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Installation Monitoring of Helical Piles and Anchors for Quality Control and Performance Verification

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Abstract

Like many other types of deep foundations, the behavior of helical piles and anchors may depend on the quality of the installation. Poor quality installation generally produces poor performance. Installation monitoring of helical piles and anchors is essential on all projects and can assist the engineer in evaluating and validating axial capacity. The installation monitoring of helical piles and anchors should be required on projects by the engineer and should be included in contract specifications as a routine part of the use of helical piles and anchors. The methodology is analogous to monitoring of other deep foundations. Key parameters for monitoring installation of helical piles and anchors include incremental torque, advance (number of rotations per unit of advance), and advance speed or rpms. Methods currently being used in the field are described and examples from several sites are presented illustrating typical results from installation monitoring and the impact of poor quality installation on behavior.

INTRODUCTION – MONITORING FOUNDATION CONSTRUCTION

One of the unique aspects of helical piles and anchors is that the installation process presents the opportunity for monitoring the progress of the installation to provide some validation of the quality of the installation and the behavior of the pile or anchor during loading. But is this aspect really unique in geotechnical engineering? In fact, in other areas of foundation construction it is now common to monitor and record installation parameters and in some cases has been in use for many years. For example, typical instrumentation for monitoring construction of auger-cast piles (ACIP) and auger-cast displacement piles (ACIPD) is shown in Figure 1. Similar technology is applicable to helical piles and anchors, except of course there is no need for measurement of grout pressure or grout volume when installing helical piles and anchors.

The installation of driven piles is often monitored using a Pile Driving Analyzer (PDA) to provide information on the relative installation resistance. In addition to using the information to provide an indication of changes in subsurface conditions, the results may also be valuable to provide an estimate of load capacity. For example, Nesmith (2002; 2003) suggested that the side resistance of ACIPD piles could be related to the energy or work exerted during installation, which makes use of the measured torque and measured rate of advance of the tooling, as shown for example in Figure 2.

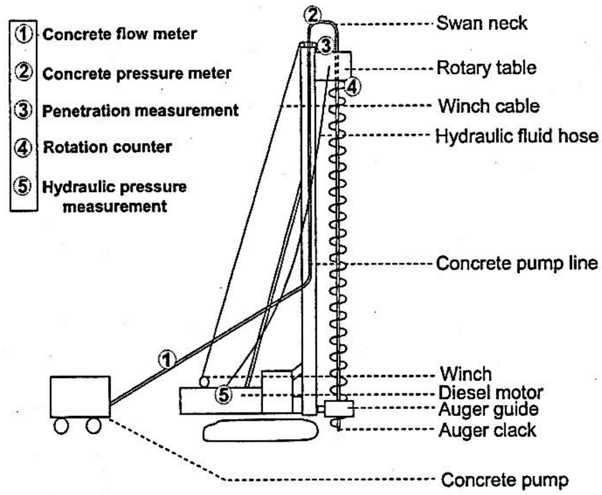

Figure 1. Typical Instrumentation for Monitoring Construction of CFA, ACIP and ACIPD Piles.

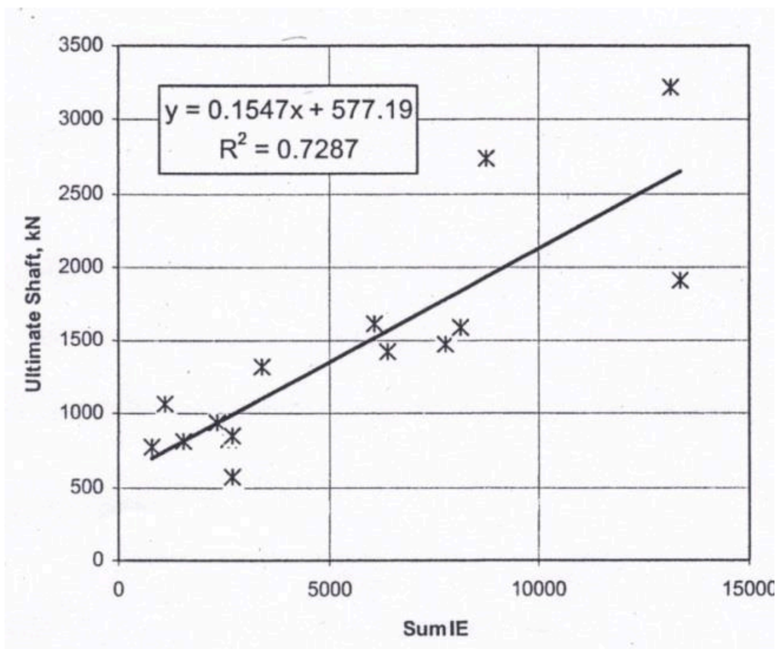

Figure 2. Relationship Between Installation Energy and Side Resistance of ACIPD Piles. (from Nesmith 2003)

