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Bored, continuous flight auger and omega instrumented piles: Behavior under compression

Comportement à compression des pieux foré, tarière creuse et omega instrumentés

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ABSTRACT
This paper presents a study on the behavior under compression of three types of piles, built in the Experimental Field for Foundations and Soil Mechanics of the UNICAMP University. Three piles of each type were built: bored (without the use of bentonite slurry), continuous flight auger (CFA) and omega. Nominal diameters of the piles were 0.40 m, 0.40 m and 0.36 m, respectively, all of them 12 m in length. Local subsoil is characterized as a diabase type soil. The first layer (0 to 6 m) is a collapsible silty sandy clay, followed by clayey sandy silt (6 to 18 m). Water level is only reached at 17 m. The piles were instrumented along their depth with electric extensometers (strain gauges), installed at 0.30 m (section of reference), 5.0m, 11.1m and 11.7m. Instrument data indicated that all the piles behaved as friction piles: in average, the tip reaction reached 2% of the total applied load for the bored piles; 7% for the CFA piles and roughly 14% for the omega piles. In the same order, the mean ultimate load test values for the SML tests were 682kN, 885kN and 1,428kN.

RÉSUMÉ
Cet article présente une étude sur le comportement à compression de trois types de pieux, exécutés dans le site expérimental de fondations et mécanique des sols de l'Université de Campinas (UNICAMP). Trois pieux de chaque type ont été mis en place: pieu foré (sans utilisation de boue de bentonite), pieu tarière creuse et pieu omega. Les diamètres nominaux des pieux étaient 0.40 m, 0.40 m et 0.36 m, respectivement, tous 12 m de longueur. Le sous-sol local est caractérisé comme sol residuel de diabase. La première couche (0 à 6 m) est argile silteuse, suivie d'un silt argileux (6 à 18 m); le niveau de la nape phréatique était a 17 m de profondeur. Les pieux ont été instrumenté avec des extensomètres électriques (jauges collées), placés au long des pieux, à 0.30 m (section de la référence), 5.0m, 11.1m et 11.7m. Les résultats obtenues ont montré que les charges apliqués en tête ont eté transmis presque totalement par frottement latéral. Les efforts de pointe ont atteint 2% de la charge em tête pour les pieux forés, 7% pour les pieux tarière creuse et 14% pour les pieux omega; les charges ultimes ont eté 682kN, 885kN et 1428kN, respectivement.

1 INTRODUCTION

During the last years, there was a great advance in developing processes to build deep foundations, due to the ever large requirements of productivity and the constant increase in loads to be transferred to the subsoil. Because of this, foundation engineering had to closely accompany this growth, developing new techniques to build deep foundations using *in situ* molded piles.

The Continuous Flight Auger (CFA) pile, built using a continuous helix auger, was first used in the United States, during the fifties. In Europe, this pile was introduced in the seventies and the Omega pile at the end of the nineties, both monitored. In Brazil, the use of CFA piles has become constant in medium and large jobs, principally in those located in the State of Sao Paulo, where the largest number of companies that build this type of foundation is located. The omega type screw pile, recently introduced in Brazil, brings another important type of foundation to our technical area.

As the use of these piles is increasing, it becomes imperative to understand their behavior. There is not enough field data available for these last two types of piles, to define design parameters. The doubt persists: how do these piles behave, in terms of resistance through lateral friction and resistance at the tip, both for bored or dislodged soil types?

The Interior of the State of Sao Paulo, as in the Campinas region, where economic growth is marked, generates a good number of medium and large construction jobs, bringing about an increase in the use of these foundations, principally because the jobs are mostly industrial, where time is essential in defining the construction method.

This paper is the result of a Doctorate research, carried out by the first author at the Escola Politecnica, Sao Paulo University, and at the University of Campinas – UNICAMP.

2 CONTINUOUS FLIGHT AUGER - CFA PILES

Since their introduction in the USA until today, much investment has been made on CFA piles and presently they can be built up to 32m deep, in diameters up to 1200mm, at an available torque of up to 390kN.m.

The CFA pile was introduced in Brazil in 1987, using locally manufactured equipment, based on foreign models, allowing the construction of 275, 350 and 425mm diameter piles, at a maximum depth of 15m. In 1993, due to changes in importation laws, it was already possible to build piles of up to 1000mm diameter and lengths of up to 25m.

