Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Numerical Analysis of Laterally Loaded Pile near Sloping Ground

Rajeswari B[1], Teja Munaga[2] and Kalyan Kumar Gonavaram[3]

[1, 2, 3] Department of Civil Engineering, NIT Warangal, Warangal, 506004, Telangana, India
[1]brajeswari.32@gmail.com, [2]mteja@student.nitw.ac.in,
[3]kalyan@nitw.ac.in

Abstract. Lateral loads are most commonly experienced by bridges, transmission towers, high rise buildings, on-shore and off-shore structures. These structures when they are resting on sloping ground the conventional analysis of laterally loaded piles proves to be ineffective in estimating the behavior of the piles accurately. The current study deals with finite element analysis of single pile and pile groups in sloping ground subjected to lateral load using PLAXIS 3D. A parametric study was considered to understand the behaviour of piles embedded in stratified soil located in sloping ground of varying slope (Horizontal, 1V:2H, 1V:3H and 1V:5H). The numerical results compared with the experimental those obtained from laboratory tests are found to be in good agreement. It is observed that, with an increase in slope from horizontal to 1V:5H, the pile head deflection decreased. The effect of slope on pile capacity, the behaviour of lateral deflections of single and group of piles and their efficiencies is also studied.

Keywords: Laterally loaded piles, Sloping ground, PLAXIS 3D.

1 Introduction

1.1 Laterally Loaded Piles

Laterally loaded piles (LLP) are frequently used for the support of bridge abutment, retaining walls, stabilized fabricated embankment and natural slopes, offshore structure etc [1 - 3]. In the case of high-rise structures and chimneys, 20% of the vertical load is expected in the form of horizontal loads due to wind [4, 5]. The soil–pile system behaviour is primarily nonlinear and a laterally loaded pile derives its load carrying capacity through soil-pile system. The performance of the pile-soil system depends on soil properties, material and diameter of pile, type of loading and bed slope of the ground [6, 7]. Due to the inherent variability of soils in nature, soil properties vary spatially and pile properties and load systems possess different degrees of uncertainty. In coastal regions, the terrain of the ground is more likely to be made of slope. Piles embedded near slopes have to resist both lateral and axial loads subjected due to the superstructure [8 - 10]. The available literature mostly considers the pile situated on horizontal ground without giving much attention to pile located on sloping ground. The work pertaining to piles located near sloping ground is very limited and its behaviour is not clearly understood so far.

The existing mechanism for load transfer in case of laterally loaded pile proves to be effective in case of horizontal ground. The mechanisms available earlier cannot be applied in case of piles embedded in sloping grounds. Mathematical modelling proves to be an economical way to analyze the response of piles embedded in sloping grounds. Numerical and experimental studies are performed for embedded in dry sloping ground to investigate the effect of ground slope and edge distance on pile response.

1.2 Finite Element Method

PLAXIS 3D is a finite element method used for the three-dimensional deformation analysis of all type of structures. It is suitable for all types of geotechnical structures such as shallow footing, deep footing, retaining walls, pile raft and pile groups with different loading conditions. Foundations form the interaction between an upper structure and the soil. Settlements depend upon native soil conditions and on the development technique. Pile group will be analyzed effectively by means of three-dimensional finite component to simulate soil behaviour and soil-structure interaction.

The overall dimensions of the model boundaries is composed of 21D along horizontal plane (where D is pile diameter) and a height of 1.7L (where L is length of the pile). These dimensions were assumed to be adequate to eliminate the influence of boundary effects on the pile performance [11]. Pile, soil and pile-cap are discretized into 20 node isoparametric continuum elements. Interface between pile / pile cap and soil is modeled using 16 node isoparametric surface elements with zero thickness. Numerical model is extended for analysis for group of pile in sloping ground. A parametric study is conducted to examine the effect of slope angle, pile configuration and soil properties.

2 Methodology

2.1 Pile and Soil properties

Free-head concrete pile is considered for the current research. The pile diameter varying from 0.15 m to 1.0 m with a length of 10 m is considered for current study. The Elastic modulus of pile is considered as 22.5×10^{6} kPa. The piles are considered to be embedded in the soil at the edge of the slope as shown in schematic diagram (Fig. 1).

