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Prediction of uplift and compression bearing capacity of screw piles in saturated sand

Prévision de la capacité de charge en compression et en soulèvement des pieux vissés dans le sable saturé

D.K. Andreasen*, A.K. Koteras, L.B. Ibsen
Aalborg University, Aalborg, Denmark
*dka@build.aau.dk

ABSTRACT: Accurate determination of bearing capacity for screw piles remains an unresolved challenge. Previous research has predominantly concentrated on uplift capacity equations for helical anchors, with limited focus on compression capacity. This study aims to assess and adapt existing methodologies for determining the bearing capacity of screw piles, accounting for the distinct geometrical features, and applying them to both uplift and compression capacities. Additionally, Cone Penetration Test (CPT)-based methods are investigated for their applicability in this context. The research methodology entails reviewing current bearing capacity determination methods, modifying them to accommodate the unique screw pile geometry, and analysing CPT-based approaches. Static load tests are conducted at Aalborg University's laboratory to obtain reference static bearing capacities. Comparisons are drawn between the outcomes of the adapted earth pressure theory-based and CPT-based methods and the lab-obtained static bearing capacities. The results indicate that the existing framework is inadequate and unreliable for determining the uplift and compression bearing capacity of the screw piles investigated. The study highlights the necessity for further research and development of novel methodologies to enhance the accuracy of screw pile bearing capacity predictions.

RÉSUMÉ: La détermination précise de la capacité portante des pieux vissés reste un défi non résolu. Les recherches antérieures se sont principalement concentrées sur les équations de capacité de soulèvement pour les ancrages hélicoïdaux, avec une attention limitée à la capacité de compression. Cette étude vise à évaluer et à adapter les méthodologies existantes pour déterminer la capacité portante des pieux vissés, en tenant compte des caractéristiques géométriques distinctes, et à les appliquer aux capacités de soulèvement et de compression. En outre, les méthodes basées sur le test de pénétration du cône (CPT) sont étudiées pour leur applicabilité dans ce contexte. La méthodologie de recherche comprend l'examen des méthodes actuelles de détermination de la capacité portante, leur modification pour tenir compte de la géométrie unique des pieux vissés, et l'analyse des approches basées sur le CPT. Des essais de charge statique sont effectués au laboratoire de l'Université d'Aalborg pour obtenir des capacités portantes statiques de référence. Des comparaisons sont établies entre les résultats des méthodes adaptées basées sur la théorie de la pression des terres et basées sur les CPT, et les capacités de charge statique obtenues en laboratoire. Les résultats indiquent que le cadre existant est inadéquat et peu fiable pour déterminer la capacité portante de soulèvement et de compression des pieux vissés étudiés. L'étude souligne la nécessité de poursuivre les recherches et de développer de nouvelles méthodologies pour améliorer la précision des prévisions de capacité portante des pieux vissés.

Keywords: Screw piles; analytical methods; CPT-based methods; experiments.

1 INTRODUCTION

Screw piles have historically been used for sustaining tension loads with minimal focus on the compressive bearing capacity. To introduce screw piles into the housing market, it is a necessity to study their behaviour under compressive loading. Screw piles are steel piles with different configurations with varying diameters of hollow, tubular shaft and thread sizes. The screw piles studied in this paper are illustrated in Figure 1. The threads are welded on with a constant pitch. Furthermore, the threads are continuous and therefore a special case of previously studied helical piles (Das and Shukla, 2013). The study of bearing capacities in this paper is based on experiments performed at Aalborg University 'Sand Box' with the dimensions of 4.4 x 2.5 x 3.2 meters and a hydraulic multi-purpose robot.

