Behavior of Omega piles, subjected to compression instrumented load tests

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ABSTRACT: A study is presented in this paper, carried out on three Omega piles (φ=0.37m and L=12m), instrumented along the shaft with strain-gages. These piles were submitted to compression load tests (slow maintained load). The tests were performed at the Soil Mechanics and Foundations Experimental Field, located at the Campinas State University - UNICAMP – Brazil. The soil of this site is composed of residual diabasic soil, and the water level is only reached at the depth of 17m. One of the tested piles was extracted from the soil to be the subject of a study on its geometry. The load tests provided an ultimate load average value of 1428kN; 14% of this value was transferred to the point. It was verified that the construction process was a preponderant factor on the value of the bearing capacity.

1 INTRODUCTION

The Omega pile was introduced into Brazil at the end of the 1990’s. Developed in Europe, the Omega pile was developed from the Atlas pile construction process. Each year, it has been progressively more employed in foundation works requiring speed of construction and good bearing capacity.

As the use of this pile increases, the knowledge of its behavior becomes imperative. The available field data for this type of pile is very small for one to define the design parameters. The doubt still remains on whether such a pile behaves as a bored pile or a settlement pile, regarding load resistance of the point and lateral surface.

The site selected to develop research was the Soil Mechanics and Foundations Experimental Field, located at the State University of Campinas - UNICAMP – Campinas, Brazil, a region with strong economical growth, which generates a large number of intermediate and large size construction work, increasing, therefore, the use of this type of foundation, especially concerning industrial works, where the time factor is preponderant.

The local subsoil is formed of residual diabasic soil (clays and silts) with low values of resistance to penetration: the water level was reached only at the depth of 17 m. Furthermore, the first 6 m layer has collapsible behavior.

Three Omega piles, 0.37m in nominal diameter and 12m long, were driven for this research. The piles were submitted to compression load testing (SML). The reaction system used was made of structural steel sections, having a 1500kN capacity and continuous flight auger piles, 0.40m in diameter and 18m deep.

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2 MATERIALS AND METHODS

2.1 Omega Pile

According to Bustamante and Gianeselli (1998), the Omega piles can be classified as a last generation displacement type and are simply named by the authors as “screw piles”. According to them, this process theoretically improves the strength by lateral friction.

The pile driving process may be summarized as follows: the head is fastened by rotation; during the fall of the perforating element, the soil is displaced downwards and to the side of the hole; at the end of perforation, concurrently to shaft removal by rotation, the concrete is injected under pressure. The concrete used is characterized as an aggregate mixture (sand and fine crushed rock) and the amount of cement used is around 400kg/m³; the slump-test must be about 240mm. The limitation for the use of such a pile is the machine’s available torque, the
available diameter and the length of the shaft. During its construction, the depth, torque, penetration rate and characteristics of concreting are monitored and registered.

The execution process of the Omega pile does not remove the soil, which is pushed laterally, and remains compressed around the shaft. Van Impe (1988) clearly presents the differences between construction processes, showing there are piles that de-compact the soil and piles that force the soil out laterally.

Its configuration is associated to the conical shape and to the screw “step” variation, which provide the specific characteristic of moving the soil down and sideways.

2.2 Test Location
The research 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 shapeless samples (characterization tests) and non-shapeless samples (triaxial, oedometer, simple compression) collected from a 16 meter deep well have already been performed at this location. Static load tests (compression, tension, horizontal) have also been performed on pre-molded concrete, bored and continuous flight auger piles, all instrumented along the shaft with strain-gages.

The local subsoil is composed of migmatites, in which occur intrusive rocks from the Serra Geral Formation (diabasic), covering 98km² 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 is quite fractured, with the formation of small blocks; the fractures are usually open or then filled with clayey material.

The experimental field subsoil profile is formed of residual diabasic soil, presenting an approximately 6.5m thick superficial layer composed of high porosity silty-sandy clay, followed by a clay-sandy silt to the depth of 19 m; the water level is reached at 18 m. The soil of the first layer 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 performed at the UNICAMP Experimental Field are presented below (Table 1).

2.3 Test Piles and Reaction System
Three 0.37m diameter and 12m deep test-piles were selected to perform this research. The piles followed a pre-defined alignment and the spacing between them is 4.80m (12 φ).

