Journal of Civil Engineering and Environmental Technology
p-ISSN: 2349-8404; e-ISSN: 2349-879X; Volume 3, Issue 3; January-March, 2016, pp. 245-249

http://www.krishisanskriti.org/Publication.html

Semi-Analytical and Numerical Solutions for Laterally Loaded Piles in Soft Clay

Sandhya Pai[1] and Ramana Murty V[2]

[1]*Master's Student, Geotechnical Engineering Dept., NIT Warangal*
[2]*NIT Warangal*
E-mail: [1]annjune.p@gmail.com, [2]vramana@nitw.ac.in

Abstract—*Pile foundations are largely subjected to not only axial loads but also lateral loads especially during earthquakes, landslides or slope failures and also due to wind, waves and lateral earth pressure. Thus it has been understood that lateral capacity and lateral deflection also plays an important role during the design of the pile foundation. There are several analytical and experimental methods available for the analysis of the lateral pile behavior. Explicit analytical methods are available for analyzing the pile behavior in homogenous soil deposits but for piles in multi-layered soil deposits the reliability of the above methods are questionable. Semi analytical solutions have been proposed by many researchers to study the behavior of laterally loaded pile passing through multi-layered soil deposits. This paper studies one such complex problem which cannot be simulated for experimental work and hence it is analyzed analytically using the various methods available. These results are then validated using three dimensional finite element method using the Plaxis 3D software. The results from both the analysis are compared and a satisfactory conclusion is reached.*

Keywords*: Piles, Soft clay, Lateral load, Lateral deflection, Bending moment, Semi-Analytical methods, Numerical Analysis.*

1. INTRODUCTION

Piles help to transfer loads from the superstructure to load bearing strata located at deeper layers when the soil located at shallow depths are not favorable in supporting the heavy loads. They transfer the loads through their end bearing and skin friction resistance. Initially piles were study from their axial load carrying capacity only but it was from the early 1900s that the lateral capacity of the piles began to be a topic of interest for the researchers.

Lateral loads can act on piles due to numerous reasons resulting from wind and wave action, earth pressure, blasting and unanticipated events like earthquakes, landslides and liquefaction induced lateral ground spreading. It is understood that piles are subjected to considerable lateral loads that affect its capacity and thus during analysis of a pile behaviour the influence of lateral loads acting on it is to be considered.

The lateral primary load transfer mechanism of piles is explained in Fig. 1. When a pile is subjected to lateral loads, it tries to shift horizontally in the direction of the load causing it to either rotate, translate or bend. This presses the soil mass in front of it which will generate compressive and shear stresses and strains within the soil mass which resists the movement of the pile.

Full scale loading tests are the best methods of studying the behaviour of a pile under lateral loading, but they are expensive and time- consuming. 1 g models and centrifuge tests are used to experimentally determine the movement of piles under lateral loading. These methods are however not preferable as it is impossible to replicate the exact field conditions. Thus analytical and numerical modelling methods are followed which saves time and energy and also gives considerably good results.

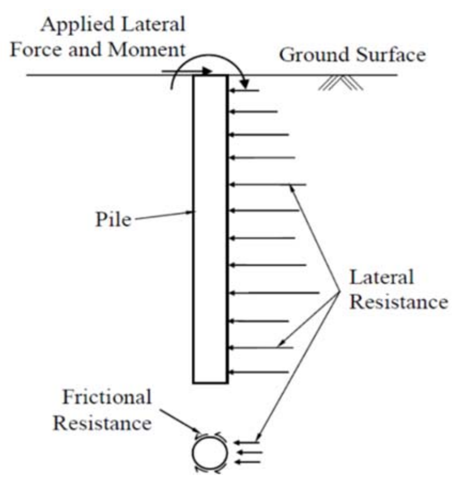

Fig. 1: Load Transfer Mechanism of Laterally Loaded Piles

The conventional analytical solutions proposed by Reese and Matlock (1956), Broms (1964) and Poulos (1980) is useful only when piles pass through a uniform soil layer. These methods cannot be used when piles pass through multi-layered soil deposits. Hence studies have to be conducted to correctly analyze the pile behaviour in multi-layered soil deposits. Researchers like Dipajan Basu, Rodrigo Salgado and Monica Prezzi (2011) and Rongqing Li and Jinxin Gong in recent times have provided with different methods and approaches to solve the ambiguity of the pile behaviour under lateral loads in multi-layered soil deposits. In the present study a semi analytical method proposed by Rongqing Li and Jinxin Gong is followed to study the pile behaviour under the present field conditions.

