Proceedings of the XVIII ECSMGE 2024
GEOTECHNICAL ENGINEERING CHALLENGES
TO MEET CURRENT AND EMERGING NEEDS OF SOCIETY

ISBN 978-1-032-54816-6
DOI 10.1201/9781003431749-32

Evaluating the reliability of existing methods for predicting installation torque of screw piles in saturated sand: A comparative study

Évaluation de la fiabilité des méthodes existantes pour prédire le couple d'installation des pieux à vis dans le sable saturé: Une étude comparative

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ABSTRACT: Screw piles have been the subject of extensive research, with various methodologies proposed to predict installation torque from earth pressure theory-based and Cone Penetration Test (CPT)-based perspectives. Accurate prediction of installation torque is crucial for determining the required equipment, assessing the suitability of screw piles as a foundation solution, and ensuring that the pile material does not yield under the installation torque necessary for a specific installation depth. This study aims to modify existing methods and adapt them to the unique geometry of the screw piles investigated at Aalborg University. The methodologies compared in this study are based on experiments in saturated sand carried out at the laboratories at Aalborg University. The results indicate that earth pressure theory-based approaches provide more consistent outcomes, while CPT-based methods exhibit greater scatter. Consequently, it is concluded that current methods for predicting installation torque are unreliable, necessitating further research.

RÉSUMÉ: Les pieux vissés ont fait l'objet de recherches approfondies, avec diverses méthodologies proposées pour prédire le couple d'installation à partir de la théorie de la pression terrestre et de l'essai de pénétration au cône (CPT). Une prédiction précise du couple d'installation est cruciale pour déterminer l'équipement nécessaire, évaluer l'adéquation des pieux vissés en tant que solution de fondation et s'assurer que le matériau du pieu ne cède pas sous le couple d'installation nécessaire pour une profondeur d'installation spécifique. Cette étude vise à modifier les méthodes existantes et à les adapter à la géométrie unique des pieux vissés étudiés à l'Université d'Aalborg. Les méthodologies comparées dans cette étude sont basées sur des expériences dans du sable saturé réalisées dans les laboratoires de l'Université d'Aalborg. Les résultats indiquent que les approches basées sur la théorie de la pression des terres fournissent des résultats plus cohérents, tandis que les méthodes basées sur les CPT présentent une plus grande dispersion. Par conséquent, il est conclu que les méthodes actuelles de prévision du couple d'installation ne sont pas fiables et qu'il est nécessaire de poursuivre les recherches.

Keywords: Screw piles; earth pressure; CPT; experiments.

1 INTRODUCTION

The common practice for installing piles in soil, is driving piles or bored piles however, for screw piles the installation procedure is different since it is being inserted into the ground by rotation and in some cases exerted an axial force. Due to the difference in installation methods, it is essential to understand the effects of rotating the pile down into the soil and how to minimize the soil disturbance during installation. Here (Ghaly and Hanna, 1991) suggested an installation rate of one pitch per rotation, which is an indication of the influence of the pile geometry on the disturbance of the soil. This effect is similar to that experienced through boring holes.

Prediction of installation torque is a necessity for ensuring a safe and reliable installation of screw piles in different soil conditions. This paper seeks to compare existing methods for predicting the installation torque based on full-scale laboratory testing in the 'Sand Box' at Aalborg University. The test setup is 4.4 x 2.5 meters and 3.2 meters in depth.

2 EXPERIMENTS

The full-scale laboratory test conducted in this study is performed on six different pile geometries, where a principle sketch is illustrated in Figure 1.

