NUMERICAL SIMULATIONS OF LATERALLY LOADED PILES

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A back analysis of a lateral load test of a bored pile is reported in this paper. Full scale laterally loaded pile tests have been carried out on 1.0m diameter bored cast in-situ piles in residual soils. This paper presents a Finite element model for simulating these lateral load tests on large diameter piles embedded in residual soils using PLAXIS 2D. The simulation is carried out for a single pile with horizontal load at ground level so as to evaluate the lateral load capacity of the pile in residual soils. The soil stratum is idealized by 15 nodded triangular elements with elastic-plastic Mohr Coulomb model and the pile behavior is assumed to be linear-elastic. Interface elements have been used to model the interface between the pile and the soil elements. Sensitivity analyses have been carried out for selecting the appropriate mesh size and its gradation and also appropriate constitutive relationships. Finally the results of the models are compared with the results of the field lateral load test. Limitations in the present methods for understanding the behavior of large diameter piles in residual soils have also been brought out.

Keywords: Pile foundation, Laterally loaded piles, Field tests, PLAXIS 2D.

1. INTRODUCTION

Structures founded on piles are often subjected to lateral loads and moments in addition to vertical loads. Laterals loads may come from wind, traffic, seismic events, waves, docking ships, and earth pressures. When a pile is subjected to lateral forces and moments, the pile tends to deflect. The deflection of the pile will experience additional stress and strain, failure to assess the effect in design will result in unacceptable pile movement or stress or both. Many analytical, empirical and numerical techniques have been used to determine the maximum deflection and the ultimate lateral capacity of the pile, facilitating its design. Residual soils are those that are formed either by rock weathering or accumulation of organic material and remain at the place where they were formed. The presence of residual soils complicates issues as methods to accurately simulate pile behavior in such soils have not been validated. Finite element packages, like PLAXIS 2D, have been used to analyze piles under different types of loading. Finite element analysis offers an excellent opportunity to study pile-soil interaction and pile response under lateral loading due to soil movement in difficult geoenvironments. This paper presents the results of a field

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Table 1. Soil data sets parameters.

		Layer 1	Layer 2
Material Model		Sandy Clay Mohr-Coulomb	Soft weathered rock Mohr-Coulomb
Weight, γ	[kN/m^3]	18.00	21.00
Young's Modulus, E_{ref}	[kN/m^2]	55000	65000
Poisson's Ratio, ν	[−]	0.330	0.330
Cohesion, C_{ref}	[kN/m^2]	15.00	42.00
Friction Angle, Ø	[°]	42.00	65.00

Table 2. Beam data sets parameters.

	Normal Stiffness, EA [kN/m]	Flexural Rigidity, EI [kNm^2/m]
Pile	2.119E07	1.32E06

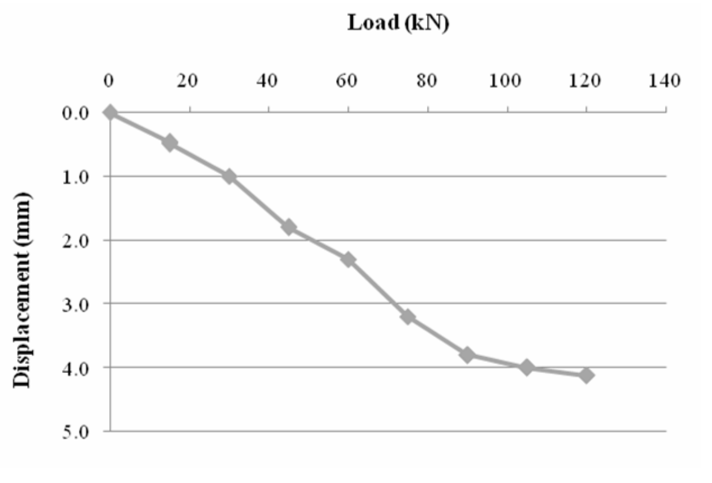

Figure 1. Field test Results.

test carried out on a laterally loaded pile and attempts to study the pile behavior under lateral loads using a two-dimensional finite element model in the horizontal plane (Kok & Huat, 2008).

2. FIELD TEST OF LATERALLY LOADED PILE

The bored cast-in situ pile considered in this study is of diameter (D) 1000 mm, length 17m and of M35 grade concrete. The site soil is composed of layers of sandy clay and soft-weathered rock. Table 1. lists the parameters of the soil stratums at the test site and Table 2. lists the parameters of the concrete pile. The same parameters have been used for the numerical simulations. A hydraulic jack, fixed horizontally between an immovable wall and the top of the pile, was used to apply lateral loads (H_u), in stages, upto 120 kN.

