Assessment of LCPC CPT method for bored piles in Brasilia clay

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ABSTRACT: An extensive testing program has been carried out at the University of Brasilia research site. This site is underlain by unsaturated and collapsible “porous clay”. Recently five bored piles were loaded to failure at this site. The results have been evaluated using a CPT empirical load capacity method. The results were compared to the experimental measured data and have indicated that it is feasible to design floating piles on this particular tropical deposit by using an internationally recognized interpretation technique of the CPT test. The paper also aimed to evaluate new software developed for this particular purpose (Geo5 pile CPT interpretation module), in order to verify its capabilities for practical local usage.

1 INTRODUCTION

The pre-designed Brazilian capital Brasilia, located in the Federal District of Brazil, was built to solely house the main Governmental administrative institutions and its public employees. Nevertheless, the population has increased (and is still expanding) much more than was initially forecast, advancing through distinct (geological) zones of this region, and allowing the use of distinct techniques for deep foundation deployment and design.

Given such conditions, one can conclude that foundation and in situ testing are indeed two demanding research (and practical) topics in the Brazilian capital. Besides, given its distance from the other major Brazilian cities (and its own foundation practice), as well as the particular conditions of the local tropical subsoil, specific local design solutions must be applied on a daily basis. For instance, initial design solutions were incorporated with the accumulated experience of “outside” engineering firms gathered during the construction of the city.

On the other hand, more sound and research-based solutions and techniques have been more recently developed (and studied) with the support of the University of Brasilia “Foundation Group”, composed by Professors, technicians, students and former students of the Geotechnical Graduation Program from this same university. This participation is not only concentrated in terms of research, but also in terms of
services such as fully instrumented pile load tests. The good academy-industry interaction has not only allowed a better knowledge of the existing technologies, but also stimulated a pioneering use of advanced in situ tests (such as the CPT and the standard penetration test with torque measurement SPTT) in the tropical clay of the city, in particular via initial studies within the university’s research site.

The paper is therefore another contribution to this line of research and knowledge, since it contains a brief summary of part of a recently defended D.Sc. Thesis (Mota, 2003), which has focused on the area of foundation design and behavior, and studied the behaviour of five fully instrumented bored piles in terms of load capacity, settlement and numerical assessment. For this purpose, this research has used the latest field and laboratory testing information available for the “porous clay” of the experimental site.

2 UNIVERSITY OF BRASÍLIA RESEARCH SITE DETAILS

The Brazilian capital Brasília and its neighboring areas (Federal District) are located in the Central Plateau of Brazil. This district has a total area of 5814 km² and is limited in the north by the 15°30’ parallel and in the south by the 16°03’ parallel. The University of Brasília (UnB) campus is located within the city of Brasília, portrayed in Figure 1 by an “airplane” shape like form. The UnB foundation and in situ testing research site is also marked in this figure.

Within the Federal District extensive areas (more than 80 % of the total area) are covered by a weathered latosol of Tertiary-Quaternary age. This latosol has been extensively subjected to a laterization process and presents a variable thickness throughout the District, varying from few centimeters to around 40 meters.

Figure 1 University of Brasilia research site
In this latosol there is a predominance of the clay mineral kaolinite, and oxides and hydroxides of iron and aluminum. The variability of the properties depends on several factors, such as the topography, the vegetal cover, and the parent rock. In localized points of the Federal District the top latosol overlays a saprolitic/residual soil with a strong anisotropic mechanical behavior and high (SPT) penetration resistance, \( N_{SPT} \), which originated from a weathered, folded and foliated slate, the typical parent rock of the region.

The superficial latosol is locally known as the Brasilia “porous clay”, forming a lateritic horizon of low unit weight and high void ratio, and often an extremely high coefficient of collapse (Cunha et al, 1999). However the soil can vary from clay to silt and in the upper portion of this site, silty sand. By breaking down the structure with a deflocculating agent, the grain size curve of this soil changes into a greater concentration of clay-size particles.

