# Pile capacity for Omega piles in an unsaturated Brazilian soil using the CPT

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ABSTRACT: An assessment of the pile capacity for omega piles through cone penetration test (CPT) is presented in this paper. Three omega piles, instrumented along the shaft with strain-gages, were built in a Brazilian tropical soil found in the experimental test site at Unicamp (State University of Campinas), Sao Paulo, Brazil. The soil profile and its properties have been carefully characterised and is composed of: a 6m thick porous clay over a residual soil classified as clayey silt. Several electrical CPT tests were done in order to use the data to estimate the pile capacity of the piles using existing CPT-based methods. Pile load tests results were also available, that provided a comparison between measured and estimated values of pile capacity. The results have shown that some methods for estimating the pile capacity of the Omega piles, give extremely low values when compared to the pile load test results. Comparisons between tip resistance and lateral friction obtained through load test and the CPT-based methods, have shown some differences as well.

## 1 INTRODUCTION

Assessing pile capacity in piles through cone penetration test (CPT) has been a research theme for many years. Geotechnical engineering practice has developed several CPT-based methods and approaches to estimate axial pile capacity. Because the CPT is a very simple test that supplies a great amount of information with depth in a short time, and also because of its similarity with pile installation, it has become a good tool to assess the capacity of piles. Unfortunately, differences are often found between the estimated and real axial pile capacity, especially in unsaturated tropical soils, and that is why further research is still needed. The assessment of pile capacity of omega piles using CPT-based methods and comparison with static load tests carried out (both in the same season, in order to avoid differences) is presented in this paper. The soil profile is composed of two soil layers, a porous clay overlying a clayey silt residual soil.

## 2 MATERIALS AND METHODS

### 2.1 *Materials*

The experimental test site at Unicamp, was used to install three omega piles. The omega piles were 11.4m is length and 0.39m diameter. The Omega pile, also called screw pile, is a soil displacement auger pile based on a screwing in - screwing out sequence. The execution can be outlined as follows: the auger head is inserted into the soil by rotation, and the same CFA piles machine may be used; the soil is displaced downward and laterally by the oriented slots fixed on the auger's head at different well-selected locations on the flanges; when drilling is over, along with auger removal with rotation, concrete is injected under pressure. Concrete, with values of slump of around 240mm, will have a minimum consumption of cement of 400kg/m$^3$.

The soil at the Unicamp experimental site is formed by the Serra Geral geologic formation (Vicente&Bjomberg, 1993). The first layer is a 6m thick transported sandy silty porous clay with an $N_{SPT} < 5$. The second layer is a residual diabasic soil (clayey silt), 14m thick, with an $N_{SPT}$ varying from 5 to 29. The ground water level was reached at 17m. High quality undisturbed block samples were recovered and an extensive laboratory testing program was carried out in order to get physical and mechanical characteristics properties of both layers, which are presented in Tables 1 and 2. Five electric CPT's were performed near the piles, to a depth of 15m. The equipment was an electrical penetrometer with a TG 73200 hydraulic system. The cone had a friction sleeve area of 150cm$^2$ and the point had 10cm$^2$ with a 60° at point. The drive speed was 2cm/s. The average electric CPT results are presented on Figure 1 (Carvalho et al. 2000).

Table 1. Principal physical soil properties at the UNICAMP experimental site. (after Albuquerque 2001)

| Depth (m) | $\omega_L$ (%) | $\omega_P$ (%) | $\gamma_f$ (kN/m$^3$) | $G_s$ | w (%) | e | n (%) | S (%) |
|---|---|---|---|---|---|---|---|---|
| 1 | 52 | 35 | 13.4 | 2.97 | 24.3 | 1.77 | 63.8 | 40.8 |
| 2 | 52 | 38 | 13.0 | 2.91 | 23.4 | 1.76 | 63.7 | 38.7 |
| 3 | 51 | 36 | 13.0 | 2.95 | 22.8 | 1.79 | 64.1 | 37.6 |
| 4 | 52 | 37 | 13.0 | 3.01 | 23.7 | 1.86 | 65.0 | 38.4 |
| 5 | 49 | 37 | - | - | - | - | - | |
| 6 | 58 | 41 | 15.4 | 3.01 | 24.6 | 1.44 | 59.0 | 51.4 |
| 7 | 62 | 43 | 15.4 | 2.91 | 26.3 | 1.40 | 58.2 | 54.7 |
| 8 | 66 | 47 | 14.8 | 2.95 | 28.1 | 1.56 | 60.1 | 53.1 |
| 9 | 69 | 48 | 15.0 | 3.01 | 29.9 | 1.60 | 61.5 | 56.2 |
| 10 | 73 | 49 | 15.1 | 3.01 | 30.5 | 1.60 | 61.6 | 57.4 |
| 12 | 70 | 46 | 16.1 | 2.96 | 33.8 | 1.46 | 59.4 | 68.5 |
| 14 | 64 | 43 | 16.4 | 3.06 | 32.8 | 1.48 | 59.7 | 67.8 |