A displacement of 4.12 mm was observed. Figure 1 shows the load-displacement curve obtained from the field test.

3. NUMERICAL SIMULATIONS OF LATERALLY LOADED PILE

3.1. *Introduction*

The finite element program PLAXIS 2D, version 9, has been used to model a single pile subjected to lateral load on top at natural ground surface. In this paper we attempt to study the response of the pile when subjected to lateral load at the top i.e. at the natural ground surface. The pile is 1.0 m in diameter and 17 m in length. The deflections at incremental loads have been simulated and the complete load-displacement curve had been generated.

Results obtained from the field test have been used to validate the finite element modeling results here. In the PLAXIS 2D model, the soil is composed of 2 layers namely sandy clay (0 to 4 m), and soft-weathered rock (4 to 25 m). Table 1 shows the physical and mechanical properties of the soil layers.

3.2. *Model and Parameters of Two-Dimensional Finite Element Analysis*

The plane strain approach had been selected in the simulations. In the plane strain approach, a 2-dimensional model where the displacements and strains in the direction perpendicular to the plane are considered to be zero is used. However, the normal stress, σ_z, is taken into account. The selection of this approach results in 2D finite element model with only two translational degrees of freedom per node.

Pile model: The pile is modeled using plate elements, which in 2D models such as the one being used here, is composed of 5-noded beam elements with three degrees of freedom per node: two translational degrees of freedom (U_x, U_y) and one rotational degree of freedom (rotation in the x-y plane and about the out-of plane axis, $\acute{\emptyset}_z$). The beam elements are based on Mindlin's beam theory. This allows for beam deflection due to shearing as well as bending. Beam elements can become plastic if a prescribed maximum deflection or maximum load is reached.

Soil model: Mohr-Coulomb, Hardening Soil and Linear Elastic models are selected for preliminary analyses. After conducting multiple trials and sensitivity analyses, we conclude that the Mohr-Coulomb model is the most suitable model (Yang, Zhaohui & Jeremi, Boris 2000).

The Mohr-Coulomb model can be considered as a first order approximation of real soil behavior. This elastic-perfectly plastic model requires 5 basic input parameters, namely Young's Modulus, E, Poisson's ratio, ν, cohesion, c, friction angle, $\acute{\emptyset}$ and dilantacy angle, Ψ. This is a basic, well-known soil model. A 15-noded triangular element is used. This type of element provides a fourth order interpolation for displacements and the numerical integration involves twelve Gauss points.

Boundary conditions: The bottom boundary is rigid, i.e., both horizontal (u) and vertical displacement (v) are zero. Standard fixities are used at the left and right boundaries of the model. These side boundaries act likes rollers such that $u = 0$ but $v \neq 0$.

Interface element: The soil-structure interaction is modeled using an elastic-plastic model to describe the behavior of interfaces. For the interface to remain elastic, the shear

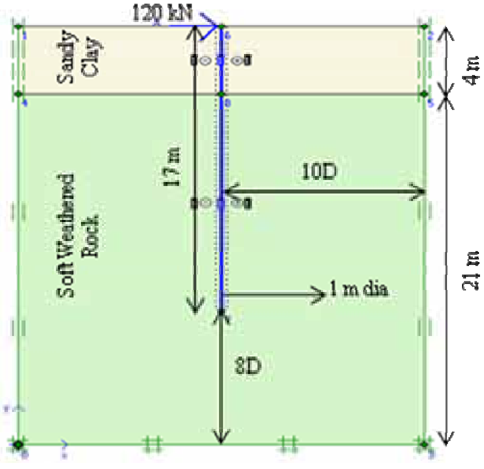

Figure 2. Model with applied lateral load of 120 kN.

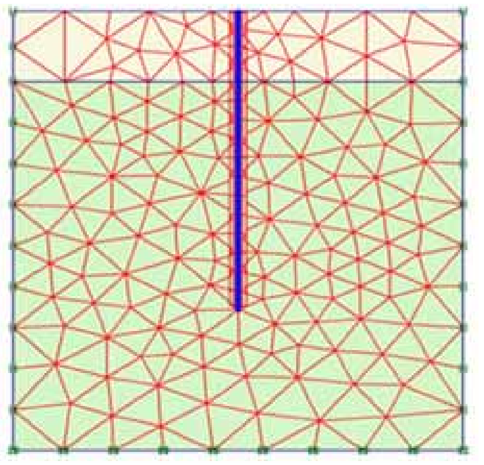

Figure 3. FEM of the Problem.

stress, $|\tau| < \sigma_n \tan \Phi_i + c_i$, where Φ_i and c_i are the friction angle and cohesion (adhesion) of the interface respectively and σ_n, the effective normal stress. The interface element properties are linked to the strength properties of the soil layers. The main interface parameter is the strength reduction factor Rinter. A strength reduction factor of 1 is used.

