International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

Static Analysis of Laterally Loaded Pile
Effect of Change in Soil Parameter

Ravi Jain[1]
P.G. Student, Civil Engg. Dept.
M.G.M. College of engineering. And technology
Navi Mumbai, India

Prof. P. J. Salunke[2]
Assistant Professor, Civil Engg. Dept.,
M.G.M. College of engineering. And technology
Navi Mumbai, India

Prof. N. G. Gore[3]
Assistant Professor, Civil Engg. Dept.,
M.G.M. College of engineering. And technology
Navi Mumbai, India

***Abstract*—In the present study the problem of laterally loaded single pile has been solved by dimensional analysis method using Excel program for performing formulation and generating results of deflection, bending moment and shear force in pile. For dimensional analysis, theory of beam on elastic foundation has been used. The parametric study involves varying soil properties keeping pile properties unchanged. At a time one of the soil parameter has been changed keeping others as a constant and results shows the impact of change in particular parameter on properties such as maximum deflection and maximum moment and results were studied.**

***Keywords* — Laterally loaded piles; static analysis; excel program; beam on elastic foundation,dimensional analysis.**

I. INTRODUCTION

Pile foundations are often proposed as supporting structures,
where adequate bearing capacity is not available for the designers at shallow depths. Such foundations are required to be analyzed for lateral loads in additions to vertical loads. The lateral loads may be due to seismic loads, wind loads, wind and wave action in case of offshore structures in which horizontal forces are generated due to the impact of ships during
berthing and wave action.

These piles or pile groups should resist not only vertical movements but also lateral movements. The requirements for a satisfactory foundation are,

- The vertical settlement or the horizontal movement should not exceed as acceptable maximum value.
- There must not be failure by yield of the surrounding soil or the pile material.

Vertical piles are used in foundations to take normally vertical loads and small lateral loads.When the horizontal load per pile exceeds the value suitable for vertical piles, batter piles are usedin combination with vertical piles.

Extensive theoretical and experimental investigation has been conducted on single vertical piles subjected to lateral loads by many investigators. Generalized solutions for laterally loaded vertical piles are given by Matlock and Reese (1960). The effect of vertical loads in addition to lateral loads has been evaluated by Davisson (1960) in terms of non-dimensional parameters. Broms (1964a, 1964b) and Poulos and Davis (1980) have given different approaches for solving laterally loaded pile problems. Brom's method is ingenious and is based primarily on the use of limiting values of soil resistance. The method of Poulos and Davis is based on the theory of elasticity.

The finite difference method of solving the differential equation for a laterally loaded pile is very much in use where computer facilities are available. Reese et al., (1974) and Matlock (1970) have developed the concept of (p-y) curves for solving laterally loaded pile problems. This method is quite popular in the USA and in some other countries.

Full–scale field tests on single vertical and group of piles, have been made from time to time by many investigations in the past. The field test values have been used mostly to check the theories formulated for the behavior of vertical piles only. Murthy and subbarao (1995) made use of field and laboratory data and developed a new approach for solving the laterally loaded pile problem.

II. DIFFERENTIAL EQUATION FOR BEAM ON ELATIC FOUNDATION

A. *Winkler's hypothesis*

Most of the theoretical solutions for laterally loaded piles involve the concept of modulus of subgrade reaction or otherwise termed as soil modulus which is based on Winkler's assumption that a soil medium may be approximated by a series of closely spaced independent elastic springs. (Figure.a) shows a loaded beam resting on an elastic foundation. The reaction at any point on the base of the beam is actually a function of every point along the beam since soil material exhibits varying degrees of continuity. The beam shown in (Figure.a)can bereplaced by a beam in (Figure.b). In this figure the beam rests on a bed of elastic springs wherein each spring is independent of the other. According to Winkler's hypothesis, the reaction at any point on the base of the beam in (Figure.b)depends only on the deflection at that point. Vesic

(1961) has shown that the error inherent in Winkler's hypothesis is not significant.

