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Analysis of pile foundation on soft consolidating soil

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ABSTRACT : *Many times the structures are constructed on soft consolidating soils which has low bearing capacity, excessive settlement characteristics and long duration for consolidation. Determination of settlement of footing constructed on these soils is one of the major problems of geotechnical engineering. In this paper a footing supported by piles on soft consolidating soil is analysed using finite element method. In this method pore pressure and displacement in soil are coupled and resulting equations are solved to obtain the displacements and pore-pressure at various time intervals from beginning till the end of consolidation. Behaviour of soil is considered as nonlinear and a cam clay model is used to simulate the behaviour of soil. The settlement of the footing resting on pile foundation is compared with the settlement of foundation without piles and it is found that the time required for consolidation for the footing on piles is considerably less than that of the foundation without piles.*

Keywords – *Cam clay model, Consolidation, Finite element method, Footing on piles.*

1. Introduction

Dissipation of excess pore pressure due to external load or due to self-weight of the soil is called consolidation. Consolidation plays major role in analysis of footing, pile foundation and embankment constructed on soft consolidating soil. It has received greater attention after Terzaghi published his consolidation theory and principle of effective stress. Consolidation settlement were obtained in most cases using Terzaghi's one dimensional consolidation theory. Biot developed a more general theory for three dimensional consolidation coupling the soil deformation and the pore pressure [1]. Stability and time required for consolidation are the two major considerations in the design and construction of structures over soft cohesive foundations. Numerical simulations by means of the finite element method (FEM) have become a valuable tool in geotechnical engineering to predict and to understand the behaviour of complex structures and extensive research has been carried out in this area [2], [3], [4]. The construction and consolidation behaviour of a structure is usually analysed by the finite element method [5], [6]. Conventional theories for consolidation analysis often neglected the nonlinearity of soil. However, the behavior of soil is nonlinear from the beginning. The true modelling of a soil requires three-dimensional (3D) non-linear analyses. However, 3D analyses are sophisticated and require large computational effort when applied to a real soil. Hence, the actual 3D problem is converted into an equivalent two dimensional plane strain model which has equivalent properties and dimensions. Sandhu and Wilson formulated analysis for coupled consolidation problem using finite element method [7]. Formulation of the nonlinear consolidation problem was first proposed by Lewis et al. [8]. Manoharan and Dasgupta studied the consolidation behaviour of strip footing by modeling the behaviour of soil as elastic – perfectly plastic satisfying the Mohr-Coulumb yield cretirion [9]. Shui-Long Shen et al. studied field performance of embankments on soft clay deposit with and without PVD-improvement [10]. Studies carried out on behavior of consolidation of embankment at Haarajoki, Finland simulated with a multi-laminate constitutive model accounting for structural anisotropy and destructuration effects [11]. In this paper, a footing supported with piles on soft consolidating soil is analysed using two dimensional plane strain finite element method. The behaviour of soil is modelled using a cam clay model. The settlement and the consolidation time required for the footing supported on pile foundation is compared with settlement and the consolidation time required for the footing without piles.

2. Finite element consolidation analysis

For a consolidating soil, the displacement u and excess pore pressure p within the finite element can be related to nodal displacement vector $\{u_n\}$ and the nodal pore pressure vector $\{p_n\}$ as
$u = [N_s]\{u_n\}$ And $p = [N_f]\{p_n\}$

N_s And N_f are shape functions defining the displacement and pore pressure distribution of soil element respectively.

$$\begin{bmatrix} K_s & L \\ 0 & H \end{bmatrix} \begin{Bmatrix} U_n \\ P_n \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ L^T & 0 \end{bmatrix} \begin{Bmatrix} U_n \\ P_n \end{Bmatrix} = \begin{Bmatrix} f \\ 0 \end{Bmatrix} \tag{1}$$