This paper presents the analysis of a concrete pile passing through deep layered soft clay bed followed by rock for its lateral capacity and ground line displacement. This problem is analyzed using semi analytical solution proposed by Rongqing Li and Jinxin Gong and then validated using the three-dimensional finite element method using Plaxis 3D software.

2. PROBLEM DESCRIPTION

The soil condition corresponding to a construction site at Direct General Naval Project, Vishakhapatnam is considered. A 48m long pile is passing through 40m deep clay deposit and anchored 7m into rock (Fig. 2.). The 40m deep clay layer consists of soft clay layer over the top 10m and medium stiff clay layer over the remaining 30m. The pile has an eccentricity of 1m above the ground surface and is subjected to a horizontal load at the pile head. The horizontal load acting on any pile is supposed to be 15-20 % of the vertical capacity of the pile. Thus for analyzing the pile behaviour five pile diameters of 0.80, 0.85, 0.90, 0.95 and 1 m subjected to five loading conditions, that is, 5, 10, 15, 20 and 25% of pile vertical capacity to be acting as the horizontal load at the pile head.

3. SEMI ANALYTICAL METHOD

This study uses the semi analytical solution proposed by Rongqing Li and Jinxin Gong. They predicted the responses of a single pile subjected to lateral loads in layered soils.

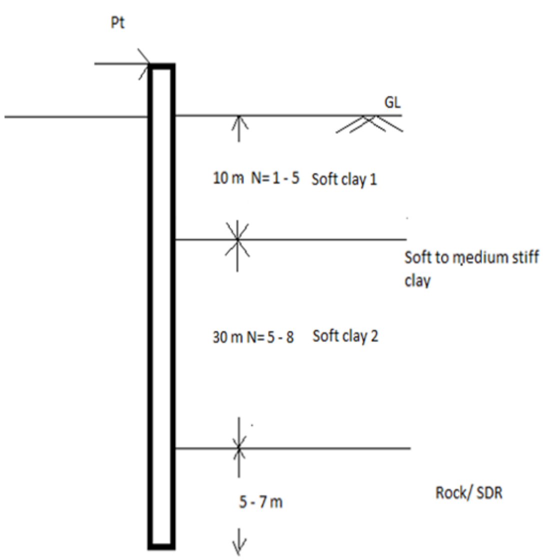

Fig. 2: Laterally loaded pile through layered soft clay deposit

The method uses the fundamental basis of structural mechanics and governing equations for the pile and soil system was formulated. Free and Fixed head piles are considered in the study. Deflection, bending moment and soil reaction and be obtained.

The pile soil interaction is studied by using an interaction model as shown in Fig. 3 where the soil is modelled initially as springs and then replaced by soil reactions. Two virtual supports are provided at the top and tip of the pile. Boundary conditions are formed and combining with deflection and moment equations governing equation of the pile soil system is obtained.

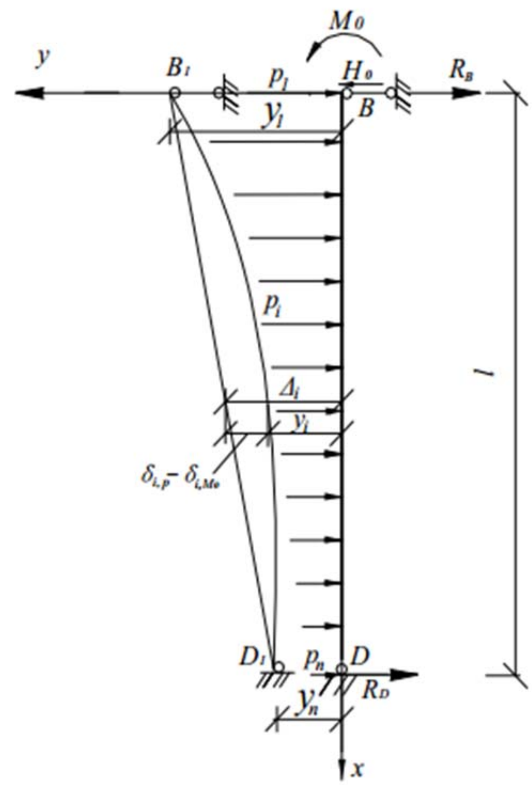

Fig. 3: Pile soil interaction model

Matlab codes are written to solve the governing equations and on running the code the solutions of deflection, bending moment and soil reaction along the length of the pile can be obtained.