CFA piles became very popular in the eighties, due to their technical advantages, combined with the relatively low cost (Brons & Kool, 1988). However, these authors warn that the production process should receive special attention, specially with pile column continuity, subsoil perturbation due to auger extraction and failure in weak soils due to high applied pressures that can lead to a great consumption of concrete. Besides, they warn that increasing competition between construction companies, with the consequent cost reduction, can lead to a reduction of quality in producing these piles.

Operator sensitivity to control construction of a CFA pile is the most severe limitation to these piles (Bottiau, 1993). Much attention must be exercised during the entire installation process, including excavation, auger extraction and placing the reinforcement. This author still mentions that CFA pile was development aiming to eliminate one of the most important disadvantages of bored piles: soil decompression. In field performed studies, using a Marchetti dilatometer, before and after building a pile, it was seen that the construction process did not cause this decompression. Bottiau (1993) emphasizes that another important advantage of the CFA pile is the possibility of continuous electronic monitoring, which furnishes documentation on the pile's construction.

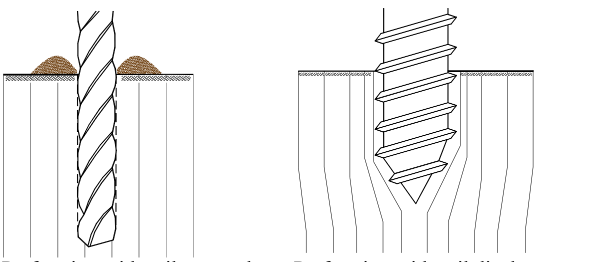
3 OMEGA PILES

According to Bustamante & Gianeselli (1998), Omega, "Atlas", "De Waal" and "Spire" piles are last generation piles, considered as displacement piles, which they prefer to simply mentioning as "screw piles". According to these authors, this process theoretically improves lateral friction resistance.

The pile construction process can be summarized as follows: the head is driven in by rotation; the same machine as that used with CFA piles can be used; while the perforating tool goes down, the soil is displacement down and to the side of the perforation; when perforation is finished, concurrently with removing the column, while rotating, concrete must be injected, under pressure. The available torque (it should be above 150kN.m) and the column length impose a limit on the use of this pile. Monitoring during construction is done, registering the parameters of depth, torque, penetration rate and concreting data.

The difference between an omega and a CFA pile is that the latter removes the soil while the former compresses it around the pile column.

Van Impe (1988) clearly presents the difference between the two construction processes, showing that there are piles that allow soil de-compaction and those which move the soil. At that time the omega pile was not yet mentioned, only the "Atlas" pile (Fig. 1). Its configuration is associated to its conical form and the variation of the 'screw pitch', which offers the exclusive characteristic of moving the soil down and to the sides.



Perforation with soil removal. Perforation with soil displacement.

Figure 1. Different forms of excavation (Van Impe, 1988).

4 TEST LOCATION

Field work was performed at the Soil Mechanics and Foundations Experimental Field, at the UNICAMP Campus, in Campinas, SP, Brazil (Carvalho et al., 2000).

Several field tests (SPT-T, CPT, "Cross-hole", Marchetti Dilatometer, Refraction Seismics, Vertical Electric Investigation), as well as laboratory tests on disturbed samples (characterization tests) and undisturbed samples (triaxial, odometer, simple compression) collected from a 16 meter deep well have already been carried out at this location. Static load tests (compression, tension, horizontal) have also been performed on precast concrete pile, besides the bored piles, the CFA piles and omega piles, all instrumented along the shaft with strain-gauges.

The local subsoil is basically composed of migmatites, in which intrusive rocks occur, from the Serra Geral Formation (diabasic), covering 98km^2 of the Campinas region, about 14% of its total area. Diabasic bodies are also found, incrusted into the Itararé Formation and in the Crystalline Complex, as "sills" and dikes. At the outcrops, it may be seen that the diabasic soil is quite fractured, with the formation of small blocks; the fractures are usually open or filled with clayey material.

At the experimental field a residual diabase soil occurs, presenting an approximately 6,5m thick superficial layer composed of high porosity silty-sandy clay, followed by a clayey-sandy silt to the depth of 19 m; the water level is reached at 17m. The soil of the first layer is weaker than the lower layer and is collapsible, presenting collapse ratios ranging from 2,4% to 24%, depending on the applied pressure, according to Vargas (1978). Some results of the field tests carried out at the UNICAMP Experimental Field are presented on Tab. 1.