Routine installation of helical piles and anchors should be no different than installation of other types of deep foundations and will provide some credibility of the technology to engineers. Monitoring the installation of helical piles and anchors should be part of the third-party inspection process that should accompany geotechnical construction, similar to footing inspection or inspection of drilled shaft construction or driven pile installation. Independent third-party inspection protects the owner and ensures that the project specifications are followed. For high quality installation of helical piles and anchors it is necessary to define specific measurements that should be obtained. This paper does not present results of an exhaustive research project. The purpose of this paper is to raise the awareness within the geotechnical profession of the importance of proper installation monitoring of helical piles and anchors by illustrating important parameters that should be monitored during installation.

REQUIREMENTS FOR INSTALLATION MONITORING OF HELICAL PILES AND ANCHORS

According to the 2015 International Building Code (IBC) the following requirements are to be included in the inspection of helical piles and anchors:

> 1508.9 **Helical pile foundations**. *Continuous special inspection* shall be performed during installation of helical pile foundations. The information recorded shall include installation equipment used, pile dimensions, tip elevations, final depth, final installation torque and other pertinent installation data as required by the *registered design professional in responsible charge*, The *approved* geotechnical report and the *construction documents* prepared by the *registered design professional* shall be used to determine compliance.

These requirements effectively provide <u>minimum</u> requirements but open the door for more stringent requirements to be implemented by the design professional. It is also implied that a geotechnical report and some form of specifications will be prepared as part of the work. An example of more stringent installation monitoring requirements is presented in the 2014 New York City Building Code:

> 1812.12 **Special inspection.** The installation of helical piles shall be subject to the special inspection requirements in Section 1704.8 and the following requirements:
>
> 1. The special inspector shall prepare a report of special inspection of helical piles, and submit each report to the department in a manner acceptable to the commissioner. In addition to the requirements of Section 1704.8, the report shall also include at a minimum the following:
>
> 1.1. Helical pile type and product specification sheet for each helical pile installed as published by the manufacturer.
> 1.2. Make and model of the equipment used for installation.
> 1.3. Make and model of the torque indicator used to measure installation torque.
> 1.4. Calibration record for the torque indicator used to install the helical piles.
> 1.5. The installation speed (rpm) of the helical pile.
> 1.6. From axial load tests and the site specific torque to capacity relationship, the minimum torque required to achieve the allowable pile load in tension or compression.
> 1.7. For each helical pile, the installation torque for each foot of depth and the final torque in the helices soil-bearing zone. The shaft advancement shall equal or exceed 85% of helix pitch per revolution at time of final torque measurement.

2. Field welds performed in the installation of a helical pile foundation system shall additionally be subject to the special inspection requirements of Section 1704.3.

These requirements provide for a much more engineering approach to installation monitoring as compared to the requirements of the IBC which are much more general and actually would not provide much usable information for evaluating the quality of the installation. In particular the requirements for measuring torque for each foot of advance and the advancement specified by the NYC Building Code provide for the engineer to quantify specific installation parameters. The requirement for measuring the installation speed (rpm) implies that the installation time must also be recorded as the advancement is measured which again will provide the Engineer with the opportunity to quantify the installation. Another important requirement of these specifications is the requirement to report the make and model of the torque measurement device and a calibration. All too often the engineer does not have this information.

In 2014, the Helical Pile and Tiebacks Committee (HPC) of the Deep Foundations Institute (DFI) published a set of Model Specifications for helical anchors. In 2015 a similar set of Model Specifications was published for helical piles. Both sets of model specifications provide recommendations for monitoring installation as follows:

A. Date and time of installation.
B. Installation equipment type and operator name.
C. Plan location of helical pile (anchor).
D. Pile (Anchor) reveal.
E. As-built helical pile (anchor) type and configuration.
F. Total length of installed pile (anchor).
G. As-built installation angle of pile (anchor).
H. Torque measurements at 1 foot intervals over the last ______ feet *(5 to 10 feet typical but not less than 3 times the diameter of the largest helix plate)* of installed length, at a minimum.
I. Effective torsional resistance and calculated geotechnical capacity based on effective torsional resistance and/or as derived from the pre-production test program.
J. Comments pertaining to interruptions, obstructions, or other relevant information.

