Grenze International Journal of Engineering and Technology, July 2015

Study of the Lateral Load Carrying Capacities of Piles in Layered Soils using PLAXIS 3D

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***Abstract*—Lateral load carrying capacity of piles is largely neglected area during the design of piles, due to various reasons like the high cost and lack of experts for carrying out insitu lateral load tests, lack of an appropriate theoretical method for the analysis etc. Thus, the lateral load carrying capacity of piles is an unresolved problem. Most studies related to the uncertainties of the lateral load capacities of piles have been done in homogeneous soils. But the response of layered soils to lateral behavior of piles is less explored. This paper studies the effect of laterally loaded piles in layered soils using PLAXIS 3D.**

***Index Terms*— Piles, Long pile, pile model, Lateral loads, Numerical Analysis, PLAXIS 3D, Layered soils, Homogeneous soil, Load deformation response, IS 2911(part IV)-1985.**

I. INTRODUCTION

Structures like tall chimneys, television/ transmission towers, high retaining walls, offshore structures, high rise buildings, quay and harbor structures and passive piles in slopes and embankments etc. are subjected to lateral loads due to wind forces, wave forces, earthquakes, lateral earth pressure etc. These piles or pile groups should resist not only vertical movements but also lateral movements. There are many cases in which the external horizontal loads act at the pile head. Such loadings are called active loading. Common examples are lateral loads (and moments) getting transmitted to the pile from superstructures like buildings, bridges and offshore platforms. Sometimes the applied horizontal load acts in a distributed way over a part of the pile shaft; such a loading is called passive loading. Examples of passive loadings are loads acting on piles due to movement of slopes or on piles supporting open excavations. Thus, piles in most cases are subjected to lateral loads. Consequently, proper analysis of laterally loaded piles is very important.

Many theoretical and experimental investigations have been done on single or group of vertical piles subjected to lateral loads. 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) 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 laterally loaded piles and many finite difference packages such as PLAXIS, ANSYS etc. are very much in use where computer facilities are available. Here the study is done in PLAXIS 3D and the factors under consideration are the modulus of

Grenze ID: 01.GIJET.1.2.508

elasticity and poisons ratio of soil and pile material, cohesion, angle of internal friction and unit weight of soils etc. But many other factors like the fixities of piles, movement of soils around the pile, history of previous loading, vertical loads coming on piles, whether piles are installed in groups, slenderness ratio of piles etc. should be made subjected for the lateral load study of piles. So, a comparative study of such various factors is possible, and the major factor causing a real difference can be found out.

II. MATERIAL USED FOR ANALYSIS

The numerical analysis has been carried out by PLAXIS 3D 2013.1. PLAXIS 3D Foundation program consists of four basic components, namely Input, Calculation, Output and Curves. In the Input program the boundary conditions, problem geometry with appropriate material properties are defined. The problem geometry is the representation of a real three-dimensional problem and it is defined by work-planes and boreholes. The model includes an idealized soil profile, structural objects, construction stages and loading. The model should be large enough so that the boundaries do not influence the results. Boreholes are points in the geometry model that define the idealized soil layers and the groundwater table at that point. Multiple boreholes are used to define the variable soil profile of the project. During 3D mesh generation soil layers are interpolated between the boreholes so that the boundaries between the soil layers coincide with the boundaries of the elements. The mesh element size can be adjusted by using a general mesh size varying from very coarse to very fine and also by using line, cluster and point refinements.

After defining the model geometry and 3D mesh generation, initial stresses are applied by using either K0-procedure or gravity loading. The calculation procedure can be performed automatically or manually.

The construction stages are defined by activating or deactivating the structural elements or soil clusters in the work-planes and a simulation of the construction process can be achieved. A construction period can also be specified for each construction stage but the soil material model should be selected as "MOHR COLUMB MODEL". The Mohr-Coulomb model requires a total of five parameters, poisons ratio, dilatancy angle, friction angle, modulus of elasticity, cohesion. The most important calculation type in PLAXIS 3D Foundation is the staged construction. In every calculation step, the material Properties, geometry of the model, loading condition and the ground water level can be redefined. During the calculations in each construction step, a multiplier that controls the staged construction process (ΣMstage) is increased from zero to the ultimate level that is generally 1.0.