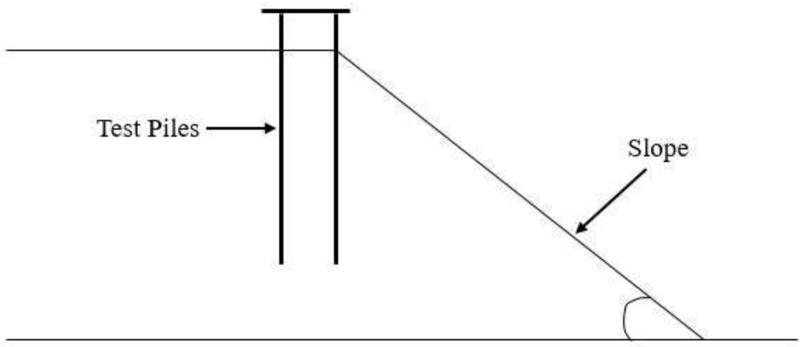

Fig. 1. Schematic diagram of test piles located at the edge of the slope

The soil strata for analysis was selected based on the bore hole data. The detailed parameters used in layered soil are given in Table 1.

Table 1. Properties of layered soil

Depth (m)	Soil	Safe bearing capacity (kPa)	Young's Modulus of soil (kPa)	Poisson ratio	K_h (kN/m^2)
0 – 1.7	Clay	90	11000	0.45	12000
1.7 - 3	Sand	SPT = 24 (175)	36000	0.35	40000
3 – 5.7	Clay	210	21000	0.45	24000
5.7 – 15.45	Sand	SPT = 45 – 50 (250-275)	60000	0.35	70000

2.2 Validation

PLAXIS 3D was validated using the experimental work related to [8]. The variation of load vs. deflection was plotted for both experimental and finite element analysis in Fig. 2. It can be inferred from the figure that the results are similar at every stage of load increment. The deviation of finite element analysis results with experimental results is found to be negligible. It indicates that, PLAXIS 3D results are in good agreement with experimental results.

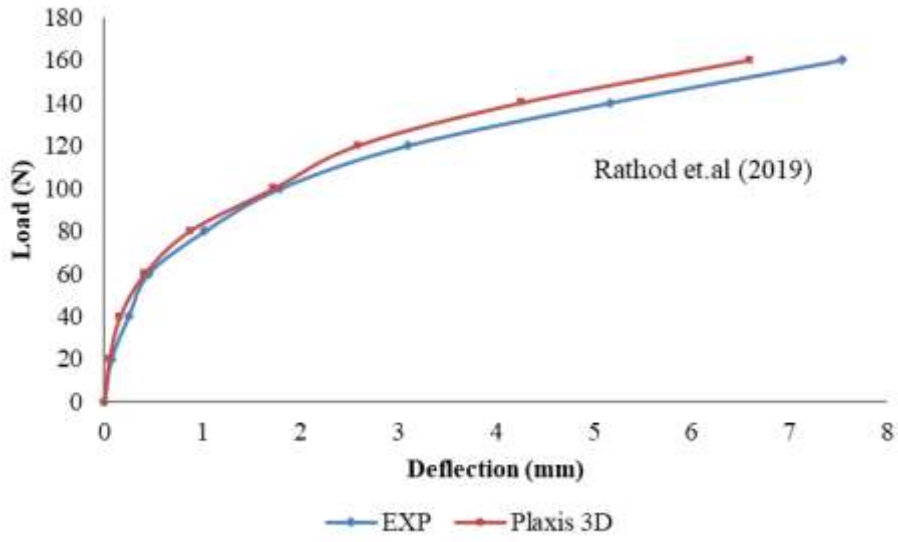

Fig. 2. Schematic diagram and validation of PLAXIS 3D

2.3 Modelling

PLAXIS 3D enables for modeling of structures with desired properties. The soil stratification is defined using the bore hole. The structural components of model are defined in Structure mode. The mesh properties are defined and the geometry model is discretized and transformed to finite element model. The excavation, activation of various structural components, defining the water level can be achieved in Staged construction mode.

