EFFECTS OF INSTALLATION ON THE CAPACITY OF HELICAL ANCHORS IN CLAY

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INTRODUCTION

Helical anchors, also known as helical piles, screw anchors or screw piles, are foundations consisting of one or more helical plates affixed to a central shaft, as shown schematically in Fig. 1. Advantages of helical anchors over other types of foundations derive from the method of installation, which involves screwing the anchor into the soil from the ground surface (Fig. 2). These advantages include cost effectiveness, capacity to resist loads immediately after installation, little or no vibration during installation, low weight of construction equipment, and ease of installation in adverse conditions. Helical anchors can be used in both tension (uplift) and compression (bearing), and they can be used to stabilize a variety of onshore and offshore structures, including transmission towers, retaining walls, pipelines, manifold platforms and pump jacks.

In attempting to predict the load-carrying capacity of helical anchors, a basic question arises as to how much the installation process affects the soil. Namely, the extent to which installation alters the soil strength is largely unknown. As the helices twist within the ground, a zone of deformed soil surrounding the blades and the shaft is created. This disturbed region contains subzones with different degrees of remoulding due to passage of the helices. Consequently, the capacity of the anchor will be affected. Although disturbance plays a role for all soil types, it is expected to play a particularly significant role for clays, which display wide variations in strength depending on the initial state and loading conditions.

Existing theoretical approaches consider an idealised problem in which the anchor appears at its final embedment depth, and such an assumption may be fully acceptable provided representative values that account for disturbance are selected for the soil strength parameters. However, little to no guidance is given as to how to evaluate the soil strength. On the other hand, the field verification method known as torque-capacity correlation implicitly accounts for installation effects by relating capacity directly to the installation torque. This relationship is typically expressed as

$$Q_u = KT_f \qquad (1)$$

where Q_u is the ultimate uplift or bearing capacity, K is the so-called torque correlation factor, and T_f is the final installation torque, averaged over the last several revolutions of the anchor. A major drawback of this method is that the uplift capacity cannot be calculated until after installation. Also, from the wide range of torque correlation factors reported in the literature, most of which have been determined empirically, it can be understood that the major factors affecting the correlation are unknown. While some quantity of data is available for sands, relatively little is available for clays.

The overarching goal of this study is to shed light on the effects of installation on the ultimate capacity of helical anchors, focusing primarily on uplift in clays. Analytical, numerical, and physical models are used to understand the three key phases involved in the physical problem: (1) the installation process itself, in which the helical anchor is twisted into the ground, (2) possible recovery of soil strength over time due to reconsolidation, and (3) failure of the soil mass during uplift.

CENTRIFUGE TESTING

Installation and uplift tests will be conducted using the beam centrifuge located at the Centre for Offshore Foundation Systems. The installation tests will be performed in flight, using torque transducers installed along the shaft to measure the installation torque. From these measurements, it will be possible to investigate the relationship between installation torque and normal force for prescribed rates of rotation and normal displacement.

Most installations occur very rapidly, and the loading is therefore undrained. As pore pressure induced during installation dissipates over time (recovery time), the strength of the soil will change. Such time-dependent effects are neglected entirely in current design methodologies. In order to study the effects of the recovery time on uplift capacity, uplift tests will be

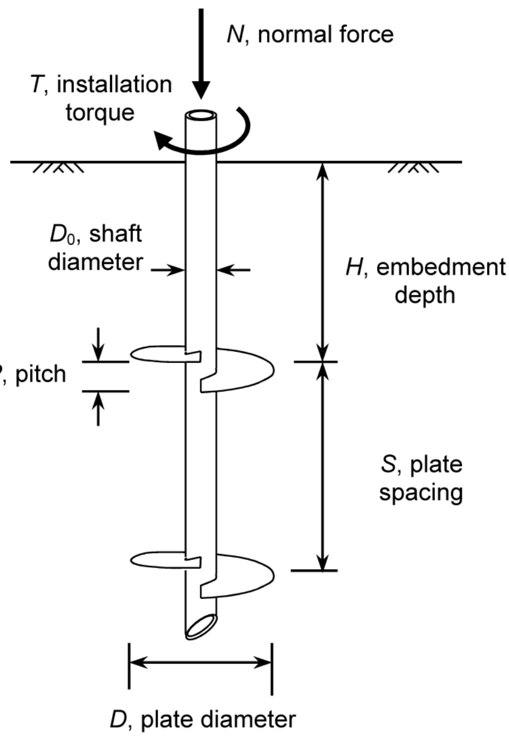

Figure 1: Schematic of helical anchor.

