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INVESTIGATION OF INSTALLATION TORQUE AND TORQUE-TO-CAPACITY RELATIONSHIP OF SCREW-PILES AND HELICAL ANCHORS

Mark Ruberti

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A Master of Science Project

Presented by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT:

Installation torque has been used in the design of helical anchors (Screw-Piles) since the late 1960s. K_T factors released by the manufacturer relating ultimate capacity of Screw-Piles to installation torque allow engineers to calculate a design installation torque which is necessary to achieve the design capacity in the field. These K_T factors have been based on shaft geometry alone (Hoyt and Clemence 1989). Recent full-scale uplift tests in both clay and sand have shown that the traditional methods of analysis for estimating uplift capacity based on microscale tests are not representative of macroscale behavior. A soil wedge does not fully develop in many cases and failure is a result of local bearing capacity in the soil immediately above the lead helix and side resistance along the pipe shaft. The relative contribution of these two components to the uplift capacity depends on the specific geometry of the Screw-Pile, not only the shaft geometry, but also the configuration of the helices, the soil type, and depth of embedment of the helical plate (Lutenegger 2015). Full-scale installations and load tests were performed on anchors of varying lead section geometry, shaft geometry, number of helices, soil type, and depth of embedment. Both direct (TORQ-PIN and Chance Digital Indicator) and indirect (hydraulic pressure) methods were used to monitor torque during installation. The direct methods were used to evaluate the reliability of hydraulic pressure readings and how different combinations of machine, torque head, and operator can affect the torque during installation. This paper will investigate how these factors affect K_T and also determine the factors that affect the accuracy of torque measurement in the field.

CHAPTER 1: INTRODUCTION

1.1 RESEARCH OBJECTIVES

The relationship between installation torque and uplift capacity of helical anchors, developed based solely on the shaft geometry of the helical anchor, has been used in the design of Screw-Piles since around the advent of the technology to monitor torque during installation. This research project was undertaken to determine other factors that influence this torque to capacity relationship. These factors include 1) number of helices; 2) geometry of helices (tapered vs. cylindrical); 3) soil type; 4) shaft geometry; 5) depth of embedment; and 6) aging effects. An additional objective was to determine differences, if any, between direct and indirect torque monitoring devices and to develop a relationship between torque and pressure differential measured during the installation of helical piles using different configurations of equipment. Also, speed of installation was varied to understand the difference between full-throttle and normal throttle installation.

1.2 SCOPE OF RESEARCH

63 helical anchors were installed and tested in axial uplift load tests at 2 different sites of varying stratigraphy within the Pioneer Valley from September 2014 to June 2015. Both shallow and deep helical foundations were part of the testing program, including steel helical pipes piles (HPP), steel pipe piles (PP), round-shaft helical anchors (RS), and square-shaft helical anchors (SS). In addition to initial loading tests, the majority of the piles were subjected to reload tests in order to investigate aging effects on the behavior of various foundations.

A series of trial helical installations were performed at each of the sites using two different torque heads and two different pile geometries. An RS2875 pile with lead section geometry consisting of an 8/10/12 triple helix configuration was installed to depths of 30’ to determine the variations in torque measurement obtained by using different torque heads and installation rates in varying subsurface stratigraphy.

In situ tests were performed in series with the testing regimen at each site that was used in this project from September 2014 to May 2015. Tests performed included Mini Field Vane Tests, Miniature Drive Probe Torque Tests, and Sowers Dynamic Cone Penetrometer Tests. Samples were collected for moisture contents at each location and Fall Cone Tests were conducted in the laboratory on the samples collected from the clay sites to evaluate remolded strength. The remolded strength was used to determine the relative loss of strength during installation of the helical anchors. Ground water level measurements were taken prior to load testing using a water level meter that was lowered into open standpipe piezometers located at each site.

1.3 ORGANIZATION

The work performed for this research project is presented in this report as follows:

Chapter 2 provides background information on Screw-Piles and Helical Anchors, methods of designing them, and the factors that affect the torque-to-capacity relationship. Also presented is a discussion of the findings in the recent literature pertaining to this torque correlation factor.