3 Results

To analyze the lateral capacity of single and group pile under static lateral load, different diameter of piles and different sloping grounds are used. All single piles are analyzed under free head condition. A concrete pile of diameter 0.15 m, embedded length of 9.5 m below the ground level and 0.5 m above the ground level was used. A concrete pile cap of 20 cm thickness was used for pile groups. Load was applied at the pile head in case of single pile. The model analysis of Single Pile on sloping ground is shown in Fig. 3. In group pile embedded length of pile was 9.5 m below the ground level and the pile cap was constructed 0.3 m above the ground to avoid the frictional resistance and passive resistance of the pile cap. A line load was applied on the cap at

0.3 m above the ground level in case of pile group. Top deformation was measured exactly on the horizontal and sloping ground level.

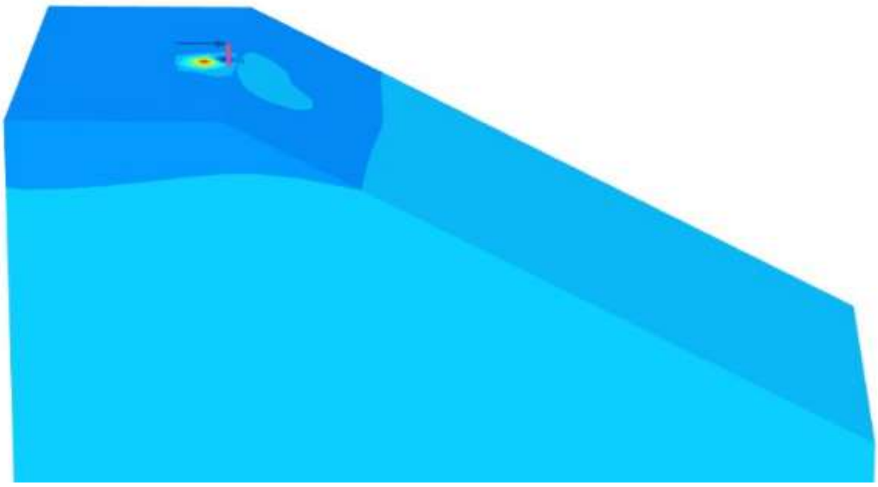

Fig. 3. PLAXIS 3D model for single pile

3.1 Load Deflection Behavior

The lateral capacity of single pile in layered soil was determined by applying incremental load and the corresponding deformation was measured for each load increment. The obtained load vs. deflection are plotted in Fig. 4. The load deflection curve was found to be initially linear. With further increase in load, deformation increased due to soil weakening. The curves also show that, at any stage of load increment the variation in the load carried by the pile in the horizontal ground is higher than that of the piles embedded on other slopes. Load capacity was measured corresponding to pile head deflection of 0.1D [12 – 14]. The variation of lateral load with increase in the slope of the ground is studied. The lateral load corresponding to a pile head deflection of 0.1D for horizontal ground, 1V:5H, 1V:3H and 1V:2H is found to be 25 kN, 23 kN, 17 kN and 15 kN respectively. It can inferred that with change in slope of ground from horizontal to 1V:2H the lateral load decreased by 40%.

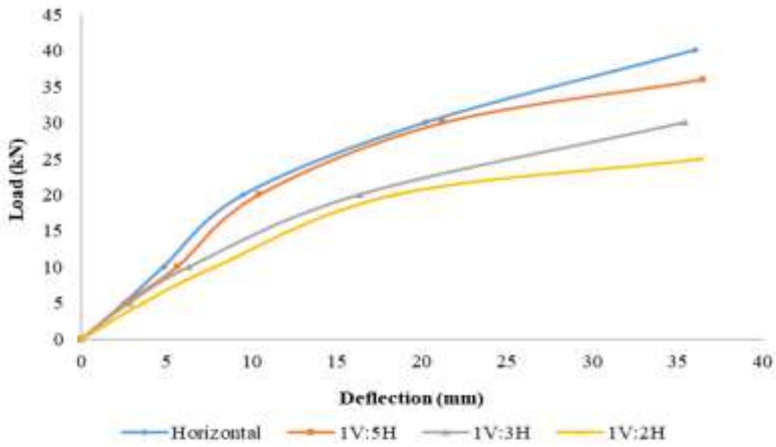

Fig. 4. Effect of Slope on Load vs Deflection behavior of Single Pile

3.2 Combined effect of Slope and Diameter of the Pile

The variation of lateral load corresponding to 0.1D with an increase in pile diameter and slope of the ground is shown in Fig. 5. It can be observed that for a considered pile diameter, with an increase in the slope from horizontal to 1V:2H the lateral load decreased. This is due to reduction in the size of the passive wedge thus leading to reduction in the passive soil resistance offered to the pile. For a considered slope of the ground, with an increase in the diameter of the pile, the lateral load corresponding to 0.1D increased. However, the magnitude of variation in lateral load for change in slope is greater for pile of diameter 1.05 m than that of 0.15 m. It can be inferred that, increase in pile diameter results in relatively increased performance of piles in sloping grounds.