4. NUMERICAL METHOD

The results obtained from the Semi analytical analysis of the laterally loaded piles are validated using Numerical analysis. The three-dimensional finite element program Plaxis 3D was used for the same in this study. The Soil clusters are modelled by 15-node toroidal triangular elements and Soft clay model was used to model the soft clay layers. The rock to which the pile is anchored to is modelled using a Linear elastic model which is an in built model in PLAXIS 3D. Piles are modelled as embedded piles which are used to specifically model piles with user defined properties. Table 1 and Table 2 summarizes the soil, rock and pile properties used in the analysis.

A three-dimensional mesh is automatically generated considering the stratigraphy of the soil and the structures mode is defined by the user. In this study a medium meshing is applied during the mesh generation.

Construction and Load simulation phases are provided in the Staged construction mode. Two consolidation phases are provided after the initial phase and the construction phase to consider any negative skin friction that might be generated due to the self-weight of the soil strata and the installation of the pile respectively. Five loading phases are provided thereafter with horizontal loads of 5, 10, 15, 20 and 25% of the total vertical capacity of the pile acting at the pile head.

5. COMPARISON OF THE RESULTS

In the present study the Ground line deflection (G.L.D), Pile head deflection (P.H.D) and Maximum Bending Moment (BM) obtained from both the methods are compared. The comparison between the semi analytical and numerical solutions are presented in Figs. 4-13.

Table 1: Soil Properties

Properties	γ (kN/m3)	C (kN/m2)	Ø	Es (MPa)	μs
Soft clay 1	13	32	5	-	-
Soft clay 2	15	50	5		
Weathered rock	25	-	-	110	0.25

Table 2: Pile Properties

Length (m)	Density (kN/m3)	Stiffness (kPa)	Eccentricity e (m)
48	25	25 x 106	1

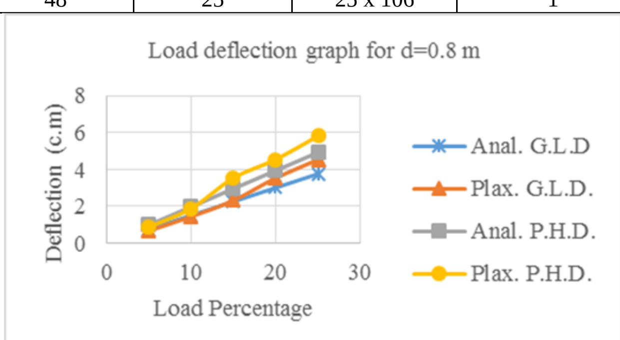

Fig. 4: Load % vs Pile deflection graph for d= 0.8 m

Figs. 4-8 load percentage vs Pile deflection curves and Figs. 9-13 shows load percentage vs maximum bending moment curves. . From the graphs it is noted that there is a considerable agreement between the values obtained for both the methods.

It is seen that the results of both numerical and semi analytical solution follow a general trend. The ground line deflection increases with both increase in load percentage and increase in the pile diameter. When comparing the pile deflection it is seen that for both G.L.D and P.H.D, majority of the results fall within 10% variation and all the results fall with 15% variation. Comparing maximum BM for both the cases it is observed that all the results fall with 12% variation from each other. From overall results it can be said that the results have a good agreement with each other and thus is successfully validated.

