Key Engineering Materials
ISSN: 1662-9795, Vol. 753, pp 285-289
doi:10.4028/www.scientific.net/KEM.753.285

Submitted: 2017-02-03
Revised: 2017-04-11
Accepted: 2017-05-12
Online: 2017-08-28

Effect of Second Loading on the Instrumented Continuous Flight Auger Concrete Pile on Porous Soil

Paulo Jose Rocha Albuquerque[1,a *] and David de Carvalho[2,b]

[1]University of Campinas, Rua Saturnino de Brito 224, Campinas, Sao Paulo, Brazil

[2]University of Campinas, Av. Candido Rondon 501, Campinas, Sao Paulo, Brazil

[a]pjra@fec.unicamp.br, [b]d33c@uol.com.br

Keywords: Load test, Instrumentation, Stiffness method, Cambefort Laws.

Abstract. This paper presents the results of two load tests carried out in a continuous flight auger pile of 0.4 m in diameter and 12 m in length. The pile was instrumented in depth with strain gages in order to obtain the load capacity along the shaft and the tip. The load tests were carried out at the University of Campinas Experimental Site Test. The subsoil where the pile was installed is constituted by a first stratum of Silty Clay, which is porous and collapsible, of 6.5 m in thickness, followed by a stratum of residual soil of Clayey Silt up to 14 m depth. The first load test was the slow type, and a quick load test in the same pile after five days. From the results obtained with the use of instrumentation, the values for both lateral and tip load were determined in each one of test carried out in the pile studied. With these results and applying the Cambefort's Law, it was could evaluate the evolution of the shaft friction and tip load in relation to the associated settlements, as well as the occurrence of residual load. The ultimate load obtained in the test was 960 kN and 810 kN for the first and second tests, respectively. The stress for the tip was 853 kPa and 655 kPa for the first and second tests, respectively.

Introduction

During the past few years, there was a major breakthrough in the development in the construction of deep foundations, because of the increasing demands for productivity and the constant increase of load being transferred to the subsoil. Because of this, foundation engineering had to closely monitor this growth with the development of new techniques to perform deep foundations using piles cast in situ. In Brazil, the use of continuous flight auger piles became constant in medium and large works, mainly in those located in the Southeast region, where the largest number of companies that perform this type of foundation are located. As the use of this pile is increasing, it becomes imperative to understand its behavior in the completion of a greater number of instrumented load tests. In the interior of the State of São Paulo, in Brazil, as well as in the region of Campinas, there is a growth of the economy, generating a large number of medium and large constructions, which have an increased need for this type of foundation, mainly because they are mostly industrial, for which time is essential in the definition of the construction methodology.

Geotechnical Characteristics

The tests were carried out in the Experimental Site at the University of Campinas (Unicamp), located in the municipality of Campinas, State of Sao Paulo, Brazil. In the region, there are basic intrusive rocks from the Serra Geral formation (diabase). There is a high occurrence of basic migmatites in the northern part of the region, which emerge in three areas, amounting to 98 km^2 and occupying 14 % of total leaf area of Campinas [1]. The subsoil is characterized by two types of soils: the surface layer, with 6.5 m in thickness, consisting of Silty Clay, which is porous, collapsible and lateritic, followed by a stratum up to 14 m layer of Clayey Silt. The water table level is not found up to 17 m. The Fig. 1, shows the average geotechnical parameters values of the subsoil and the position of the strain gauges: reference section (-0.4 m), levels -5 m, -11.1 m and -11.7 m.

