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COMPARATIVE ANALYSIS OF THE LOAD CAPACITY OF CONTINUOUS AUGER PILES THROUGH LOAD TESTS AND SEMI-EMPIRICAL METHODS

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Abstract: In this work, the results of research carried out in works with the objective of comparing load capacity of continuous auger piles will be presented, obtained through load tests and by semi-empirical methods, adopting the methods of Décourt-Quaresma and Aoki Velloso. For the development of this research, technical and executive information from field trials was used, in partnership with foundation companies, and from bibliographic reviews relevant to the referenced design methods.
Keywords: Foundations, Continuous Helix Pile, Aoki Veloso, Décourt-Quaresma, Load Test.

INTRODUCTION

Since the beginning of time, the great civilizations have left as one of their historical legacies the construction of temples and civil works, many of which are considered wonders of the ancient and contemporary world. The implantation of increasingly taller and more robust structures, which occurred in prominence after the industrial revolution, moved humanity in the search for increasingly sophisticated, modern and complex techniques, starting to incorporate the use of cement materials and metal alloys.

As a consequence of the change in the size of the structures and the increase in structural loads, it was necessary to develop studies and expand the types of structural foundation elements, their interaction with the soil, their performance and safety; This fact led to the development of semi-empirical design techniques, based on the results of field experiments as well as taking into account the types of foundation elements, their constitution, shape, dimensions and soil characteristics.

Throughout the 20th century, there was the development of several sizing and executive techniques of foundations of the group called deep; giving rise to alternatives for the use of precast piles and excavated in loco. From this period we can mention the Franki Pile (1910), the Strauss Pile (1909) and more recently the Continuous Helix Pile (1950), in addition to its evolution in the form of the Displacement Pile (1970). The focus of the present research is the excavated pile called continuous monitored helix, as it is the most used technique nowadays in Brazil.

This type of foundation consists of a pile molded in loco, where a mechanical auger continuously drills the soil, with concreting at the time of removal of the auger, with the reinforcements being positioned later manually or with the help of cranes. The diameter used commercially in regional works varies between 25 and 100 centimeters, reaching depths of up to 40 meters, giving it a high load capacity. In Brazil, its execution is regulated by NBR 6122 (ABNT, 2019).

For the dimensioning of these piles, semi-empirical methods are used, mostly based on information obtained from the SPT drilling report, types of piles, their dimensions and parameters assigned by the creators of the existing methods, which depends on the type of soil and stake. The two most used methods in Brazil are the methods proposed by Aoki-Velloso (1975) with table updates by Marangon (2018), and Décourt-Quaresma (1978), these being the methods used in the comparison proposed by this research, in in relation to proof-of-load tests.

RESEARCH PURPOSE

According to the NBR 6122 standard (ABNT, 2019), in works with more than 100 piles or pressures above 5 MPa on the piles, it is recommended to carry out at least one load test, preferably on an instrumented pile. This procedure consists of simulating the final loads that a pile will be subjected to in operation, through the efforts of a hydraulic jack positioned at its base.

It is possible to carry out the dimensioning of piles from the results of the load test, because through these field results, carried out before the implantation of all the foundation elements, the real load capacity of the pile is verified, being able to change the foundation design. This confidence is reflected in a minimum safety factor lower than the other methods, according to NBR 6122 (ABNT, 2019) the safety factor adopted in dimensioning based on load tests must be at least equal to 1.6 or higher. When proposing the proposed methods, a safety factor equal to or greater than 2.0 is recommended.

This research project aims to check the real safety factors obtained in foundation works of real estate projects located in the North and Midwest regions; through the design allowable load capacity, obtained by the proposed design methods, comparing the results with the values obtained in the load tests, carried out in the field.

SEMI-EMPIRICAL SCALING METHOD AOKI-VELLOSO

This method was proposed by Aoki & Velloso during the 5th Pan-American Congress of Soil Mechanics and Foundation Engineering held in 1975 in Buenos Aires. The method was developed based on correlations between static penetration tests (CPT) and dynamic soundings (SPT). The load capacity depends on the values referring to the lateral friction of the pile and the point resistance. To obtain the tip resistance in Kgf/cm², Equation 1 is used.

$$R_p = K.N \tag{1}$$

Where we have, for ''N'', the soil resistance value on which the tip is supported, obtained by the SPT sounding, and for ''K'' values determined for each type of soil according to Table 1.

