ISC'2 experimental site – prediction & performance of instrumented axially loaded piles

Site expérimental ISC'2 - prédiction et performance des pieux instrumentés chargés sur son axe

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ABSTRACT
This paper is part of a joint research project to study the behaviour of piles in residual soil. An experimental test site on residual (saprolitic) soil from granite was constructed at the Faculty of Engineering of the University of Porto. A very extensive site characterization has been held, including a large variety of in situ tests in order to develop an International Prediction Event (Class A) of Bored, CFA and Driven Piles. Researchers and designers were invited to deal with this investigation results in order to predict the real response of the pile foundations. Several in-situ testing techniques were used - Penetration tests: SPT and CPTU; Pressure-dilatometer tests: PMT and DMT; Seismic: Cross-Hole (CH) and Down-Hole (DH). Undisturbed samples were recovered and an extensive laboratory-testing program was carried out, including oedometric consolidation tests, CK_0D triaxial tests using local strain measuring devices and bender-extender elements, as well as resonant column tests. This paper focuses on the axial pile load tests and a analysis of the predictions is presented.

RÉSUMÉ
Cette communication fait partie d'un projet de recherche commun pour étudier le comportement de pieux en sol résiduel. On a construit un site expérimental sur sol résiduel (saprolitic) du granit à la Faculté d'Ingénierie de l'Université de Porto. Une caractérisation très intensive de ce site a été tenue, y compris une grande variété de tests in situ afin de développer un Événement International de Prédiction (Classe A) du comportement de pieux foré tubé, tarière creuse et battu prébabriqué. Les chercheurs et les dessinateurs ont été invités à traiter les résultats des investigation in situ pour prédire la vraie réponse des pieux. Plusieurs techniques d'essai in situ ont été utilisées : les essais de Pénétration, SPT et CPTU, les Pressiomètres e Dilatomètres, PMT et DMT, et des essais sismiques, le Cross-Hole (CH) et Down-Hole (DH). Des échantillons intactes ont été essayés en laboratoire. Le programme d'essai a compris les tests de consolidation en oedometric, essais triaxiaux CK_0D, utilisant instrumentation locale des déformations, et aussi des tests en colonne résonnant. Cet article se fixe sur les essais de chargement vertical des pieux et présente une analyse des prédictions.

1 INTRODUCTION

In the north-western region of Portugal residual soils from granite are dominant. The thickness of these regional saprolitic soils may some times exhibit more than 20m, with more common values of 5 to 10m. Due to their specific genesis such soils present complex characteristics, which are a consequence, on the one hand, of their overall variability and heterogeneity and, on the other hand, of the spatial arrangement and distribution of the particles and pore spaces. Coarse and resistant quartz grains are bonded by fragile clayey plagioclase bridges, resulting in a fabric with medium to high porosity. The feldspars are subjected to heavy weathering processes, typical of high average annual precipitation and well-drained ground profiles. The mechanical and hydraulic behaviour of these soils is often quite distinct from sedimentary soils with similar densities and grain size distributions.

The current design practice of bored and driven piles in residual weathered formations is merely semi-empirical and based on bearing capacity analysis (in general, without deformations analysis). Fully instrumented pile load tests are very much informative for the elaboration of specific correlations between load-deformation behaviour and in situ tests results (and also fundamental soil mechanics parameters obtained from precise laboratory tests), for establishing well-based design criteria.

The ISC'2 experimental site (International Site Characterization Conference) were located within the campus of the Faculty of Engineering of the University of Porto (FEUP). A very extensive site characterization including a large variety of in-situ tests and also pile load tests were prepared in this experimental site, under the sponsorship of 4 construction companies.

2 SOIL PROFILE

Residual soils from granite are very common in the north-western part of Portugal where ISC'2 experimental site is located within the campus of the Faculty of Engineering of the University of Porto (FEUP). The site is geologically formed by an upper layer of heterogeneous residual (saprolitic) granite soil of varying thickness, overlaying more or less weathered granite contacting high grade metamorphic rocks. According to the identification tests results the main composition of this saprolitic soil is a fine to medium grade and low plasticity material, classified as silty sand.

The data compiled during the extensive in-situ and laboratorial investigation and characterization of ISC'2 experimental site, comprising the application of several geotechnical and geophysical surface and borehole techniques, namely SPT, CPT, DMT, PMT, surface and borehole seismic, laboratory tests and, is a valuable opportunity to compare different methodologies and assess their relative advantages and limitations. The information are compiled in several papers presented by Almeida et al. (2004), Carvalho et al. (2004), Viana et al. (2004) and Lopes et al. (2004).

