c' \qquad \text{----------(45)}$$

Where, c is the average cohesion at base.

c' is the average cohesion along pile length.

The first term denotes the P_{ubg} (base capacity)

and the 2 nd term denotes P_{usg} (shaft resistance) .

ξ =0.5

N_c = 9 , depends on L/B_r .

Recap

In this section you have learnt the following.

- Group Deficiency Factor
- Block Failure Criteria

Module 5 : Design of Deep Foundations

Lecture 25 : Pile Groups [Section 25.3 : Design value of ultimate load ; Settlement of a pile]

Objectives

In this section you will learn the following

- Design value of ultimate load
- Settlement of a pile

Design value of ultimate load

For piled raft foundation : The minimum of block failure value and the sum of individual pile capacities.

For free standing pile : The minimum of block failure value and 2/3 rd the sum of individual pile capacities.

Minimum of block failure value & 2/3 of sum of individual pile capacity

Bearing capacity of block plus bearing capacity of

1. Extra width of pile group and times bearing capacity of each pile + bearing capacity of (area of cap – area of pile, n)
2. $P_{ug} = n(c_a A_s + A_b c_b N_c) + n^c{}_c c_c (B_c L_c - \frac{n \pi d^2}{4})$ ---------(46)

where $N^c{}_c$ is the N_c value at cap base, c_c is the cohesion, and B_c , L_c are width and length of cap

Settlement of a pile

At centre of pile, $w_i = \frac{(3-4\mu)(1-\mu)}{4E_s(1-\mu)} pa$ ---------(47)

where p is the perimeter of the pile and a is the radius from centre of the pile

In reality, settlement of a single pile is, $w = w_s + w_{ps} + w_{pp}$

where w is the total settlement, w_s is the settlement due to axial deformation of pile shaft because of pile material, w_{ps} is the settlement of a pile tip or point due to load transmitted along pile shaft, and w_{pp} is the settlement pile tip due to load transmitted at pile tip.

$$w_s = \frac{(P_{ub} + \xi P_{us})L}{A_p E_p} \quad w_{pp} = \frac{q_{ub} d}{E_{soil}}(1 - \mu^2) I_{ub} \qquad \text{---------(48)}$$

$$w_{ps} = \frac{P_{us}}{PL}\frac{d}{E_s}(1 - \mu^2{}_s) I_{us} \qquad \text{---------(49)}$$

$$q_{ub} = \frac{P_{ub}}{area} = \text{ultimate at base} \qquad \text{---------(50)}$$

d is the diameter of the pile and I_{ub} is the influence factor for tip of the pile, p is the perimeter

Generally ξ =0.5 and it is a function of skin friction (f_s)

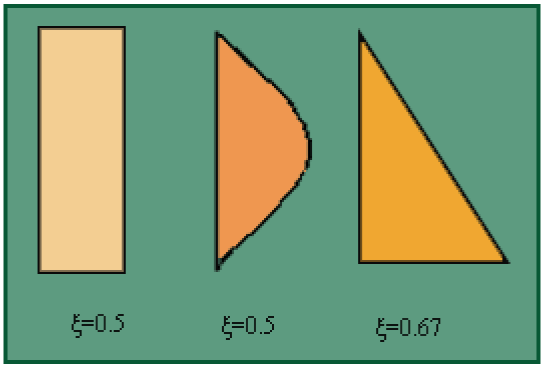


Fig 5.44 Variation of ξ

Compression pile

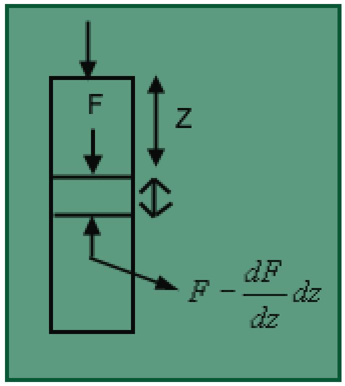


Fig 5.45 Free body diagram of a compression pile

Z is at any depth, w is the settlement

Strain= $\frac{dw}{dz}$

Stress= $E\frac{dw}{dz}$

Force= $EA\frac{dw}{dz}$

$F_s = Ps = \tau s\,dz = sk_s\,w\,dz$ Where s is the perimeter

Elemental force= $\frac{dF}{dz}dz$

$\frac{dF}{dz}dz = sk_s w dz$ or $\frac{dF}{dz} = sk_s w$

Now, $\frac{dF}{dz} = \frac{d}{dz}(EA\frac{dw}{dz}) = EA\frac{d^2w}{dz^2}$

$$EA\frac{d^2w}{dz^2} = sk_s w$$

$$EA\frac{d^2w}{dz^2} - sk_s w = 0 \quad \frac{d^2w}{dz^2} - \frac{sk_s w}{EA} = 0$$

$$\frac{d^2w}{dz^2} - \lambda w = 0$$

where $\lambda = \sqrt{\frac{sk_s}{EA}}$ where k_s is the sub grade modules, E is elasticity modules of pile material and A is the cross sectional area.