III. STUDY BACKGROUND

The previous studies show that, there are several factors that influence the lateral load carrying capacity of piles. For example adhesion between soil and the pile shaft has a significant effect on lateral response of piles. When adhesion increases, the lateral load capacity increases. In case of sloping ground, the ground inclination directly influences the increase in lateral deflection of piles (K. Georgiadis and M. Georgiadis, 2010). The increase in the frequency of cyclic loading as in the case of earthquakes, susceptibility to liquefaction etc increases the lateral pile deflection (S. Kucukarslan and P.K Banerjee, 2002). When the pile is vertically loaded, the soil around the pile gets confined which supports the pile in case of action of lateral loads (M.N Hussein et al., 2013). Similarly the recent load history also influences the lateral load capacity of piles (N.H Levy et al., 2007). The difference in response of single piles and pile group is very profound and the group piles deflect more than a single pile under same lateral load due to the shadow effect of pile group, by which the leading piles in group tend to take more loads than the trailing ones (Poulose and Davis, 1980). Behavior of short and long piles is also very different in case of lateral loads. Long piles fail when the moment at any point exceeds the resisting moments at that point on the shaft of the pile, whereas the short pile fail when the lateral deflection exceeds the limiting value(Duncan and Philip, 1994). And, the layering effect of the soil is also an important factor which is really different from the behavior of pile in homogeneous soil (Yang and Jeremic, 2004). These factors including the water table effect can be made the subject for the studies.

IV. EXPERIMENTAL STUDY

Study has been carried out by modeling an embedded pile using PLAXIS software. Pile was modeled as a long pile, to be installed in layered soil first and lateral load was applied to it at various depths and most reliable result was sought. The soil includes five layers namely dense clayey sand, dense sand, medium dense sand, silty clay with gravel and very dense sand. Then the behavior of this pile in layered soil was compared with the same pile installed in homogeneous medium dense sand soil under same loading. The parameters used for the analysis have been taken from the journals which are given as tables below.

TABLE I: SOIL LAYERS AND CORRESPONDING PARAMETERS

Soil	γ (kN/ m^3)	γ_{sat} (kN/ m^3)	Modulus of elasticity, E (N/ mm^2)	Poisson's ratio	Cohesion, C (kN/ m^3)	Friction angle (Degrees)
Dense clayey sand	17	20	250E3	0.35	10	30
Dense sand	16	18	75E3	0.3	0	40
Medium dense sand	16	17	50E3	0.3	0	40
Silty clay with gravel	19	21	45E3	0.3	50	28
Very dense sand	17	18	80E3	0.4	0	45

TABLE II: PILE PROPERTIES

Modulus of elasticity, E	30E6 N/mm^2
Unit weight	6 kN/ m^3
Diameter	1000 mm
Max. traction at top and bottom	200 kN/ m and 500 kN/m
Base resistance	10000 kN

A. Lateral Load – Deformation Response and Lateral Load Capacities of Piles

The lateral load capacity of pile is estimated based on the maximum permissible deformation criteria as prescribed in IS: 2911 (Part 4) - 1985 and the minimum of the following is taken a) fifty percentage of the final load at which the total displacement increases to 12 mm b) final load at which the total displacement corresponds to 5 mm c) load corresponding to any other specified displacement as per performance requirements. Figure 1 and figure 2 depicts the load displacement curve of the pile in layered soil and homogeneous soil respectively. It can be observed that the deflection steadily increases with the increase in load in both cases.

