Behavior of Large Diameter Pile Resting on Sloping Ground

A. Kranthikumar[1] and Ravi S. Jakka[2]

[1&2] Department of Earthquake Engineering, IIT Roorkee, Roorkee – 247 667, India

Abstract. Piles are generally used to support superstructures such as bridge abutments, high rise buildings, and transmission towers, which are subjected to heavy axial forces as well as lateral forces. Nowadays construction of these structures near the natural or man-made slopes has been increased due to the unavailability of flat grounds. To support the heavy loads coming from the superstructure, normal conventional piles (0.3 m - 0.6 m as per IS 2911) may not be sufficient for some situations, especially located near slopes. The mobilization of the ultimate load-carrying capacity of large diameter piles is different from standard conventional piles given in IS 2911. In this study, the behavior of large diameter piles resting on or near the cohesionless soil slopes is studied using a finite element method. The effect of various influencing parameters like slope gradient, the diameter of pile, length to diameter ratio of pile, and location of water table on the axial and lateral load-carrying capacity of the pile have been studied.

Keywords: Sloping Ground, Large Piles, Finite Element Method, Load Carrying Capacity.

1 Introduction

Pile foundations can able to support large vertical loads as well as horizontal loads due to the wind, wave action, the impact of berthing ships, and operating machinery constructed on level ground. Recently, the construction of heavy structures like bridge piers, transmission towers, high rise buildings, and power stations on/near hilly areas or slopes are increased due to unavailability of level grounds. The behavior of piles on sloping ground is different from piles on the level ground due to the reduction of lateral confining pressure as well as passive resistance of the soil. Most of the previous studies mainly concerned about the behavior of piles resting on sloping ground in cohesive soils using laboratory as well as numerical methods (Georgiadis and Georgiadis, 2010; Sawant and Shukla, 2012; Sivapriya and Gandhi, 2013; Deendayal et al., 2016; Deendayal et al., 2017; Vinay and Sawant, 2017). At present, most of the research has been carried out piles on sloping ground in cohesionless using model laboratory tests (Mezazigh and Levacher, 1998; Begum et al., 2008; Muthukkumaran et al., 2008; Muthukkumaran, 2014).

Gabr and Borden (1990) performed a very small number of field tests on both cohesive and cohesionless slopes soils, and these results are validated using analytical equations developed for rigid piers using stress wedge approach. Boufia and Bouguerra (1995) and Mezazigh and Levacher (1998) carried out centrifuge model testing to study the lateral load-carrying capacity of the long flexible piles located in cohesionless soil slopes. A very few studies are available on numerical simulation to analyze the behavior of small diameter piles located in cohesionless soil slopes using the three-dimensional finite element method (Chae et al., 2004; Muthukkumaran and Gokul, 2012). From the critical literature, it is found that there is currently no detailed analysis has been performed on the large diameter piles on sloping ground in cohesionless soils. Therefore, in this study, a three-dimensional finite element software is used to model the large diameter piles located at the crest of cohesionless soil slopes. In the simulation analysis, the influence of slope gradient, diameter, *L/D* ratio, and location of water table on the large diameter piles under axial as well as lateral loading condition is studied.

2 Numerical Modeling

Numerical analysis of a pile resting on the sloping ground under static loading condition is carried out using three-dimensional finite element software PLAXIS 3D. In this study, a soil domain of 20 m x 20 m x (*L*+10) m is selected such that stress conditions will not be affected by the boundary conditions. A basic finite element model of the pile and surrounding soil with boundary conditions is shown in Figure 1. From the figure, it can be seen that vertical sides are normally fixed and bottom of the model is fixed in all the degree of freedoms to simulate the actual stress conditions similar to the field the conditions.

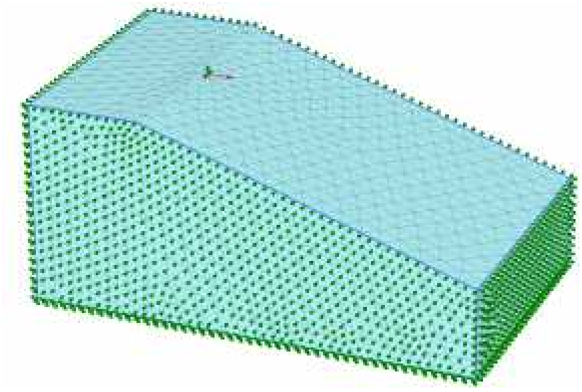

Fig. 1. Finite element model of a pile located at the crest of cohesionless soil slope (not to scale).