A MAIT HR-200 drill press was used to build the piles, with a depth capacity of 32m. The equipment’s torque ranges 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/m³) and aggregates (sand and fine crushed rock). For the pile head blocks (0.7x0.7x0.7m³), fck=25MPa concrete was used.

The piles’ longitudinal reinforcement was composed of 4 φ b16.0mm (≅8cm²), 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 Figure 1.

![Figure 1. Pile location on the Experimental Field.](image-url)

Table 1. Average results of the field tests

<table>
<thead>
<tr>
<th>Soil</th>
<th>Depth (m)</th>
<th>N_{SPT}</th>
<th>q_c (kPa)</th>
<th>f_c (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>4</td>
<td>392</td>
<td>28</td>
</tr>
<tr>
<td>Reddish brown silt-sandy clay</td>
<td>2</td>
<td>2</td>
<td>589</td>
<td>19</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>883</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>1324</td>
<td>63</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>1864</td>
<td>85</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>2502</td>
<td>130</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>2453</td>
<td>168</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>2256</td>
<td>193</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>2158</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>Clay-sandy silt, mixed (residual soil)</td>
<td>10</td>
<td>6</td>
<td>2009</td>
<td>221</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>2551</td>
<td>254</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>10</td>
<td>2404</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>10</td>
<td>2600</td>
<td>265</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>2551</td>
<td>224</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>6</td>
<td>2354</td>
<td>198</td>
<td></td>
</tr>
</tbody>
</table>
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 instrumentation 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.

2.5 Load Tests

Slow maintained load tests were performed for each type of pile, according to the directions established by the Brazilian Standards (NBR12131/91), adopting slow load (SML); the loadings were performed in increases of 120kN, up to the load in which the displacements indicated rupture of the pile-soil connection. Unloading was made in consecutive stages, in load reductions of 25% of the total load achieved in the test.

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 unit was used, installed between the reaction beam and the pile head block.

3 RESULTS OF THE LOAD TESTS

The curves for ‘load x top settling’ (Figure 2), obtained from the slow load tests, as well as the rupture load and the maximum displacement, are presented in this item.

The values of the rupture load and maximum displacement for each pile and for each type of loading are presented in Table 2.

The ultimate load average values obtained for this type of pile were about 1428kN, with standard deviation of 113kN. The piles reached the rupture level with settlements of about 6.3% of the diameter, on average (25mm). The value of the mean average unit lateral friction was about 86kPa.

4 EXTRACTION OF A PILE

After performing the load tests, a pile was extracted (2), with the objective of knowing its geometric characteristics. For this work to be possible, a complete study was required on the possible ways of extracting the pile. Several field works were performed to make the extraction viable. All steps taken at this stage of the research are described below.

Table 2. Values of load and maximum displacement obtained on load tests.

<table>
<thead>
<tr>
<th>Pile</th>
<th>Ultimate Load (kN)</th>
<th>Settlement (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omega 1</td>
<td>1545</td>
<td>64.57</td>
</tr>
<tr>
<td>Omega 2</td>
<td>1420</td>
<td>61.83</td>
</tr>
<tr>
<td>Omega 3</td>
<td>1320</td>
<td>22.52</td>
</tr>
</tbody>
</table>

4.1 Removal of the pile head block

For the pile removal to be possible, the pile head block had to be demolished, to reduce the mass to be hoisted and also not to jeopardize the soil excavation along the shaft.

4.2 Device to fix the hoist

To permit hoisting the piles, it was seen that the most adequate means would be to fix a split metallic ring at the top of the pile. To build the ring, it was necessary to determine the pile perimeter with the objective of obtaining its diameter with maximum accuracy, so that each ring would fit perfectly onto the pile. The ring was fixed onto the pile by uniting its two parts and filling the pile-ring interface with cement slurry, to assure the connection between them. Ring details are presented in Figure 3.

Figure 2. Load x settlement curves.

Figure 3. Arrangement to fix the pile.
manually excavate around its shaft. To lift the piles, an appropriate hoist was employed, since it should lift the pile at least 1 m above the ground (Figure 4).

4.4 Post-extraction analysis of the pile

A complete examination of the pile was performed, revealing important data of the shaft surface, its geometry and point shape.