K_s And H are the stiffness and fluid conductivity matrices respectively and L is the coupling matrix which is formed from the equation

$$L = \int_s N_s^T \begin{Bmatrix} \frac{\partial}{\partial x} \\ \frac{\partial}{\partial y} \end{Bmatrix} N_f^T \tag{2}$$

If Δf is the change in load between successive times, the incremental form of equation 1 can be written as

$$\begin{bmatrix} K_s & L \\ 0 & H \end{bmatrix} \begin{Bmatrix} \Delta U_n \\ \Delta P_n \end{Bmatrix} + \begin{bmatrix} 0 & 0 \\ L^T & 0 \end{bmatrix} \begin{Bmatrix} \Delta U_n \\ \Delta P_n \end{Bmatrix} = \begin{Bmatrix} \Delta f \\ 0 \end{Bmatrix} \tag{3}$$

ΔU_n And ΔP_n are the resulting changes in displacement and excess pore pressure respectively. The displacement u_i and excess pore pressure p_i at the end of i^{th} time step is

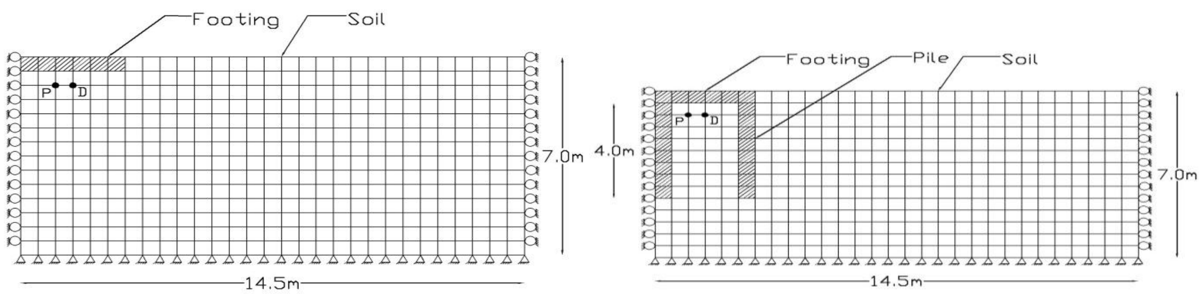
$$u_i = u_{i-1} + \Delta u_n \tag{4}$$

$$p_i = p_{i-1} + \Delta p_n \tag{5}$$

Several procedures were adopted for solving the finite element time dependent problem. Lewis et al. solved the equation using finite difference approximation [8] while Manoharan and Dasgupta solved the equation in iterative form using Modified Newton Raphson's method [9]. In the present study, the equation 3 is solved using Newmark's method. Owing to its unconditional stability, the constant average acceleration scheme (with $\beta = {}^1/_4$ and $\gamma = {}^1/_2$) is adopted.

3. Results and discussions

Fig. 1(a) shows the finite element discretization of a rigid foundation on soil and Fig. 1(b) shows the foundation supported on piles resting on soil. Two noded rectangular elements with two translation degree of freedom at each node are used to model the soil deformation and pore-pressure. Piles are also modelled using four noded rectangular elements. Due to symmetry only half of the soil and footing are considered for the analysis. Half width of footing considered for the analysis is 3.0 m and depth of pile is 4.0 m. Bottom of the soil is considered as rough, impervious and both vertical and horizontal movements are restrained along the base. Horizontal displacements are restrained along sides as shown in the figure. Water is allowed to drain at the top surface of the soil and footing. Uniformly distributed load of intensity 25kN/m^2 is applied in increments at time interval Δt=7 days till it reaches to 100kN/m^2 at 21 days and is then maintained constant at 100kN/m^2.



(a)

(b)

Figure 1 finite element discretization model of footing on soil mass.

