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Behavior Of Instrumented Omega Pile In Porous Soil

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Abstract. Results obtained from in-situ load tests carried out on omega displacement piles sunk in a porous, lateritic and unsaturated soil deposit, are analyzed in this paper. Three slow-maintained load tests were performed on deep instrumented piles with a diameter of 0.37 m and around 12 m long. The soil deposit consists of a superficial, silty clay "porous" layer 6 m thick. Under this layer there is a lateritic stratum 10 m thick, geotechnically consisting of a residual clayey silt. The results of the field load tests yielded a maximum pile load (average for the tests) of 1428 kN, which is twice as high as corresponding experimental values from standard bored piles with similar geometric conditions. Numerical finite element analyses, were performed in order to back-analyze the geotechnical soil parameters for a post-execution pile condition. The results permitted a better understanding of the improvement of the subsoil given the intrinsic execution characteristics of this particular pile. It was also possible to note that omega displacement piles have great potential to become an economically viable solution in tropical soils, given the enhanced behavior of such piles when compared to alternative techniques.

Introduction

Most buildings in tropical soils use, as the main type of foundation, deep bored or auger type piles. These types of foundations can be performed in various ways, for example with or without soil extraction, with or without bentonite mud and so on. Two main processes may be formulated: the first execution process is typified by bored pile types, continuous flight auger piles etc., which do not cause excessive soil displacement during excavation. With respect to the second process, one could mention, amongst others, driven piles (precast concrete or steel), Franki piles and drilled displacement piles, which do displace the soil during excavation by pushing the soil laterally around the hole in order to allow either the penetration of the pile or the excavator auger.

It is also common knowledge in the technical community that the executive process of the pile interferes with load capacity. Therefore this paper aims to analyze the performance of three omega displacement piles that were executed in a deposit of diabase origin, i.e. related to a porous, laterized soil, in the city of Campinas, in the interior of Brazil. This soil is unsaturated, at least down to a depth of 17 m, where the water table is reached. Load tests were conducted on three instrumented piles. The behavior of this type of pile in the particular (tropical) conditions of the site is presented and analyzed together with 3D numerical analyses using Cesar LCPC software, permitting overall conclusions to be drawn that are of practical and academic interest.

Aspects of Omega Displacement Piles

The advantages of using the drilled displacement pile lie in the fast implementation process, together with noise-free excavation. It also increases the load capacity when compared to standard CFA piles. Daily production, over eight working hours, can range from 120 to 200 linear meters [1]. [2] have demonstrated the high performance of omega displacement piles, in terms of capacity gain, when compared to other piles. This was done via load tests on instrumented piles, with a new technique exclusively developed to insert the instrumented bar inside the drilled displacement auger.

Some further considerations regarding the execution of this pile type can be cited, such as [3]: (1) the shape of the drilling member leads to beneficial penetration, although the increase in load capacity cannot be directly proven (further work is needed); (2) the torque of the machine is of great importance for its implementation; (3) the penetration rate depends on the diameter of the pile and on the soil type; (4) the penetration expends more energy removing the soil than overcoming the friction between the auger and the soil; (5) there is no problem when this is carried out in saturated, loose, granular deposits and finally, (6) no soil is excavated during drilling, which is of great interest in brown field or contaminated sites.

Geological-Geotechnical Characteristics of the Site

The experimental site related to the present paper is located in the city of Campinas, in the state of São Paulo, Brazil. This site has a surface layer 6 m thick, composed of a highly porous, silty clay on top of a layer of silt clay (“residual” soil) the thickness of which ranges from 10 m to 20 m. The water table level is located at a depth of around 17 m. The average profile, together with SPT-T and CPT results, are schematically depicted in Figure 1. These in-situ tests were performed near the piles.

