Analysis of pile-load tests using the finite-element method

Analyse d'un essai de charge sur un pieu utilisant la méthode des éléments finis

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SYNOPSIS A plane-strain finite element model is developed herein, for the analysis of the results of pile-load tests. The caracteristics of this model are ajusted in order to reproduce the expected pile behaviour, based on the theory of elasticity. The results obtained in this way are analyzed and some conclusions of practical interest are presented.

INTRODUCTION

The reaction devices more widely used presently for performing pile-load tests are the ones composed by anchor rods or tension piles. It is known, however, that the interaction between the loads transmitted through the piles and the corresponding reaction loads in the anchor rods or tension piles, can lead in some cases to remarkable discrepancies between the pile-load tests measured results and the theoretically expected ones [see for instance, Tschebotarioff, 1973 and Poulos and Davis, 1980). This effect is specially significant when the soil layer where the anchor devices are installed is not much stiffer than the remaining superior soil layers, being therefore not accomplished the full-fixity condition for the anchor devices.

The interest in the analysis of the results of load tests performed in 1.60m diameter, 50m long concrete piles, placed in a strongly heterogenous media and the meagreness of results in similar conditions found in the available literature, lead to the development of a finite element model, intending to obtain numerical results for a qualitative insight of the problem. Some of the obtained main results and derived conclusions are presented in this paper.

CASE HISTORY

The concrete pile and the considered soil layers with their corresponding elastic properties are displayed in Fig. 1. The indicated soil properties were obtained from dynamic penetration tests through correlations and laboratory tests.

The anchor rods were disposed following the Brazilian Standards NB-51/78 which impose a minimum average distance between the anchor point in the soil and the pile axis of three times the pile diameter, being this valve at least equal to 1,50 m.

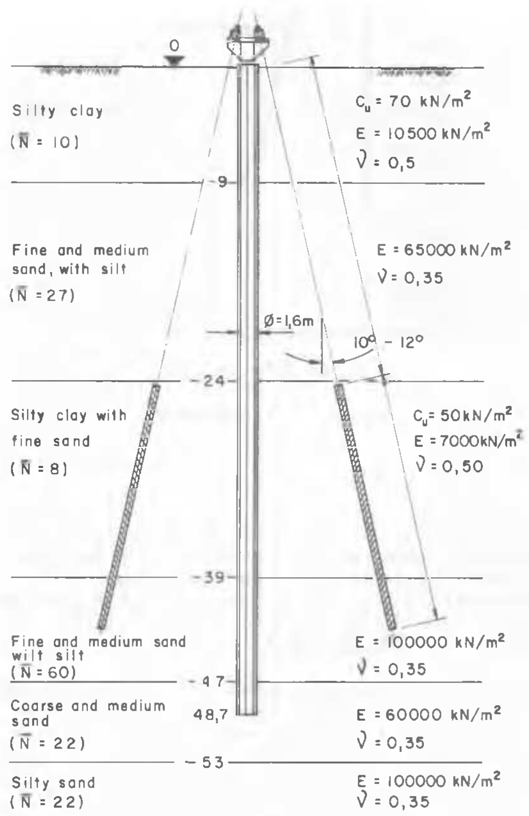


FIG.1 - Pile, anchor-rods and soil - profile
(N̄ = Standard Penetration Test)

ANALYSIS THROUGH THE F. E. METHOD

Although being the analyzed problem intrinsically an axisymmetric one, reasons of economical and practical character led to the use of plane-strain finite elements available in the computer program GSAP, developed by PROMON Engenharia S.A..

Several numerical tests performed with different meshes shown that a good agreement can be found between results using a plane-strain model and the theoretical ones from the Theory of Elasticity through an adequate choice of the model thickness in the problem under analysis, a thickness of 10m (about 6 times the pile diameter) was found to be adequate.

