Visakhapatnam Chapter

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

Numerical Analysis of Finned Pile in Clayey Soil under Combined Loading

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Abstract. Pile foundations are generally used in tall structures like transmission towers, offshore structures like bridge abutments, ocean engineering structures, dolphins etc. In case of offshore structures, the lateral loads acting due to wind load and waves are significantly large. Therefore, the effect of lateral load has significant importance in the design of pile for such structures. In order to improve the lateral capacity of pile the diameter of the pile has to be increased which in turn increase the manufacturing and transportation costs. In order to cater lateral loads, provision of fins to monopiles is evolving as an option for enhancing their lateral load capacity. In the present study, the behaviour of finned pile embedded in clayey soil subjected to combined vertical and lateral load is investigated. Here the fins were provided near to the top end of the embedded pile. Numerical analysis of finned pile to study the influence of fin length, keeping fin width as constant, on the lateral resistance of pile was conducted using Abaqus software. The results show that finned piles show better lateral resistance than regular piles. It was also evident that length of the fin influences the lateral capacity of finned pile and as length of the fin increases lateral capacity also increases.

Keywords: Lateral load; Combined loading; Numerical investigation; Finned pile; Clayey soil

1 Introduction

Pile foundations are extensively used to support various structures like power transmission line foundations, high-rise buildings, offshore structures, bridge abutment chimneys, and wind farms built on loose or soft soils, where shallow foundations would undergo excessive settlements or shear failure. These piles are used to support vertical loads, lateral loads, or a combination of vertical and lateral loads. The lateral capacity of the pile is dependent on three main parameters, the soil type, the loading direction and the pile geometry. Thus to improve the pile capacity it is necessary to modify any of these parameters. This lead to the introduction of the novel idea of finned pile foundations. These are piles improved by adding fins on the top of the pile. Fins are provided by attaching steel plates at 90^0 on top of the pile. The addition of fins increases the cross-sectional area of the pile thereby increasing the lateral load capacity.

Several experimental and numerical researches were conducted on the influence of finned piles on the lateral capacity of piles. Experimental studies conducted by [1] and [2] conclude that the geometry and number of fins influences the lateral capacity of piles. Finite element analysis on finned piles was conducted by [2], [4] and [7] to study the influence of fins on pile capacity. All these studies were conducted on sandy soil under lateral loading condition. The research done by [5] shows the impact of vertical load along with lateral load on the lateral capacity of piles. Therefore this study focuses on finned piles on clayey soil under combined loading condition. The effect of fin width to pile length ratio and the effect of fin length on the lateral resistance of pile is also analysed in this research. The numerical analysis is conducted using 3-dimensional finite element platform ABAQUS.

2 Finite Element Analysis

In the present study the piles are modelled and analysed using ABAQUS Software. This is non-linear 3-dimensional finite element software widely used in modelling and analysis of various engineering problems. The pile and soil are created as three-dimensional solid extrusion parts. The properties of the materials are defined and assigned to the pile and soil sections. The properties of the pile and soil used in the present study are given in table 1 and 2. The pile is treated as a linear elastic material. Mohr Coulomb model is used to define the elasto-plastic behaviour of the clayey soil.

Table 1. Material properties of soil

Property	Clay
Undrained Cohesion	100 kPa
Friction Angle	0^0
Dilation Angle	0^0
Young's Modulus	40 MPa
Poisson's Ratio	0.4
Unit Weight	18 kN/m^3

Table 2. Material properties of pile

Property	Mild Steel
Density	7850 kg/m^3
Young's Modulus	200000 N/mm^2
Poisson's Ratio	0.2

The three dimensional standard model is created to study the lateral response of finned pile in clayey soil under combined loading condition. To study the influence of fin width and fin length on the lateral response of pile in clayey soil, the simulations are done on piles attached with rectangular fins on the head of the pile with width 0.5, 1, 1.5 and 2 times the diameter of pile and fin length of 0.2, 0.4, 0.5 and 0.6 times the embedded length of the pile. Figure 1 shows a model of the finned pile used in this study. The diameter of pile, embedded length of pile and thickness of the fin are kept constant throughout the analysis. The dimensions of the pile used in this study are shown in table 3.