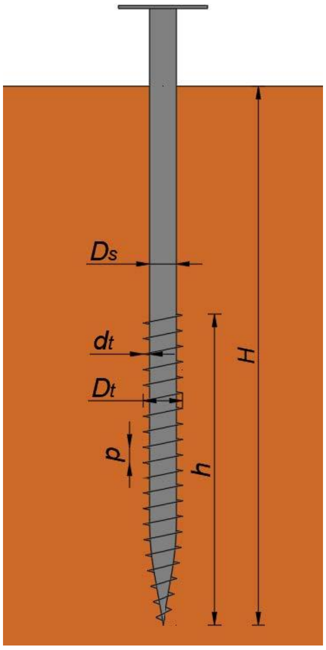

Figure 1. Principle sketch of screw piles used at Aalborg University.

For all piles, the installation depth, *H*, is kept constant at 1.7 meters and the pitch, *p*, for all pile configurations are the same, 50 millimetres and the thickness, *t*, of the steel is 5 millimetres and finally, the threaded length, *h,* is 1 meter. The geometrical sizes of the screw piles are listed in Table 1. The naming of the piles is based on the diameter, D, and the thread size, T.

Table 1. Geometrical sizes of studied screw piles.

Pile Name	D_s [mm]	d_t [mm]	D_t [mm]
D76T10	76	10	96
D76T20	76	20	116
D89T10	89	10	109
D89T20	89	20	129
D115T20	115	20	155
D140T20	140	20	180

2.1 Preparation of the Sand Box

Before installation of the screw piles, the test set-up must be prepared for desired soil state. This is carried out by liquefying the soil and reverting it back to the loosest state, which subsequently is vibrated to the desired soil state. The vibration of the saturated sand is carried out in a manner to minimise boundary effects and obtaining relative densities of approximately 50%, 70% and 85%. The soil state is investigated with small cone penetration tests (CPTs), where six CPTs, at different locations in the Sand Box, are performed to study the uniformity of the prepared saturated sand.

2.2 Installation

The screw piles are installed at the desired positions by applying torque with a steady rate of one pitch per rotation minimising the soil disturbance (Ghaly and Hanna, 1991). During installation, the installation torque and depth are measured with a torque measurement device and LiDAR measurements. The output of the installation is an installation curve, which is illustrated in Figure 2 for a D89T10 pile.

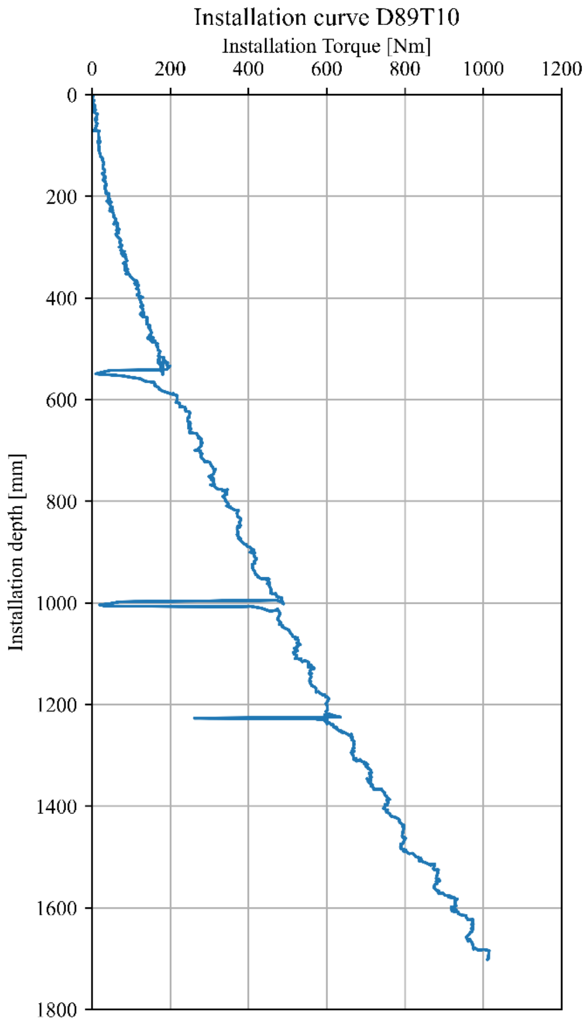

Figure 2. Example of installation curve of a D89T10 pile.

