

NUMERICAL SIMULATION OF VERTICALLY LOADED PILES

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ABSTRACT: Full scale vertical loaded pile tests have been carried out on 1.2m diameter bored cast in-situ piles in residual soils. This paper presents a FEM model for simulating these field vertical load tests on large diameter piles embedded in residual soils using PLAXIS 2D. The simulation is carried out for a single pile with vertical load at pile top, so as to evaluate the settlement of the pile in residual soils. The soil stratum is idealized by 15 noded triangular elements with elastic-plastic Mohr Coulomb model and the pile behaviour is assumed to be linear-elastic. Interface elements have been used to model the interface between the pile and the soil models. The vertical load versus settlement plots on single pile is obtained from field tests and are compared with the finite element simulation results using PLAXIS 2D, showing reasonable agreement. Sensitivity analyses have been carried out for selecting the appropriate mesh size and its gradation and also appropriate constitutive relationships.

INTRODUCTION

Pile foundation is one of the most popular forms of deep foundations. Piles are generally adopted for structures in weak soils, characterized by low shear strength and high compressibility, as well as in good soils, in cases where structures are subjected to heavy loads and moments. The maximum settlement of the pile and its ultimate load bearing capacity are the governing criterion in the design of vertically loaded piles. These are evaluated by carrying out a number of theoretical and numerical approaches. However, the evaluation of the magnitude of soil movement and settlement, with reasonable confidence and accuracy, is difficult. Soils that form from rock weathering or accumulation of organic material and remain at the place where they were formed are called residual soils[1]. Particularly, in these kinds of soils, it is challenging to decide the termination depth. Methods to evaluate the skin resistance for friction piles and socket length for end bearing piles are not well understood. Finite element software, like PLAXIS 2D, are usually used to perform the analysis of piles under different types of loading. Finite element analysis offers an excellent opportunity to study pile-soil interaction, pile response and soil movement under vertical loading in difficult geoenvironments. This paper presents the results of a field test carried out on a vertically loaded pile and attempts to study the pile behaviour under vertical loads using a two-dimensional finite element model.

FIELD TEST

The bored cast-in situ pile considered in this study is of diameter (D) 1.2m, length 15m and of M30 grade concrete. The site soil is composed of clay, and soft-weathered rock. Table.1 lists the parameters of the soil stratum at the test site. The same parameters have been used for the numerical simulations. A hydraulic jack of 250T capacity was used to apply the vertical load on the pile head through a 20mm thick MS plate. The jack was supported by a 7m X 6.2m

loading platform made of ISMB 500 and ISMB 300 I-sections. 2 dial gauges fixed on diametrically opposite points on the pile were used to measure the settlement as the load was applied in increments upto 8250kN. A maximum settlement of 2.56mm was observed. Fig.1 shows the pile load test being carried out for 1.2m diameter pile. Fig. 2 shows the load-settlement curve obtained from the field test.



Fig. 1 Shows the pile load test

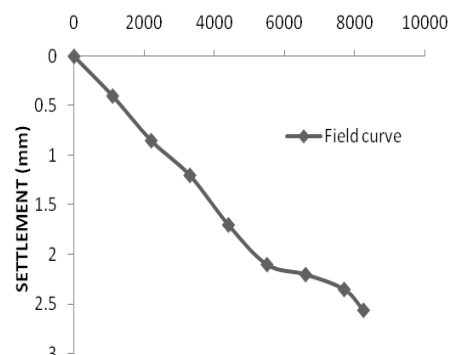


Fig. 2 Load-Settlement curve from Field Test

NUMERICAL SIMULATIONS

An attempt to study the load-settlement behaviour of a large diameter pile under vertical load applied at the pile head is made in this paper. The finite element package PLAXIS 2D, Version 9, is used for this purpose. The pile is 1.2m in diameter and 15m in length. The settlements at incremental loads have been simulated and the complete load-settlement curve has been generated.

The field results have been compared with the PLAXIS 2D results. As in the field, the PLAXIS 2D model consists of 2 layers of soil, clay (upto 6m), and soft-weathered rock(6m to 20m). Table 1 shows the physical and mechanical properties of the soil layers.