Figure 2 shows the model with applied lateral load. Figure 3 shows the generated mesh. A global coarseness parameter as well as a local parameter is used while generating a mesh. The average element size and the number of generated triangular elements depend on the global coarseness setting. The global coarseness setting of medium, with around 323 triangular elements, was found to be most suitable. Situations where some areas have large stress concentrations or large deformation gradients require the use of the local coarseness parameter. This gives the element size relative to the average element size as determined by the global coarseness setting. Local coarseness parameters as generated automatically by PLAXIS 2D have been used.

4. COMPARISON OF FIELD TEST AND NUMERICAL ANALYSIS

From Figure 4 we can find that the curve obtained using PLAXIS 2D simulations is close to field test results. However, a link in the field test results attributed to some problems in field tests. The issues in large diameter piles in residual soils are:

- Currently, know-how on prediction of load-displacement relationships of large diameter piles in residual soils is scarce. Here we find that the prediction of the adopted method is reasonably close to the field test results.
- IS 2911–Part IV says that the maximum permissible displacement is 12 mm. Testing should be conducted until such displacements are reached so as to determine ultimate bearing capacity. This has not been carried out in the field test presented here; non-availability of jacks and supports of adequate capacity might be the reason. This become more common due to large diameter piles.

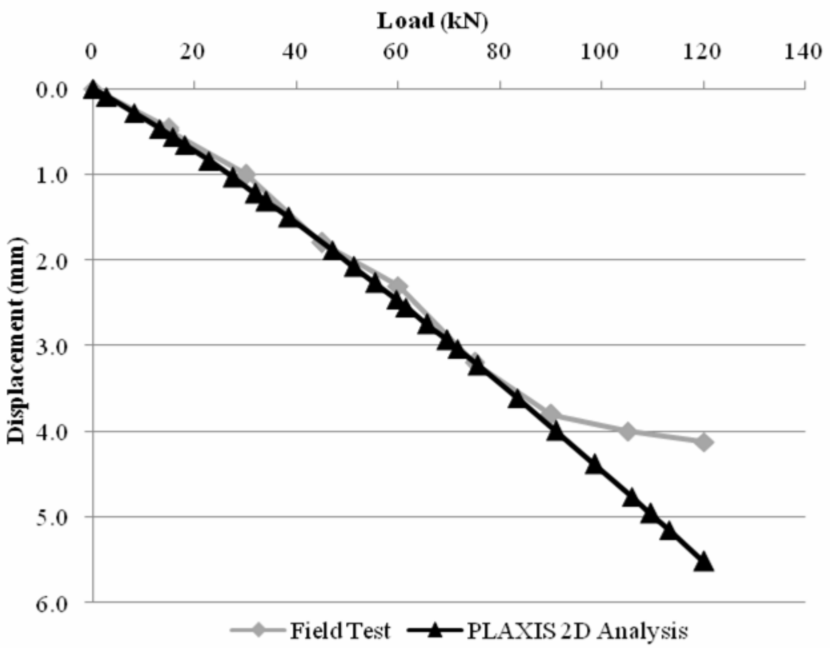

Figure 4. Comparison: Field Test and FEM Analysis.

Table 3. Displacement corresponding to load of 120 kN.

Methods	Displacement (mm)
Field Test	4.12
PLAXIS 2D Analysis	5.51

- Also, codes suggest the load producing a deflection of 10% of the diameter as the ultimate bearing capacity. Required Loads are very large enough to produce 12 mm, let alone 10% of diameter, i.e., 100 mm, displacement have not been used in the field test.
- Accurate numerical simulations the present can be used for this purpose, to simulate pile behavior, for large loads, till failure, conditions for which exiting field test techniques cannot be used.

5. CONCLUSIONS

The laterally loaded pile test was performed in a site with predominantly sandy clay residual soil with soft weathered rock. The laterally load tests were subsequently analyzed using a plane strain finite element model.

- It can be concluded that there is good comparison of load–displacement relation obtained through field test and that obtained by numerical methods.

- The adopted numerical method can be used to simulate displacements such as the 12 mm code requirement or 10% of diameter, displacements that cannot be produced in the field test using existing techniques.
- From above study it can also be concluded that the Mohr-Coulomb (MC) model with a medium mesh (around 323 elements) is optimum to simulate the displacements of a laterally loaded pile in residual soil.

It is suggested that the boundaries in the model be placed at about 10D on either side of the pile model and about 8D-10D below the bottom of the pile model.

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