The installation torque, which is determined from the installation curve, is taken as the mean torque over the last rotation, which alleviates some of the uncertainty associated with the measurement, such as observing a spike in the torque.

2.3 Extend of experiments

In this paper, a sample size of 64 piles is studied however, some are regarded as outliers and thereby neglected when evaluating the studied methods. Three piles were omitted due to the following reasons:

- Unexpected low torque measurements, the measuring device failed.
- Abrupt change in installation speed and, thereby greater disturbance of soil

Thereby, the sample size was reduced to 61 piles.

3 METHODS

Predicting the installation torque is evaluated based on different methods where two different approaches are studied, earth pressure-based methods and CPT-based methods, respectively. The older methods were based on earth pressure theory, whereas newer studies have been based on CPT measurements. The following methods have been adapted in accordance with the screw pile geometries illustrated in Figure 1 and listed in Table 1.

3.1 Earth pressure-based methods

Two earth pressure-based methods are investigated. The original approach defined by Ghaly and Hanna was based on a single-pitch helical pile and is a summation of resisting torque contributions from the earth pressure which occur during installation (Ghaly and Hanna, 1991). Later the Ghaly and Hanna method was modified by Sakr with the same considerations with respect to torque contributions of earth pressures occurring during installation (Sakr, 2015). The difference between the two methods lies in the stress analysis where Ghaly and Hanna use total stresses and Sakr studies effective stresses.

3.2 CPT-based methods

Newer approaches are based on utilization of CPT measurements where three different CPT-based methods are studied in this paper. Tsuha and Aoki proposed a model for deep helical piles in sand based on the assumption that the installation torque consists of a resisting moment acting on each helix in conjunction with a moment acting on the shaft (Tsuha and Aoki, 2010). Further development of Tsuha and Aoki's method was done by Gavin who correlated both contributions of the installation torque to CPT measurements and thereby it will be the Gavin method which will be evaluated (Gavin et al., 2013). The prediction of installation torque was further investigated by Al-Baghadi. Initially, the method was modelled for straight shafted piles with two contributions to the installation torque from the shaft and the base of the pile. Later the model was expanded to govern single helix piles with an additional contribution from the helix (Al-Baghadi et al., 2017). Lastly Davidson altered some of the contributions from (Al-Baghadi et al., 2017) and introduced an additional contribution from a helix angle (Davidson et al., 2018).

3.3 Adaptations

The adaptations of the methods are mainly based on geometrical differences since they were developed for single helix piles, thereby the contribution from each helix is summed excluding the first and last helix which will have contributions from the base and leading edge.

4 RESULTS

Based on the adaptation of the earth pressure and CPT-based methods installation torque is calculated. The predicted installation torque based on the described methods is compared to the measured torque. To evaluate the method's accuracy and reliability the predicted torque is plotted against the measured torque and results for all the methods are illustrated in Figure 3. Here it is shown the method proposed by Gavin significantly overpredicts the installation torque and shows great scatter at higher values of the installation torque. For quantifying the reliability and accuracy of the methods linear regression has been performed on all methods with the intersection being zero due to no torque should be predicted when no installation torque is being measured the results of the linear regression are listed in Table 2.

Table 2. Results of linear regression for all methods.

Method	**Regression fit slope**	R^2
Ghaly and Hanna	0.607	0.946
Sakr	2.567	0.898
Gavin	8.998	0.887
Al-Baghadi	1.809	0.882
Davidson	2.052	0.883

For an ideal fit, the regression fit slope should be equal to 1 which indicates that the methods predict the experimental measurements. The Ghaly and Hanna method has the highest R^2-value which stipulates that the reliability of the earth pressure-based method is a more consistent predictor of the installation torque for the screw piles studied at Aalborg University. Generally, the earth pressure-based methods indicate that they are more consistent in comparison to the CPT-based methods.