In the model, pile and surrounding cohesionless soil are modeled using volumetric elements, and the interface between soil and pile boundary is modeled using interface elements. Both soil and pile modeled using ten noded tetrahedral elements and interface elements are modeled using twelve noded triangular elements. In the finite element analysis, type and size of the element also play an important role in the accuracy of results. So, mesh convergence studies has been carried out before starting the parametric analysis and from the results, it is found that medium-mesh in the software giving the efficient results as compared to the other mesh sizes with time and accuracy. Material properties and parameters considered in the study are given in Table 1. For interface, properties are given the same as that of surrounding soil with a reduced strength factor of 0.667. The parametric analysis is performed for dry cohesionless soils as well as completely saturated soils.

Table 1. Material properties and parameters considered in the study.

Parameter & Properties	Cohesionless Soil	Solid Concrete Pile
Material Model	Mohr-Coulomb	Linear-Elastic
Unit Weight (in kN/m^3)	17.00	24.00
Young’s Modulus (in MPa)	45.00	27386.00 (M30)
Poisson’s Ratio	0.30	0.15
Angle of Internal Friction (°)	35.00	-
Slope Gradient (V: H)	1:3, 1:2, 2:3	-
Diameter of Pile (in m)	-	0.30*, 0.70, 1.00, 1.50, 2.00
L/D Ratio of Pile	-	5.00, 7.50, 10.00, 12.50, 15.00, 20.00

Analysis of a single pile is carried out in three phases: in the initial phase, only soil volume will be activated, and initial soil stresses are calculated using gravity loading condition instead of K_o procedure due to the sloping ground. In the second phase, all structural elements are activated (like pile and interfaces). In the last phase, loading (i.e., vertical loading as well as lateral loading) is applied in terms of prescribed displacement and analyzed using direct solver.

3 Results and Discussions

From the parametric analysis, results like load-displacement, depth-deflection, and depth-bending moment curves were extracted to study the behavior of a large diameter pile located at the crest the slope under vertical as well as lateral loading conditions. Results and behavior of piles discussed clearly in the following sections.

3.1 Effect of Slope Gradient

Figure 2 shows the variation of axial load carrying capacity with the settlement of a pile for different slope gradients. It can be noticed that the slope gradient has an imperceptible effect on the axial load carrying capacity. Because the axial loading capacity is initially taken by pile only (at the top) and as depth increases, the load will be transferred to the pile and surrounding soil. So, the loss of a very small amount of overburden pressure on one side of the pile is not showing any significant effect.

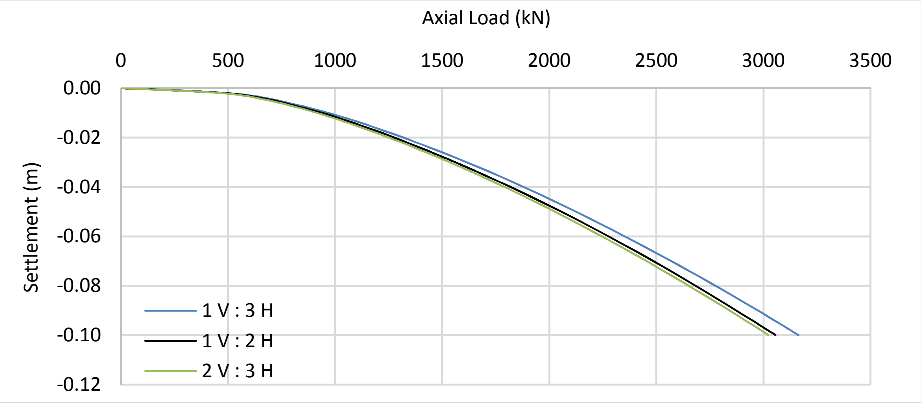

Fig. 2. Variation of axial load with the settlement of a pile for different slope gradients.