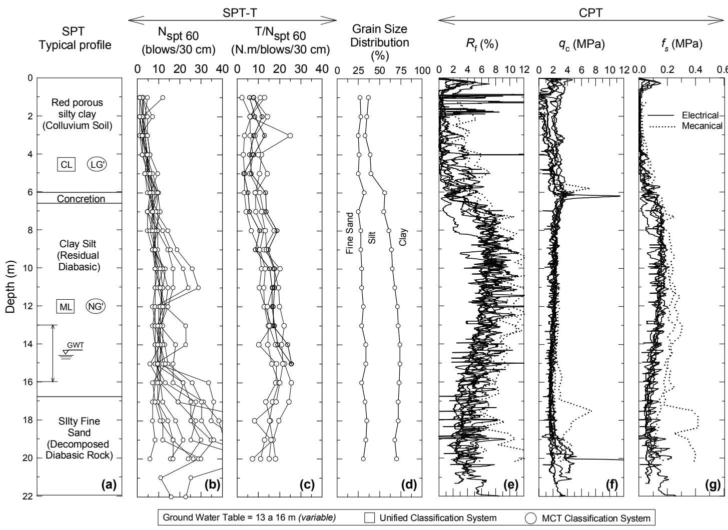

Figure 1 –Electrical and Mechanical SPT-T and CPT test results [4].

Results, Analyses and Discussion of the Experiments

Instrumentation and Load Tests

The testing piles had a nominal diameter of 0.37 m and were 12 m long. The instrumentation employed instrumented bars with strain-gages at the specific levels of 0.5 m (reference), 5.0 m and tip, along the depth of the shaft.

Slow-maintained type load tests were carried out with successive load stages of no more than 20% of the predicted work load for each of the tested piles. This procedure followed the prescripts of [5]. All tests were performed until the loads were approaching the limiting capacity of the reaction system, allowing final displacements on the tested piles in the range of the capacity of the dial gauges. Small pile displacements in the order of 5 mm were required to “fully mobilize the lateral friction along the shaft. Maximum stabilized loads and displacements are: pile 1 (Q_{ult}=1545 kN, δ_{max}=65 mm), pile 2 (Q_{ult}=1420 kN, δ_{max}=62 mm) e pile 3 (Q_{ult}=1320 kN, δ_{max}=23 mm).

Numerical Analyses

Numerical modeling was performed by adopting a mesh with a layout of ¼ of the whole problem, due to the symmetry along the z (vertical) axis. This resulted in a rectangular "block" section of 12 m x 12 m with a total depth of 22 m that allowed a base layer 10 m thick below the pile tip. A traditional, theoretical, elasto-plastic Mohr Coulomb model was used with a finite element mesh composed of triangular elements with quadratic interpolation.

A parabolic model, valid for elements with a brittle-type behavior, was assigned to the pile's structural element, i.e., the concrete, thus with values related to their compressive resistance (Rc), tensile strength (Rt), specific gravity and elastic parameters, such as the elasticity modulus and the Poisson's coefficient. The software Cesar LCPC v.5 from Itech-Soft Ltd. was employed in these analyses, which considerably facilitated the use of the abovementioned model, and soil / pile characteristics and the loading sequence.

Figure 2 presents the load *vs*. displacement curves obtained through the experimental load tests and the numerical simulation (for a typical pile equivalent to those experimentally tested). An average underestimation was found, in the range of ~ 20 %, together with an overestimation with pile displacement under working conditions (considering a safety factor (SF) of two, the numerical result was almost 4x the experimental predictions).

