Numerical Modelling of Laterally Loaded Piles

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Abstract.
The behavior of a laterally loaded pile depends on the subsoil condition, sectional properties of pile, boundary condition of pile at top and bottom and rigidity of the structure. Early attempts have been made to analyze laterally loaded pile using finite difference method to obtain non-dimensional curve. Such curves are being used for determination of ultimate horizontal capacity as well as deflection, shear force, bending moment, soil reaction etc., under design horizontal load. The current study focuses on determining the lateral load capacity of single pile using Finite Element Method (FEM) for pile diameter varying from 0.15 m to 2.0 m in layered soil. The performance of the pile-soil system depends on the properties of soil and pile. The results obtained from the study indicates that the lateral capacity of pile foundation depends on cross-section area and material of pile, boundary conditions of the pile at top and bottom and modulus of horizontal subgrade reaction of top soil (6D, where D is diameter of pile). For an increase in the diameter of pile (D to 2D), lateral capacity of pile increased by 2.5 times.

Keywords: lateral loaded pile, finite element method, and finite difference method

1 Introduction

1.1 General

Piles are generally used to transmit vertical and lateral loads to the surrounding soil media, when a soil of low bearing capacity extends to a considerable depth. Piles used to support tall chimneys, television towers, high rise buildings, high retaining walls, offshore structures, etc. are normally subjected to high lateral loads. These piles or pile groups should resist not only vertical movements but also lateral movements. A major concern for engineering is not only finding the lateral capacity but also to check the maximum bending moment and depth of maximum bending moment below the ground level. In case of soft clay deposits, deflection will be large which can cause structural damage to foundation and superstructure, so it is essential to restrict lateral movement.

Extensive theoretical and experimental investigations have been conducted on single vertical piles subjected to lateral loads by many investigators. Matlock and Reese [1] proposed generalized solutions for laterally loaded vertical piles. Davisson [2] has evaluated the effect of vertical loads in addition to lateral loads in terms of non-dimensional parameters. Different approaches were proposed by several researchers [3-5] for solving the problem of laterally loaded piles. Brom's method is ingenious and is based primarily on limiting values of soil resistance. The method proposed by Poulos and Davis [5] is based on the theory of elasticity. Both these methods have had considerable use in practice, but these methods are applicable to only soil of uniform layers. By using a variational approach and based on few assumptions, Yang et al. [6] and Yang and Liang [7] proposed numerical solutions to analyze the behaviour of a laterally loaded pile in two layered soil. In this study, an attempt is made to study the effect of stratification on the pile head behavior, deformation of pile over depth and variation of bending moment.

1.2 Finite Element Method

PLAXIS 3D Foundation is a finite element package intended for the three-dimensional deformation analysis of foundation structures. It also enables the analysis of simple pile-raft foundations and offshore foundations. Foundations form the interaction between the upper structure and the foundation soil. Settlements depend on local soil conditions and on the construction method. Especially for pile-raft foundations there is an important interplay between the pile, the raft and the soil to support the forces from the upper structure. Such a situation can only be analyzed effectively by means of three-dimensional finite element calculations in which proper models are incorporated to simulate soil behaviour and soil-structure interaction.

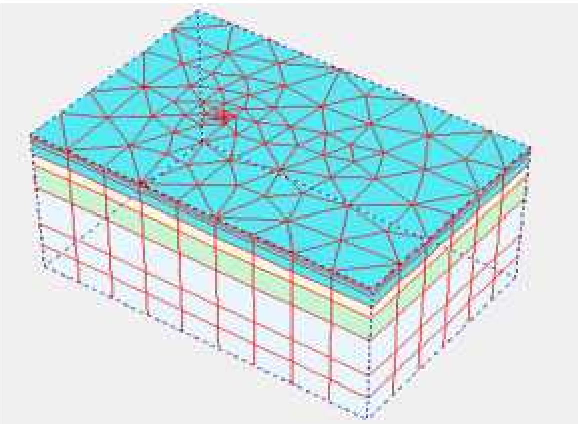

Fig. 1. 3D mesh generated from PLAXIS 3D Foundation

The overall dimensions of the model boundaries comprise of a width of 22 times the pile diameter (*D*) and a height equal to the pile length (*L*) plus a further 0.7 L below the pile-toe level. These dimensions were considered adequate to eliminate the influence of boundary effects on the pile performance [8]. The 3D model of mesh generated for foundation is shown in Fig. 1. During the generation of the mesh, the geometry is divided into 15-node wedge elements. These elements are composed of the 6-node triangular faces in the work planes. In addition to the volume elements, which are generally used to model the soil, compatible 6-node plate elements and 16-node interface elements may be generated to model structural behaviour and soil-structure interaction respectively. A 15-node wedge element contains 6 stress points. However, stress points are only used in the calculation kernel. For output purposes the data in the stress points is extrapolated to the nodes.