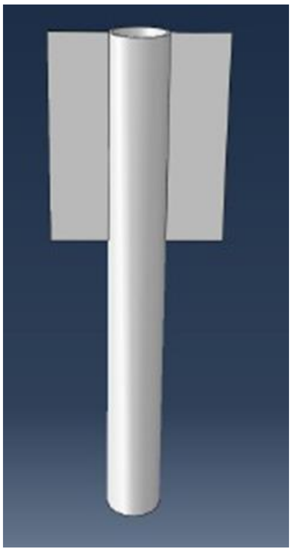

Fig. 1. Model pile

Table 3. Dimensions of finned pile

Fin length	80 mm, 160 mm, 200 mm, 240 mm
Fin width	22.25 mm,44.5 mm, 66.75 mm, 89 mm
Fin thickness	2.1 mm
Inner radius of pile	20.25 mm
Outer radius of pile	22.25 mm
Length of pile	400 mm

The pile is embedded in a 1m x 1m x 1m soil tank. Embedded element technique is used to define the interaction between clay and pile where clay is the host. This technique restrains the translational degree of freedom and allows rotational degree of freedom of the embedded element. The soil and pile assembly is meshed using three dimensional continuum 8 noded reduced integration elements (linear hexahedron)(C3D8R). In this study encastre boundary condition is applied to the bottom of the tank which makes it fixed and the sides of the tank are restrained in X, Y and Z directions. Figure 2 shows the model with boundary conditions.

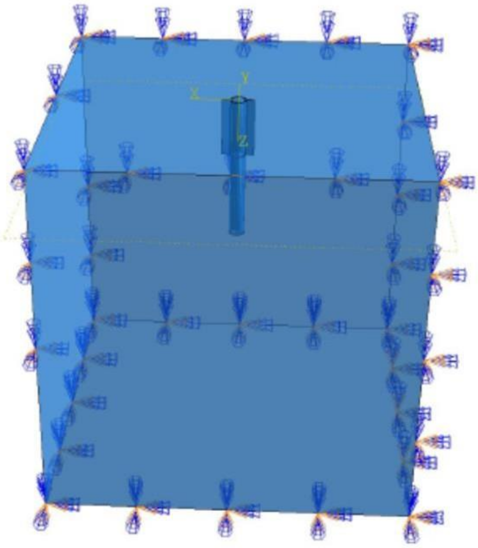

Fig. 2. Model with applied boundary conditions

The loading is applied to the model in two steps. In the first step a dead load equal to one- third of the maximum load carrying capacity of pile is applied. This is similar to the dead weight of the structure acting on the pile. In the second stage a lateral load of 300N is applied on the ground surface where the top of the pile and ground surface coincides. This resembles the wind and wave force acting of the structure. The vertical load is applied as pressure force on the top surface of the pile and the lateral load is applied as concentrated force at the point of contact of fin and pile.

In the initial step the boundary conditions and interaction are defined. The step following the initial step is the analysis step. In this study two analysis steps are created, one for dead load analysis and other with lateral load. Nonlinear analysis is adopted to account for the deflection of pile. Each step is divided into a maximum of 100 increments. Full-Newton method is used to solve the analysis. The lateral displacement of the pile in the direction of loading is the field output request. The load will vary linearly with time over each step.

In the visualization module the results of the analysis are displayed. The output data requested in the step module is obtained in this module. The lateral displacement of the pile in the direction of the applied load verses time is obtained as the X-Y plot. In the obtained plot load is defined as a linear function of time. Thus from the X-Y data the lateral load verses deflection graph can be developed.