Chapter 3 presents the site locations, subsurface conditions, and the geology of each site on which research was conducted. In addition, results from various site characterization tests are included.

Chapter 4 details the methods of investigation used for this project. Included is a description of the in situ tests and laboratory tests performed to determine properties of the soil along with the procedure in which helical anchors were installed and tested in uplift.

Chapter 5 includes the presentation and discussion of results from the in situ tests, trial installations, and load testing regimen that was implemented as part of this project.

Chapter 6 lists the conclusions determined from the results of the research conducted and offers suggestions for continuing research to help verify the conclusions made and expand upon areas of interest related to this project that were not evaluated.

CHAPTER 2: BACKGROUND AND LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents a brief history of screw-type foundations and the typical design methods used for deep installations in both clay and sand. Also included is a literature review on the influence of torque head specifications, specifically differential pressure correlations, and factors affecting the torque correlation factor.

2.2 HISTORY OF SCREW-TYPE FOUNDATIONS

Screw-type foundations have been in use for almost 180 years, supporting a vast array of civil engineering structures from light posts to light houses. Because of their clever design, helical anchors allowed for construction projects normally thought to be unsafe or too expensive, to be completed. Since the use of helical anchors during the mid to late 1800s was so commonplace, sparse detailed documentation that is project specific can be found on the subject. This lack of information is responsible for the scarcity of technical literature on the subject of their use during this period (Lutenegger 2011). A self-proclaimed civil engineer by the name of Alexander Mitchell is credited with the invention and application of helical anchors as a solution to the problem of mooring ships to the ocean floor. The bearing plate, or helix, resists the tensile load produced by the harsh turbulence of the ocean. The design required less energy and resulted in a higher uplift capacity than its driven pile counterpart. Screws during this time period were installed using various clever methods of manually rotating the screw, allowing the torque being applied at the plate to screw the anchor into the subsurface.

Among one of these innovative method’s was Mitchell’s endless rope, shown in Figure 2.1. It allowed the men to stand on the already completed portion of the pier and install the piles sequentially from the land to the sea (Lutenegger 2011).