*$\gamma_f$: in situ unit weight of the soil, $G_s$: specific gravity, w: moisture content, e: void ratio, n; porosity, S: degree of saturation, $\omega_L$: liquid limit, , $\omega_p$: plastic limit.*

Table 2. Grain size distribution, mechanical properties and $N_{SPT}$ data of the soil at the UNICAMP experimental site. (after Albuquerque 2001)

| Depth | Clay | Sand | Cohesion* | Friction angle $\phi$ * | $N_{SPT(72)}$ |
|---|---|---|---|---|---|
| (m) | % | (%) | (kPa) | ( ° ) | |
| 1 | 63 | 27 | 5 | 31.5 | 4 |
| 2 | 65 | 25 | 11 | 31.5 | 3 |
| 3 | 67 | 26 | 2 | 30.5 | 2 |
| 4 | 61 | 26 | 0 | 26.5 | 4 |
| 5 | 60 | 26 | - | - | 5 |
| 6 | 44 | 34 | 18 | 18.5 | 6 |
| 7 | 45 | 25 | 31 | 22.5 | 6 |
| 8 | 39 | 28 | 18 | 22.5 | 6 |
| 9 | 36 | 28 | 64 | 14.5 | 7 |
| 10 | 35 | 29 | 78 | 22.8 | 8 |
| 12 | 29 | 31 | 87 | 18.3 | 8 |
| 14 | 26 | 34 | 76 | 19.1 | 10 |

* Friction angle and cohesion – total stress values

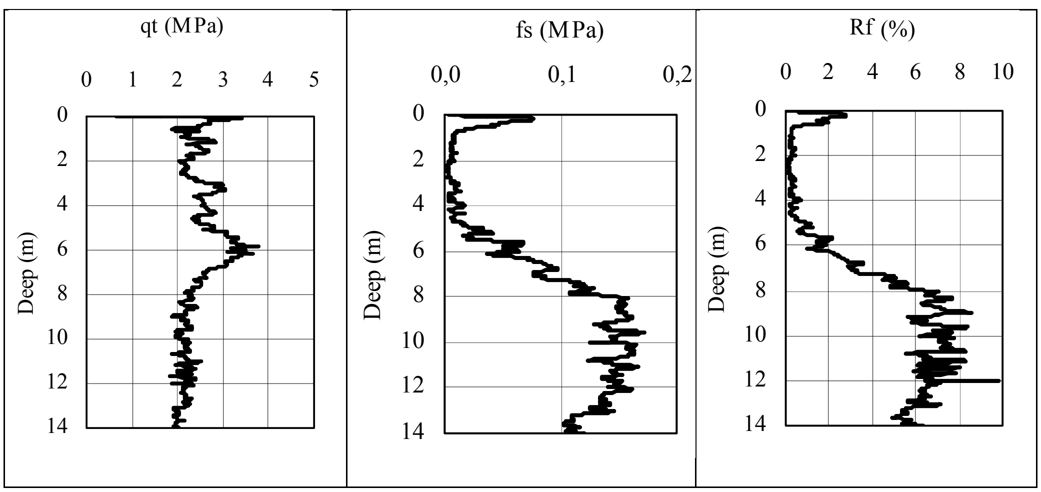

Figure 1. Average results of electric cone with the depth at experimental site of Unicamp

## 2.2 *Pile Load Tests*

Slow maintained load tests were performed for each pile, according with the Brazilian Standards (NBR12131/92), adopting slow load (SML). The loadings were performed in increments of 120kN, up to the load at which the displacements indicated rupture of the pile-soil connection. Unloading was made in consecutive stages, with load reductions of 25% of the total load achieved in the test. To perform the load test, a 2000kN capacity load unit was used, installed between the reaction beam and the pile head block.