Table 1. Soil data sets parameters

		Layer 1	Layer 2	Layer 3
Material (Depth)		Clay (0-6m)	Soft weathered rock (6-20m)	Concrete Pile (15m)
Model		Mohr-Coulomb	Mohr-Coulomb	Linear Elastic
Weight, γ	[kN/m ³]	21.00	22.00	25.00
Young's Modulus, E	[kN/m ²]	40E3	10E5	30E6
Poisson's Ratio, ν	[-]	0.300	0.330	0.2
Cohesion, c_u	[kN/m ²]	30.00	50.00	-
Friction Angle, ϕ	[°]	20.00	25.00	-

Model and parameters of two-dimensional finite element analysis

Large diameter vertical pile in residual soil has been modelled as an axi-symmetric problem. In PLAXIS 2D, 15 noded triangular element has been chosen which results in a two-dimensional finite element model with two translational degrees of freedom per node. The 15-noded triangle provides a fourth order interpolation for displacements and the numerical integration involves twelve Gauss points.

The pile is made up of reinforced cement concrete and the behaviour is assumed to be linear-elastic. The Soil behaviour as described by Mohr-Coulomb, and Hardening Soil models is selected for preliminary analyses. After conducting multiple trials and sensitivity analyses, we conclude that the Mohr-Coulomb model is the most suitable model for all the layers of soil [3,4].

The Mohr-Coulomb model can be considered as a first order approximation of real soil behaviour. This elastic-perfectly plastic model requires 5 basic input parameters, namely Young's Modulus, E, Poisson's ratio, ν , cohesion, c, friction angle, ϕ and dilatancy angle, ψ . This is a basic, well-known soil model.

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 like rollers such that $u=0$ but $v \neq 0$.

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

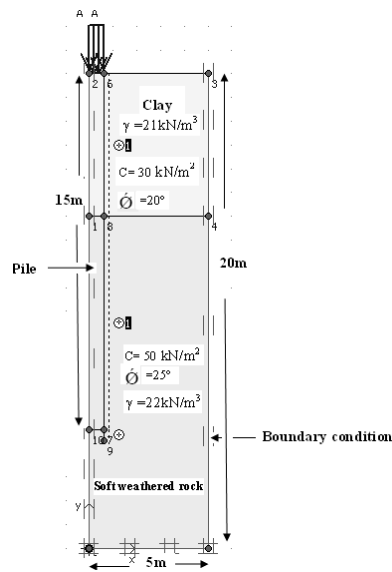


Fig. 3 Model with applied Vertical Load

Fig 4 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 328 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.

Boundary dimensions of 5m X 20m was found to be optimum as it was found that a decrease in dimensions resulted in poor results whereas an increase in the boundary dimensions did not influence them [2].

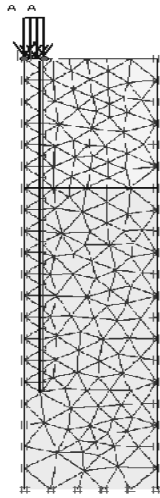


Fig 4 Shows the generated mesh

COMPARISON OF FIELD TEST AND FEM ANALYSIS

The vertical settlement corresponding to 8250 kN (ultimate load upto which the pile load test was carried out) has been presented in the following table.

Table 2 Comparison of load vs settlement curve by different methods corresponding to a load of 8250 kN

Methods	Vertical Settlement (mm)
Field test	2.56
PLAXIS 2D analysis	4.91

From Fig 5, it is shown that the curve obtained using PLAXIS 2D simulations is close to field test results. This implies that numerical simulation is applicable.

It is also noticed that field curve has shown a different shape starting from 2mm settlement, which may be attributed to field test problems.

Fig 6 shows the Deformed mesh of pile-soil interaction problem corresponding to 4.91mm settlement. Fig.7 shows the Effective stress distribution around the pile at the same settlement. Orientation is shown to be effected closer to the pile and as one goes away from the pile, the maximum effective stress is nearly vertical. Vectors indicate both the magnitude and direction. Interaction closer to the pile is greater in the Soft weathered rock than in the top clayey soil. Fig.8 shows the total displacement vectors around the pile corresponding to maximum settlement. Fig.9 shows the total vertical stress contours around the pile corresponding to a

settlement of 4.91mm. From all these figures, it is evident that frictional component is more in soft weathered rock than in the top clay layer.

