Comparative Assessment of Methods to Predict the Bearing Capacity of Continuous Flight Auger Piles

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ABSTRACT: In the last years, the construction industry growth has encouraged researches in Brazil about more efficient foundations in terms of bearing capacity. This paper identifies the most efficient Brazilian methods of bearing capacity prediction of Continuous Flight Auger (CFA) piles. The data used in this research was collected from bearing tests carried out in piles and Standard Penetration Tests (SPT) performed in the two different constructions in the metropolitan area of Fortaleza, Brazil. For the bearing capacity analysis, two methods were carried out i) Van der Veen using the bearing test data and ii) semi-empirical Aoki and Velloso and Antunes and Cabral using SPT data. Thus, their failure bearing was compared. By the results, it can be concluded that the most appropriated method is Aoki and Velloso. This method presented approaching values to the Van der Veen reference method.

Keywords: Continuous Flight Auger Piles; SPT; Bearing Capacity; Van der Veen method.

1. Introduction

The construction industry is the main contributor to economy and employment in all nations, surpassing a good portion of their gross domestic product (GDP). In Brazil, after the creation of the Growth Acceleration Program (PAC 01) in 2007, followed by the PAC 02 in 2010 and the 2014 FIFA World Cup, there was an exponential growth in construction throughout the country.

Civil construction activities are very impacting, both during production and product use phase, and solving this equation involves the interaction between ecological, economic and socio-cultural sectors, with issues related to its dynamics [1]. In the period comprising PAC 01 and PAC 02, Brazil underwent a process of adaptation to international competition standards in all areas. The level of demand from more attentive consumers, with more freedom and rights (Consumer Code), the speed of social and cultural changes, stimulated by information technology, resulted in changes in the civil construction practice in the country [2].

Studies on the best methods of forecasting some aspects of construction were necessary. Among the main elements of a building, foundation structures deserve particular emphasis. These elements are one of the most difficult to enhance construction performance due to the challenging control of soil behaviour and the negligence with which these kinds of structures are addressed.

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According to Barros [3], one of the designer's challenges in foundation engineering is to predict the settlements that foundation elements will suffer in both the short and long term. Thus, it is necessary to set a limit for settlement values to ensure the good behaviour of the designed structure throughout its entire life cycle.

The assessment of foundation structures' settlements is vital for realizing ground behaviour and how building performance will develop after construction. In foundation elements such as piles, these settlements vary according to the bearing surface formed by the pile tip within the geotechnical mass that was determined during design. In the construction supported by these structures, these phenomena depend on the deformability of the soil, the deformability of the materials and the dimensions of the pile. The soil-structure interaction of the construction also depends on these factors [3].

Mucheti [4] explains that continuous flight augers piles were introduced in Brazil in 1987 and began to be widely used in construction due to their technical advantages combined with low cost and speed of execution.

In Brazil, semi-empirical methods are a widely used tool to predict the load capacity of piles. These are developed from soil testing of specific regions and thus do not apply to all parts of the world [5].

A comparative study between well-established calculation methods is needed to bring the predictions closer to reality. Such applicability checks have been made by comparing semi-empirical predictions with the failure criteria applied to load-settlement curves of load tests.

These methods can be classified as "conservative" or "non-conservative", most of the time without even proposing any corrections that would allow its application to the local soil. This paper aims to analyze the feasibility of applying well-established calculation methods in continuous flight augers piles by comparing the results of static load tests in some construction sites in Fortaleza-Ce.

2. The site characterization and data

The data used in this study were collected from two companies that perform geotechnical tests in the state of Ceará-Brazil and corresponds to five Standard Penetration Tests (SPT) and three load tests performed on continuous flight augers piles with 300mm and 700mm diameter, respectively. In the load, tests performed a slow compression loading was used. The selected data correspond to two construction sites: one from housing at the Federal University of Ceará (UFC), in Fortaleza, and another from a wind farm in Paracurú-Ce.

The housing built at the Federal University of Ceará used two processes during the SPT tests: initially, the 4" auger was used until the water level, or an impenetrable layer was reached. Then the holes were encased with a 2 1/2" steel pipe, and excavation proceeded with water circulation.

Sampling was carried out by driving a standard sampler with an inner and outer diameter of 13/8" and a 2" respectively. The penetration tests were performed for each drilled meter and consisted of counting how many blows of a 65kg weight, falling from a 75cm height, were necessary to deepen the standard sampler 45cm in the investigated layer. The total of the blows from the last 30cm can be found in the Individual - Geological - Geotechnical profiles for all 4 holes that were analyzed using the soils and rocks classification proposed by Serratrice [6], Clayton *et al.*, [7] and Clayton *et al.*, [8] presented in Figure 1.