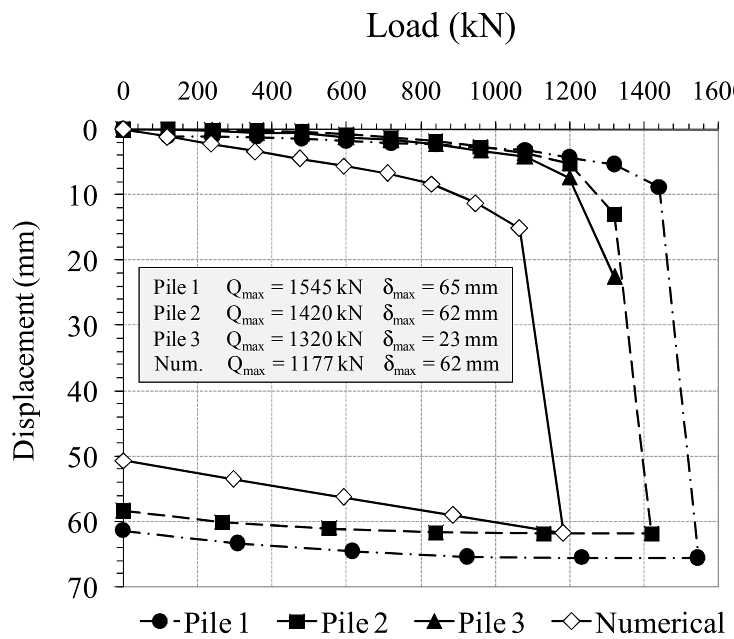

Figure 2 – Load *vs*. Displacement curves of the tested piles versus the numerical prediction.

Comparison of Numerical and Experimental Results

The differences between the drilled displacement pile and the traditional bored pile behavior are astonishing. Using the data of the instrumentation and calculating the average (assuming a constant along the depth) unit friction stress on the shaft, and the unit tip stress on the base, one can derive the values displayed in Table 1. This comparison clearly demonstrates that the execution process of piles does improve the soil characteristics and the overall pile behavior, during ultimate as well as during working load conditions.

Table 1 – Ultimate values of avg. unit lateral friction and tip stress for all studied cases

Pile	Shaft Friction (kPa)	Tip (%)
Omega displacement Pile	86	14
Bored	40	2
FEM	78	11

The results of these tests are shown in Table 1 where it is in fact demonstrated that the samples closer to the auger suffered a process of compaction to a higher degree than those further away. It is important to notice that the void ratio of the virgin soil before pile execution was 1.60. This aspect is clearly noticeable through all depicted experimental state variables such as the natural weight, the void ratio and the porosity. A slight decrease in moisture content is also noted, perhaps given the heat exchange process (accentuated at distances closer to the auger) and localized evaporation phenomena.

Conclusions

The executive process intrinsically related to omega displacement pile has indeed improved the soil characteristics around the shaft of the pile and enhanced pile performance when compared to other similar foundations, such as standard bored piles. The omega displacement pile execution has "imprinted', in the surrounding soil, certain beneficial characteristics, such as increasing its density and overall shear resistance. It has probably also increased the level of horizontal "locked-in" stresses in the soil confined around the shaft of the auger, although this aspect should be researched further.

The gain in load capacity in comparison to typical bored piles is astonishing (2x in the present series of analyses) and demonstrates that a higher productivity in the field, in terms of capacity, and a lower number of piles in the design, can eventually match, or even outweigh, the higher costs associated with the execution of this particular type of foundation;

There is a considerable improvement in terms of residual loads absorbed in the pile tip in comparison to common results observed for standard bored piles. Nevertheless, in both cases, it seems that these foundations have predominantly behaved as floating piles rather than end-bearing piles. More research effort must also be afforded in this context;

There is still some difficulty with the numerical simulations of omega displacement type piles, which can be associated with a series of factors, such as (a) the lack of adequate knowledge of the soil parameters (and the behavior of the soil constituents) around the shaft and the auger of drilled displacement piles; or (b) the lack of proper rheological models and numerical tools capable of envisaging and taking into account all the complex nuances of the boring process with the special drilled displacement auger; or finally (c) the lack of adequate experience and experimental comparative data in Brazil, and elsewhere, with this type of foundation, that would allow researchers to forecast with more certainty the "closer to reality" field phenomena associated with this type of pile.

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