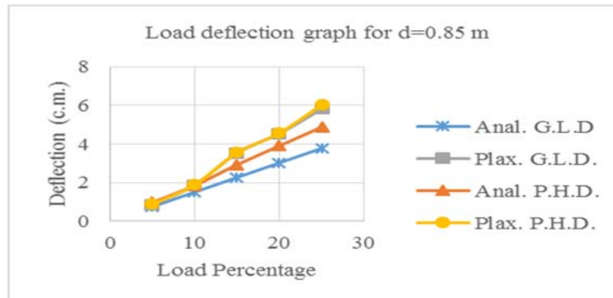

Fig. 5: Load % vs Pile deflection graph for d= 0.85 m

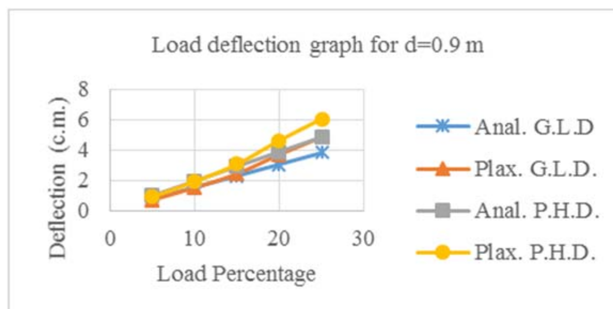

Fig. 6: Load % vs Pile deflection graph for d= 0.9 m

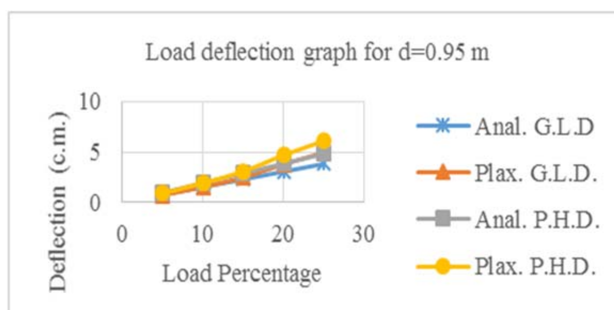

Fig. 7: Load % vs Pile deflection graph for d=0.95 m

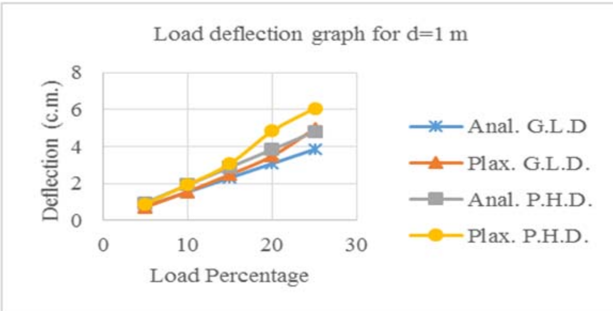

Fig. 8. Load % vs Pile deflection graph for d= 1 m

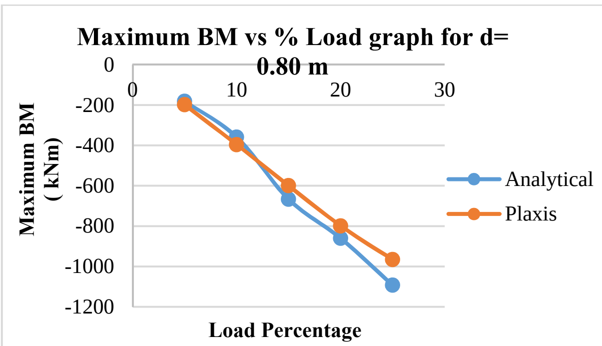

Fig. 9. Maximum BM vs Load percentage for d=0.8m

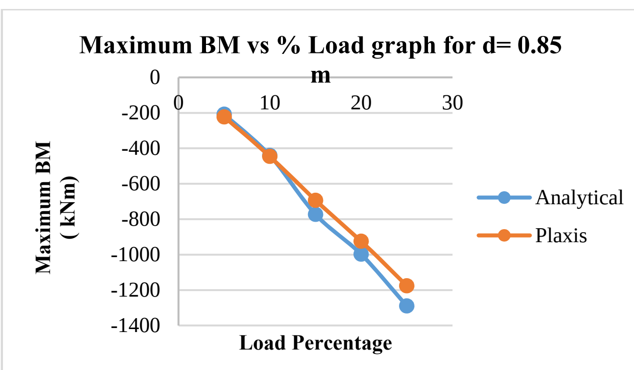

Fig. 10. Maximum BM vs Load percentage for d=0.85m

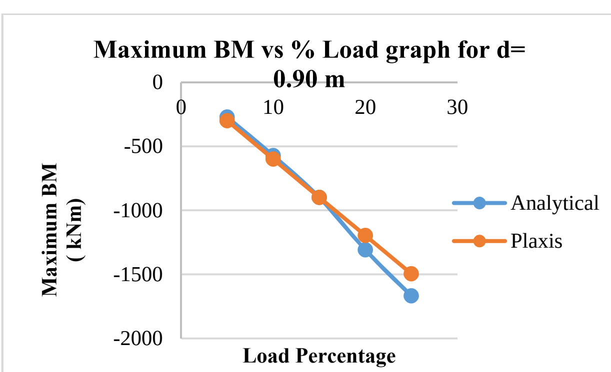

Fig. 11. Maximum BM vs Load percentage for d=0.9m

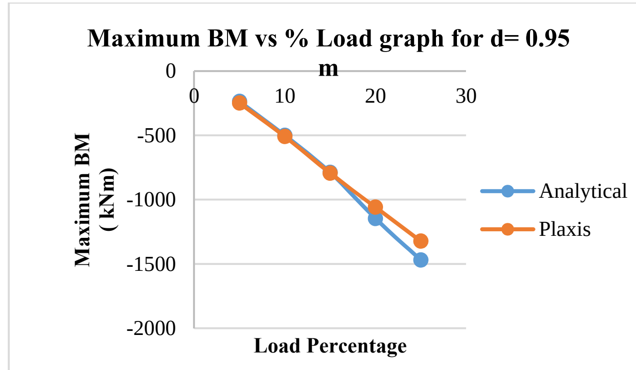

Fig. 12. Maximum BM vs Load percentage for d=0.95m

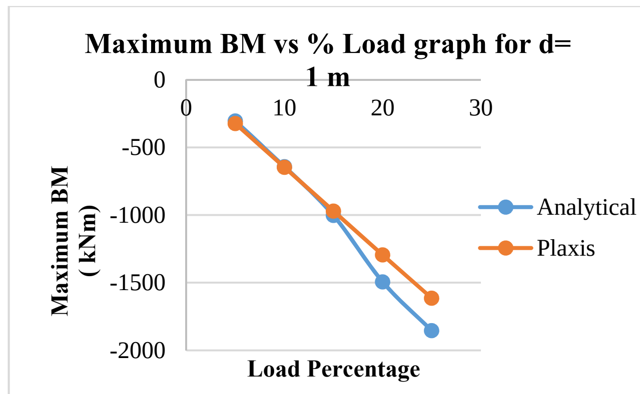

Fig. 13. Maximum BM vs Load percentage for d=1m

6. CONCLUSION

Due to the complexity of many field conditions it is very difficult to simulate and thus experimental studies is practically difficult to be performed. Thus in such conditions analytical and numerical methods are the only solution to analyze the pile behaviour. This case study is one such complex problem as the pile passes through 40m of layered soft clay deposit and it behaves like a free standing pile. The conventional analytical methods for studying the behaviour of laterally loaded piles cannot be used here as they are only suitable for uniform soil deposits. As the present study is of a pile in layered soil deposit Semi analytical solutions coined by recent researchers are used.

The Semi analytical solution proposed by Rongqing Li and Jinxin Gong is used in this study and the reliability of this method is validated by using three dimensional finite element analysis.