Figure 2 presents the average results of SPT blow counts, and CPT tip resistance and lateral sleeve friction, for each meter along the site. It also contains a simplified profile of the deposit, characterized by a surficial lateritic layer overtopping a transition zone and a saprolite formed by the native rock of the region.

![Figure 2. Typical soil profile at the research site at UnB](image)
3 TESTING AT EXPERIMENTAL SITE

3.1 Bored piles

The field load tests were carried out from Feb. 2000 to Oct. 2001 to include both rainy and dry seasons, as part of a D.Sc. thesis from the University of Brasília (Mota 2003). The piles were mechanically bored, cast-in-place piles, 0.3 m in diameter and lengths as noted in Table 1.

Each pile was excavated by using a standard mechanical flight auger, which was introduced into the soil by rotation. The hydraulic mechanical auger was assembled in the back part of a truck specially devised for this type of work. The soil was successively removed during continuous auger introduction and withdrawal, and, after the final depth was reached, the auger was withdrawn leaving a freshly excavated hole. This hole was subsequently filled with concrete poured by using the transport service of a local concrete company. Each pile was loaded up to near its estimated geotechnical failure limit.

The layout of the piles and the CPT’s is presented in Figure 3.

Figure 3. Plan of experimental site showing test piles (E1-E5) and CPT PROBES (CP1-CP17).

The instrumentation used strain gauges in all piles. They were connected to a 16 mm diameter smooth surface bar, which was positioned centrally to the foundation’s transversal cross section. The strain gauges were placed at distinct positions...
along the pile, allowing the knowledge of the load transfer mechanism during the load test, at different (head) load levels.

Details of the piles, experimental load, maximum settlement, and the estimated failure loads based on various published methods are given in Table 1. It was concluded by Mota (2003) that the Van der Veen method seemed to give a reasonable approach to define the failure loads, being both reasonably easy to apply and conservative enough to be used within this region of Brazil.

<table>
<thead>
<tr>
<th>Pile</th>
<th>(\phi) (m)</th>
<th>L (m)</th>
<th>Date</th>
<th>(P_{\text{max}}) (kN)</th>
<th>(\delta_{\text{max}}) (mm)</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>E-1</td>
<td>0.30</td>
<td>7.65</td>
<td>Feb.2000</td>
<td>270</td>
<td>16.10</td>
<td>270</td>
<td>294</td>
<td>300</td>
<td>254</td>
</tr>
<tr>
<td>E-2</td>
<td>0.30</td>
<td>7.25</td>
<td>Aug.2000</td>
<td>300</td>
<td>3.82</td>
<td>360</td>
<td>500</td>
<td>520</td>
<td>310</td>
</tr>
<tr>
<td>E-3</td>
<td>0.30</td>
<td>7.80</td>
<td>Oct.2001</td>
<td>270</td>
<td>4.85</td>
<td>270</td>
<td>322</td>
<td>321</td>
<td>268</td>
</tr>
<tr>
<td>E-4</td>
<td>0.30</td>
<td>7.30</td>
<td>Mar.2001</td>
<td>210</td>
<td>5.72</td>
<td>260</td>
<td>370</td>
<td>370</td>
<td>300</td>
</tr>
<tr>
<td>E-5</td>
<td>0.30</td>
<td>7.85</td>
<td>June 2000</td>
<td>270</td>
<td>8.92</td>
<td>310</td>
<td>416</td>
<td>398</td>
<td>330</td>
</tr>
</tbody>
</table>

Legend:

Table 1. Experimental pile results and estimated failure loads.

3.2 Cone penetration results

A Hogentogler cone was used for a series of 17 CPT tests at various locations and at various times (see Figure 5). The CPT hole closest to each of the piles was selected as representative for calculating the ultimate pile capacity. The method adopted (and by the tested software) to estimate pile capacity used only \(q_c\) and these values next in Figure 4.