To obtain the values of the unitary resistance by lateral friction, this method used the correlations established by Begemann (1965), expressed in Equation 2. Table 2 indicates the values for ‘’α”.

$$R_1 = \alpha.R_p \tag{2}$$

Finally, in order to work with the general equation, it is necessary to have the coefficients F1 and F2 at hand, which vary according to the type of pile used. In the elaboration of the method, original values were established whose F2/F1 ratio = 2, undergoing variations in its second version.

Currently, the values used for the coefficients are those proposed by Eng. Paulo Frederico de Figueiredo Monteiro, expressed in Table 3.

After obtaining these data, it is possible to work with the general equation of the method. It is expressed through Equation 3.

$$P_R = \Delta_p.\frac{K.N}{F1} + \sum_{Cp}^{Ca} U.\Delta l.\frac{\alpha.K.N}{F2} \tag{3}$$

Where:
A_p = tip or base area of the pile;
U = perimeter of the pile cross section;
Ca = razing quota;
Cp = Quota from the tip.

SEMI-EMPIRICAL DIMENSIONING METHOD DÉCOURT-QUARESMA

The method contemporary to Aoki-Velloso, developed by Luciano Décourt in 1978, is presented in a simpler way with fewer variables and coefficients in its equation. Capacity prediction is obtained as the sum of the tip resistance and the lateral resistance. Being expressed by the general equation below (Equation 4).

$$Q_c = \frac{A.Q_p.A_p}{4} + \frac{B.Q_L.A_L}{1{,}3} \tag{4}$$

Where:
Q_p = Soil resistance at tip (SPT);
Q_L = Lateral friction resistance (SPT);
A_L = Side area of the stake;
A_p = Tip area;
A = Alpha factor (set to 0.3 for continuous auger piles);
B = Beta factor (set to 1.0 for continuous auger piles).

Being Q_p defined by:

$$Q_p = C.N_p \tag{5}$$

Where:
N_p = Represents the value of N_{SPT} point average, obtained from three values: the one corresponding to the point level, and the immediately anterior and posterior values.
C = Soil characteristic coefficient, specified in Table 4.

While Q_L is defined by:

$$Q_L = 10\left(\frac{N_L}{3}+1\right)\left[\frac{kN}{m^2}\right] \tag{6}$$

Where:
N_L = average value of the Nspt penetration resistance index along the bole.

DEVELOPMENT

For the development of the research, the installation of a load test equipment was monitored in some works in three cities in the north and central-west regions, where its assembly consists of: hydraulic jack, rigid plate and a reaction system type sustained beam. by trestles and fixed by Diwidag bars. In addition to the measurement system, which is composed of: strain gauges, which measure the settlement, the manometer (which measures the pressure) and a small anchoring system, which uses reference beams fixed to the ground by small metal stakes. Below is Figure 1, which shows part of the equipment used in a load test test.

Type of soil	K (Kgf/cm²)	Soil type	K (Kgf/cm²)	Type of soil	K (Kgf/cm²)
Sand	10,0 - 6,0	Silt	4,0 - 4,8	Clay	2,0 - 2,5
Silty sand	8,0 - 5,3	sandy silt	5,5 - 4,8	Sandy clay	3,5 - 4,8
Silty clay sand	7,0 - 5,3	sandy silt - clayish	4,5 - 3,8	sandy clay-silty	3,0 - 3,0
Clayey sand	6,0 - 5,3	Clayey silt	2,3 - 3,0	silty clay	2,2 - 2,5
clay sand - silty	5,0 - 5,3	Clay silt - sandy	2,5 - 3,8	silt clay - sandy	3,3 - 3,0

Table 1. Values for K.

Source: Marangon (2018).

Type of soil	α (%)	Type of soil	α (%)	Type of soil	α (%)
Sand	1,4	silt	3,0	Clay	6,0
silty sand	2,0 - 1,9	sandy silt	2,2 - 3,0	Sandy clay	2,4 - 4,0
silty clay sand	2,4	sandy silt - clayish	2,8 - 3,0	sandy clay - silty	2,8 - 4,5
clayey sand	3,0	clayey silt	3,4	silty clay	4,0 - 5,5
clay sand - silty	2,8	clay silt - sandy	3,0	silt clay - sandy	3,0 - 5,0

Table 2. Values for α.

Source: Begemann (1965).

Stake Type	F1	F2
bentonitic	3,5	4,5
Franki shaft rammed	2,3	3,0
Franki Vibrated Fuste	2,3	3,2
Continuous Propeller	3,0	3,8
micropile	2,2	2,5
Source	2,2	2,4
anchor pressure	2,2	2,1
metallic	1,75	3,5
Percussion driven precast concrete	2,5	3,5
Precast concrete driven with pressing	1,2	2,3
Strauss	4,2	3,9
VibroFranki	2,4	3,2

Table 3. Values of F1 and F2 coefficients.