The various properties of soil, footing and piles considered for the analysis are as follows

Properties of footing	
Elastic modulus, E	: 2x10^6 kN/m^2
Poisson's ratio, μ	: 0.15
Properties of piles	
Elastic modulus, E	: 2x10^6 kN/m^2
Poisson's ratio, μ	: 0.15
Properties of soil	
Elastic modulus, E	: 5000 kN/m^2
Poisson's ratio, μ	: 0.25
γ	: 17 kN/m^2
c'	: 0 kN/m^2
$\varnothing'$	: 30
k_x	: 8.7x10^{-5} m/day
k_y	: 8.7x10^{-5} m/day
λ	: 0.22
κ	: 0.02
τ	: 3.26
N	: 3.40

Fig. 2 shows the settlement of footing at various time intervals from the beginning of loading till the end of consolidation for the footing supported on soft soil with and without piles. It can be observed from the figure that the settlement of the footing increases with time and reaches maximum after nearly 12000 days in the case of footing without piles whereas it reaches maximum settlement at about 5000 days in the case of footing with piles. The settlement at the end of construction for the footing without piles is 0.1023 m whereas it is equal to 0.0675 m for the footing with piles and settlement at the end of consolidation for the footing without piles is 0.9319 m whereas it is equal to 0.3212 m for footing with piles. Also, the maximum pore pressure at the end of loading for the footing without piles is 105.444 kN/m^2 whereas it is equal to 34.135 kN/m^2 for the footing with piles at point P in Fig.1. From the relationship of pore pressure versus time shown in Fig. 2, it can be observed that the time taken for consolidation for the footing without piles is 12000 days whereas it is nearly equal to 5000 days for the footing on piles. Thus, as expected, soil consolidates faster and the settlement decreases considerably in the case of footing supported by piles compared to the consolidation of soil in the case of footing without piles. The settlement during the construction of a footing on piles is also lesser compared to the footing without piles. Thus, the total settlement after construction for the footing with piles decreases compared to the footing without piles.

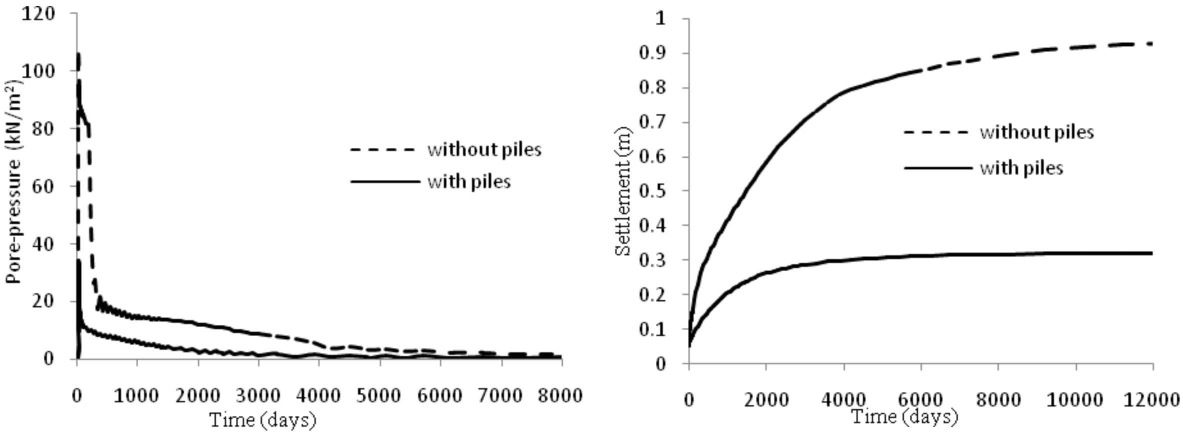


Figure 2 Variation of excess pore-pressure and footing settlement with time.

4. Conclusion

A footing supported by piles is analysed by finite element method. The behaviour of soil is modelled using a cam clay model. The behaviour of footing supported with pile is compared with footing without piles. From the analysis it is concluded that the footing on piles consolidates faster and the settlement decreases during and after construction compared to footing on soft soil without piles.

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