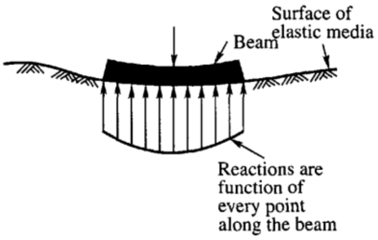

Fig. 1. Winkler's hypothesis

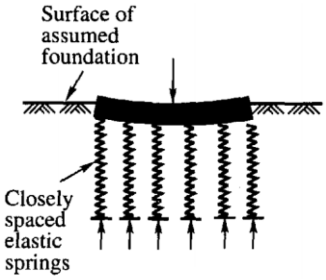

Fig. 2. Winkler's hypothesis

B. *Concept of laterally loaded pile soil system.*

The nature of a laterally loaded pile-soil system is illustrated in (Figure.c)for a vertical pile. The same principle applies to batter piles. A series of nonlinear springs represents the force deformation characteristics of the soil. The springs attached to the blocks of different sizes indicate reaction increasing with deflection and then reaching a yield point, or a limiting value that depends on depth; the taper on the springs indicates a nonlinear variation of load with deflection. The gap between the pile and the springs indicates the molding away of the soil by repeated loadings and the increasing stiffness of the soil is shown by shortening of the springs as the depth below the surface increases.

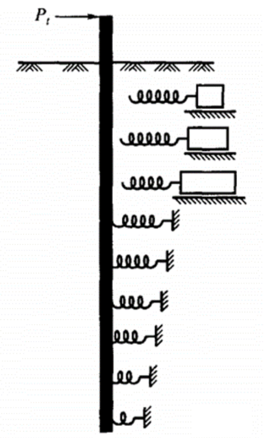

Fig. 3. Concept of laterally loaded pile-soil system.

C. *The Differential equation of elastic curve.*

The standard differential equations for slope, moment, shear and soil reaction for a beam on an elastic foundation are equally applicable to laterally loaded piles.

The deflection of a point on the elastic curve of a pile is given by y. The x-axis is along the pile axis and deflection is measured normal to the pile-axis.

The relationships between y, slope, moment, shear and soil reaction at any point on the deflected pile may be written as follows.

Deflection of the pile = y (1)

Slope of the deflected pile, $s = \frac{dy}{dx}$ (2)

Moment of pile, $M = EI\frac{d^2y}{dx^2}$

(3)

Shear, $V = EI\frac{d^3y}{dx^3}$ (4)

Soil Reaction, $p = EI\frac{d^4y}{dx^4}$ (5)

The key to the solution of laterally loaded pile problems lies in the determination of the value of the modulus of subgrade reaction (soil modulus) with respect to depth along the pile.

D. *Non-Dimensional solutions*

Matlock and Reese (1960) have given equations for the determination of y, S, M, V and p at any point x along the pile based on dimensional analysis. The equations are

Deflection, $y = \left[\frac{P_t T^3}{EI}\right]A_y + \left[\frac{M_t T^2}{EI}\right]B_y$ (6)

Slope, $S = \left[\frac{P_t T^2}{EI}\right]A_S + \left[\frac{M_t T}{EI}\right]B_S$ (7)

Moment, $M = [P_t T]A_m + [M_t]B_m$ p (8)

Shear, $V = [P_t]A_V + \left[\frac{M_t}{T}\right]B_V$ (9)

Soil Reaction, $p = \left[\frac{P_t}{T}\right]A_P + \left[\frac{M_t}{T^2}\right]B_P$ (10)

Where T is the relative stiffness factor expressed as,

$T = \left[\frac{EI}{n_h}\right]^{\frac{1}{5}}$ (11)

Where A and B are sets of non-dimensional coefficients whose values are given by Matlock and Reese (1960)

III. DIMENSIONAL ANALYSIS OF LATERALLY LOADED PILES

The key to the solution of a laterally loaded vertical pile problem is the development of an equation for n_h. The present state of the art does not indicate any definite relationship between the properties of the soil, the pile material, and the lateral loads. However it has been recognized that n_h depends on the relative density of soil for piles in sand and un-drained shear strength c for piles in clay.