Although not specifically stated above, elsewhere in the Model Specifications (section 7G.) the following is noted:

> "The helical pile (anchor) sections shall be engaged and advanced into the soil in a smooth, continuous manner at a rate of rotation of 5 to 25 rpm. Sufficient crowd shall be applied to uniformly advance the helical pile (anchor) sections a minimum of 80% of the distance equal to the pitch of the helix plate (*pitch is typically 3inches*) per revolution. The rate of rotation and magnitude of crown shall be adjusted for different soil conditions and depths."

This section implies that in order to monitor the installation to be compliant with the above rotation rates and advance measurements of the time and distance of advance must be taken; similar to the NYC Code. Section H only implies for monitoring over some final depth interval (to be specified by the engineer), however the author is a strong proponent of monitoring installation over the full depth of penetration.

FIELD MEASUEMENT OF INSTALLATION AND INSTALLATION PARAMETERS

Torque

One of the most important problems related to installation torque is that there are a variety of methods available and used by contractors to obtain the field measurement of torque. These methods fall into two basic categories: 1) indirect methods; and 2) direct methods.

Indirect Methods Indirect methods for measuring installation torque usually involve measurement of the hydraulic pressure applied to the torque head, as shown in Figure 3. Because of differences in hydraulics among different machines used in the field and the wide range in available torque heads, the relationship between hydraulic pressure and torque is not unique. That is, a calibration is required for each combination of machine and torque head. A complication factor involved in using hydraulic pressure is that there will generally be some back pressure on the back side (reverse) of the torque head since the system is a closed loop. The back pressure will affect the applied (forward) pressure to some degree which can lead to an error in the calibration using only applied pressure. This has led some installers to develop a differential pressure system, measuring both inflow and back pressure.

Figure 3. Examples of Indirect Torque Measurement Using Hydraulic Pressure.

Direct Methods As a contrast to indirect methods of measuring torque, direct methods involve an in line device that is placed between the torque head and the pile/anchor being installed. Typically, these devices are equipped with an internal electronic load cell and a digital readout or hand-held data logger that provides a direct measurement of torque, independent of the hydraulics of the machine and the torque head being used. These types of devices are preferred over Indirect hydraulic pressure systems previously described and should be used whenever possible. Examples of commercial direct digital readout devices are shown in Figure 4.

Periodic calibration of electronic torque devices is essential to the quality of information that they provide. There is currently no standard specifying the frequency of calibration however as a practical matter a minimum of calibration once a year might serve as a starting point. A standard should consider both time and frequency of use. The calibration should be required as a deliverable as part of the project specifications. If an indirect method is used to measure torque, a calibration of the combined system (torque head + installation equipment) should be provided. If the contractor uses the same hydraulic drive unit on different pieces of installation equipment on a project, individual calibrations should be provided.

Figure 4. Examples of Direct Torque Measurement Systems.

Speed of Rotation

Regardless of how torque is measured, one of the factors that can influence the measured installation torque but have little to no effect on the ultimate capacity is the rate of installation or rate of rotation. To illustrate how installation rate can influence the measured torque, the left hand plot given in Figure 5 shows results of installation torque measured on a round shaft triple-helix pile (73 mm dia. shaft with 203 mm, 254 mm, 305 mm helices) at two speeds at a site consisting of about 4.6 m of medium dense silty sand overlying stiff to medium stiff silty clay. Identical helical anchors were installed adjacent to each other on the same day at a distance of about 2 m using the same compact excavator, same hydraulic torque head and the same operator. The water table was at a depth of about 3.7 m at the time of the installations. Torque was measured using the direct method with a digital torque indicator.

At first glance, there may not appear to be a substantial difference in the torque measurements at the different speeds. However, the right hand plot of Figure 5 shows the % torque difference, taken as the difference between the fast speed and slow speed divided by the slow speed and expressed as a percentage. These results show that the difference can range from 0 to about 75% (one data point being negative) but in general there is an increase in measured torque with higher installation speed. It is well known that most soils are rate sensitive with shear strength increasing at higher strain rates or for example higher load capacities observed at higher loading rates for driven piles. In the author's view, the data in Figure 5 are in agreement with general soil behavior. In other soils, the difference may be greater and may also be greater as the speed is increased by the operator to increase contractor productivity on a project. It is in the interest of the contractor to install foundations as quickly as possible, but perhaps not necessarily in the best interest of the project. Higher torques might be considered to indicate stronger soil conditions and higher pile/anchor capacities, when in fact they are simply an artifact of the installation process and in this case might give a false indication of pile/anchor capacity. If an engineer is estimating helical pile capacity using torque-to-capacity correlations, the results may indicate higher capacities than are actually achievable. Of course these data represent only a single comparison and other results are needed to validate these observations. Recently however, Harnish (2015) also found that rotation rate influence torque measurements.