- Its shaft had a “spiral” shape screw (“ribs”), with spacing of about 30cm on the first 6m, and about 12cm on the last 6m (Figure 5).
- Visual examination of the shaft showed that the soil was compacted and attached to the pile, with a thickness ranging from 5 to 8cm. This appearance had already been verified during excavation around the pile. From information provided by the professionals responsible for the excavation, it was verified that the soil around the shaft was more compact.
- The pile tip is shown in Figure 6. It was verified that it had a round shape.
- With regard to the shaft surface, a high roughness was verified, as a result of the fine crushed rock used in the concrete, for it had been separated from the cement slurry and compacted next to the wall.
- The shaft perimeter may also be determined, thus obtaining its average diameter; it was verified that the actual diameter (39.2cm) was on average 5% greater than the nominal diameter (37cm).

5 EFFECTS OF PILE INSTALLATION ON SUBSOILS

Based on observations performed on soil compaction around the shaft of the extracted pile, it was decided to perform static penetration tests, using the electric cone. The objective was to evaluate the compacting effect along the pile shaft.

Two tests were performed near the T-3 Omega pile (pile not tested), at 0.15m (CE 4) and 0.40m (CE 2) from the shaft and one test at 0.25m (CE 5) away from the shaft. Tests closer than 0.15m were not performed in order not to harm the equipment. In addition, other tests were performed, away from the pile influence area, in order to obtain maximum and minimum limits of lateral friction and point resistance. These limits are used as parameters in the analysis of holes next to the pile.

The graphs of the lateral and point resistances obtained are presented in Figures 7 and 8. Through the analysis of these figures, it is verified that, in general, the values of $f_s$ and $q_c$ ranged within the maximum and minimum limits. It was verified that, on the first 6m, the values referred to the distance of 0.15 m went beyond the maximum limit in some stretches along the pile lengths.

It is also verified that the $f_s$ curves of the test, performed at 0.40m from the shaft (CE2), were
Based on the analyses performed, one concludes that, for the first 5m of depth, the lateral ($f_s$) and point ($q_c$) resistances, determined 0.15m from the T-3 Omega pile, went beyond the maximum values obtained for the soil (first layer) in its natural status. Below 5m, the strengths ranged within the variation interval for the soil (second layer) in its natural status.

Through tactile-visual analysis, it was verified that the soil sample extracted at 5cm from the Omega 2 pile shaft seemed to have a more compact appearance than samples extracted at 50cm.

Soil samples were taken to the laboratory, where tests of natural specific weight determination, moisture content, void ratio and porosity were performed. The results are presented in Table 3.

<table>
<thead>
<tr>
<th>Distance from shaft</th>
<th>$\gamma_{nat}$ (kN/m$^3$)</th>
<th>w (%)</th>
<th>e</th>
<th>n (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil 1 – 5cm</td>
<td>17.53</td>
<td>31.1</td>
<td>1.23</td>
<td>55.1</td>
</tr>
<tr>
<td>Soil 2 – 50cm</td>
<td>16.10</td>
<td>33.5</td>
<td>1.48</td>
<td>59.7</td>
</tr>
</tbody>
</table>

From the analysis of Table 3, noting the void ratio, one can conclude that Soil 1 presented a more compacted characteristic than the other soil, corroborating the evaluation made by tactile-visual examination.

### 6 CONCLUSIONS

The piles provided an ultimate load average value of about 1428kN, showing that the construction process was a preponderant factor for achieving this value, since load tests were performed on 3 flight auger piles and on 3 bored piles at the same location, obtaining ultimate load average values of 885kN and 682kN, respectively. The flight auger and bored piles were of the same length as the Omega piles and their diameters were 40cm.

With regard to the total load, the piles absorbed an average load on the tip of about 14% of the load applied on the head. With regard to the lateral friction distribution along the shaft, an increase of this value was verified along the depth, as expected, since the lower soil layer is more resistant.

After piles were extracted, the following was verified: the degree of roughness was high, presenting ribs at 30cm spacing one from the other on the first 6m along the shaft, and 12cm, on the last 6m; the soil was strongly attached to the pile, and it had a round shaped tip.

The soil around these piles suffered an intense densification process due to its displacement, confirmed by the soil samples collected from the area around the piles and also though the electric cone tests performed next to the pile shaft.
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REFERENCES