Source: Marangon (2018).

Soil characteristic coefficient C	
Ground	**C (KPa)**
Clay	120
clayey silt	200
sandy silt	250
Sand	400

Table 4. Soil characteristic coefficient C.

Source: Farias, R. e Paranhos, H. (2018).

In the selected works, the load test process was monitored, which according to NBR 12131 (ABNT, 2006), is developed as follows: The load is applied in successive stages, and in each application the respective settlements of each time interval (2min, 4min, 8min, 15min, 30min, 1h, 2h, 4h etc.) and that a new load increase will only be applied after the stabilization of the settlements has been verified (with a maximum tolerance of 5% of the settlement total at this stage, between successive readings). The test must proceed until a settlement of 25 mm is observed or until twice the rate allowed for the soil is reached. If the maximum test load does not result in failure, a period of at least 12 h shall be maintained. In addition, the discharge is carried out in successive stages not exceeding 25% of the total charge. Figure 2 illustrates the assay being performed.

DATA COLLECTION AND CALCULATIONS

A step that preceded the development of the calculations was the survey together with the collaborating companies, seeking data related to foundation projects and drilling reports.

The calculations of the admissible load capacity of all piles took into account the dimensions of the sacrificial piles implanted, with diameters of 600 and 800 mm and depths ranging from 8 to 13 m, in a total amount of 9 experiments with Helix piles Continuous in three different works located in the cities of Brasília-DF, Jataí-GO and Palmas-TO.

With the information obtained from the project and drilling, aided by spreadsheets, the load capacity (Qc) and the allowable load capacity (Qadm) were determined, using the arithmetic mean of the values referring to three load tests of the tested locations, by the Decourt-Quaresma and Aoki-Velloso design methods. Complementing the research, the values obtained in the design were compared with the load capacity obtained in the load proof tests and their respective admissible tensions considering the prescribed in NBR 6122 (ABNT, 2019), whose safety factor in this situation is 1,6.

The graphs represent the Load Capacity (Qc) obtained in the load test and the Calculated Allowable Load Capacity (Qadm) (Figures 3 to 5), for each of the methods, with the Safety Factor determined by the relationship between the values obtained from Qc over Qadm.

With the results of the real safety factors calculated, a comparative analysis chart of the averages of these values was produced in each of the two sizing methods compared with the minimum safety factor stipulated by the standard. Below is the graph shown in Figure 6.

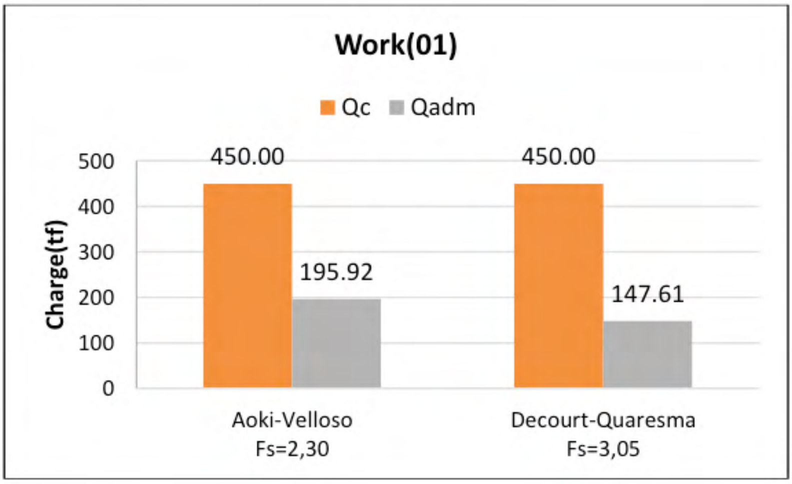
CONCLUSION

With the methodology and results found, it is concluded that both design methods, Décourt-Quaresma and Aoki-Velloso, met the assumptions and determinations specified by the NBR 6122 standard (ABNT, 2019), presenting an overall safety factor greater than 1.6 for Strength determined by static load tests. By comparing the safety factors achieved through the two semi-empirical methods, it was possible to determine a relativized level of conservatism of the methods, with the Aoki-Velloso method being the most conservative among the two analyzed methods.

*1- reaction beam; 2- Hydraulic jack; 3- easels; 4- strain gauges; 5-Reference beams; 6- rigid board.