## 3. METHODS DESCRIPTION

The CPT-based methods by; Philippont (1978); De Ruiter &Beringen (1979); P.P. Velloso (1981) and Bustamante & Gianeselli (1998), were used to assess the ultimate capacity of the omega piles, but just the Bustamante–Gianeselli method, was developed to Omega piles. The procedures of each method used in this paper are:

### *3.1.Philipponat (1978) method.*

The Philipponat (1978) method, uses the CPT results to estimate the ultimate bearing capacity of the piles. The rupture load is considered as the sum of the skin friction plus the point resistance.

$$Q_{total-calc} = \sum_{i=1}^{n} U.f_{ui} \Delta z_i + A_p \alpha_p q_c \tag{1}$$

$$f_u = \alpha_f . \frac{q_{ci}}{\alpha_s} \tag{2}$$

Where: U = perimeter of the pile, $\Delta Z_i$ = considered depth over which $U_i$ and $f_{ui}$ are taken constant, $A_p$ = cross section area of the pile tip, $\alpha_p$ = coefficient which depend on the soil type, $q_c$ = point resistance of the cone, $\alpha_s$ = coefficient which depend on the soil type and $\alpha_f$ = coefficient which consider the pile type

The proposed values for $\alpha_s$ and $\alpha_f$ can be found in Philipponat (1978). In this case, the $\alpha_f$ value was taken as for a pressed pile.

### *3.2. De Ruiter and Beringen (1979) method*

In the De Ruiter and Beringen (1979) method the rupture load is considered as the sum of the skin friction plus the point resistance. The values of unit skin resistance and unit point resistance are illustrated in table 3

$$Q_{total-calc} = \sum_{i=1}^{n} U.f_p \Delta z_i + A_p q_p \tag{3}$$

Table 3. De Ruiter e Beringen method (1979)

| | Sand | Clay |
|---|---|---|
| Unit skin resistance ($f_p$) | Minimum value of:<br>$f_1$ = 0.12 MPa<br>$f_2$ = cone friction sleeve<br>$f_3 = q_c/300$ (compression)<br>$f_4 = q_c/400$ (traction) | $f_p = \alpha \, S_u$<br>where:<br>$\alpha$ = 1 for NC clays<br>$\alpha$ = 0.5 for OC clays |
| Unit point resistance ($q_p$) | Minimum $q_p$ found near to the point tip | $q_p = 9S_u$ |

The author adopted a limit point resistance value of 15MPa.

*3.3. P.P. Velloso (1981) method*

The P.P. Velloso (1981) method considers both the pile type (driven or bored) and the kind of load applied (compression or traction). The frictional resistance can be computed as:

$$Q_{total-calc} = \alpha_{pp} \lambda p \sum_{i=1}^{n} U_i f_{ui} \Delta Z_i + \alpha_{pp} \beta q_{cp} A_p \qquad (4)$$

Where: $\alpha_{pp}$ = coefficient which consider the pile type (for driven pile $\alpha_{pp}$ is taking as 1 and for bored pile $\alpha_{pp}$ is taking as 0.5), $\lambda_p$ = coefficient which consider the kind of load applied on the pile (1 for compressed pile and 0.7 for tensioned one), $f_{ui}$ = cone sleeve friction, $A_p$ = cross section area of the pile, $q_{cp}$ : average cone resistance near to the pile tip, $\beta$ = coefficient of point load, For compression piles → $\beta = 1.016 - 0.016\ (d/Dc) \geq 0.2$, For tensioned piles → $\beta = 0$, d : diameter of the pile, Dc: cone diameter

In this method, the omega pile was considered as a driven pile.

*3.4. Bustamante and Gianeselli (1998) method*

Bustamante and Gianeselli (1998) presented a method for computing the ultimate pile capacity for omega piles. The ultimate pile capacity is assumed to be:

$$Q_{total-calc} = f_s.A + k_{BG}.q_c.A_p \qquad (5)$$

Where: $f_s$ = soil-pile friction obtained for correlations according with the pile type and cone resistance, A = perimeter of the pile section, $k_{BG}$ = coefficient which depend on soil type, $A_p$ = cross section area of the pile tip, $q_c$ = cone resistance near to the pile tip.

The friction sleeve values from the electrical cone used in all methods were taken as the average for each soil layer. The pile was taken as a driven pile in order to consider the pressed effect produced by the auger into the soil during execution of the hole.

## 4. RESULTS AND DISCUSSION

*4.1 Results of the Pile Load Tests*

The pile load vs settlement curves obtained from the slow load tests are presented in Figure 2.