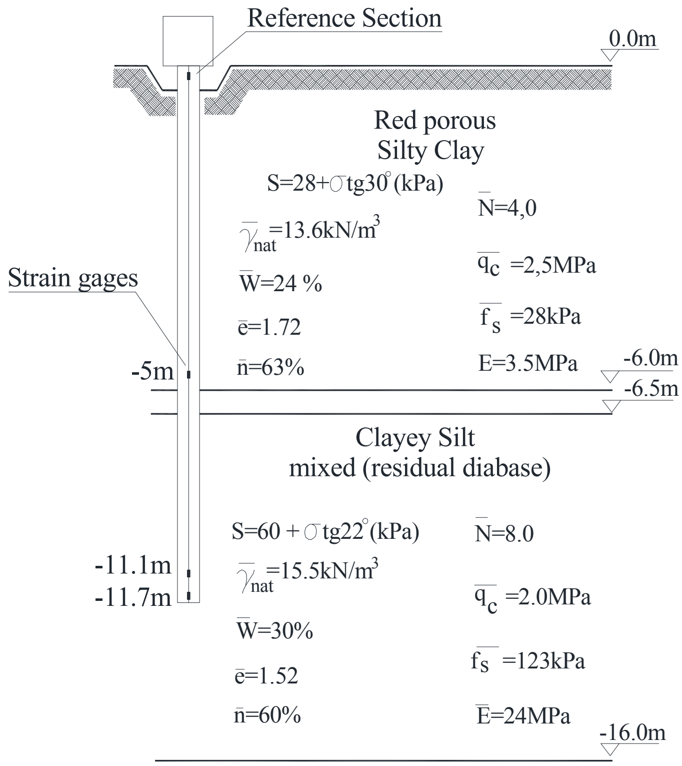

Fig. 1 Geotechnical parameters of the subsoil.

Test Pile and Reaction System

The continuous flight auger pile is a type of cast in situ pile, characterized by the excavation of the soil through a continuous auger with helical screw blades around a hollow central tube. The concrete used is characterized by mixing aggregates (small gravel and sand), and the minimum consumption of cement is 400 kg/m^3; the slump must be 240 mm. For this paper, the pile dimensions were 0.40 m in diameter and 12 m in length. They were executed two reaction piles aligned and spaced 2.40 m (6ϕ) from the test pile, with 0.40 m in diameter and 18 m in length. The cages were placed of 6 m in length, consisting of 4ϕ_b16.0 mm (longitudinal), and stirrups of ϕ_b6.4 mm every 20 cm (fyk_{steel}= 500 MPa). The reaction system was composed of a reaction beam, bolting system (Dywidag - ST-85/105) and nuts, steel plates and sleeves, all made from the same material used on the tie rods.

Instrumentation

The instrumentation consisted of steel bars instrumented with strain gauges. For its confection, were used steel rods, 12.5 mm in diameter and 0.60 m in length, for the bonding of the strain gauges (KFG-2-120-D16-11 – Kyowa Electronic Instruments) suitable for use in steel. Complete the instrumentation; all the instrumented bars were taken to the laboratory for the tension tests in order to verify their perfect functioning. These bars were then put together and placed inside the galvanized tube in pre-set position to form a continuous bar put in the test pile during the construction of the pile. The instrumentation was installed at the test pile head (reference section) and -5 m, -11.1 m and -11.7 m deep, along the shaft of the pile.

Results and Analyses

It is presented in this item the results obtained by conducting a slow maintained load test (SML) then a quick maintained load test (QML) with intercalation of five days. All tests were carried out with subsoil in natural moisture conditions. Based on the tests, were obtained: the loads and the displacement at the top; the loads at the instrumented levels, skin friction along the shaft and the tip loads. The purpose of the second load test (QML) was to verify the effect of the first load on the load *vs* displacement curve and the effect of the second load on the behavior of the skin friction and tip load.

The first test was implemented the slow loading with phases of at least 30 min or until the stabilization of the displacements [2]. After five days of the end of the first loading, it was began the quick test, in which the loads were inserted every 15 min, without the need to stabilize the displacements. The values of maximum load and maximum displacement for each type of loading are shown in Table 1, as well as the load *vs* displacement curves at the top (Fig. 2).

Table 1 Load values and maximum displacements.

Test	Load [kN]	Displacement [mm]
First Loat Test (SML)	960	80.24
Second Loat Test (QML)	810	70.48