Figure 1. Load proof equipment.

Figure 2. Load proof tests, a) first rehearsal and b) other trials followed.



* Work located in Jataí-GO. Pile with a diameter of 800 mm and a total depth of 8 m.

Figure 3. Results of work 01.

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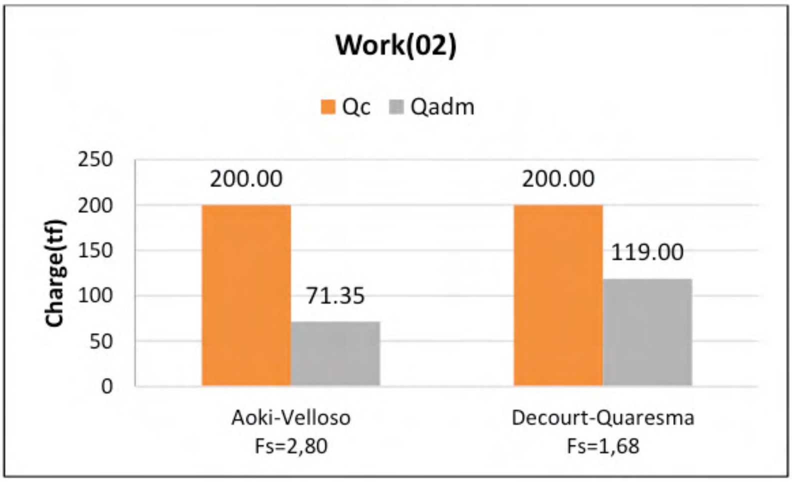
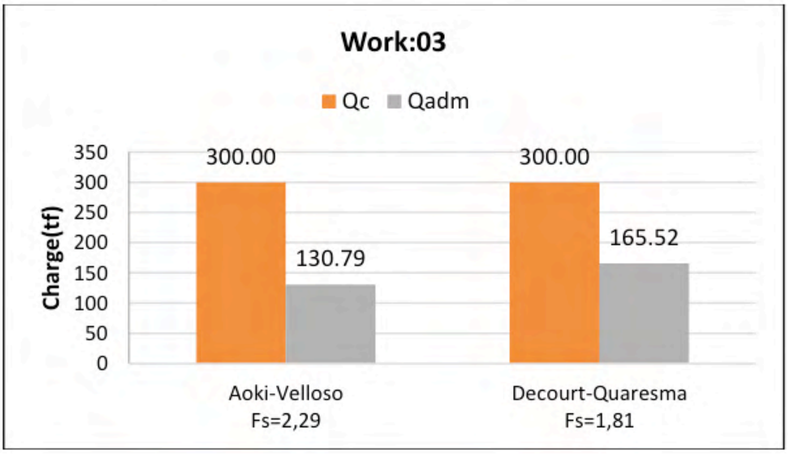


* Work located in Brasília-DF. Pile with a diameter of 600 mm and a total depth of 12 m.

Figure 4. Results of the work 02.



* Work located in Palmas-TO. Pile with a diameter of 600 mm and a total depth of 13 m.

Figure 5. Results of the work 03.

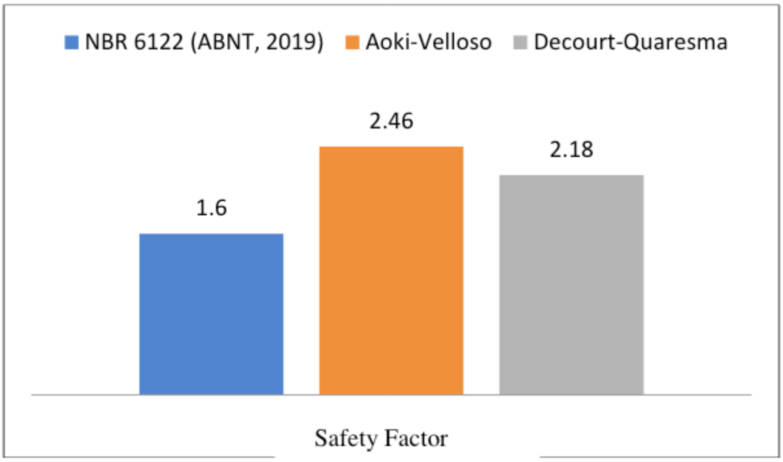


Figure 6. Comparative graph of the averages of the safety factors of the Decourt-Quaresma and Aoki-Velloso methods and the minimum stipulated by NBR 6122 (ABNT, 2019).

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