2 Methodology

2.1 Properties of Soil and Pile

The soil strata for analysis was selected based on the bore hole data. For this soil profile lateral load carried capacity was calculated using FEM analysis. The detailed parameters used in layered soil are given in Table 1. The length of the concrete pile used in this analysis is considered as 10 m with a diameter varying from 0.15 m to 2.0 m with an Elastic modulus of 22.5×10^6 kPa. Free-head pile is used in this analysis.

Table 1: Properties of layered soil

Depth (m)	Soil type	Safe Bearing Capacity (kPa)	Modulus of soil (kPa)	Poisson Ratio	Horizontal sub-grade modulus K_h (kN/m^3)
0.00-1.70	Clay	90	11000	0.45	12000
1.70-3.00	Sand	SPT = 24	36000	0.35	40000
3.00-5.70	Clay	210	21000	0.45	24000
5.70-15.45	Sand	SPT = 45-50	60000	0.35	70000

2.2 Validation

The FEM was validated using the available field test data [8]. The variation of load with lateral deformation is given in the Fig. 2. Lateral capacity was measured corresponding to 12 mm settlement. The results indicated that up to 30 mm deformation, the deviation of FEM analysis with field results is found to be negligible. It indicates that, PLAXIS 3D Foundation results are in good agreement with the results of field test.

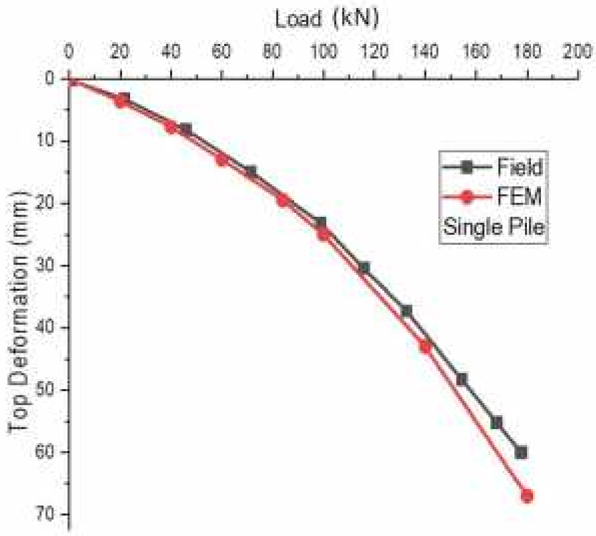

Fig. 2. Load vs top deformation of the pile

3 Results and Analysis

Pile was modeled in PLAXIS 3D Foundation and load was applied 0.3 m above the ground surface. The lateral capacity of single pile was determined corresponding to a pile head deflection of 12 mm by varying the diameter of pile. It is observed that with an increasing in diameter of the pile, load carrying capacity increases. However, increasing in the length of flexible pile resulted in no change in the lateral load capacity of pile. The variation of lateral load with deflection for different diameter of pile is given in Fig. 3. From these curves, it can be observed that the load deflection curve is initially linear and further increase in the load leads to rapid increase in the pile head deflection.

It is also evident that pile head deflection is dependent on the properties of top layer of soil up to a depth of 6D (D is diameter of the pile). Further increase in the length of the pile led to little or no change in the pile head deflection. Fig. 4 shows the difference between the flexible behavior and rigid behavior. The lateral load carrying capacity corresponding to 12 mm deformation was found to be 25 kN, 95 kN, 235 kN, 500 kN and 1250 kN for pile diameter of 0.15 m, 0.3 m, 0.6 m, 1.0 m and 2.0 m respectively. With an increasing in the diameter of pile by two times, the load carrying capacity increased by an average of 2.3 – 2.5 times.