Table 1: Average results of the field tests

Soil	Depth (m)	NSPT	q_c (kPa)	f_c (kPa)
Reddish brown silty-sandy clay	1	4	392	28
	2	2	589	19
	3	3	883	36
	4	4	1324	63
	5	5	1864	85
	6	6	2502	130
Clayey-sandy silt, mixed (residual soil)	7	5	2453	168
	8	5	2256	193
	9	5	2158	204
	10	6	2009	221
	11	7	2551	254
	12	10	2404	238
	13	10	2600	265
	14	7	2551	224
	15	6	2354	198

Legend: q_c and f_c are respectively the point resistance and lateral friction from CPT (Cone Penetration Test)

5 TEST PILES AND REACTION SYSTEM

Three piles of each type were built: bored (without the use of bentonite slurry), CFA and omega piles. Pile dimensions are indicated on Tab. 2. The piles followed a pre-defined alignment (see Fig. 2) and the spacing between them was 4.80m (12ϕ).

Table 2: Extracted Pile Dimensions

Pile	Diameter (cm) Nominal	Diameter (cm) Actual	Length (m)
Bored 1	40	45	12
CFA 2	40	40	12
Omega 2	36	39	12

A MAIT HR-200 drill press was used to build the piles, with a depth capacity of 32m. The equipment's torque ranged from 220kN.m to 380kN.m; such variation is a function of the rotation speed and diameters used.

The concrete used in the piles (± 240mm slump and transportable by pump) consumed cement at a rate of 400kg/m^3 and aggregates (sand and fine crushed rock). For the pile head blocks (0.7x0.7x0.7m^3), concrete with fck=25MPa was used.

The piles' longitudinal reinforcement was composed of 4ϕ_b16.0mm ($\cong$8cm^2), 6m in length and stirrups of ϕ_b=6.4mm every 0.2m (CA-50 steel).

The reaction system was composed of a reaction beam, double "I" section, designed to support loads applied on its axis, 5.3m in length and by a steel tie-rod system composed of ST85/105 (Dywidag) special bars, 32mm in diameter, nuts, plates and steel sleeves, all manufactured with the same material. The piles' location is presented in Fig. 2.

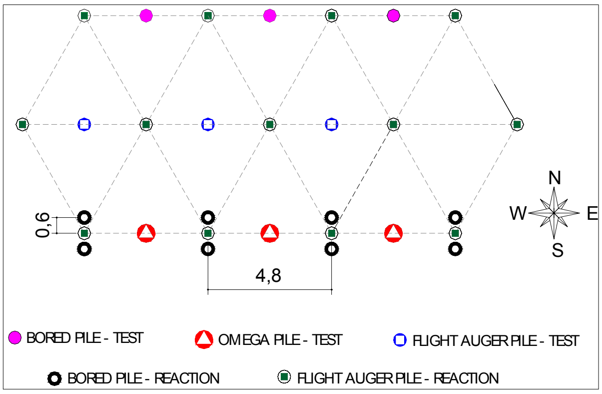


Figure 2. Pile location on the Experimental Field.

6 INSTRUMENTATION

Steel bars, 12.5mm diameter and 0.60m long were used for the installation of the strain-gages, bonded in a complete bridge. After installing the instruments, the bars were submitted to tension loadings in order to verify the quality of the instrumentation. At the test location, these bars were later united as they were being placed into the steel tube (ϕ=50mm), which was placed shortly after pouring the pile concrete. The bars were threaded at the ends, and connected by threaded sleeves of the same material.

The strain gages was installed at four locations: the top of the pile (reference section) and at depths of 5m, 11.1m and 11.7m along the shaft. After this process, a cement mixture was injected from bottom to top, through a plastic hose previously placed next to the steel bars.

7 LOAD TESTS

Slow maintained load (SML) tests were performed for each type of pile, according to the directions established by Brazilian Standards (NBR12131/91); the loads were applied in steps of 120kN, up to the load in which the displacements indicated rupture of the pile. Unloading was made in four stages.

From the base of the pile head block to the depth of 0.6m, the soil was excavated, keeping this area as a reference section, to determine its Modulus of Elasticity. To perform the load test, a 2000kN capacity load cell was used, installed between the reaction beam and the pile head block.