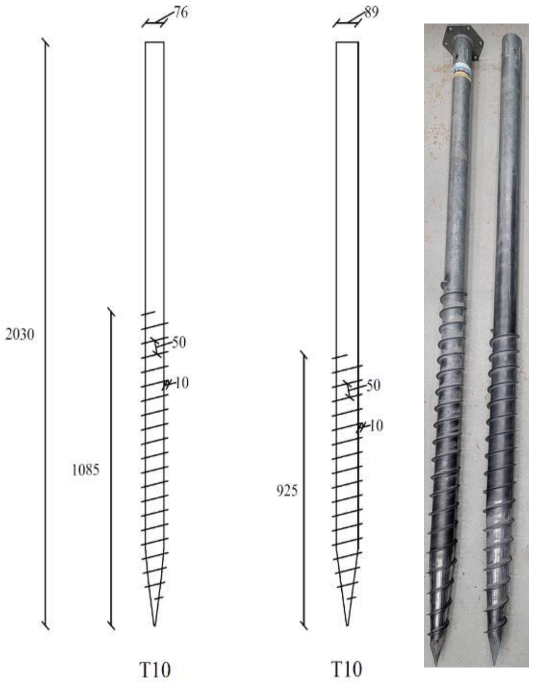

Figure 1. Screw piles used at Aalborg University with geometries in [mm] on the left.

2 EXPERIMENTS

The experimental procedure is separated into different steps which are described in the following subsections. The experiments are carried out in saturated silica sand where Aalborg Sand No. 1 is used with parameters listed in (Nielsen and Nielsen, 2018).

2.1 Soil preparation

For testing the soil in the 'Sand Box' the soil must be able to be returned to initial conditions, this is achieved by liquefaction using pumps to generate a water gradient sufficient to subdue the generated stresses through compaction of the soil. Subsequently the soil is vibrated in a pattern to achieve uniform soil conditions which is ensured by performing small cone penetration tests (CPT's) and to minimize the boundary effects which arise from vibrating the soil.

2.2 Cone penetration test

To verify the uniformity of the soil conditions, before performing the installation and testing of the screw piles, six CPT's are conducted at six different positions in the 'Sand Box'.

2.3 Installation

The installation is controlled to ensure reliable and reproducible results. Furthermore, to minimize soil disturbance the screw pile is installed with a rate of one pitch per rotation which equivalently was used in previous studies of screw piles (Ghaly and Hanna, 1991).

2.4 Static load testing

The method for determining bearing capacities is carried out using a displacement-controlled static load test performed with a hydraulic piston.

2.4.1 Tensile load test

The pile is subjected to a tensile load, during the test load and displacements are measured. Failure during the tensile load test is determined as the point at which a sudden drop in the exerted tensile load occurs. This is equivalent to the maximum tensile load during the test.

2.4.2 Compression load test

The compression load test is started, and the load and displacement are measured, the displacement-controlled test is loaded until 100 mm with unloading at 50 mm. The compressive bearing capacity is determined at 50 mm and D/10 of displacement based on experience from load-displacement curves.

2.5 Extent of experiments

In this paper, the results of 6 tensile tests and 28 compressive tests are studied. Two different pile configurations are illustrated in Figure 1 and the geometrical sizes are given in Table 1.

Table 1. Geometrical sizes of studied screw piles.

Pile Name	Diameter [mm]	Thread size [mm]	Pitch [mm]
D76T10	76	10	50
D89T10	89	10	50

The tests were carried out in different relative densities varying from 41% to 97%.

3 METHODS

Different methods for determining the uplift and compressive static bearing capacities are investigated and adapted to the geometry of the screw piles shown in Figure 1. The bearing capacities are studied by two solution approaches, both analytical methods and CPT-based methods.