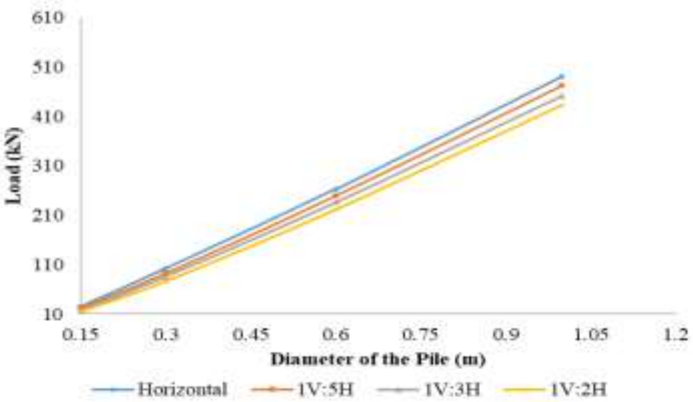

Fig. 5. Slope effect on diameter of Pile

3.3 Effect of spacing on behavior of Pile groups

The variation of load vs. deflection for 3 x 3 pile group is shown in Fig. 6. For the considered pile configuration, with an increase in the spacing from 3D to 7D the lateral load corresponding to a Pile head deflection of 0.1D increased. This is due to reduction of overlapping stress zones between the piles in the pile groups.

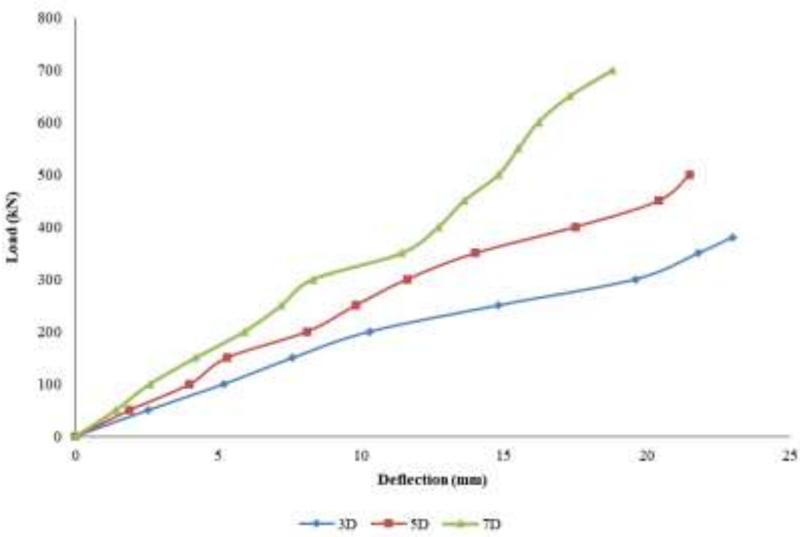

Fig. 6. Load vs deflection curve with varying spacing from 3D to 7D

The influence of pile spacing on the load carrying capacity is estimated in terms of Pile Group Efficiency. The efficiency of pile group is computed using the following expression:

$$\text{Efficiency}, \eta = Q_g / (n_g Q_s) \text{ [14]}$$

Q_g = Pile group capacity corresponding to 0.1D pile head deflection
n_g = No of piles in Pile Group
Q_s = Single pile capacity corresponding to 0.1D pile head deflection

Correspondingly the efficiency of pile groups is calculated for considered pile configurations and plotted against the slope of the ground for different pile spacing in Fig. 7. It can be observed that pile groups embedded in horizontal ground has an efficiency of more than 90 % for all the spacing considered. However, with the change in the slope from horizontal to 1V:2H, the efficiency of pile groups decreased for all the spacing considered. This is due to the reduction in the passive soil wedge infront of the pile groups.