To compare and evaluate the two different methodologies one method has been chosen to represent the different approaches. For the earth pressure-based methods, Ghaly and Hanna are chosen due to the higher R^2-value however, the slope is below 1 which indicates that it underpredicts the installation torque. Contrary to the earth pressure-based method the CPT-based methods overpredicts the installation torque since all slopes are above one, the chosen representative method for CPT-based methods is Davidson. The two representative methods are illustrated in Figure 4 where the regression line and ideal line are added Here it becomes apparent that the Ghaly and Hanna method is the most accurate and consistent method. This is attributed to the theoretical approach from the earth pressure theory and is furthermore, better at predicting installation torque at greater torque measurements where Davidson method shows greater scatter which is further indicated by the lower R^2-value.

5 CONCLUSION

Based on the results depicted in Figure 3-4 and the results from the linear regression listed in Table 2 it can be concluded that existing methods accuracy of predicting the installation torque is inadequate, however, the method shows consistent results which is indicated by the R^2-value. Thereby, the reliability in terms of consistency of existing methods are acceptable. Regarding the overall reliability of existing methods further studies are necessary to achieve a sufficient and adequate method for predicting installation torque for the screw piles studied at Aalborg University.

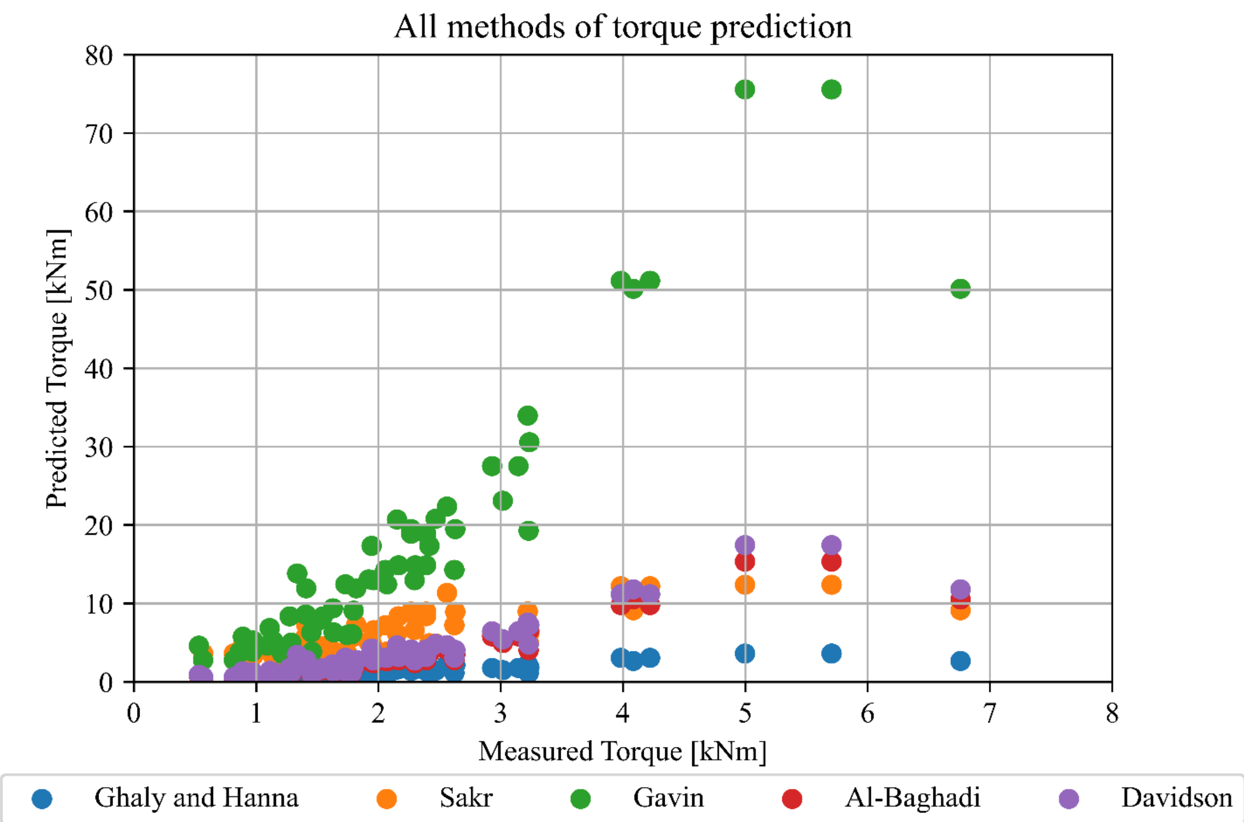

Figure 3. All methods illustrated with predicted and measured torque.

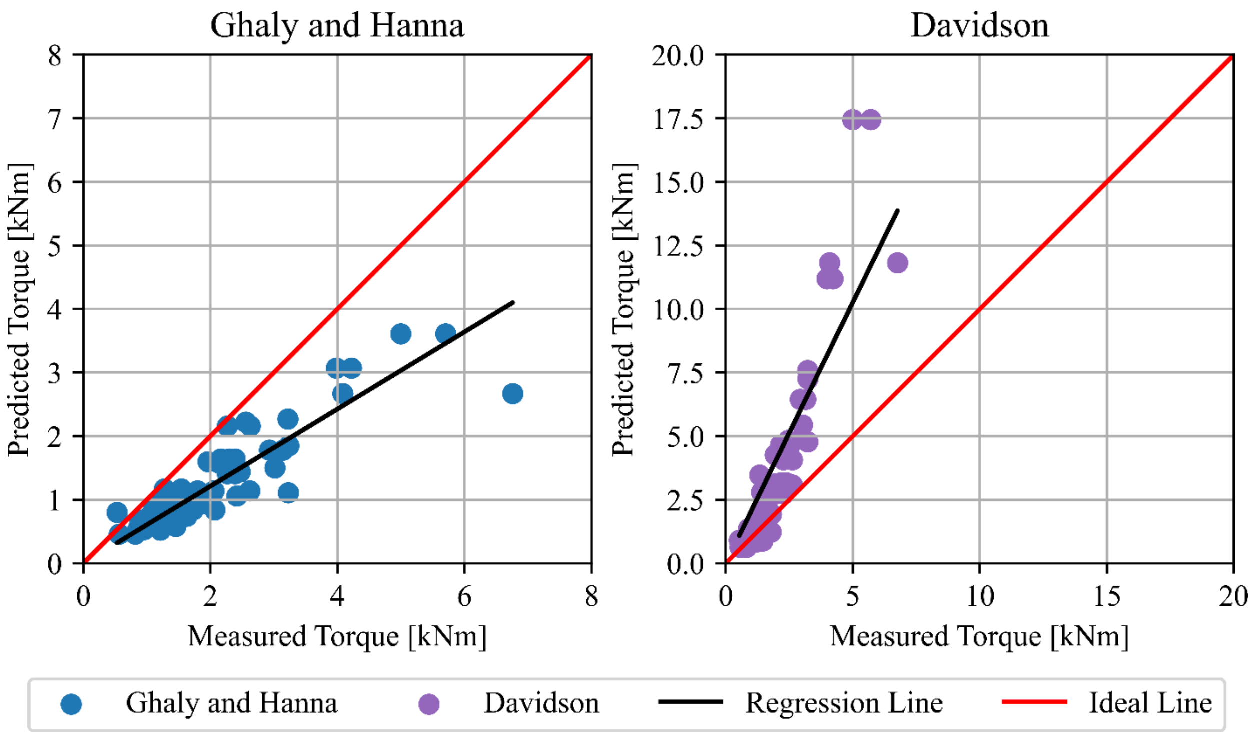

Figure 4. Chosen methods illustrated with predicted and measured torque.

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