The lateral load-carrying capacity of a pile decreases with slope gradient for any given diameter of the pile (Figure 3). The decrease in load capacity is due to the reduction in the confining pressure and resistance due to the surrounding soil. The percentage decrease in lateral load capacity lies in the range of 13 to 30% for any given soil and pile. But the variation of the percentage decrease in axial and lateral load-carrying capacity is very significant with an increase in the length to diameter ratio of a pile.

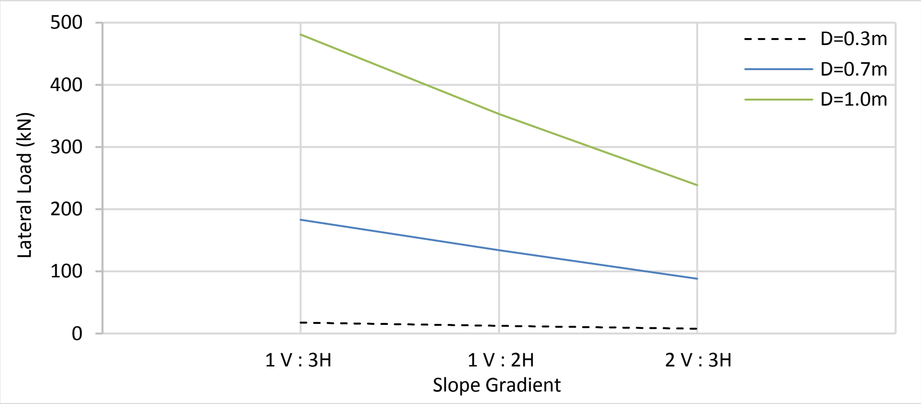

Fig. 3. Variation of lateral load with slope gradient for different diameters of a pile.

3.2 Effect of *L/D* Ratio of Pile

From Figure 4, it can be observed that load-carrying capacity increases with an increase in the length to diameter ratio of the pile for a constant pile diameter of *D*=1.5m. It can also be observed that the settlement at which maximum load mobilization occurs will also increase with an increase in the length to diameter ratio of a pile. The settlement at which maximum load mobilization of a pile occurs varies with the length and diameter of a pile and soil properties. This settlement varies 0.60 to 6.67 % *D* for a piles range considered in this study.

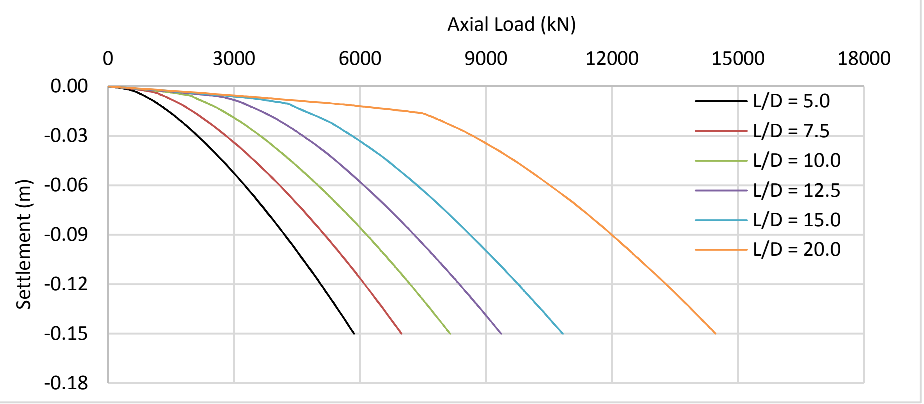

Fig. 4. Variation of axial load with settlement for different *L/D* ratios of a pile.

From Figure 5, it can be seen the normalized lateral load-carrying capacity of a pile increases with increase in diameter of a pile for a slope gradient of 1 V: 2 H. This is due to increase in the contact area of the pile with the surrounding soil. As the contact area increases, skin friction between the pile and surrounding soil also increases, it increases the lateral load capacity of the pile. As compared to the axial load carrying capacity, lateral loading capacity is not continuously increased with increase in the length to diameter ratio of the pile for a given pile diameter. It can also be observed that the normalized lateral load becomes one at *L/D* ratio 12.5 whereas in small diameter piles it becomes one at *L/D* ratio 15.0 for loading and slope configuration considered in this study.