The layout map of the site, Fig. 1, shows the location of the borings, SPT, CPT, DMT and seismic survey.

An extensive geological and geotechnical characterization was undertaken, including in situ testing, which was conducted in two stages, before and after the installation of the driven piles. Figs. 2 and 3 summarizes some technical data but much more information can be found in Almeida et al. (2004), Carvalho et al. (2004), Viana et al. (2004) and Lopes et al. (2004).

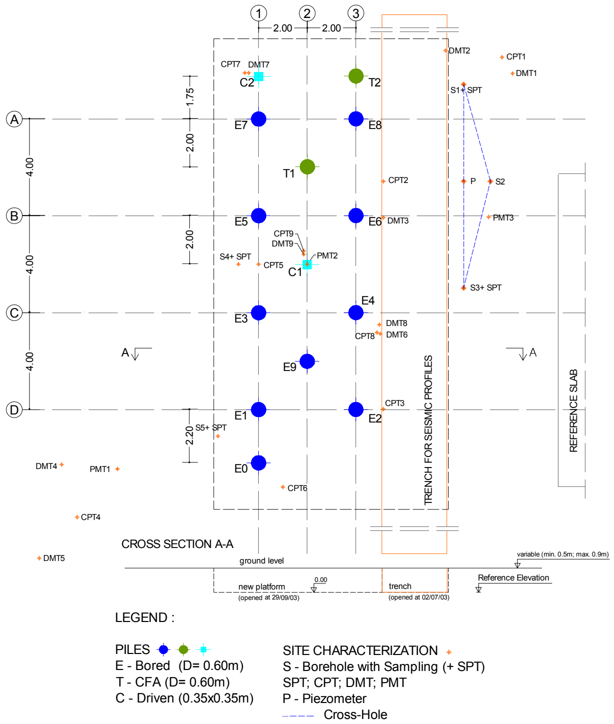

Figure 1. Layout of ISC'2 experimental site.

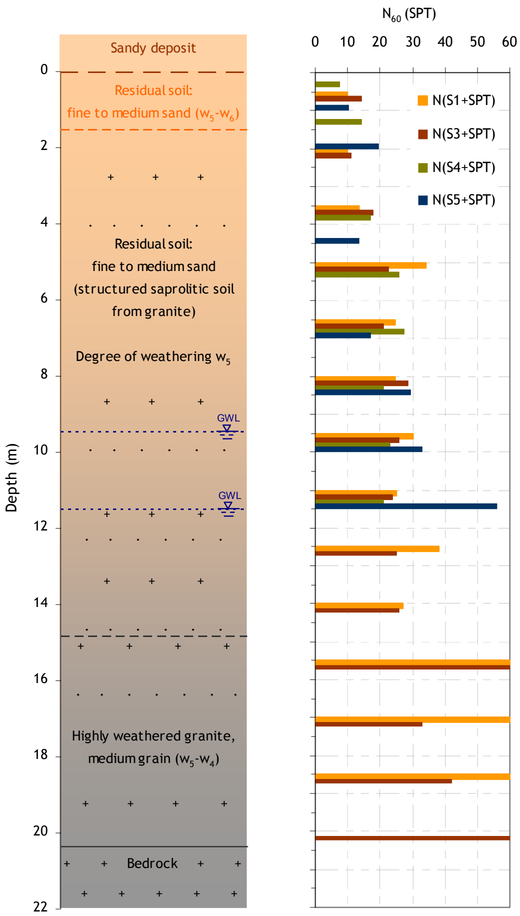

Figure 2. Soil profile and SPT results.

After the installation of piles C1 and C2, noticeable increase in cone resistance was observed in the surrounding soil (Fig. 3 - before installation of piles: CPT1/2/3/4/6; after installation of piles:CPT5/7/8/9; compare for example CPT5 with CPT9).

3 PILE PREDICTION EVENT

A pile prediction event were organized by FEUP and IST-UTL (High Technical Institute of the Technical University of Lisbon) under the auspices of TC-18 of the ISSMGE. It was a class A prediction event, i.e. all the predictions were submitted before the static pile load tests performed in January 2004. The event was part of a Special Session at the ISC'2 Conference in September 2004.