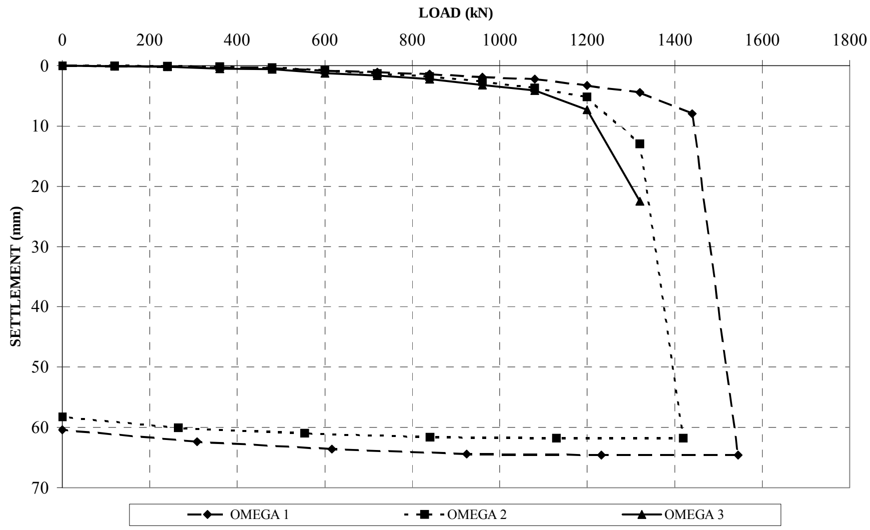


Figure 2. Pile load vs settlement curves

The values of the rupture load and maximum settlement for each pile are presented in Table 4.

Table 4. Values of load and maximum settlement obtained from load tests

| Pile | Ultimate Load (kN) | Settlement (mm) |
|---|---|---|
| Omega 1 | 1545 | 64.57 |
| Omega 2 | 1420 | 61.83 |
| Omega 3 | 1320 | 22.52 |

The average ultimate load values obtained for this type of pile were about 1428kN, with a standard deviation of 113kN. The average unit lateral shaft friction resistance was about 86kPa and the ultimate pile tip stress was about 16.65MPa.

### *4.2 Estimation of pile capacity*

Notice that in Figure 3 the diagonal lines indicate perfect agreement between calculated and estimated pile capacity. The broken line represents a deviation of ± 20 % from perfect agreement which has been assumed as an acceptable difference in the estimated value by Eslami & Fellenius (1997). The estimated values presented on Figure 3 for all the methods used in this paper, correspond with the estimated pile capacity considering the minimum, average and maximum value of $q_c$, $f_s$ and $R_f$ from all the field CPT's done at the experimental test site. The measured pile capacity plotted on the same figure corresponds with the average load test value obtained.

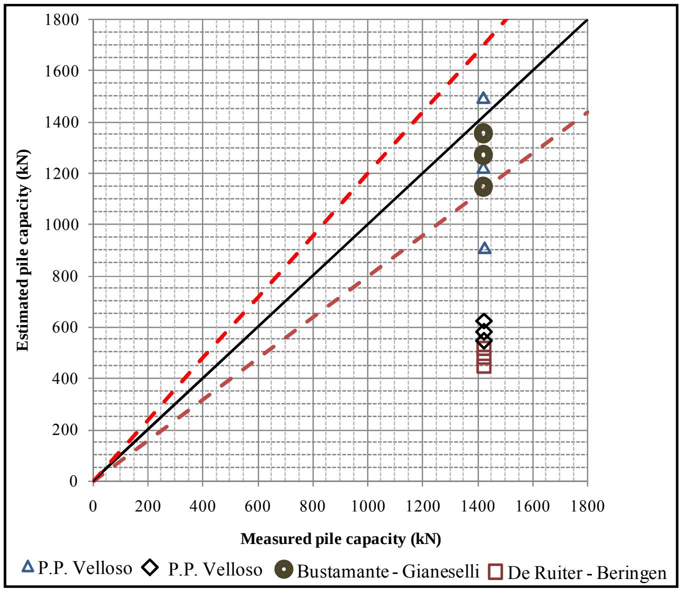


Figure 3.Correlation between measured and estimated pile capacity for an omega pile by different methods

According to the results presented in Figure 4 it can be seen that there is a large scatter between the estimated results of pile capacity and real (measured) values. Only the P.P. Velloso (1981) and Bustamante-Gianeselli (1998) method's give an estimated value approximately near the measured one. However the P.P.Velloso (1981) method gives a large dispersion (variation coefficient = 24%), despite it shows a good average, while the Bustamante-Gianeselli (1998) method, gives a good estimation of load capacity with the variation coefficient of about 7%. Figure 4 shows the results of all the methods using in the average value of cone ($q_c$, $f_s$ and $R_f$).