Figure 2: Installation of helical anchor (photo courtesy of Viking Helical Anchors).

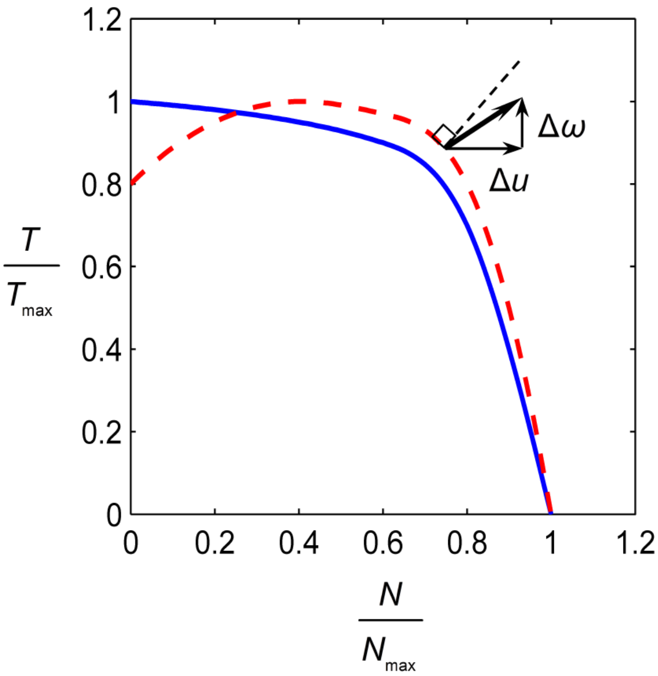

Figure 3: Qualitative relationship between installation torque and normal force.

completed at various times following installation. Also, some uplift tests on pre-embedded multi-helix anchors will be completed to establish a benchmark for the level of disturbance caused during the installation process.

INSTALLATION MODEL

The interaction between a helical anchor and soil during installation is incredibly complex, and modelling the process using conventional numerical techniques (e.g., finite element method) represents a significant challenge. In light of the difficulty, this study explores the viability of approximate analytical techniques. A preliminary model for installation based on plasticity theory for plate anchors has been developed. The predictions can be represented using the framework shown qualitatively in Fig. 3. In this figure, the installation torque T and normal force N are normalised by T_{max} and N_{max}, the maximum possible values of the installation torque and normal force, respectively. Both T_{max} and N_{max} depend on the anchor geometry and soil shear strength.

Rigid-plastic analysis predicts the solid blue curve shown qualitatively in Fig. 3, which suggests that the installation torque decreases with increasing normal force. A questionable aspect of this result is whether the relationship is in fact monotonic, or whether the installation torque increases over some range of normal force, as depicted by the dashed red line. Such an increase at low normal force is consistent with the torque-tension relationship observed for threaded fasteners (e.g., Nassar and Zaki 2009).

In a manner consistent with flow theory of plasticity, kinematics can be represented in Fig. 3 by superposing axes corresponding to the incremental rotation $\Delta\omega$ and the incremental normal displacement Δu. If one postulates associativity (normality), the normalised installation rate $p\Delta\omega/u$ is determined directly from the torque-normal envelope. However, a high degree of non-associativity is expected, as shown in Fig. 3.

The installation model provides information on the extent of the disturbed zone and magnitude of shearing experienced by the soil. In particular, the model offers a framework for assessing whether the helical anchor is under-rotated ($p\Delta\omega/u \leq 2\pi$), neutrally rotated ($p\Delta\omega/u = 2\pi$), or over-rotated ($p\Delta\omega/u \geq 2\pi$), with each scenario inducing different degrees of soil disturbance.

OUTCOMES

This study will improve the understanding of the impact of the installation process on the ultimate capacity of helical anchors, and it will lead to safer and more economical designs, as well as possible technological breakthroughs. This work will also provide a physical basis for the torque-capacity correlation given in Eq. (1), thereby potentially transforming an empirical method into an elegant method for assessing *in situ* soil strength and anchor capacity.

REFERENCES

Nassar SA, Zaki AM (2009). Effect of coating thickness on the friction coefficients and torque-tension relationship in threaded fasteners. *Journal of Tribology*, 131(2), 1-11.