General solution is $w = c_1 e^{-\lambda z} + c_2 e^{-\lambda z}$ the values of c_1 & c_2 are obtained by applying boundary conditions.

Module 5 : Design of Deep Foundations

Lecture 25 : Pile Groups [Section 25.2 : Group Deficiency Factor (η) ; Block Failure Criteria]

Recap

In this section you have learnt the following.

- Design value of ultimate load
- Settlement of a pile

Objectives

In this section you will learn the following

- Problem

Problem

Determine the total settlement for the pile group shown in the fig. 5.46

Ans :

The load is assumed to be distributed in a ratio of 1H:4V on the equivalent mat at a distance of (2/3)rd of the pile length ie (2/3*9 =) 6m. Ref. fig.5.46.

Width of equivalent map = 3 + 2 * (6/4) = 6m

Length of equivalent map = 2.1 + 2 * (6/4) = 5.1m

Udl acting on the equivalent map = 150/(6 * 5.1) = 4.902 t/m^2

Below the equivalent map it is analyzed as shallow foundation, by dividing it into no. of layers as shown in fig. 5.47.

The Effective overburden pressure at center of each layer:

σ_1' = (16.4 x 2) + (2 x 19.1) + (5.5 x (19.1-9.81)) = 122.095 KN / m^2

σ_2' = 122.095 + (3 x (19.1-9.81)) = 149.965 KN / m^2

σ_3' = 149.965 + (1.5 x (19.1-9.81)) + (1.25 x (20-9.81)) = 176.64 KN / m^2

σ_4' = 176.64 + (1.25 x (20-9.81)) = 189.375 KN / m^2

The settlement at center of each layer (s) = $\frac{C_c}{1+e_0}\Delta H \frac{\sigma' + \Delta\sigma'}{\sigma'}$

Where,

C_c = compression index of that layer,

e_0 = initial void ratio,

ΔH = height of the layer,

σ' = effective overburden pressure at center of the layer,

$\Delta\sigma'$ = increase in the effective pressure due to load.

Total settlement will be the summation of the settlement at center of each layer. The calculations are given in tabular form in table 7.

Table: 5.7 Final settlements

Layer no.	Depth of the center of the layer (Z) (m)	Effective overburden pressure (s') (KN/ m^2)	Increase in effective pressure $\Delta\sigma'$ = $\frac{1500}{(6+Z)(5.1+Z)}$ (KN / m^2)	ΔH (m)	Settlement at center of each layer (mm)
1	1.5	122.095	30.3	3	38.94
2	4.5	149.965	14.88	3	16.62
3	7.25	176.64	9.17	2.5	6.58
4	9.75	189.375	6.14	2.5	4.1

Total settlement = 66.24 mm

Ans Total settlement is 66.24 mm.