From the results we could come to a conclusion that there is a good agreement between the semi analytical solution and numerical analysis. Considering pile deflection the results show a less than 15% variation and maximum bending moment shows a variation of less that 12% between semi analytical and numerical solutions. Semi-analytical solutions have certain simplifying assumptions involved and Numerical analysis gives faster results and also considers all the complexities of the field. This might be the reason for the slight variation in results that were obtained during the analysis. Thus inference of this study is that though Semi analytical solution gives considerably good results it has to be validated to conform the same.

REFERENCES

[1] Chia- Cheng Fan, and James.H.Long, Assessment of existing methods for predicting soil response of laterally loaded piles in sand, Computers and Geotechnics, Vol. 32, 274–289, 2005.

[2] Dipanjan Basu, Rodrigo Salgado and Monica Prezzi, A new model for analysis of Laterally Loaded Piles, Geo-Frontiers, ASCE 2011.

[3] D. Basu and R. Salgado, Analysis of laterally loaded piles with rectangular cross sections embedded in layered soil, International Journal for Numerical and Analytical methods in Geomechanics, Vol. 32, 721-744, 2008.

[4] Jasim M Abbas, Zamri Hj Chik, and Mohd Raihan Taha, Single Pile Simulation and Analysis Subjected to Lateral Load, Electronic Journal of Geotechnical Engineering, Vol. 13, Bund. N., 2001.

[5] M.R. Maktabipour and M.R.Motahari, Analysis of Laterally Loaded Piles using Analytical and Numerical Methods, Current World Environment, Vol. 10, 1043-1051, 2015.

[6] Rongqing Li and Jinxin Gong, Analysis of Laterally Loaded Pile in Layered Soils, Electronic Journal of Geotechnical Engineering, Vol. 13, Bund. J.

[7] Youngho Kim, and Sangseom Jeong, Analysis of soil resistance on laterally loaded piles based on 3D soil–pile interaction, Computers and Geotechnics, Vol. 38, 2011, 248–257.

[8] Zakia Khelifi, Nazihe Terfaya, and Abdelmadjid Berga, Modeling the Behavior of Axially and Laterally Loaded Pile with a Contact Model, Electronic Journal of Geotechnical Engineering, Vol. 16, 2011, Bund. N.