4. RESULTS AND DISCUSSION

The CPT test nearest to each pile was used as the input data, along with the pile type and geometry. This data was provided to the PILES CPT module of the commercial program GEO5 (Fine 2007). The program only uses the tip data \(q_c\) and allows four different methods of analysis. For this paper, only one method will be used and discussed, that is the LCPC method, (Bustamante & Gianeselli, 1982).

For the LCPC method, the program uses the average cone tip resistance as given by Lunne et al (1997). The original LCPC method used limits on the shaft resistance (maximum of 15-35 MPa in clay depending on \(q_c\)). The program uses no limits on the unit shaft resistance and therefore is a modified version of the LCPC method. An Excel calculation was done for one pile and it was found that the shaft resistance increased about 24% when the limits are ignored. Nevertheless, the pile capacities were closer to the measured values when the limits are ignored and these capacities were used. Fellenius (2009) indicates that it is common for users to either remove the limits or to adjust them.
Figure 4. CPT records used to analyze piles using Geo5 program.

Figure 5 presents a picture of the 100 kN mobile hydraulic rig adopted for the CPT tests at the site.

Figure 5. CPT rig used at the UnB site.
The output from the program is summarized in Table 2, which presents the pile characteristics and their maximum load and the forecasts given by the extrapolation method (Van der Veen, VDV) and by the modified LCPC method. Table 2 also presents the percentage of the relationship between calculated to reference values, respectively for both maximum and VDV reference loads.

Some major points can be noted:

- As already observed before by Mota (2003), the Van der Veen method yields reasonable value of failure loads, equal to or slightly above the maximum measured capacity at each pile load test;
- By adopting the maximum load as the failure criteria, for instance, one concludes that the modified LCPC method provides a close relationship between forecast and experimental results. By averaging all the results, it is noticed that the modified LCPC method yields an average estimated value around 90% of the experimental average one;
- By adopting the VDV load as the failure criteria, instead of the maximum load, the average percentages will slightly decrease, towards the safe, conservative, side. Nevertheless, the modified LCPC method will continue to give reasonable estimates to be used in practice, allowing economical and safe estimates.

<table>
<thead>
<tr>
<th>Pile</th>
<th>L (m)</th>
<th>P_{max} (kN)</th>
<th>Van der Veen (kN)</th>
<th>LCPC (kN)</th>
<th>% P_{max}</th>
<th>% VDV</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>7.65</td>
<td>270</td>
<td>270</td>
<td>234</td>
<td>91%</td>
<td>91%</td>
</tr>
<tr>
<td>E2</td>
<td>7.25</td>
<td>300</td>
<td>360</td>
<td>219</td>
<td>77%</td>
<td>64%</td>
</tr>
<tr>
<td>E3</td>
<td>7.8</td>
<td>270</td>
<td>270</td>
<td>197</td>
<td>77%</td>
<td>77%</td>
</tr>
<tr>
<td>E4</td>
<td>7.3</td>
<td>210</td>
<td>260</td>
<td>203</td>
<td>106%</td>
<td>86%</td>
</tr>
<tr>
<td>E5</td>
<td>7.85</td>
<td>270</td>
<td>270</td>
<td>267</td>
<td>102%</td>
<td>102%</td>
</tr>
</tbody>
</table>

Table 2. Results of LCPC Analyses from Geo5 Pile CPT program.

5. CONCLUSIONS

The results of the modified LCPC analyses from the Geo5 pile CPT program gave reasonable results compared to both the maximum experimental load and the estimated failure loads using the Van der Veen method. The Geo5 pile CPT program seems to hold promise for local usage in pile design, but it adopts a distinct approach from the original authors of the LCPC method. This point needs further discussion in the future, as it seems that, without the limitations put forward by the original method, better results (and less conservative ones) are obtained.

Although limited in number, types of foundation, and geographic area, these results provide a trend that can be readily adopted in preliminary analyses of foundation design of floating mechanically excavated piles founded in the typical Brasilia porous clay.
REFERENCES


Van der Veen, C. 1953. The bearing capacity of a pile. *3rd international conference on soil mechanics and foundation engineering, Zurich*. 