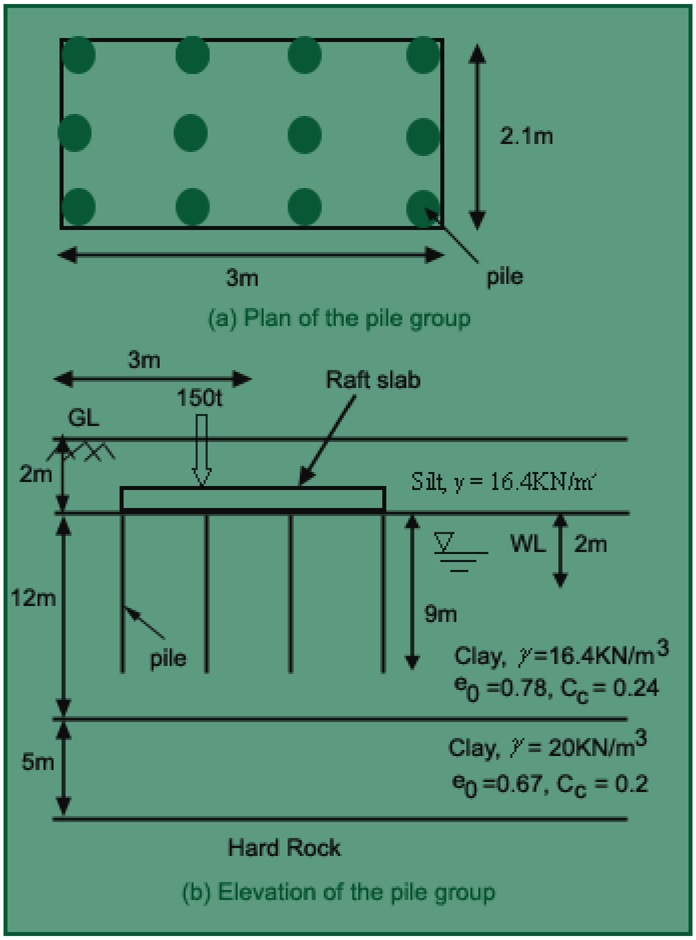


Fig. 5.46 Pile group

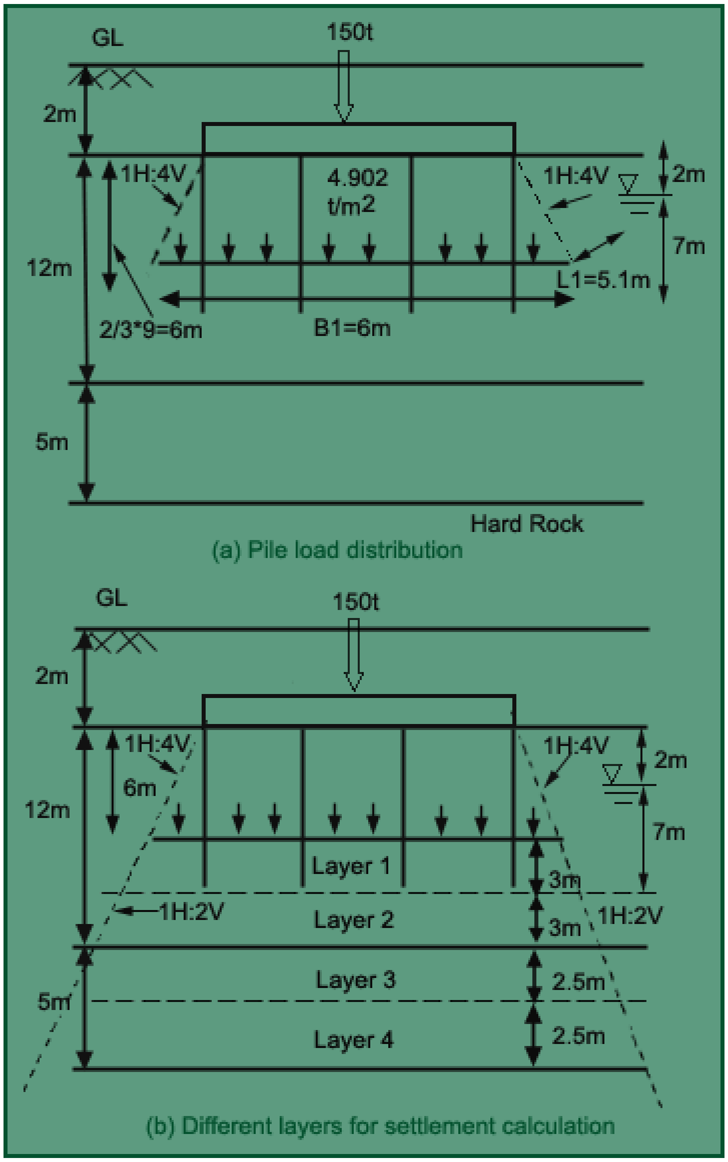


Fig. 547 Pile group settlement analysis

Recap

In this section you have learnt the following.

- Problem

Module 5 : Design of Deep Foundations

Lecture 25 : Pile Groups [Section 25.5 : Negative Skin Friction]

Objectives

In this section you will learn the following

- Negative Skin Friction

Negative Skin Friction

In the weak soil zone pile moves up with respect to surrounding soil. It is same as tension uplift,i.e. surrounding soil moves down with respect to pile. This is known as negative skin friction as shown in figure. It is also known as downdrag phenomenon and occurs when the soil layer surrounding the pile settles more than the pile. Negative skin friction develops when the soft or loose soil strata are located anywhere in between and the pile shaft is subjected to compressive load. Also negative skin friction develops due to increase to effective stresses.

F.S.= (Ultimate Pile capacity – Negative Skin Friction force)/ Working Load.

The net effect is to reduce the F.S.

F.S.= (Q_u – Q_{nf})/ Q_w ----------(45)

Q_{nf} = $P.D_nC$, for cohesive soils.

where P is the perimeter, D_n is the depth of compressible layer, C is cohesion.

Q_{nf} = 0.5 P $D_n^2\, \gamma k \tan\delta$, for cohesionless soil.

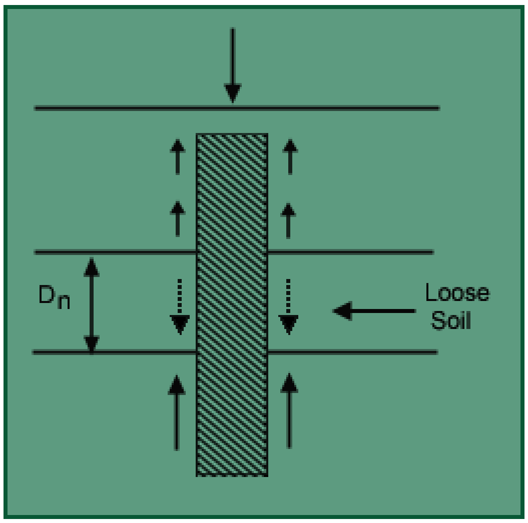


Fig. 5.48 Development of negative skin friction on piles