For piles in sand, $n_h = \frac{150\, C_{\phi}\gamma^{1.5}\sqrt{EId}}{P_e}$ (12)

For piles in clay, $n_h = \frac{125\, c^{1.5}\sqrt{EI_\gamma d}/(1+\frac{e}{d})^{1.5}}{P_e^{1.5}}$ (13)

It can be seen in the above equations that the numerators in both cases are constants for any given set of pile and soil properties.

The above two equations can be used to predict the non-linear behavior of piles subjected to lateral loads very accurately.

ISSN: 2278-0181
Vol. 4 Issue 02, February-2015

IV. PARAMATRIC STUDY

The behavior of a laterally loaded pile is a complex function of a number of parameters. In this chapter, a number of soil and pile parameters were varied to determine the effect that these variations had on the computed pile behavior. In each case, one input parameter was varied while the other parameters were held constant. It was then determined what effect the variation of this single parameter had on the pile behavior. For parametric study pile parameters were kept constant and soil parameters have been changed and effect of change of one soil parameter by keeping other soil parameters kept constant is studied and effect of the same has been shown results.

In conducting this study, the criteria for stiff clay above the water table were termed Stiff A, the criteria for stiff clay below the water table were termed Stiff B, and the criteria for sand were not further identified. Each of the sets of criteria were used to determine what effect changes in soil parameters would have on the computed pile behavior. The initial soil parameters which were selected for each set of criteria are shown in Table I.

TABLE I. INITIAL SOIL PARAMETER

Soil Properties	Stiff A	Stiff B	Sand
c (KN/m2)	80	80	-
φ	-	-	300
γ (KN/m3)	15	9.5*	8.75*

In the present study soil parameters which were varied are c and γ for clay and φ and γ for sand. The percentage change of the input parameters was computed from the following equation.

$$\Delta = \frac{Newvalue - Initialvalue}{InitialValue} \times 100$$

The initial pile parameters which were used in all of the analysis are shown in table II. The pile head was free to rotate in these analysis and the lateral load was applied at the ground surface.

TABLE II. Pile Parameters.

Pile Properties	Values
Length	15 m
Diameter	0.7 m
Material	Concrete
Grade	M40
Flexural Rigidity (EI)	372702 KN-m2

A. *Stiff A soil study*

The results of the analysis for stiff A soil parameters were plotted for different stages of loading. A range of lateral load of 5 KN to 100 KN were applied at ground level on pile of properties shown in Table II. The results of the analysis for a ±50% variation in c are shown in Fig 4 and Fig.5. A ± 50% variation in c would correspond to values for c of 40 and 120 KN/m2. The results shows that variation of c parameter have very little effect on maximum moment. It is also seen than that analysis were more sensitive to an increase in c then to a decrease in c.

Lateral deflection is much more sensitive to variations in c then the maximum moment. As seen in graph in Fig. 5 at lower values of loading there is very less difference on maximum deflection on variation of c parameter. At higher values of loading there is a large difference in maximum deflection of pile on variation in c parameter. Hence following study concludes that c value of soil has large effect on maximum deflection of pile.

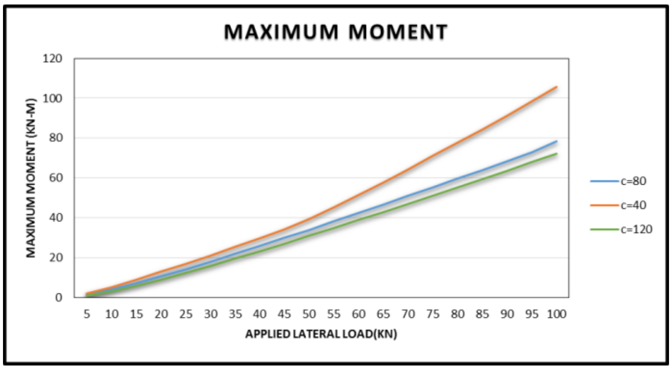

Fig. 4. Comparison between results for ±50% variation in c using stiff A criteria