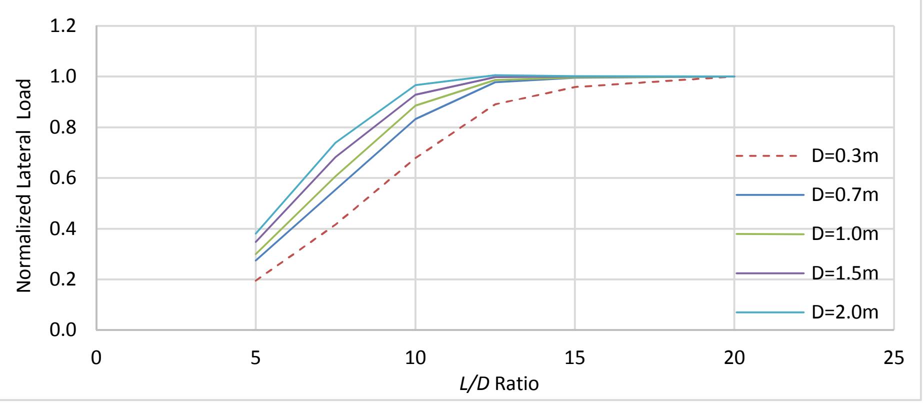

Fig. 5. Variation of normalized lateral load with *L/D* ratios for different diameters of a pile.

3.3 Effect of Diameter of Pile

The axial load carrying capacity of a pile in the sloping ground increases with an increase in the diameter of the pile under both dry and saturated condition. From Figure 6, it can be observed that load-carrying capacity of a pile increases with increase in diameter of the pile for any *L/D* ratios of the pile due to the increase in the contact area between pile and soil increases the end bearing capacity as well as skin friction of a pile.

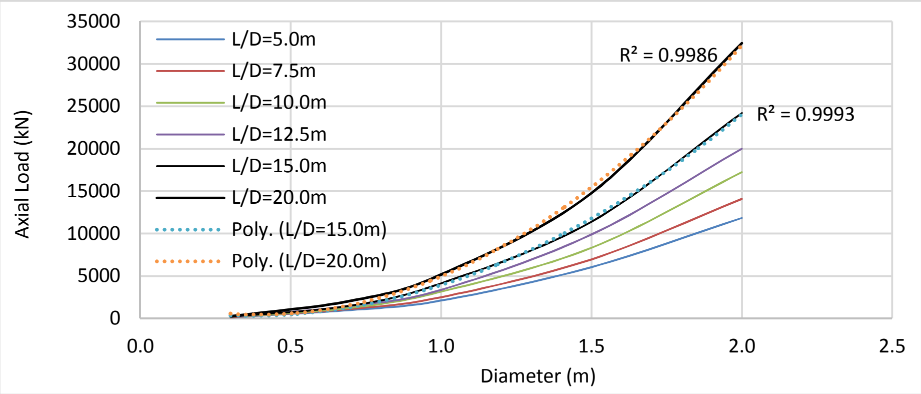

Fig. 6. Variation of axial load with a diameter of a pile for different *L/D* ratios (1V:3H).

The lateral load-carrying capacity of a pile also increases with increase in the diameter of the pile for different *L/D* ratios of the pile. From Figure 7, it can be observed that load-carrying capacity increases with an increase in the *L/D* ratio of the pile for a constant pile diameter. It can be noticed the both axial, as well as lateral load-carrying capacity of a pile, varies quadratically with the diameter of a pile for a given condition.