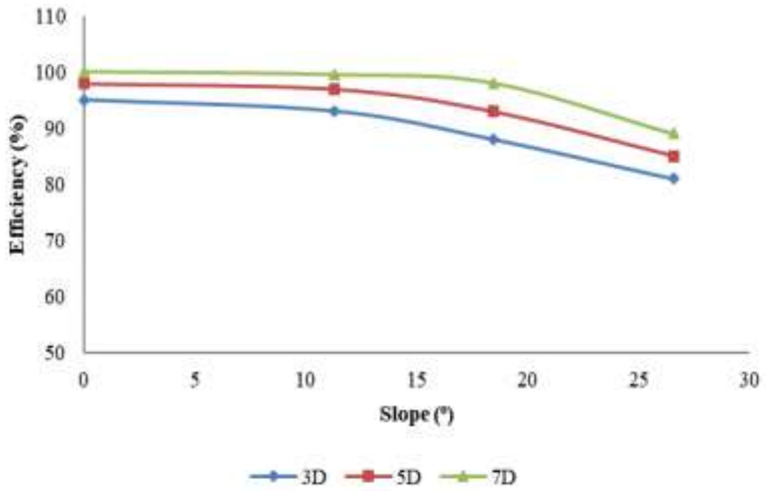

Fig. 7. Effect of Pile spacing and Slope on Efficiency of Pile groups

4 Conclusions

1. With an increase in slope from horizontal to 1V:2H the load carried by the pile decreased by 40 % due to decrease in passive resistance offered by soil.
2. With an increase in diameter of pile the effect of slope on load carrying capacity is found to be significantly increasing due to passive wedge on the side of slope.
3. With an increasing spacing from 3D to 7D the effect of slope on efficiency pile group is decreasing due to passive wedge of soil and decreasing shadowing effect on pile.

References

1. Madhusudan Reddy K, Ayothiraman R (2015) Experimental studies on behavior of single pile under combined uplift and lateral loading. J Geotech Geoenviron Eng 141(7):04015030
2. Rollins KM, Peterson KT, Weaver TJ (1998) Lateral load behavior of full-scale pile group in clay. J Geotech Geoenviron Eng 124(6):468–478
3. Prakash, S., 1962. Behavior of pile groups subjected to lateral loads. University of Illinois.
4. Matlock H, Reese LC (1960) Generalized solutions for laterally loaded piles. J Soil Mech Found Div 86(5):63–94
5. Matlock, H. and Reese, L.C., 1962. Generalized solutions for laterally loaded piles. Transactions of the American Society of Civil Engineers, 127(1), pp.1220-1247.
6. Reese, L.C. and Welch, R.C., 1975. Lateral loading of deep foundations in stiff clay. Journal of Geotechnical and Geoenvironmental Engineering, 101

7. Poulos HG (1971) Behavior of laterally loaded piles I. Single piles. J Soil Mech Found Div 97(5):711–731
8. Rathod, D., Muthukkumaran, K. and Thallak, S.G., 2019. Experimental investigation on behavior of a laterally loaded single pile located on sloping ground. International Journal of Geomechanics, 19(5), p.04019021.
9. Muthukkumaran, K., Sundaravadivelu, R. and Gandhi, S.R., 2008. Effect of slope on py curves due to surcharge load. Soils and foundations, 48(3), pp.353-361.
10. Deendayal, R., Muthukkumaran, K. and Sitharam, T.G., 2020. Analysis of laterally loaded group of piles located on sloping ground. International Journal of Geotechnical Engineering, 14(5), pp.580-588.
11. Kim, Youngho, and Sangseom Jeong. "Analysis of soil resistance on laterally loaded piles based on 3D soil–pile interaction." Computers and geotechnics 38.2 (2011): 248-257.
12. Broms, B.B., 1964. Lateral resistance of piles in cohesionless soils. Journal of the Soil Mechanics and Foundations Division, 90(3), pp.123-156.
13. Chandrasekaran, S.S., Boominathan, A. and Dodagoudar, G.R., 2010. Experimental investigations on the behaviour of pile groups in clay under lateral cyclic loading. Geotechnical and Geological Engineering, 28(5), pp.603-617.
14. Chandrasekaran, S.S., Boominathan, A. and Dodagoudar, G.R., 2010. Group interaction effects on laterally loaded piles in clay. Journal of geotechnical and geoenvironmental engineering, 136(4), pp.573-582.