After performing the load tests, an Omega pile was extracted, with the objective of knowing its geometric characteristics. A complete examination of the pile was performed, revealing important data of the shaft surface, its geometry. Albuquerque et al. (2004) showed that the shaft presented a screw spiral-shape (like a 'nervure') and a good rough surface that could help to increase the lateral friction of the pile significantly.

## 5. CONCLUSIONS

Pile load tests were performed on three omega piles installed in soils at a test site at Unicamp (Sao Paulo, Brazil). Four CPT-based methods were evaluated to predict the axial pile capacity: the Bustamante-Giasenelli (1998) method gave results similar to average the measured axial capacity, although the estimated values were approximately 20 % less than the measured value. The Bustamante-Gianeselli (1998) method also showed that using the minimum, medium and maximum parameters obtained from the five CPT tests, the variations of results was very small, at about 7%.

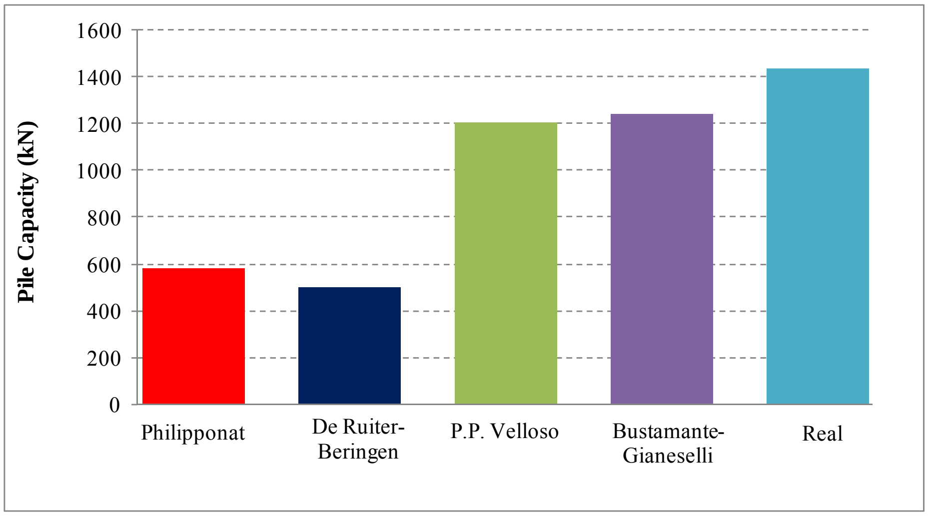


Figure 4. Pile capacity assessment

## REFERENCES


Albuquerque, P. J. R., 2001. Bored, continuous auger and ômega piles. Study of the behavior in residual soils. *PhD These*. University of Sao Paulo. "(in Portuguese)"

Albuquerque, P. J. R., Carvalho, D., Massas, F. 2004. Behavior of Omega piles, subjected to compression instrumented load tests. *Proceeding of the 2nd Geotechnical and Geophysical Site Characterization*. ISC 2. Porto-Portugal. A.A. Balkema. P.1551-1556.

Bustamante, M. and Giasenelli, L., 1998. Instalation parameters and capacity of screwed piles. *Proceeding of the 3rd International Geotechnical Seminar on Deep Foundations on bored and auger piles*. BAP III. Ghent-Belgium. A.A. Balkema. P.95-108.

Brazilian Technical Standards Association: *Static load tests: NBR 12.131/92*. 1991. Rio de Janeiro: A.B.N.T. "(In Portuguese)"

Carvalho, D., Albuquerque, P. Giacheti, H., 2000. Experimental field for geotechnical studies and foundation engineering. SEFE IV, *Proc. Nat. Seminar*. Sao Paulo. "(In Portuguese)"

De Ruiter, J. and Beringen, F.L., 1979. Pile foundations for large North Sea structures. *Marine Geotechnology*, 3 (3)..

Philipponat, G., 1978. Méthode pratique de calcul des pieux à l'aide du pénétrométre statique. *Informations Techniques Bulletin*. Paris. France.

Velloso, P.P., 1981. Considerations about bearing capacity assessement and vertical and horizontal displacements of piles in soils. *Publications*. Civil Engineering Departament. University of Brasilia. "(In Portuguese)"

Eslami, A and Fellenius, B.H., 1997. Pile capacity by direct CPT and CPTu methods applied to 102 case histories. *Canadian Geotechnical Journal*. No 34.

Vicente, J.F.and Bjomberg, A .J.S., 1993. *Geology. Soils in São Paulo area*. University of Sao Paulo - Sao Carlos. "(In Portuguese)"