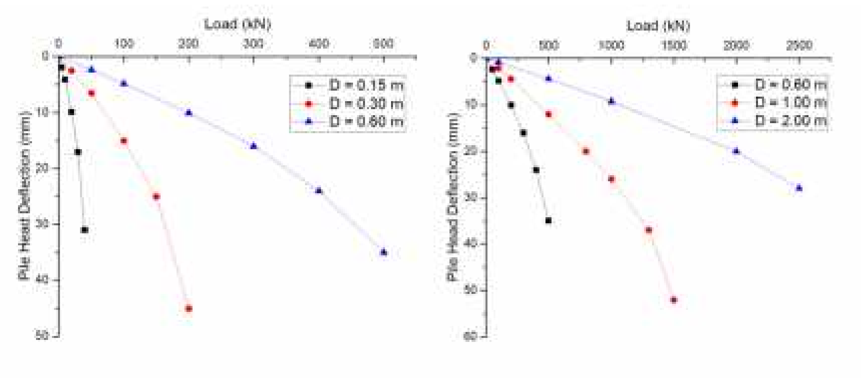

Fig. 3. Load vs Pile head deflection at ground level for different diameter of pile

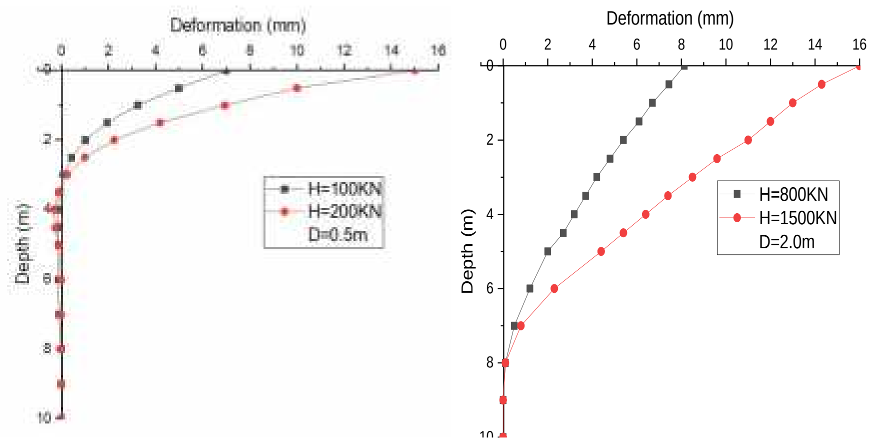

Fig. 4. Deformation over the depth for different diameter of pile (a) D=0.5 m (b) D=2.0 m

The variation of deformation over the depth was analyzed using FEM analysis as shown in Fig. 4. It clearly shows that deformation of the pile is almost negligible beyond certain depth. Hence, it can be inferred that, deformation of the pile is dependent on the top soil layer. In case of rigid pile, the load is distributed throughout the length of pile, however in case of flexible pile; pile reaction is limited only to the top portion. It can also be observed that, the depth of occurrence of zero deformation is constant for all the loads. But, with an increase in the diameter of the pile, the depth of occurrence of zero deformation shifted downwards. Hence, the depth of maximum bending moment also shifts downwards.

4 Conclusions

In this study, Finite Element Analysis was performed to study the behavior of laterally loaded piles in layered soil. Based on this study, the following conclusions have been drawn.

i. Lateral capacity of the pile is dependent on the soil properties, up to a depth of 6 times the diameter of pile
ii. Increasing in the diameter of pile by two times increases the lateral load capacity by 2.3-2.5 times.
iii. For a flexible pile, increasing in the length of pile leads to no change in the lateral load capacity.
iv. With an increase in the diameter of the pile, the depth of occurrence of zero deformation i.e., depth of maximum bending moment shifts downwards.

References

1. Matlock, H., Reese, L. C.: Generalized solutions for laterally loaded piles. Journal of the Soil Mechanics and foundations Division, 86(5), pp.63-94 (1960).
2. Davisson, M.T.: Behavior of flexible vertical piles subjected to moment, shear, and axial load. Doctoral dissertation, University of Illinois at Urbana-Champaign. (1960)
3. Broms, B.B.: Lateral resistance of piles in cohesive soils. Journal of the Soil Mechanics and Foundations Division, 90(2), pp.27-64 (1964)
4. Broms, B.B.: Lateral resistance of piles in cohesionless soils. Journal of the Soil Mechanics and Foundations Division, 90(3), pp.123-158 (1964)
5. Poulos, H. G., and Davis, E. H.: Pile foundation analysis and design. Rainbow-Bridge Book Co.. (1980).
6. Yang, Zhaohui, and Boris Jeremić.: Numerical analysis of pile behaviour under lateral loads in layered elastic–plastic soils. International Journal for Numerical and Analytical Methods in Geomechanics, 26.14, pp.1385-1406 (2002).
7. Yang, Ke, and Robert Liang: Numerical solution for laterally loaded piles in a two-layer soil profile. Journal of geotechnical and geoenvironmental engineering, 132.11, pp.1436-1443 (2006).
8. Kim Youngho, and Sangseom Jeong: Analysis of soil resistance on laterally loaded piles based on 3D soil–pile interaction. Computers and geotechnics, 38.2, pp.248-257 (2011).