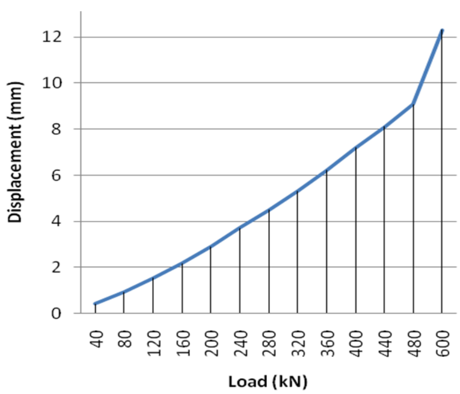

Figure 1: Load – displacement curve for the layered soil

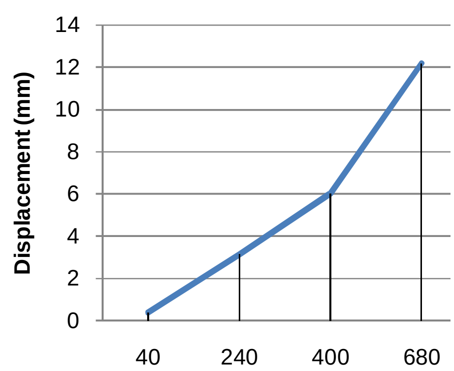

Figure 2: Load – Dspalcement curve of homogeneous medium dense sand

The deformation mesh for the soils are obtained from the software as shown below

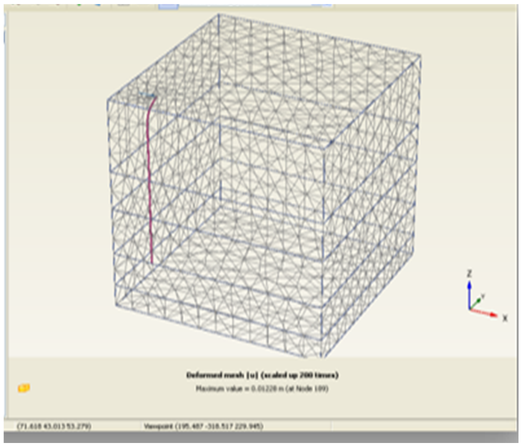

Figure 3: Deformation mesh for layered soil as obtained from PLAXIS

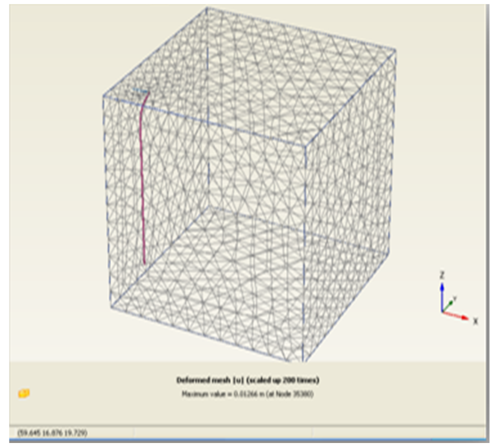

Figure 4: Deformation mesh for homogeneous medium dense sand as obtained from PLAXIS

Table III and Table IV enlist the pile deflection corresponding to various applied loads in layered soils and homogeneous soils. The table shows that increase in pile load in turn increases the lateral deflection.

TABLE III: LOAD-DEFELCTION RESPONSE OF PILES IN LAYERED SOILS

Loads (kN)	Displacements (mm)
40	0.43
80	0.93
120	1.53
160	2.18
200	2.90
240	3.70
280	4.50
320	5.31
360	6.20
400	7.20
440	8.10
480	9.07
600	12.30

TABLE IV: LOAD-DEFLECTION RESPONSE OF PILE IN MEDIUM DENSE SAND

Loads (kN)	Displacements (mm)
40	0.3898
240	3.15
400	6.025
680	12.18

The ultimate lateral load capacity of pile is evaluated as below.
By interpolation,

a) load for the pile in layered soil, at 12 mm settlement = 589 kN;
   pile capacity = ½ x 589 =294.5 kN
b) load at 5 mm settlement = 304 kN

Therefore, the pile capacity in layered soil = 294.5 kN (least of two)

a) load for the pile in homogeneous soil (medium dense sand), at 12 mm settlement = 673 kN ;
   pile capacity = ½ x 673 kN = 336.5 kN
b) load at 5 mm settlement = 345 kN

Therefore, the pile capacity in homogeneous medium dense sand = 336.5 kN

V. Conclusion

The computed results when compared reveals that the lateral load carrying capacity for the pile in layered soils is lower than the homogeneous medium dense sand as expected. This accounts for the ideal homogeneous and isotropic condition of homogeneous soil. The software can be used in the prediction of lateral load carrying capacity of piles. However additional research needs to be done to understand how the software responds to the additional factors like adhesion between soil and pile, previous loading history, combined loading, pile group effect, pile length, pile diameter etc.

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