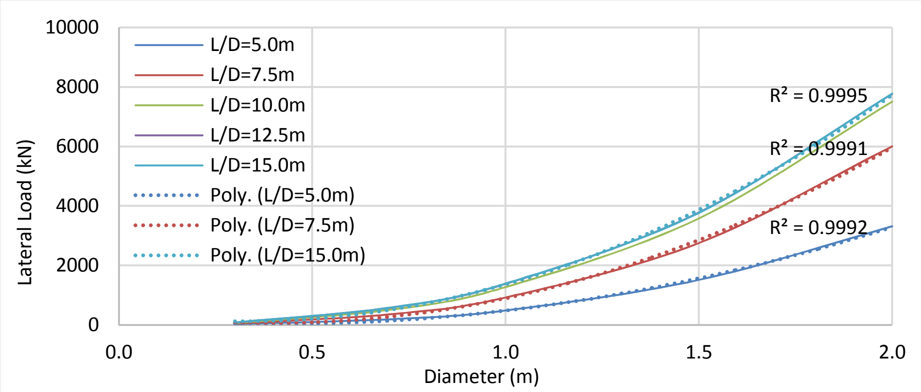

Fig. 7. Variation of lateral load with a diameter of a pile for different *L/D* ratios (1V:3H).

3.4 Effect of Water Table Location

Figure 8 shows the variation of axial load carrying capacity of a pile with the location of the water table for a slope gradient of 1 V: 3 H. For dry to saturated condition, the percentage decrease in axial load carrying capacity of a pile increases with increase in the *L/D* ratio of the pile, whereas the diameter of the pile shows an imperceptible effect. The percentage decrease in capacity lies in between 19 to 32 % for a given soil and pile.

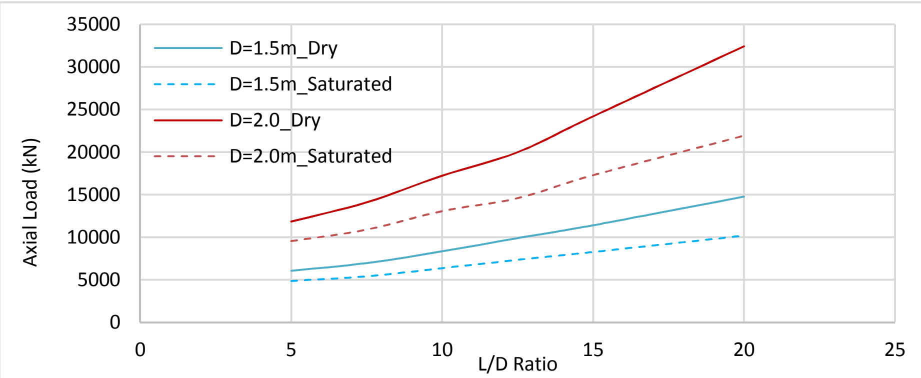

Fig. 8. Variation of axial load with *L/D* ratios of a pile for different water table conditions.

The lateral load-carrying capacity of the pile also decreases with increases in the depth of the water table for a slope gradient of 1 V: 3 H (Figure 9). The percentage decrease in lateral load-carrying capacity trend is opposite to the percentage decrease in the axial load carrying capacity of a pile. The percentage decrease in lateral load capacity lies in the range of 20 to 40 % for any given soil and pile. But the variation of the percentage decrease in lateral load carrying capacity is very significant with an increase in the length to diameter ratio of a pile.

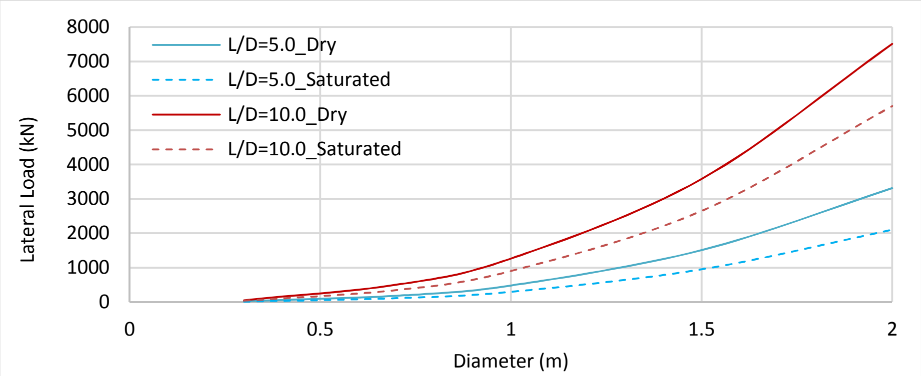

Fig. 9. Variation of lateral load with a diameter of a pile for different water table conditions.