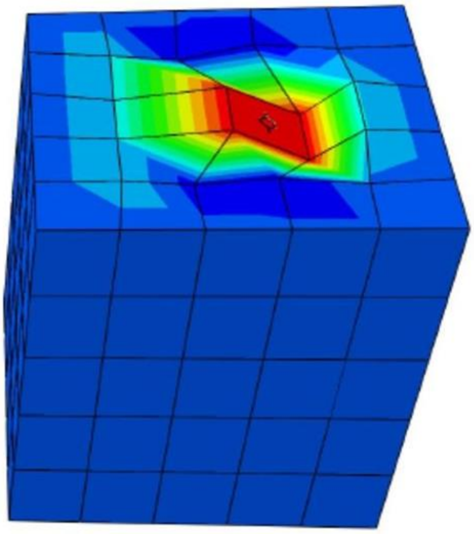

Fig.3. Deformed shape

3 Results and Discussions

3.1 Influence of Fin Length

To study the influence of fin length on lateral capacity of pile, piles with various fin lengths are compared. The following graphs show the lateral deflection curve of finned piles with various width of the fin. It is seen that finned piles show better lateral resistance than regular pile under combined loading condition. It is also noticed that as the length of the fin increases the lateral resistance also increases and the maximum resistance is show by pile with length of the fin equal to 0.6 times the embedded length of pile. On comparing the results of piles under combined loading with that of laterally loaded pile it is seen that piles show greater lateral resistance under combined loading. From the graphs it can be seen that the maximum increase in improvement is obtained when length of the fin is equal to 0.4 times the embedded length of pile for all cases of fin width studied. Beyond this length of the fin the increase in improvement of lateral capacity is less.