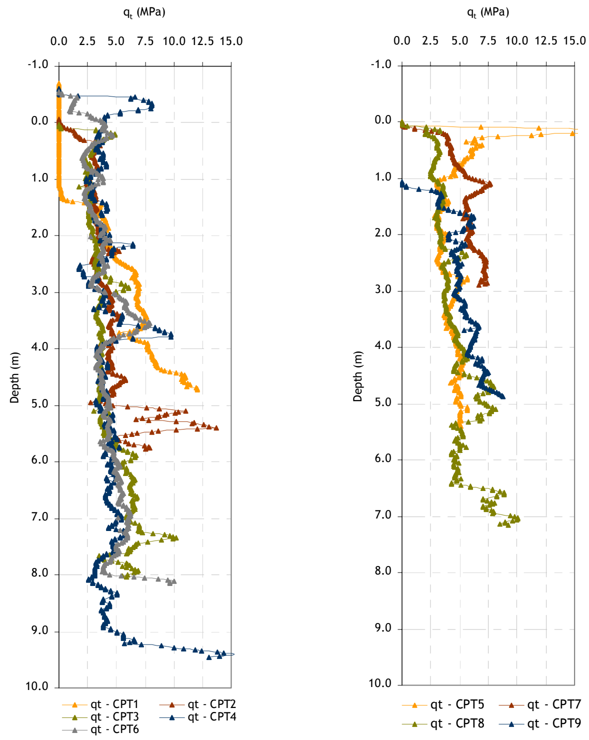

Figure 3. CPT results before and after installation of piles.

In the experimental site, 3 different kinds of piles were executed: bored piles with temporary casing, continuous flight auger, CFA, piles (bored and CFA piles with circular section - nominal diameter Ø600mm) and driven piles (with square section - width b=350mm). For the former types, a hydraulic rotary rig on a base machine, allowed a temporary casing, installed by jacked and rotary crowd system, followed by a dry concretion, while, in CFA, an injection of concrete (slump of 190mm) with a pressure of 60 bar at the beginning, was made while pulling out the auger. The equipment used for driving the precast piles was a 4+1 ton hydraulic hammer, falling from about 23cm, mounted on a base machine.

These 3 different types of piles were loaded axially side by side up to failure (piles E9-bored, T1-CFA and C1-driven). The location of the piles is represented in the layout map (Fig. 1).

The participants were provided information on pile geometry, soil profile, equipment and high strain dynamic tests results. They were challenged to predict the static load bearing behaviour of piles including:

(i) a table giving load vs. settlement at the pile head;
(ii) parameters and models used;
(iii) calculation methodology;
(iv) pile base resistance and shaft resistance, separately if applied;
(v) ultimate compressive resistance and criteria used to determine such resistance;
(vi) allowable bearing capacity and factor of safety used to determine such capacity;
(vii) explanation of the method used to reach all the previous

items.

A total of 33 predictions were received from 17 countries as can be shown in Fig. 4.

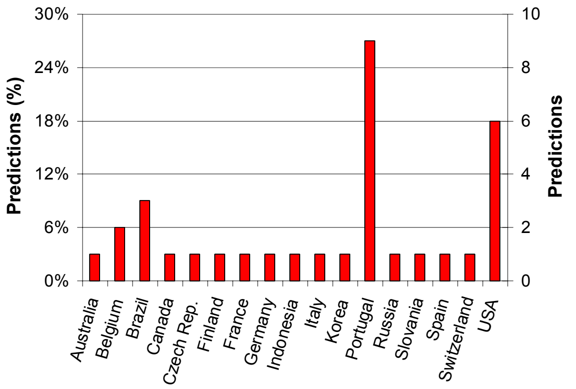

Figure 4. Predictions received.

A compilation of the predictions for the ultimate compressive resistance is represented in Figs. 5, 6 and 7 for piles E9 (bored), T1 (CFA) and C1 (driven), respectively. The pile base resistance (Rb) and shaft resistance (Rs) are indicated separately when applied otherwise the total resistance (Rt) is showed.

The predictors applied different kind of calculation methods namely: analytical or empirical methods, results of dynamic load tests or a combination of them. It is also important to be noted that different criteria or calculation approaches were used to define the ultimate compressive resistance.

The predictions presented in Figs. 5, 6 and 7 are very scatter which demonstrate that the accurate estimation of pile axial capacity is still a very difficult task. Similar scattered results tendency were obtained by the pile prediction event at the 2002 ASCE GeoInstitute’s Deep Foundation Conference (Fellenius et al., 2004).