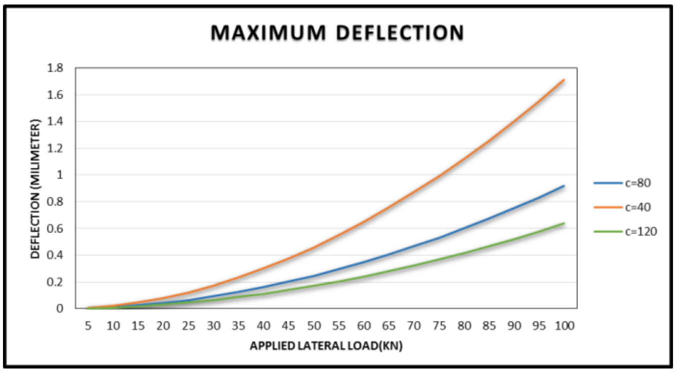

Fig. 5. Comparison between results for ±50% variation in c using stiff A criteria

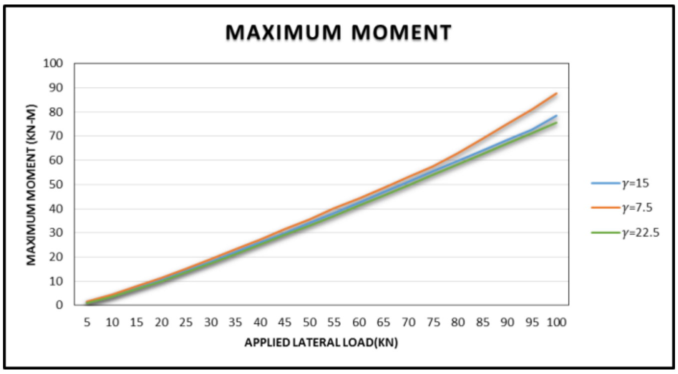

Fig. 6. Comparison between results for ±50% variation in γ using stiff A criteria

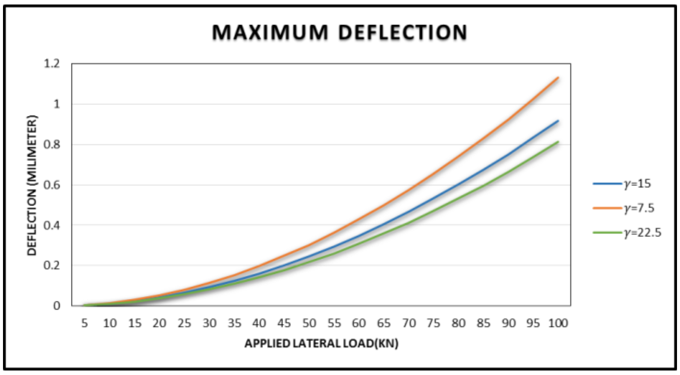

Fig. 7. Comparison between results for ±50% variation in γ using stiff A criteria

The results of the analysis for a ±50% change in γ are shown in Fig. 6 and Fig.7. The ±50% change in this case corresponds to a change of between γ = 7.5 KN/m^3 to γ = 22.5 KN/m^3 from the initial value of γ = 15 KN/m^3.

Fig. 6 shows as change in maximum moment due to change γ parameter of soil. As seen in figure in maximum moment of pile there is Almost no change when γ was varied by 50%. From these results of maximum moment, it is evident that γ does not have to be known with higher degree of accuracy for the analysis of piles in Stiff A type of soil.

The results of ±50% change in γ for maximum deflection are shown in Fig. 7. At higher stages of loading there is little higher difference in maximum deflection. But at lower loading stages the difference in deflection is very less. So for case of maximum deflection also, γ need not to be known with higher accuracy.