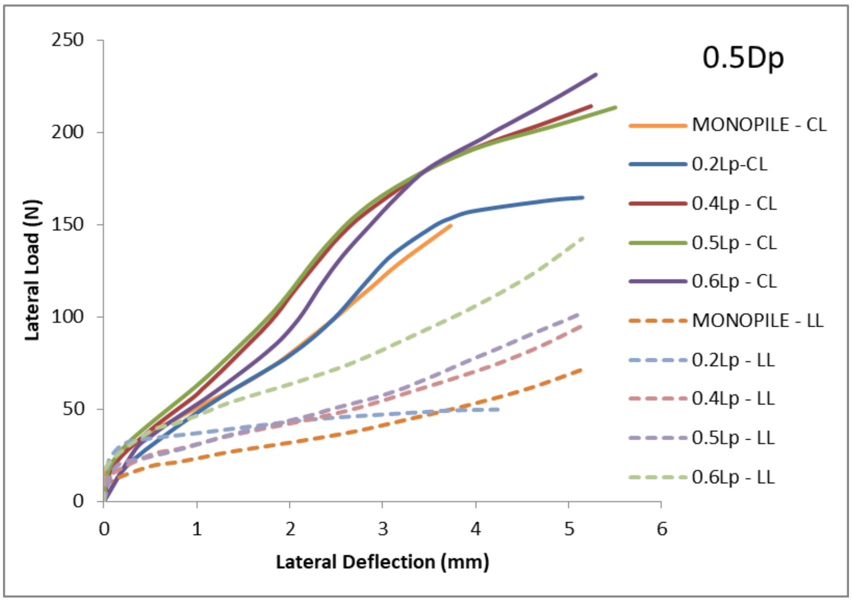

Fig.4. Lateral load deflection curve for Wf = 0.5Dp

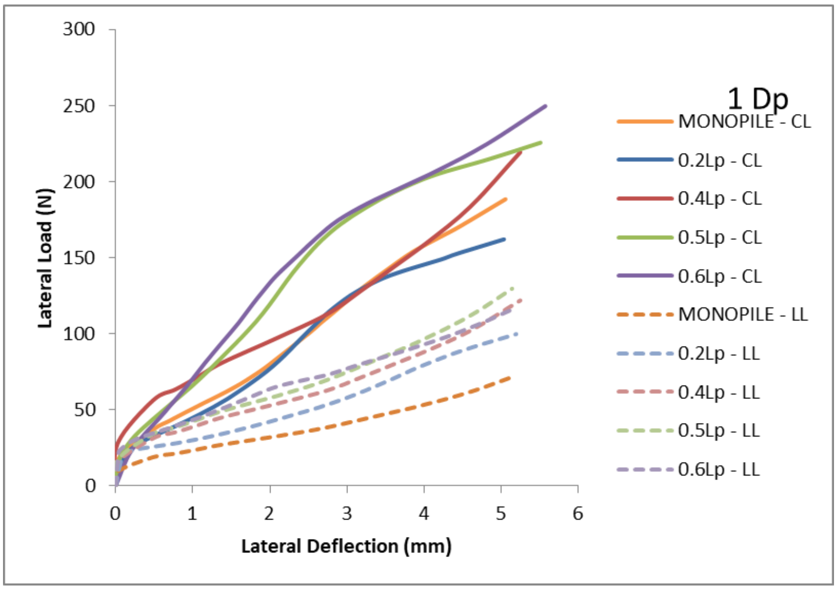

Fig.5. Lateral load deflection curve for Wf = 1Dp

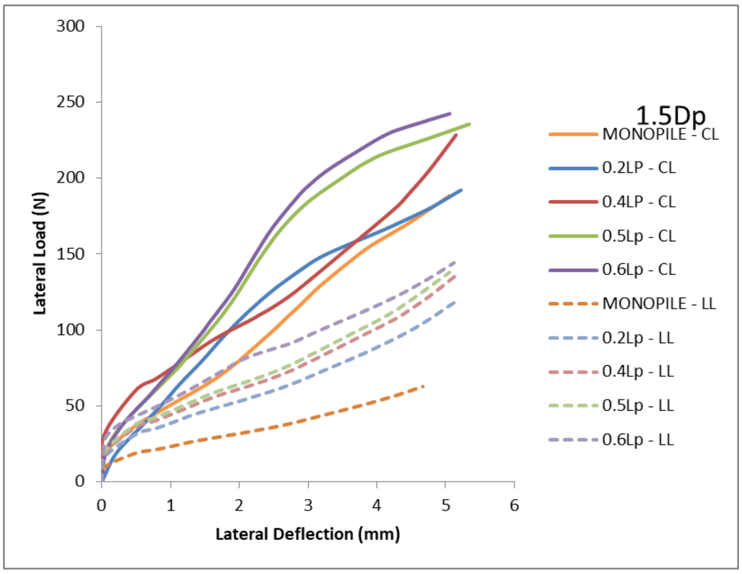

Fig.6. Lateral load deflection curve for Wf = 1.5Dp

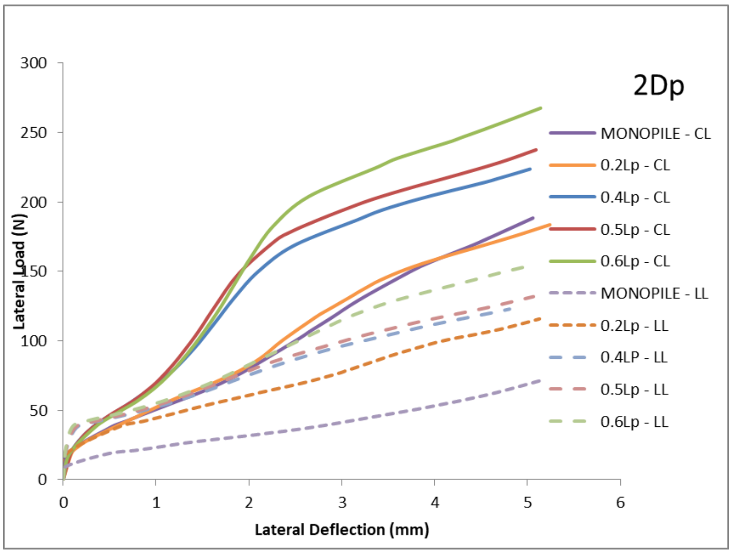

Fig.7. Lateral load deflection curve for Wf = 2Dp

3.2 Influence of Fin Width

To study the influence of fin width on the lateral capacity of pile, piles with fin width equal to 0.5, 1, 1.5 and 2 times the diameter of pile are analysed. The following graphs show the lateral load deflection curve of piles. It is seen that the lateral resistance of piles increases with increase in fin width. It is noticed that in case of pile with fin length 0.2 times the embedded pile length no significant improvement in lateral capacity is shown. In the case when length of the fin is 0.4 times the embedded length piles with fin width 0.5 and 1 times the diameter of pile show similar improvement and on further increasing the fin width the rate improvement is less. When the length of the fin is 0.5 times the embedded length of pile, fin width of 1.5 times the diameter of pile shows maximum improvement beyond which the very small. In case of pile with fin length of 0.6 times embedded length all fin widths show similar improvement.