Figures 2 and 3 correspond to the load tests performed on the continuous flight augers piles named as columns P-26 and P-28. Ten successive 180 kN (18 tf) stages were applied with the aid of a hydraulic jack. The process lasted approximately 20h and was carried out until a maximum load of 1.800 kN (180 tf). The maximum settlement observed in the two tests was 10.62 mm and the residual settlement, after unloading, was equal to 10.33 mm.

In the wind farm construction, data was collected from only one SPT survey, Figure 4. The single test was carried out at the location where wind turbines would be installed and were performed with slow compression loading on a pilot pile, as shown in Figure 5.

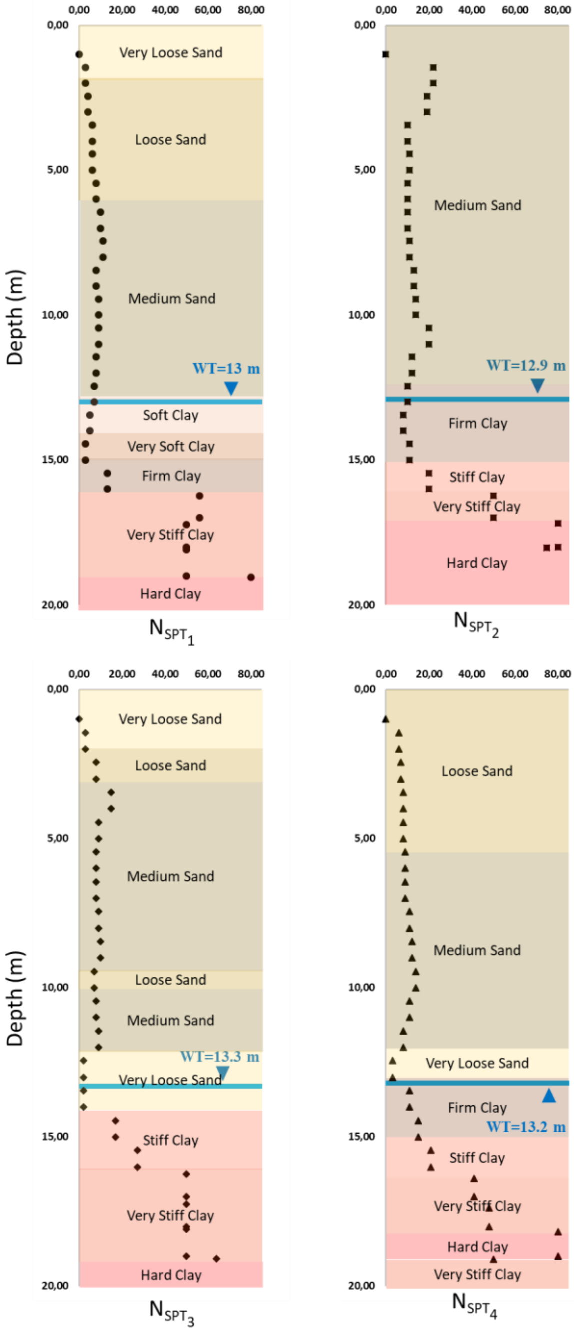

Figure 1. SPT-based soil and rock classification for 4 holes in Federal University of Ceará (UFC) site.

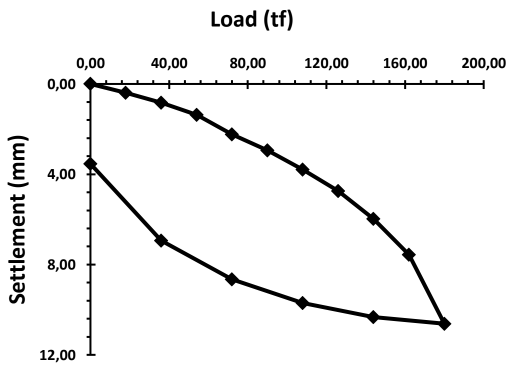

Figure 2. Bearing capacity for P-26.

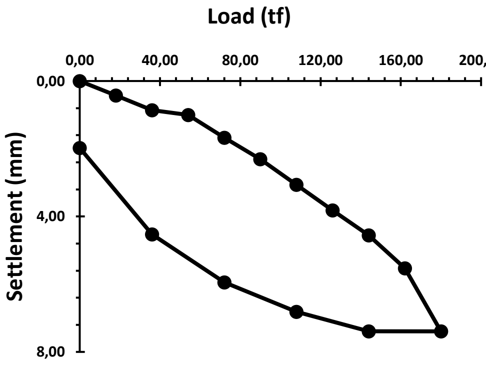

Figure 3. Bearing capacity for P-28.