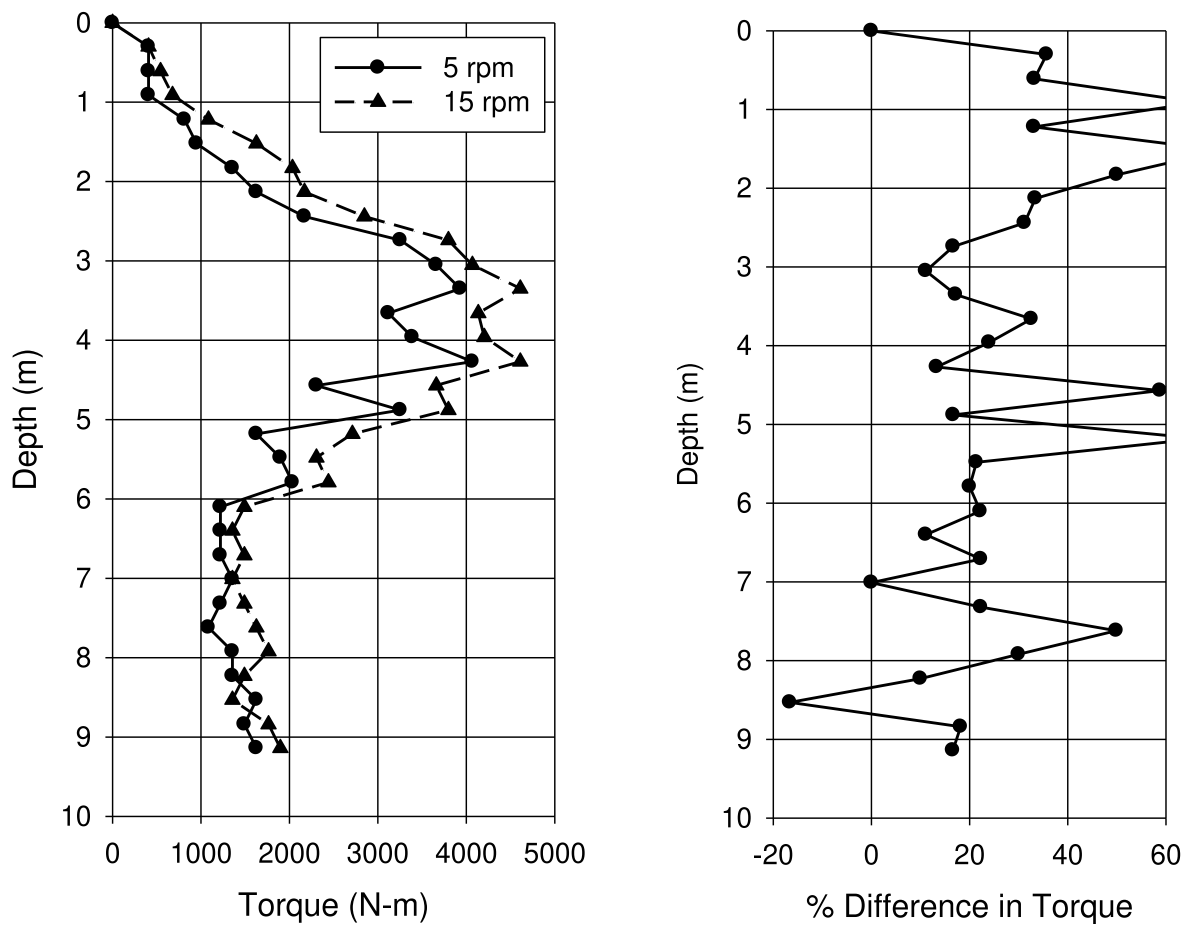

Figure 5. Influence of Rotation Rate on Measured Torque.

Advance

Ideally, the blade of a helical pile or anchor should advance one pitch length for each full revolution of the blade. This is considered ideal or best possible installation possible. So for example if the pitch of each helical plate is 76 mm then the ideal advance would be 4 revolutions per 0.3 m of advance. In the field, this is often difficult to achieve either because of the soil conditions or the equipment operator is using a rotation rate that is too fast, or a combination. Generally, slow rotation allows the lead helical plate to "dig" into the soil and advance the pile/anchor. In some cases, a small downforce or "crowd" on the shaft is needed to start the advance but once it begins, it usually progresses with little or no need to apply downforce. It is common in the field to record 4 to 5 revolutions of a 76 mm pitch helical plate for each 0.3 m of advance.