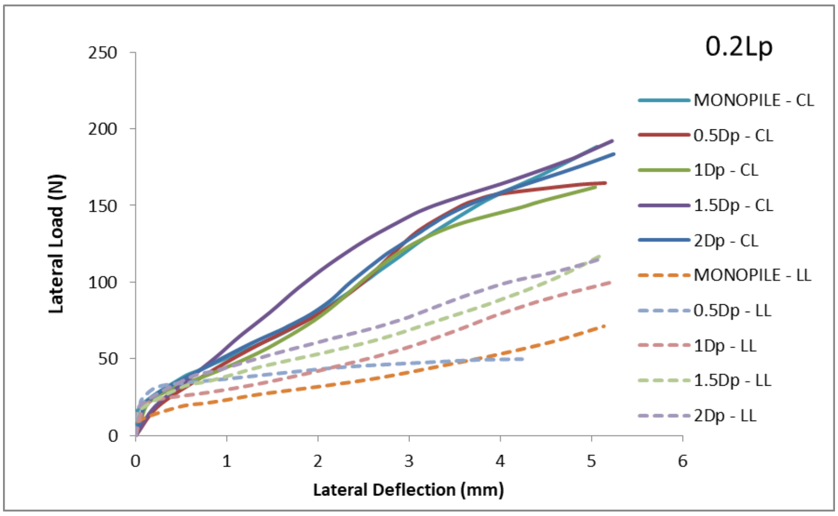

Fig.8. Lateral load deflection curve for Lf = 0.2Lp

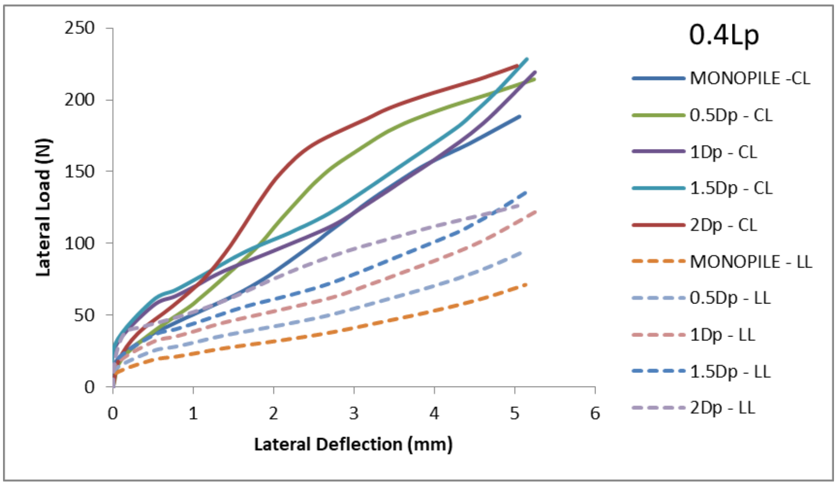

Fig.9. Lateral load deflection curve for Lf = 0.4Lp

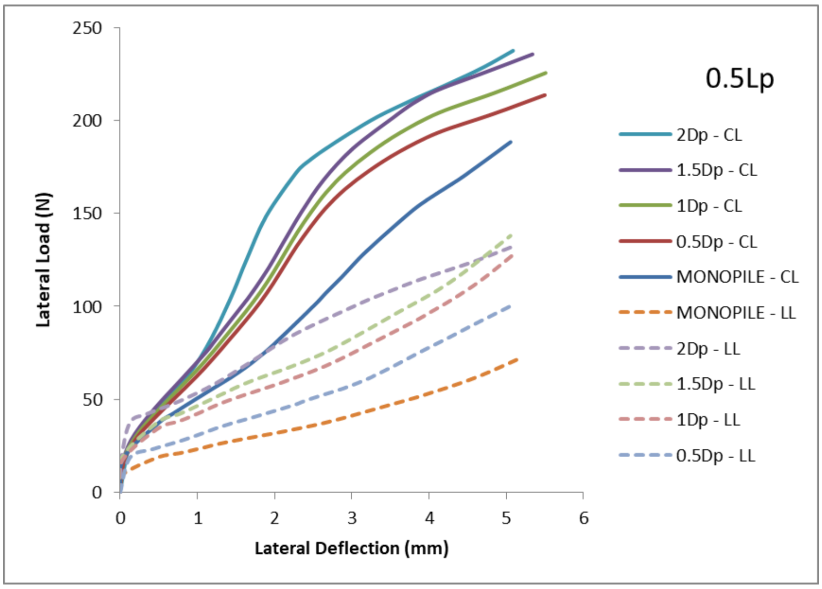

Fig.10. Lateral load deflection curve for Lf = 0.5Lp

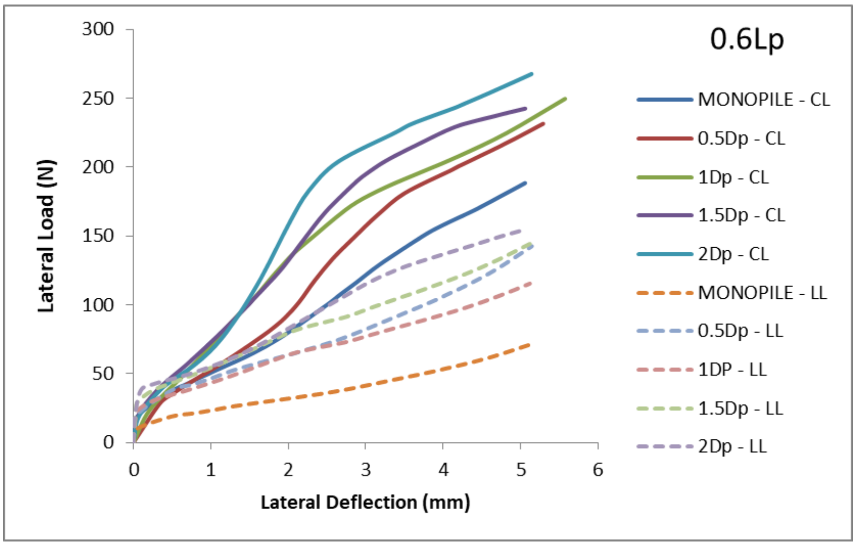

Fig.11. Lateral load deflection curve for Lf = 0.6Lp

4 Conclusions

Based on the numerical analysis conducted on 16 models of finned piles embedded in clayey soil the following conclusions were derived:

1. The addition of fins to regular piles improves the lateral resistance of pile under combined loading condition in clayey soil.
2. The lateral resistance of pile increases with increase in fin length in clayey soil. The optimum length of the fin can be taken as 0.4 times the embedded length of the pile to make it economical.
3. The lateral resistance of pile increases with increase in the width of the fin and the optimum width of the fin is equal to the diameter of the pile as it can be economical for fin lengths.
4. The increase in lateral resistance may be due to the increase in the area of soil resisting the lateral load.
5. The lateral load capacity of finned pile is more under combined loading condition than under lateral loads.

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