3.1 Analytical methods

In this paper, two analytical methods are investigated. Firstly, the Mitsch and Clemence method (M&C method) is studied which is based on the failure mechanism of cylindrical shear (Mitsch and Clemence, 1985). Originally this method was developed for predicting the uplift capacity of helical anchors however, it is modified to account for compressive loading by introducing the bearing capacity factor instead of the uplift capacity factor (Mohajerani, Bosnjak and Bromwich, 2016). The other analytical method studied is a further development of the Mitsch and Clemence cylindrical shear method where Perko's method is derived from soil pressures and static solution, unlike Mitsch and Clemence theory, which is based on failure lines and a kinematic solution (Perko, 2009). The main factors studied by Mitsch and Clemence are the coefficient of lateral earth pressure and friction angle, where Perko's method is more focused on the ultimate bearing pressure and soil shear strength (Perko, 2009) (Mitsch and Clemence, 1985).

3.2 CPT-based methods

Similarly, to analytical methods, different CPT-based methods have been studied. In this paper, four different methods have been investigated. Firstly, the LCPC method which is calibrated for drilled, driven, and cast screw piles which are reliable for complex layered soils. However, this is not considered as a stand-alone method consequently supplementary for analytical methods (Perko, 2009). Secondly, the ICP-05 method which is developed for large-diameter driven tubular piles in very dense sands, is common in offshore structures. The failure is studied as local shear failure using the Coulomb criterion (Jardine, Merritt and Schroeder, 2015). The NGI-05 method is developed for driven piles in sandy soils and uses empirical factors to determine the ultimate skin friction. Furthermore, a triangular distribution of soil pressures with depth, and homogeneous soil deposits is assumed (Clausen, Aas and Karlsrud, 2005). The last CPT-based method studied is the UWA-05 method which similarly to the other methods are developed for driven piles. However, the UWA-05 method is based on siliceous sands and the pile having a large diameter (Lehane, Schneider and Xu, 2007).

3.3 Adaptations

The adaptations of the methods are mainly based on geometrical differences. The LCPC method is similarly to the analytical methods adapted primarily to the geometrical part. However, the other CPT-based methods do not have the same degrees of freedom and thereby the geometrical difference is not capable of being captured. Furthermore, the CPT-based methods are developed for driven piles which differs significantly from the installation procedure of the screw piles studied in this paper and therefor is suspected to yield unfavourable results. Thereby the screw piles are assumed to be tubular and hollow piles for the CPT-based methods.

4 RESULTS

Based on the adaptation of the analytical and CPT-based methods the uplift and compressive static bearing capacities are determined. To quantify the precision of these models a percentage level of exceedance (PLE) has been chosen to represent the credibility of the studied methods, which is determined by Equation (1).

$$PLE = \left(\frac{Q_{theory} - Q_{measured}}{Q_{measured}}\right) \cdot 100 \qquad (1)$$

where Q_{theory} (kN) is the calculated bearing capacity based on the methods, $Q_{measured}$ is the measured bearing capacity that is derived from the static tests. Based on all the experiments the percentage level of exceedance has been calculated and shown in Figure 2 for tensile bearing capacity and Figure 3 for compressive bearing capacity.

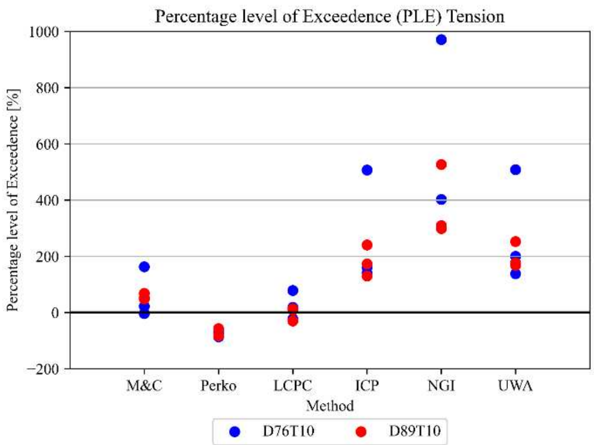

Figure 2. Percentage level of exceedance from tensile tests. Red indicates the results for the D89T10 pile, and blue indicates the results for the D76T10 pile.