In contrast to the ideal installation described above, it is more likely that most installations occur in a more imperfect manner. That is, the number of rotations of the helical plate for each unit of advance is greater than the ideal and in some extreme cases may even approach stationary condition or no advance. Operators in the field refer to this condition as "spinout" which effectively signals when the helical plate is no longer moving. This produces substantial disturbance to the soil simply because the helical plate is now acting partially or completely as a section of auger and is in effect churning the soil. Since different degrees of imperfect installation can occur depending on the geometry of the pile/anchor and the subsurface conditions encountered by the helical plates it is not unusual in the field to record 6 to 16 revolutions per 0.3 m of advance on a 76 mm pitch helical plate as compared to 4 to 5 which is preferred. The consequence is that torque decreases and as a result of the disturbance, pile/anchor capacity decreases.

This is illustrated in Figures 6 and 7 which show installation and load test results from two side-by-side 73 mm round shaft single-helix 305 mm helical anchors. Figure 6 shows a comparison of the installation torque and the advance for the two anchors. Initially, the installation torque is the same, but after a depth of about 1.5 m it can be seen that the two anchors start to diverge. This is the result of the larger number of rotations required for the SCG anchor as compared to the P anchor. As the number of rotations increases, the torque decreases; the anchor is "augering".

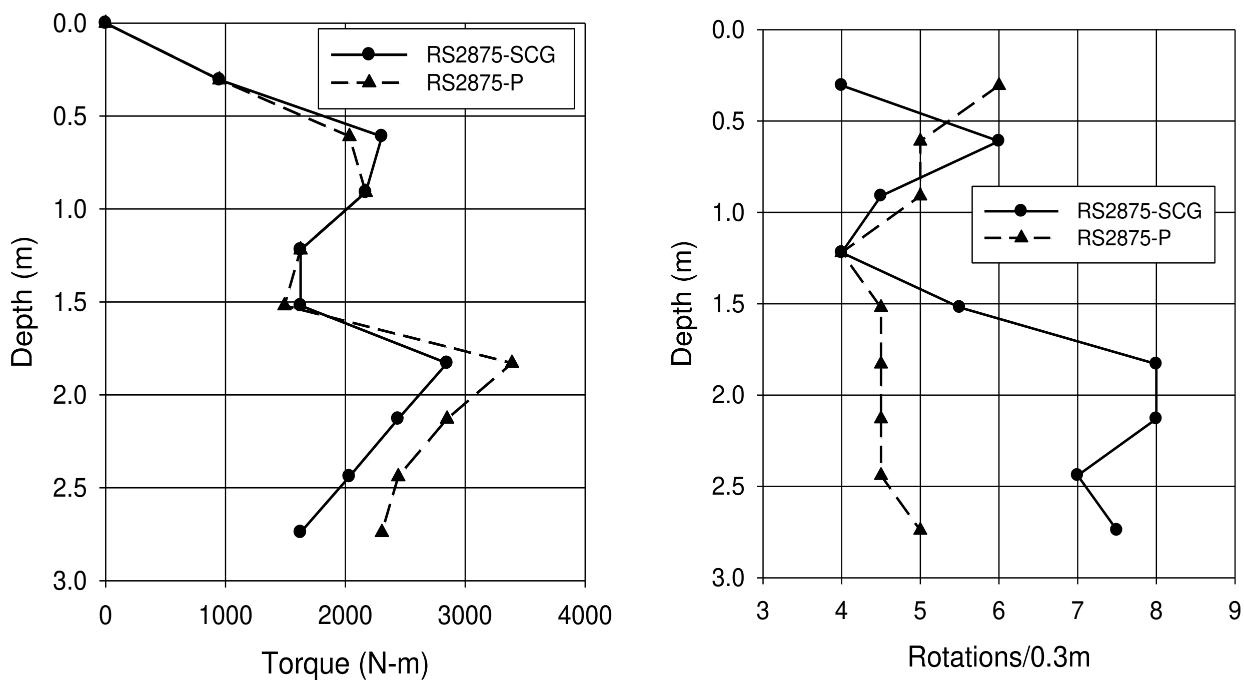

Figure 6. Installation Torque and Advance for two Round Shaft Helical Anchors.