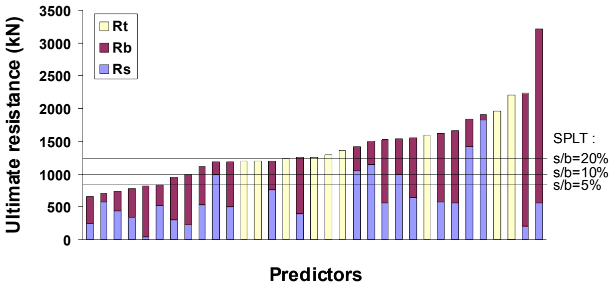

Figure 5. Ultimate resistance: predictions for bored pile E9.

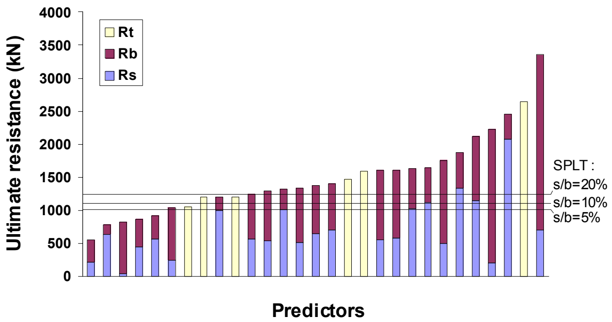

Figure 6. Ultimate resistance: predictions for CFA pile T1.

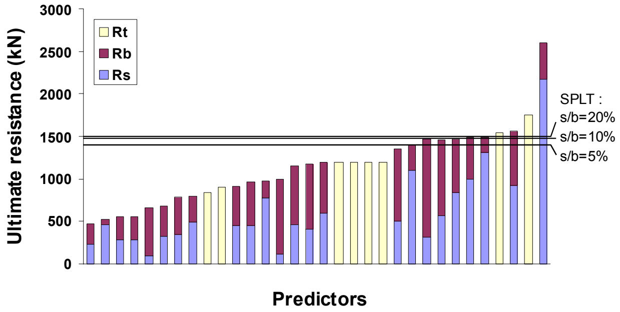

Figure 7. Ultimate resistance: predictions for driven pile C1.

4 RESULTS OF THE STATIC LOAD TESTS

The static pile load tests (SPLT) were performed taking into account the recommendations of ERTC3-ISSMGE (De Cock et al., 2003) and ASTM D1143-81. For each loading stage the load was maintained until the displacement rate was less than 0.3mm/hour, with a minimum of 0.5h and a maximum of 2h.

The piles E9 and T1 were instrumented with retrievable extensometers, allowing the measurement of the mobilized resistance along pile shaft. In addition, a load cell was placed at the tip of pile E9 to measure the base resistance.

In order to be able to compare the predictions with the SPLT results, the latter are referenced to a certain level of relative displacement. Three levels were considered: s/b=5%, 10% and 20% (s=pile head settlement, b=pile diameter or pile width).

Figs. 5 and 6 show that a significant number of predictions overestimate the capacity for piles E9 and T1, meanwhile the predictions for pile C1 are conservative but 9 of them are very close to the SPLT results (with differences less than 10%).

The load-settlement curves for piles E9, T1 and C1 are plotted in Fig. 8.

The pile C1 although having a smaller cross-section (43.3%) showed a stiffer response than the other two piles. This is a clear indication that the installation effects play an important role in the pile behavior. In this case, the pile driving process should have induced a significant increase of the horizontal stresses in the surrounding soil.

For the piles E9 and T1 the ultimate resistance cannot be clearly defined from Fig. 8.

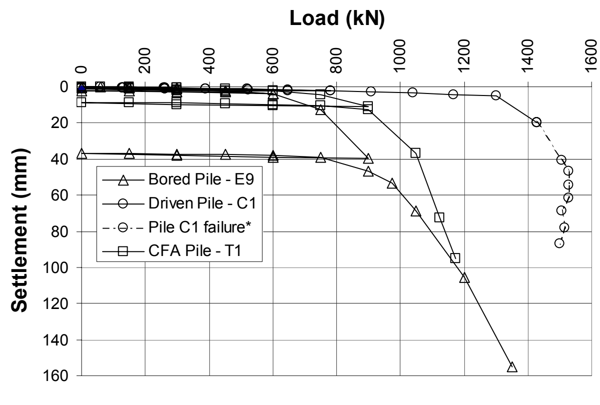

Figure 8. Load-settlement curves from static load tests.