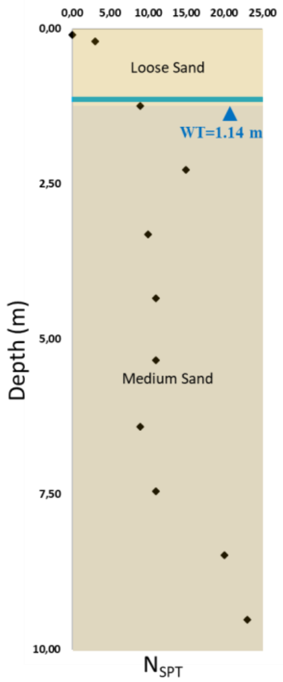

Figure 4. SPT-based soil and rock classification for the wind farm site.

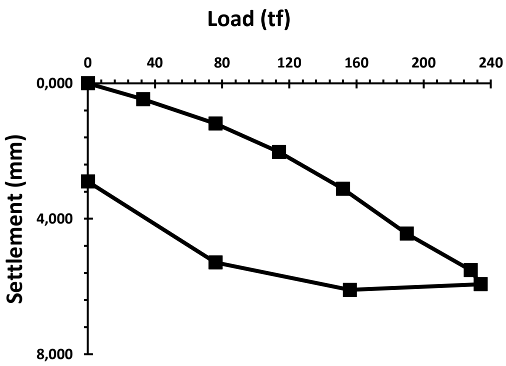

Figure 5. Bearing capacity for pilot pile in the wind farm construction.

3. Results and Discussion

Estimate calculations of pile rupture load performed on this study were carried out using the data from the load tests that haven't reached failure. The Van der Veen [9], was used to estimate the bearing capacity. Figure 6A shows the application of the Van der Veen [9] for the load tests estimate of load capacity shown in Figure 2. The graph shows a failure load of 2.150 kN (215 tf), with a trend line drawn from the highest determination coefficient' value.

The Graph in Figure 6B shows the estimated load capacity from the load test shown in Figure 3. A failure load of 2.220 kN (222 tf) is identified for the highest determination coefficient value.

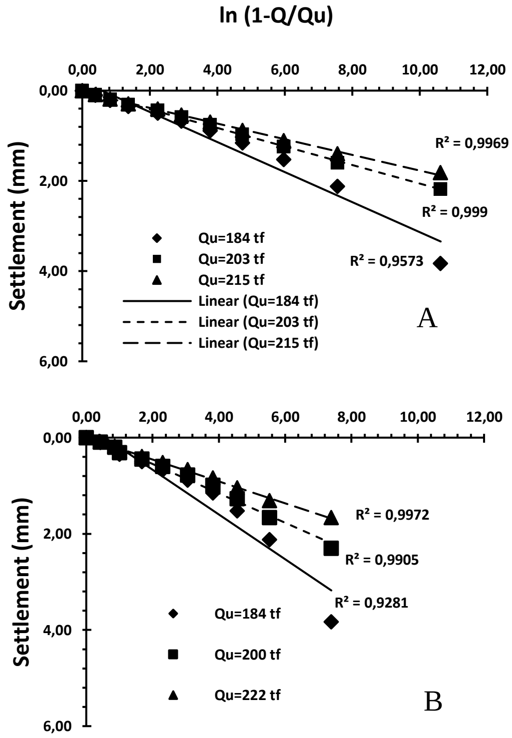

Figure 6. Bearing capacity for P-26 (A) and P-28 (B) for Van der Veen [9]

The estimate failure load of the Paracaru wind farm pile was carried out with the data of a load test that haven't reached failure. The method of calculus used the data from Figure 5 and fallowed the same procedure for piles P-26 and P28. The Figure 7 graph shows the estimated load capacity.

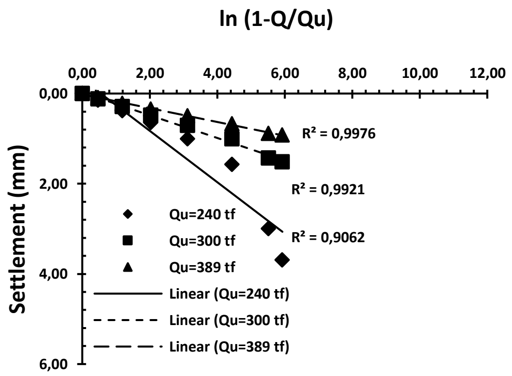

Figure 7. Bearing capacity for pilot pile using Van der Veen [9].