4 Conclusions

A parametric analysis has been carried out using the finite element method on large diameter piles resting on cohesionless soil slope under axial as well as lateral loading conditions. From the results, the following conclusions have been made on the behavior of large diameter piles:

- The effect of slope gradient on axial load carrying capacity of a pile is found to be imperceptible for the configurations considered.
- The lateral load-carrying capacity of a pile decreases with slope gradient for any given condition. The percentage decrease in lateral load capacity lies in the range of 13 to 30 %.
- The maximum settlement value required to achieve completed mobilization of a pile varies significantly with length as well as the diameter of a pile for a given soil.
- The lateral load-carrying capacity of a pile increases continuously with increase in the length up to a certain length (*L/D*=12.5 for 1 V:3H) after that it remains constant, for a given range of large pile diameter considered in this study.
- Both axial and lateral load-carrying capacity of a pile increases non-linearly with an increase in the diameter of a pile for any given *L/D* ratio of a pile.
- Both axial and lateral load-carrying capacity of pile decreases with increases in the depth of the water table for any given soil and pile.
- For dry to saturated condition, % decrease in axial load carrying capacity of a pile increases with increase in the length to diameter ratio of the pile for a given diame-

ter of pile. The % decrease in capacity lies in between 19 to 32 % for any given soil and pile.

- Whereas, this trend is the opposite in the case of the lateral load-carrying capacity of a pile. The % decrease in lateral load capacity lies in the range of 20 to 40 % for any given soil and pile.

References

1. Begum, A. N., Seethalakshmi, P., Muthukkumran, K.: Lateral loaded capacity of single pile located at slope crest. Indian Geotechnical Journal 38(3), 278-294 (2008).
2. Chae, S. K., Ugai, K., Wakai, A.: Lateral resistance of short single piles and pile groups located near slopes. International Journal of Geomechanics 4(2), 93-103 (2004).
3. Deendayal, R., Muthukkumaran, K., Sitharam, T. G.: Development of non-dimensional p-y curves for laterally loaded piles in sloping ground. Indian Geotechnical Journal 47(1), 47-56 (2017).
4. Deendayal, R., Muthukkumaran, K., Sitharam, T. G.: Response of laterally loaded pile in soft clay on sloping ground. International Journal of Geotechnical Engineering 10(1), 10-22 (2016).
5. Gabr, A. M., Borden, H. R.: Lateral analysis of piers constructed on slopes. Journal of Geotechnical Engineering 116(12), 1831-1850 (1990).
6. Georgiadis, K., Georgiadis, M.: Undrained lateral pile response in sloping ground. Journal Geotechnical and Geoenvironmental Engineering 136(11), 1489-1500 (2010).
7. Mezazigh, S., Levacher, D.: Lateral loaded piles in sand: slope effect on p-y reaction curves. Canadian Geotechnical Journal 35(3), 433-441 (1998).
8. Muthukkumaran, K., Begum, A. N.: Experimental investigation of single model pile subjected to lateral load in sloping ground. Geotechnical and Geological Engineering 33(4), 935-946 (2015).
9. Muthukkumaran, K.: Effect of slope and loading direction on laterally loaded piles in cohesionless soils. International Journal of Geomechanics 14(1), 1-7 (2014).
10. Sawant, V. A., Shukla, S. K.: 3D Finite element analysis of laterally loaded piles in sloping ground. Indian Geotechnical Journal 42(4), 278-286 (2012).
11. Sawant, V. A., Shukla, S. K.: Finite element analysis for laterally loaded piles in sloping ground. Coupled system Mechanics 1(1), 59-78 (2012).
12. Sivapriya, S. V., Gandhi, S. R.: Experimental and numerical study on pile behaviour under lateral load in clayey slope. Indian Geotechnical Journal 43(1), 105-114 (2013).
13. Vinay, C., Sawant, V. A.: Effect of slope angle on pile response. Indian Journal of Science and Technology 9(48), (2017).