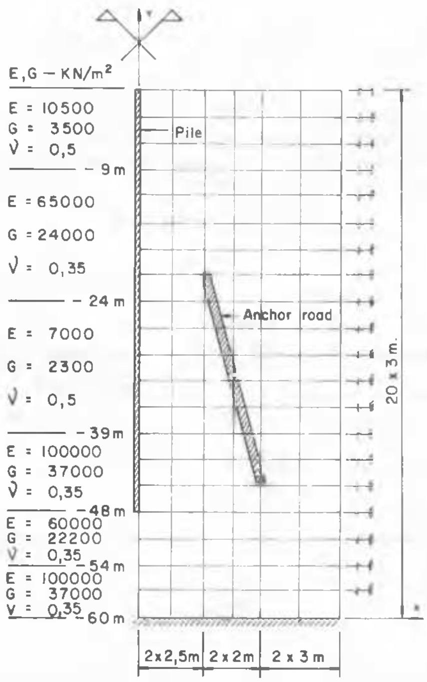
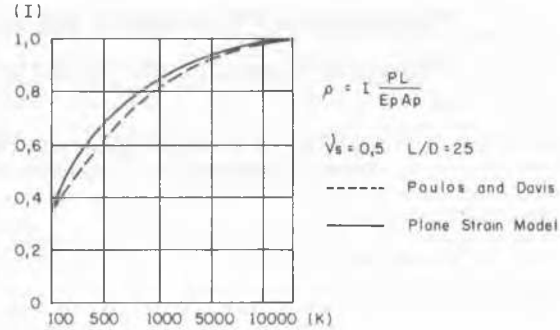
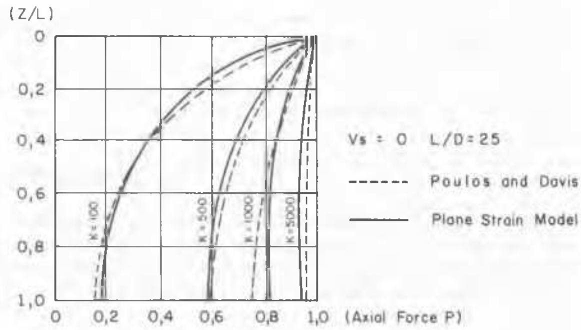


FIG. 2 – Finite - element mesh



TOP DISPLACEMENT
(END-BEARING PILE)

FIG. 3



AXIAL FORCE DISTRIBUTION
(END - BEARING PILE)

FIG. 4

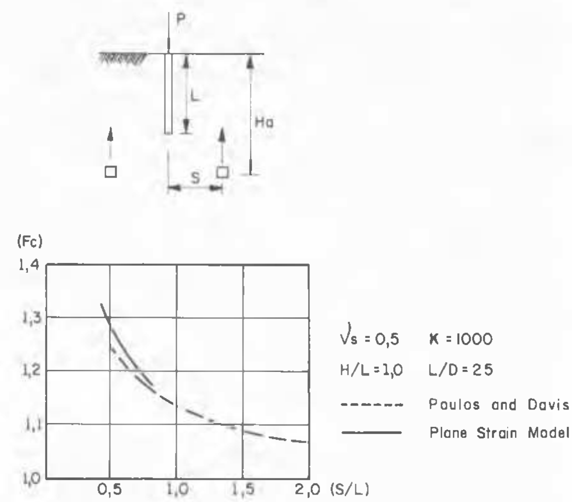
The adequacy of the adopted model for the required purpose was corroborated by the following parametric studies, where numerical results are compared with the ones based upon Theory of Elasticity, from Poulos and Davis, 1980.

a) vertical top displacement in an isolated end-bearing pile, varying the relative stiffness K = Ep/Es (E pile/E soil) between 100 and 10000 (homogeneous case), Fig. 3.

b) Axial force distribution throughout an end bearing pile, varying K between 100 and 5000, Fig. 4.

c) Correction factor to be applied to the vertical top displacement in a floating pile load test (K = 1000), Fig. 5.

The very good agreement found in the three groups of comparisons above authorized the heterogeneous problem to be analyzed. This model is displayed in Fig. 6. It is important to note that the value of K in



CORRECTION OF THE TOP DISPLACEMENT

FIG. 5

each soil layer remained within the limits investigated in a) and b) (E pile = 3 x 10^7 KN/m²).