8 PILE EXTRACTION

One pile of each type was extracted after testing to allow full examination of their dimensions (see Table 2) and shape.

Two anomalies were observed: a) the formation of ribs on the omega pile (Photo 1); and b) an enlargement (bulb) on the CFA type, between 1 to 3 m depth, with a maximum diameter of 49 cm. Furthermore, a film of soil was strongly adhered to the rough omega pile shaft, with a very dense consistency.

Cone Penetration Tests were carried out on the side and along the shafts, to verify the influence of the pile installation in the subsoil. For the omega piles, there was a significant increase in the tip and lateral resistances for these tests, between 0 and 5 m depth, corresponding to the layer of porous soil.

9 RESULTS OF THE LOAD TESTS

The load-settlement curves from the SLM tests are shown on Fig. 3. The values for ultimate load and maximum displacement, for each pile, are presented in Tab. 3, which also shows the ultimate load mean values and their standard deviations. In this work, it was convened to adopt, as ultimate load that referred to a minimum displacement of 60mm, equivalent to about 15% of the pile diameters.

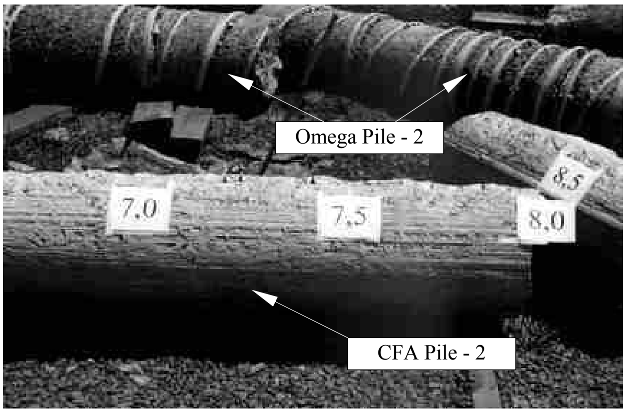


Photo 1: shape of the Omega 2 shaft as compared to CFA 2 shaft

Table 3: Load and displacement values reached in the loading tests.

Pile	Ultimate Load (kN)	Maximum Displacement (mm)	Ultimate Loads (kN) Mean (kN)	Standard Deviations
Bored 1	684	112		
Bored 2	670	108	682	12
Bored 3	693	66		
CFA 1	960	80		
CFA 2	975	86	885	143
CFA 3	720	88		
Omega 1	1545	65		
Omega 2	1420	62	1428	113
Omega 3	1320	23		

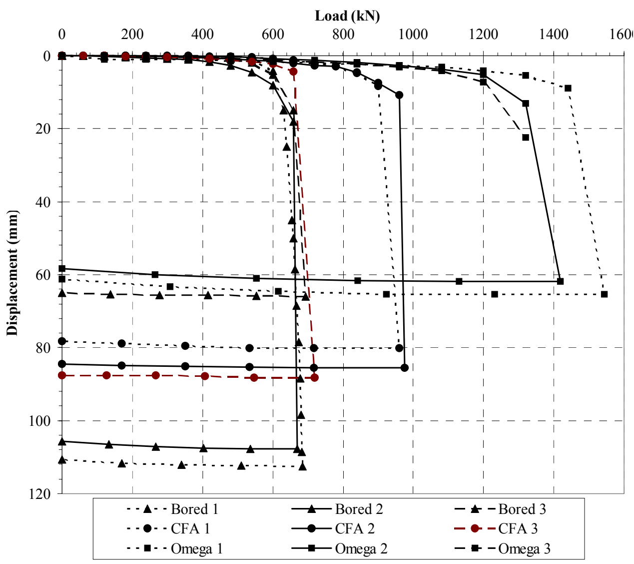


Figure 3. Load x settlement curves for all piles.