5 CONCLUSION

Based on the results shown in Figure 2 and 3 it can be concluded that the current framework is inadequate for reliably predicting the bearing capacity of the screw pile configurations studied at Aalborg University. In compression, the variation in predictions is significant, which indicates the reliability of the results is low however, the Perko method indicates the lowest deviation of results, which is indicative that it consistently predicts wrong. For tensile bearing capacities, it is shown that most of the CPT-based methods overpredict the uplift capacity significantly, whereas the NGI-05 method, in the worst case, has a percentage level of exceedance of 970%. However, the Perko method shows relatively low scatter, which indicates that this is the most consistent method for both uplift and compression. Furthermore, most methods underpredicts the compressive bearing capacity and over predicts the uplift bearing capacity. In conclusion the current framework is not sufficient to determine the bearing capacities of the screw piles used at Aalborg University and thereby, further adaptations or developments are required.

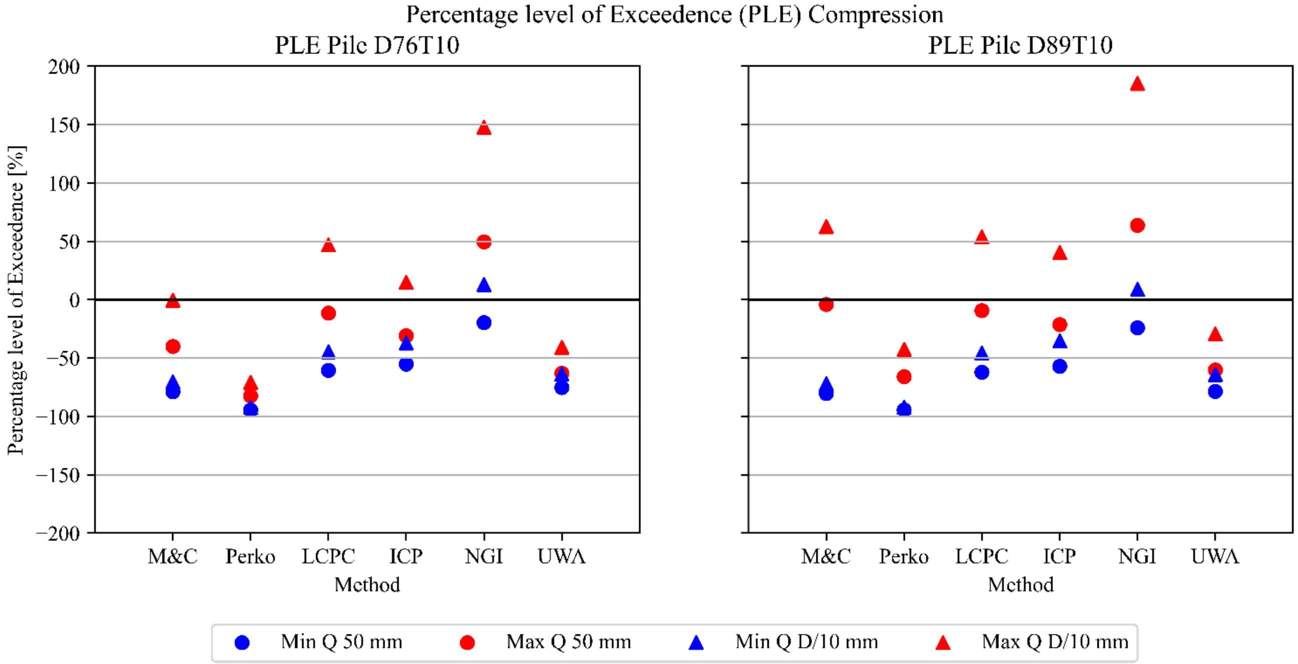

Figure 3. Percentage level of exceedance from compression tests. Red indicates the maximum value of PLE and blue indicates the minimum value of PLE. Triangles and circles indicate the two different definitions of failure at D/10 mm and 50 mm respectively.

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