The load capacity was estimated through semi empirical methods, which use the results of the SPT of the construction site. Figure 8 shows the summary of the load estimates results found for Site 1, using only the maximum values when calculating by the semi-empirical method of Aoki and Velloso [10] and in the method proposed by Antunes and Cabral [11], comparing them with Van der Veen [9] reference values.

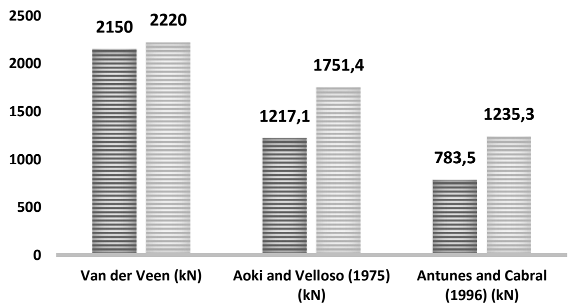

Figure 8. Comparative graph of the results obtained for P-26 and P-28.

On-site 1, the comparison between the values obtained by the load tests were extrapolated by the Van der Veen [9] since failure wasn't reached. The values estimated by the semi-empirical methods pointed out that in the pile number 2 (P-28) there is a good correlation between estimated values. The estimated value by the semi-empirical method of Aoki and Velloso [10] is 21% lower than the reference value. For pile number 1 (P-26), there is a very marked difference in estimates, approximately 43% lower for the same comparison. By applying the same process and comparing the reference values with the estimation obtained by the semi-empirical method of Antunes and Cabral [11], it was observed that for pile number 1 values were 44% smaller, while for pile number 2 difference is even greater, with values over 60% lower, both when compared to the reference values obtained by the Van der Veen [9] method.

Figure 9 shows the summary of the results of the load capacity estimates from Site 2, for the pilot pile. Since they also didn’t reach failure, the values obtained by the load tests were extrapolated by the Van der Veen [9] method. Comparing the load tests values and the values estimated by the semi-empirical methods, it was observed that the difference between the estimation by the semi-empirical method of Aoki and Velloso [10] and the reference value is equal to 22%, while for the Antunes and Cabral [11] method the value difference was 43% lower for the same pile.

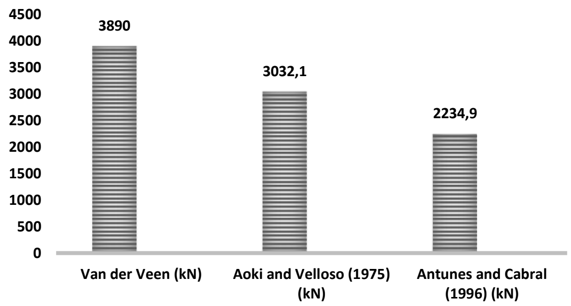

Figure 9. Comparative graph of the results obtained for pilot pile.

4. Conclusion

Lopes and Velloso [12] proposed some methods for forecasting the bearing capacity\ of continuous flight augers piles, such those created by Aoki and Velloso [10] and Antunes and Cabral [11]. These methods were evaluated by comparing around 100 load tests. The results of this evaluation showed that the Aoki and Velloso [10] methods presented safe predictions for failure loads up to about 2.500 kN (250 tf.). The Antunes and Cabral [11] method gave reliable estimates until higher failure loads.

This work pointed that the results obtained by the semi-empirical method of Aoki and Velloso [10] presented load estimates more approximate from the reference values of Van der Veen [9], both for values below and over the 2.500 kN load, which was the case for the Paracuru wind farm, disagreeing with the assessment made by Lopes and Velloso [12]. It is noteworthy that the Antunes and Cabral [11] method was specially created for the case of continuous flight augers piles, and the Aoki and Velloso [10] methods were adapted to estimate the bearing capacity of this type of foundation.

This can be explained by the value variation of some soils evaluated by each method. While Aoki and Velloso [10] have parameters obtained from testing on 15 different soil types, the Antunes and Cabral [11] method use data from only 3 soil types. Since the calculations of each method are based on SPT values, the soil type will directly influence the load capacity calculations.

Another fact that can influence the load estimation in both methods is the way the SPT is executed. As it is a test with a large percentage of inaccuracy, it can be inferred to it the responsibility of the significant differences in the values obtained in the load estimation by semi-empirical methods, as the existence of several criteria makes it difficult to determine an objective value for the failure load through load test results, however, coherently interpreted load tests are still the most reliable way to obtain pile capacity.

Since this study was carried out in only two sites in the city of Fortaleza, it is not convenient to certainly state the existence of a pattern in load prediction for piles that haven't failed. Therefore, it is suggested for future works that the study be expanded to include a greater number of sites, types and dimensions of foundation piles, thus being able to represent better the possible situations encountered.

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