For other soil type Stiff B and Sand similar results were determined and results of that study is discussed in conclusion.

For the purpose of accuracy results of present study were compared with Reese et.al. and results were found in good agreement with Reese et.al.

V. Conclusion

For the present study following results were concluded

1. Parametric study done shows that change in un-drained shear strength c of clay has less effect on maximum moment of pile, but has a higher effect on maximum deflection in pile for both type of clay i.e. Stiff A and Stiff B.

2. It also shows that change in unit weight of clay has very less effect on maximum moment as well as maximum deflection of pile.

3. For sandy soil change in angle of internal friction φ has a large impact on maximum moment of pile.

4. For sandy soil change in angle of internal friction φ has a very large impact on maximum deflection of pile.

5. The effect of change in unit weight of sandy soil has a small impact on maximum moment as well as maximum deflection of pile.

References

[1] Murthy VNS, Subba Rao KS (1995) “Prediction of nonlinear behavior of laterally loaded long piles”. Foundation Engineer, vol. 1, no 2, New Delhi

[2] Barry J. Mayer and Lymon C. Reese (1979),”Analysis of single piles under lateral loading”, Centre for transportation research.

[3] M. Budhu and T. G. Davies, “Analysis of laterally loaded piles in soft clays”, Journal of Geotechnical Engineering, January (1988), pp.21-39.

[4] W. Y. Shen and C. I. Teh, “Analysis of Laterally Loaded Piles in Soil with Stiffness Increasing with Depth”, Journal of Geotechnical and Geoenvironmental Engineering, august (2004), pp.878-882.

[5] Akhiro takahashi, Hideki sugita and Shunsuke Tanimoto, “Beam on winkler foundation method for piles in laterally spreading soils”, (2005), pp.1-12.

[6] D. Basu and R. Salgado, “Method of initial parameters for laterally loaded piles”, International Association for Computer Methods and Advances in Geomechanics, October (2008), pp.3335-3343.

[7] T. Ilyas, C. F. Leung and Y. K. Chow, “Analysis of laterally loaded pile group in clay”, (2008), pp.1-4.

[8] V. John Kurian and Chee hiong Ng, “Behaviour of piles subjected to lateral load”, Engineering Conference on Sustainable Engineering, December (2008), pp-1-7.

[9] K. Rajagopal and S. Karthigeyan, “Influence of combined vertical and lateral loading on the lateral response of piles”, International Association for Computer Methods and Advances in Geomechanics, October (2008), pp.3272-3282.

[10] Krishnamoorthy and K. J. Sharma, “Analysis of single and group of piles subjected to lateral load using finite element method”, International Association for Computer Methods and Advances in Geomechanics, October (2008), pp.3111-3116.

[11] Y. Nanda Kishore, S. N. Rao and J.S. Mani, “Influence of the scour on laterally loaded piles”, International Association for Computer Methods and Advances in Geomechanics, October (2008), pp.3283-3288.

[12] N. Almas Begum and K. Muthukkumaran, “Numerical modeling for laterally loaded piles on a sloping ground”, International Association for Computer Methods and Advances in Geomechanics, October (2008), pp.3368-3375.

[13] P.K. Basudhar, A. Dey, S. Kundu, R. Singhal and A. Kumar., “Flexural analysis of laterally loaded piles using cpt and pmt results: a comparative study, (2009), pp.718-722

[14] Ashish Mehta and P.D. Pachpor, “Behaviour of laterally loaded pile”, International Journal of Engineering Science and Technology, (2010), pp.7252-7254.

[15] Broms B, “The lateral resistance of pile in cohesive soils”, Journal of soil mechanics and foundation division.

[16] Murugan m., Natarajan C. and Muthukkumaran K., “Behavior of laterally loaded piles in cohesionless soils”, International Journal of Earth Sciences and Engineering, October (2011), pp.104-106.