10 ANALYSIS OF THE RESULTS

For the soil under study, a diabase residual soil, the omega piles revealed the highest ultimate loads: in average 1428kN against 885kN for the CFA piles and 682kN for the bored piles (see Tab. 3). This means that the ultimate loads of the omega piles were, in average, 2.1 times the corresponding values of the bored piles and 1.6 times those of the CFA piles. It should still

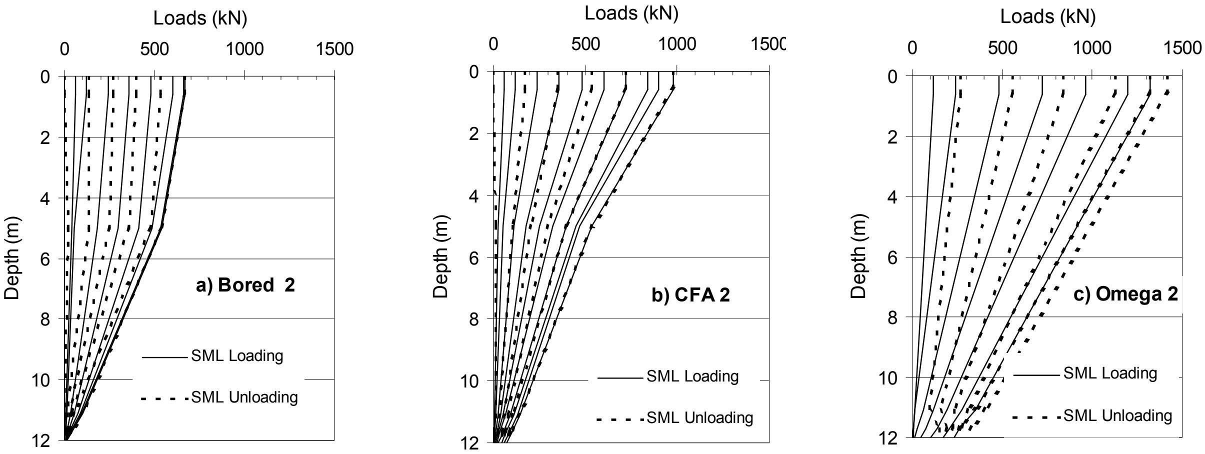


Figure 4. Load Transfer Diagrams

Table 4: Lateral friction and tip reaction

Pile	Max Lateral friction unit (kPa)			Tip Reaction	
	0- 5m	5 – 12m	0-12m	Max (kPa)	% (*)
Bored 1	39	44	40	21	0.5
Bored 2	21	54	40	83	2.0
Bored 3	35	46	41	157	3.6
Mean			41	87	2.0
CFA 1	80	47	60	760	10.6
CFA 2	80	53	63	530	7.3
CFA 3	69	36	49	182	3.2
Mean			57	491	7.0
Omega 1	-----	-----	97	1411	10.9
Omega 2	-----	-----	80	2430	20.5
Omega 3	45	108	82	1153	10.4
Mean			86	1665	13.9

Legend: (*): Maximum Tip Reaction as a % of the Ultimate Load

be mentioned that the omega piles had a smaller diameter than the other two types of piles.

The data furnished by the instrumentation confirmed that all the piles behaved as floating piles: in average, the tip reaction (see Tab. 4) reached 2% of the total applied load for the bored piles; 7% for the CFA piles and roughly 14% for the omega piles. In absolute values, the mean tip reaction of the omega piles were 19.1 times the corresponding values of the bored piles and 3.4 times those of the CFA piles. It is worth mentioning that for a precast concrete pile, 0.18 m in diameter, and with its point resting at the same level than the omega piles, the tip reaction was 16% of the total applied load.

As far as the lateral friction is concerned, the same trend can be drawn (see Tab. 4), that is, the omega piles also presented a better behavior than the other two piles: their mean lateral friction were 2.1 and 1.5 times higher than that of the bored and CFA piles, respectively.

Finally, a comment should be made concerning the lateral friction of the CFA piles. As it can be seen in Tab. 4 and Fig. 4-b, the values associated with the upper layer (0-5m) were greater than those of the lower layer (5-12m). This result is inconsistent with the soil data, presented in Tab.1: the upper layer is weaker than the lower layer. This can be explained by the already mentioned enlargement revealed by the CFA 2 pile, that was extracted from the field. Taking this fact in consideration, the lateral friction became almost the same for the bored and CFA piles, as the lower layer (5-12m) discloses (see Tab. 4).

11 FINAL COMMENTS

The results of the load tests on diabase residual soils, presented in this paper, authorize to say that the construction process of the omega piles alters the soil conditions along the shaft and at the tip. This must be related to the fact that, besides not presenting tension relief in excavation, the soil is displaced and compacted during pile installation. Corroborating this statement are the roughness and ribs observed along the shaft of omega 2 pile, that was extracted from the field, and the soil strongly adhered to it.

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