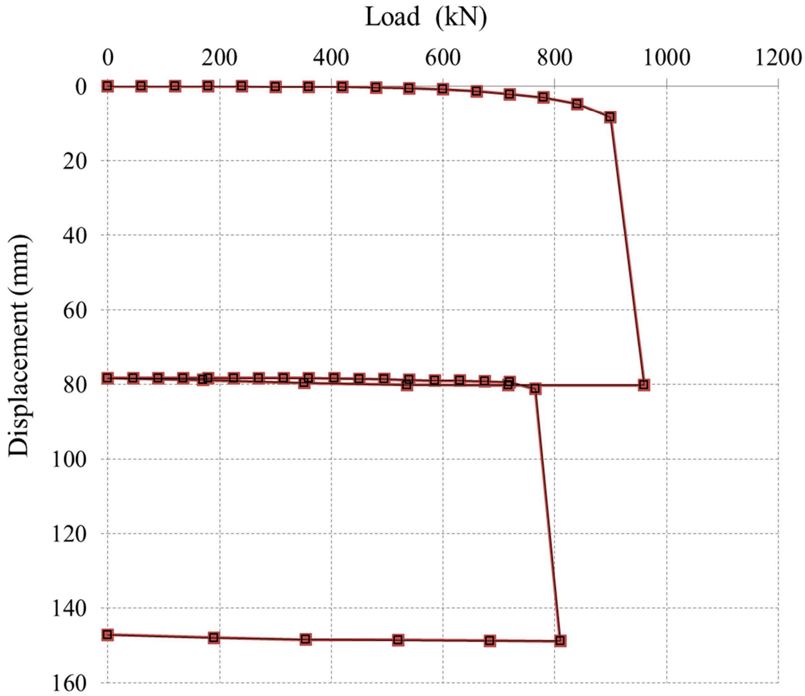

Fig. 2 Load *vs* displacement curves.

Through the analysis of Table 1 and Fig. 2, shows that the maximum loads obtained in the two loadings were little different, and the second loading was 15 % smaller than the first one. From the instrumentation data, it was obtained the loads in the levels for all load increments and the skin friction. The Table 2 shows the load for each level obtained for the maximum value of both tests and the Table 3 the skin friction for maximum load.

Table 2 Load values and maximum displacements.

Test	Level				Lateral Load	% tip
	5 m	11.1m	11.7m	tip		
First Loat Test (SML)	516 kN	170 kN	125 kN	102 kN	858 kN	10.6
Second Loat Test (QML)	434 kN	128 kN	88 kN	67 kN	743 kN	8.3

Table 3 Skin friction.

Test	0 - 5 m	5 m - 12 m	Average
First Loat Test (SML)	82 kPa	40 kPa	57 kPa
Second Loat Test (QML)	69 kPa	35 kPa	49 kPa

The pile provided maximum unit value of skin friction in the first instrumented level (0 to 5 m) that was superior to the other height (5 to 12 m). This fact was not expected, as, through the in-situ tests (CPT and SPT), although the top soil layer offers lower resistance values, which contradicts the skin friction results obtained. After the extraction of a continuous flight auger pile performed at the same location and with the same characteristic presented in this paper, it was found a bulging in its shaft, which may explain this phenomenon (Fig. 3). The occurrence of the increased diameter in the pile, in the previous part, is associated with the pressure of the concrete in its execution, because the soil has a weak nature and the concreting pressure was elevated, there must have been breaks in the soil in these points, because of the cylindrical expansion, causing a larger section on the pile and it can speculate, and this will be admitted in the sequence.

For this reduction to occur in the results, the first loading needs to be carried out until the saturation of the skin friction causing a great displacement of the pile along the shaft. Another factor that may have influenced the reduction of friction in the second test was the bulging, as we verified that it can, after the end of the first loading, entail a region of the shaft without contact with the soil, as we show in Fig. 3, which would reduce the pile contact area with the ground, thus decreasing the skin friction. In fact, the region without pile-soil contact was between 1 and 3 m deep (Fig. 4). This implies a reduction of the lateral area of approximately $\frac{1}{12} \cong 9\%$.

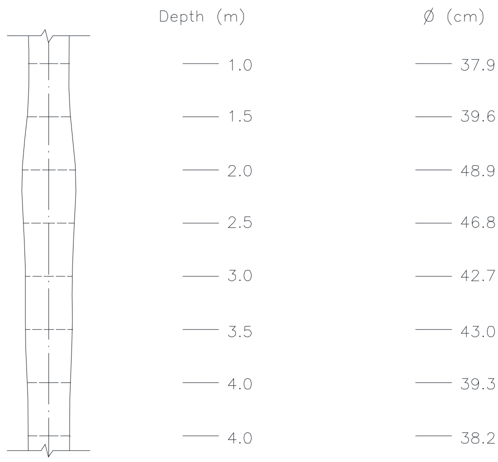

Fig. 3 Geometry of the pile extracted from the location.