The inferior boundary nodes were considered as fixed; to the lateral boundary nodes (right), vertical and horizontal springs were accordingly disposed in order to approximatelly reproduce the stiffness of the soil regions not represented in the model; in the lateral boundary nodes (left), the symmetry conditions were adequately introduced (in this way, only one-half of the pile is represented). It should be noted that the fixity condition in the tip of the pile, shown to be of irrelevant importance in the analysis.

Three loading cases were considered:

a) Unitary vertical load in the top of the pile, without participation of the anchor rods. This case corresponds to the normal operating conditions of the pile.

b) Unitary load in the top of the pile equilibrated by the anchor rod reactions.

c) Unitary load in the top of the pile equilibrated by an equal load applied in the pile 24m below the ground level. This case represents an extreme condition for the effect herein analyzed.

The diagrams of axial forces along the piles for the three analyzed cases are shown in Fig. 6 e 7. Top displacements for Q_1 = 1 kN are as follows:

CASE	DISPLACEMENT (x 10^{-6})m
a	2.08
b	1.47
c	0.58

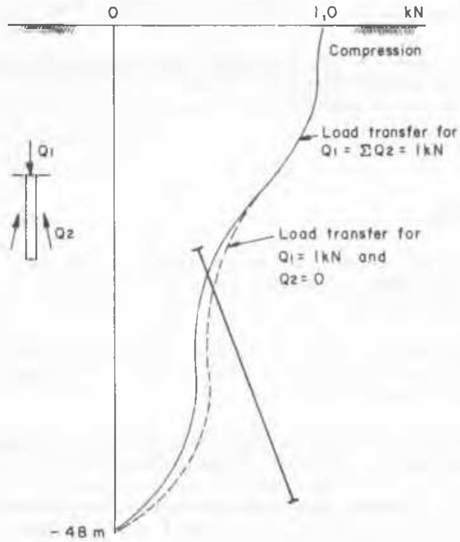


FIG. 6 - Load - transfer for the pile load test with anchor rods

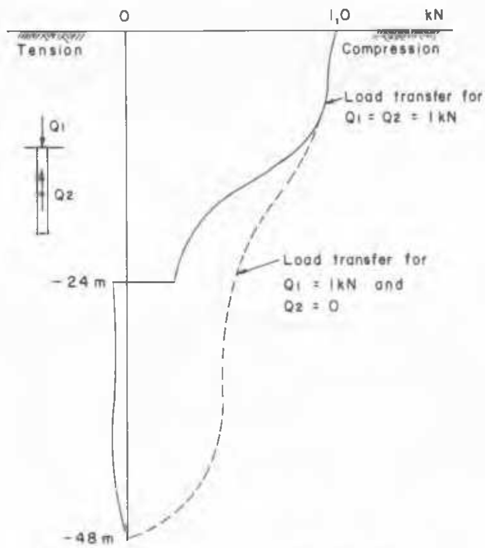


FIG. 7 - Load transfer : Extreme limit case

DISCUSSION OF RESULTS AND CONCLUSIONS

The analysis of Fig. 6 and 7 leads to the following conclusions:

In the present case, the interaction anchor rod x pile through the soil masked two main results in different extent: the load transfer is practically unaffected, and the top displacement is remarkably reduced.

Theoretically, tension forces in the inferior part of the pile can appear due to the analyzed effect. Nevertheless, in the present case, tension forces of small magnitude appeared only in the extreme load case c).

For a more general case of analysis of a pile-load test, the following facts should be pointed out:

In certain conditions, the results of pile-load tests can be masked by the interaction anchor rod x pile.

When the disposition of the anchor rods foloows the recommendations of the standards, a maximum of about 20% in the reduction of compressive force to be transferred to the inferior part of the pile and a maximum of about 30% of reduction in the pile top displacement are to be expected.

Due to the great simplicity of the problem, results with an adequate degree of accuracy can be obtained even using rough models. Phane-strain finite element models can be used, as long as parametric analysis be performed showing an reasonable agreement betweem numerical and theoretical results.

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