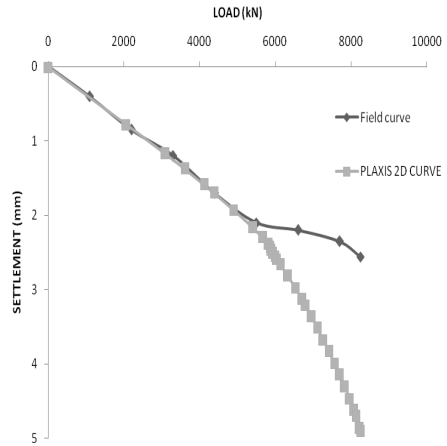


Fig. 5 Load –Settlement curve

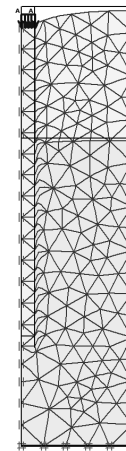


Fig. 6 Deformed mesh

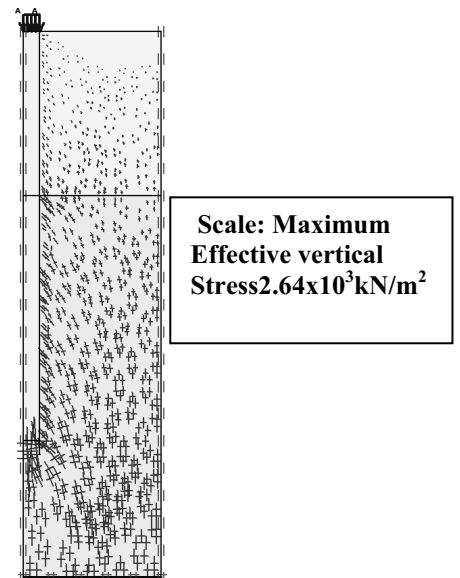


Fig. 7 Effective stress distribution with magnitude and direction (vectors indicate the direction)

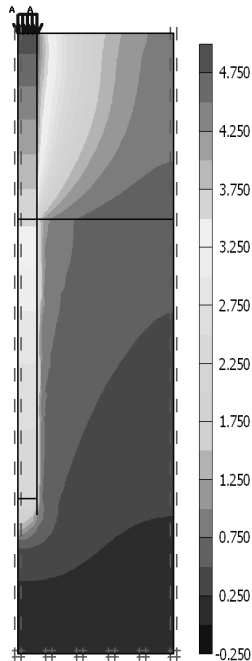


Fig. 8 Total displacement vectors

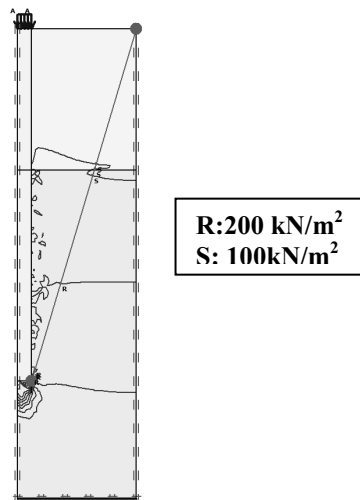


Fig. 9 Total vertical stress contours

CONCLUSIONS

The vertical loaded pile test was performed in a site with predominantly clay soil with soft weathered rock. The vertical load tests were subsequently analyzed using an axisymmetric 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.
- From above study it can also be concluded that the Mohr-Coulomb (MC) model with a medium mesh (328 soil elements and 31 interface elements) is optimum to simulate the settlement of a vertical loaded pile in residual soil.
- It is suggested that the FEM boundaries be placed at about 5D beside of the pile model and about 3D-5D below the bottom of the pile model. This is evident from the displacement vectors presented in the Fig.7.
- The skin resistance is maximum in soft weathered rock layers.

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