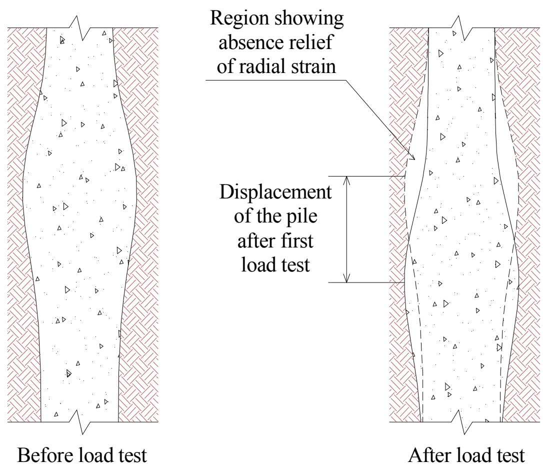

Fig. 4 Graphical representation of the displacement of the continuous flight auger pile.

In the two load tests, was verified the skin friction failure of the pile-soil. At the end of the quick load test, it was aimed to reach a displacement value that, added to the first test, would be 160 mm (40% of the ϕ_{pile}). The purpose of taking the load test to a displacement exceeding 30% of the diameter was to mobilize a greater percentage of load on the tip. Since the mobilization is small for this type of pile for small displacements, it is characterized by the fact that the load on the tip has no peak, even when large displacements are performed [3, 4]. At the end of the first loading, it was made various readings in the strain gage located at the tip during the five days interval between loads, checking the load dissipation over time, reaching the null value two days before the second loading.

Cambefort Analysis

The Fig. 5 presents the behavior of the pile tip load according to the type of loading. It can note that, on the slow test, the tip load was 853 kPa with tip displacement of 79 mm, and, on the quick test, these values were 655 kPa and 70 mm, respectively. It can be observed that in both cases there was no failure of the tip load, because the lines did not tend to horizontality. Observing Fig. 6, it can verify that the displacement values upon the saturation of the unit skin friction, obtained in the slow loading, were 8.0 mm with skin friction values of 58 kPa. In the quick test, the displacement was 2.5 mm and the skin friction was 49 kPa. It can observe that with small displacements we achieved the saturation of the unit skin friction on the quick test.

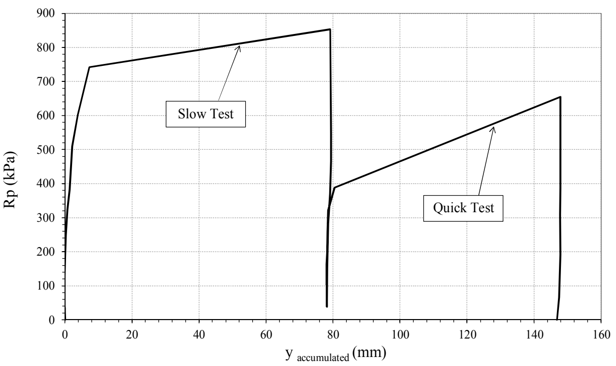

Fig. 5 Tip load *vs* displacement accumulated of the tip (Cambefort's 1st Law).

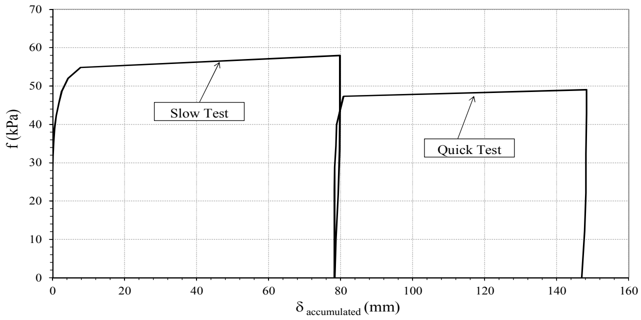

Fig. 6 Skin friction *vs* displacement accumulated of the shaft (Cambefort's 2nd Law).

Conclusion

- In the second load test, the load *vs* displacement curve shows that there was practically no displacement up to the maximum load of the first load test;
- The tip load of the second test was lower than that obtained for the first test, but if compare the values of tip load for the same level of displacement between the two tests, we can verify that the values are of the same order, thus showing that the tip presented similar behavior in the two loadings;
- The instrumentation indicated that there was no residual load on the tip after the first load test;
- The skin friction on the second load test was lower than the first one and can be explained by the geometry of the pile, which created a displacement of the pile after the displacement of the first test, thus reducing its lateral area;
- The saturation of the skin friction for both tests did not exceed 2 % of the diameter of the pile, thus showing that, for the local condition, small displacements are sufficient for the mobilization of the skin friction.

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