The SPLT results can be interpreted in a more convenient way when using the relative settlement (s/b). Fig. 9 shows the load-relative settlement of the driven pile C1. The ultimate pile capacity was reached for a relative settlement of about 10%. This value seems to be in good agreement with recent studies in centrifuge tests on displacement piles in sands (Fioravante et al, 1995).

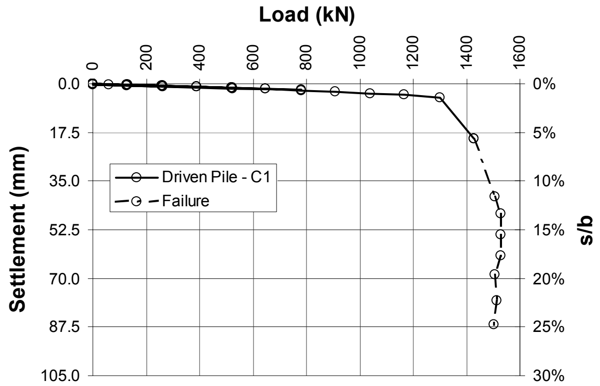

Figure 9. Load-relative settlement curve: pile C1.

The results of piles E9 and T1 are plotted in Fig. 10. In this case, even for a relative settlement of about 25% the ultimate resistance was not reached.

Fig. 11 shows the evolution of the load distribution during the static load test on pile E9. The base resistance was considered equal to the value measured at the load cell placed at the pile tip. It is clear from this Fig. 11 that:

i) the ultimate shaft resistance was reached for a relative settlement of about 10 to 20%;

ii) the base resistance was not fully mobilized.

Similar behavior can be expected and applied for pile T1.

These experimental results are also in good agreement with Fioravante et al. (1995). Centrifuge tests on non-displacement piles in sands showed that a very large relative settlement is required to mobilize the base resistance (s/b ≥ 100%).

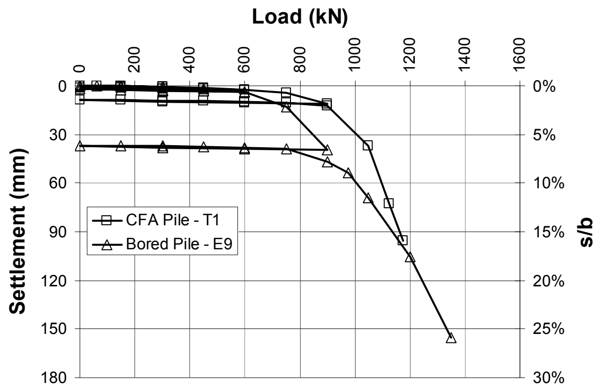

Figure 10. Load-relative settlement curves: piles E9 & T1.

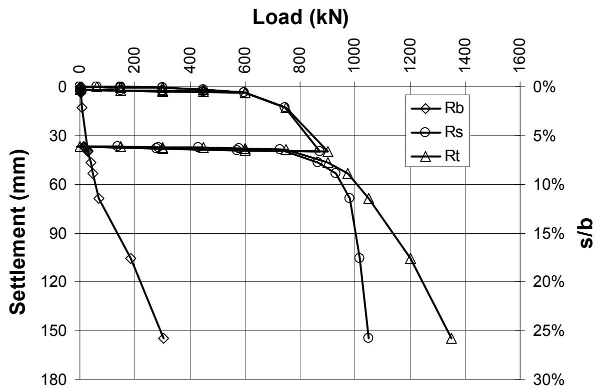

Figure 11. Load-relative settlement curves: pile E9.

5 CONCLUSIONS

This paper focuses on the prediction and performance of 3 axially loaded piles in ISC'2 experimental site – FEUP.

The predictions overestimate the capacity of the non-displacement piles (bored pile and CFA pile) because the pile relative settlement induced in the static tests did not allow the full mobilization of the base resistance. Meanwhile the predictions for the displacement pile (precast driven pile) are conservative, i.e. underestimate the gains due to pile installation effects.

The pile head load-relative settlement curves obtained in the static load tests are in good agreement with previous studies in centrifuge tests on model piles in granular soils. It means that, for large strains, the behaviour of the piles in this residual soil is similar to a one in granular soils deposits.

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