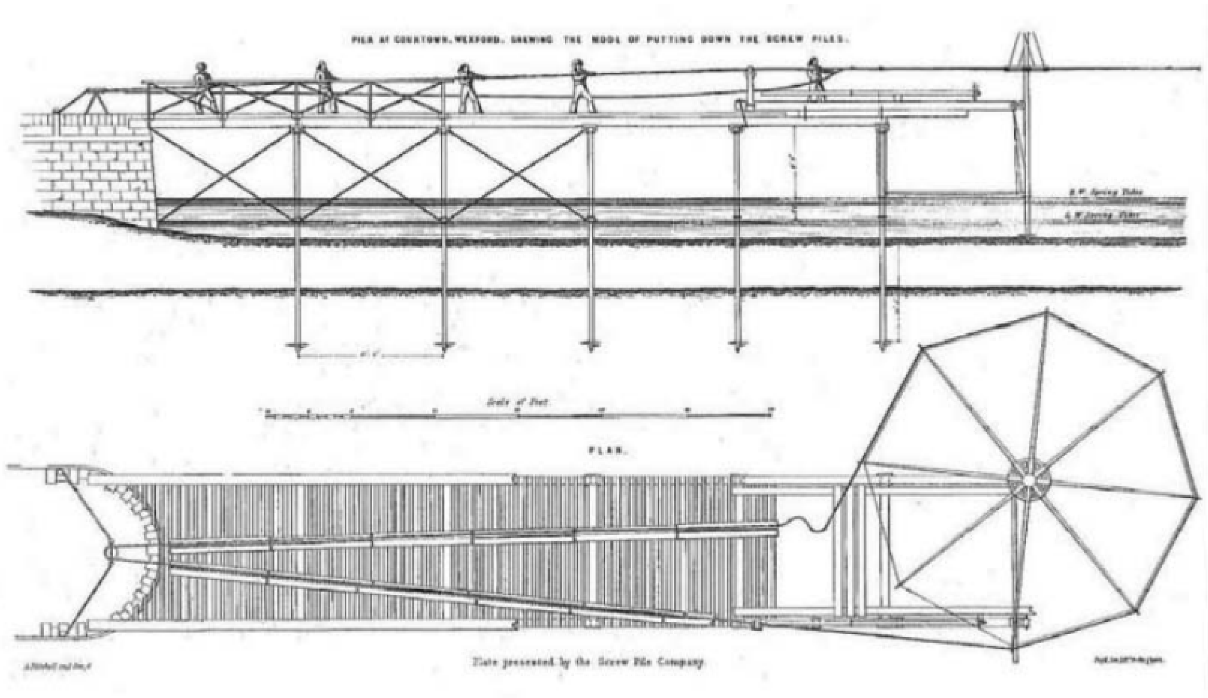

Figure 2.1 Diagram Showing Construction of Courtown Pier (Lutenegger 2011).

Today, the A.B. Chance Company, a division of Hubbell Power Systems, Inc., is the leading manufacturer of helical foundation products (CHANCE 2015). In the late 1950's, A.B. Chance Company came out with the patented PISA® (Power Installed Screw Anchors) system. This system involved all-steel components, including one or two helical plates welded to a square hub, a rod threaded on both ends, a forged guy wire eye nut, and a special installing wrench. Rods come in 5/8", ¾" and 1" diameters and installation times were boasted at 8 to 10 minutes (CHANCE 2014). Round Rod (RR) anchors came next in 1961. Although the 1-1/4" diameter shafts were sufficient in weak, surficial soils, improvements for a wider range of applications needed to be made, resulting in the development of high-torque, shaft-driven, multi-helix square shaft (SS) anchors in 1964-1965. Requirements for higher capacities and larger dimensions led to the introduction of large diameter round shaft (RS) piles. Larger diameter RS anchors of 2-7/8", 3-1/2", 4-1/2", 6", and 8" had much higher capacities and were utilized as foundations for utility substations and transmission towers. Modern technology, including hydraulic equipment, digital torque indicators, and more advanced load testing capabilities, have changed the helical anchor industry, allowing for installation and testing of screw-piles almost anywhere. Backhoes, skid-steer loaders and mini-excavators can be adapted to fit a torque head in order to install helical anchors inaccessible to the larger equipment necessary to install typical deep foundations. This versatility, coupled with new advances in helical foundation design, have led to the replacement of H-piles in solar arrays, drilled shafts for lightly loaded light posts, and concrete piers for structural deck columns (Toombs 2013). Helical anchors are now being utilized in earth-retaining systems as tie-backs and also used in underpinning residential structures to reduce settlement.

2.3 DESIGN METHODS FOR HELICAL ANCHORS

There are three main factors affecting ultimate bearing capacity of helical anchors: strength of the soil, the projected area of the helix plates which is a function of the net helix area, and the depth of embedment. Soil strength can be evaluated using a variety of field and laboratory tests. The Field Vane Test is one of the most efficient tests for directly measuring undrained shear strength in softer clays to use in the bearing capacity equation for helical anchors. This test will be described in detail in the methods section. Screw-Piles and helical anchors are classified as either “shallow” or “deep” foundations depending on the depth of embedment, measured from ground surface to the top helix, usually with respect to the average helix diameter. Various researches have defined the delineation between shallow and deep equal to between three and eight times the helix diameter. CHANCE® provides a minimum recommended embedment depth for helical piles and anchors to be five helix diameters (5D).

Two main failure modes are considered when analyzing helical anchors for ultimate capacity, which require two separate methods of analysis. For helical anchors with helix spacing greater than or equal to three times the diameter ($s/B \geq 3$), considered wide spacing, the method used is the Individual Plate Bearing Method; for close helix spacing ($s/B \leq 3$), the Perimeter Shear Method is used. These methods, which represent different modes of failure, are illustrated in Figure 2.2.

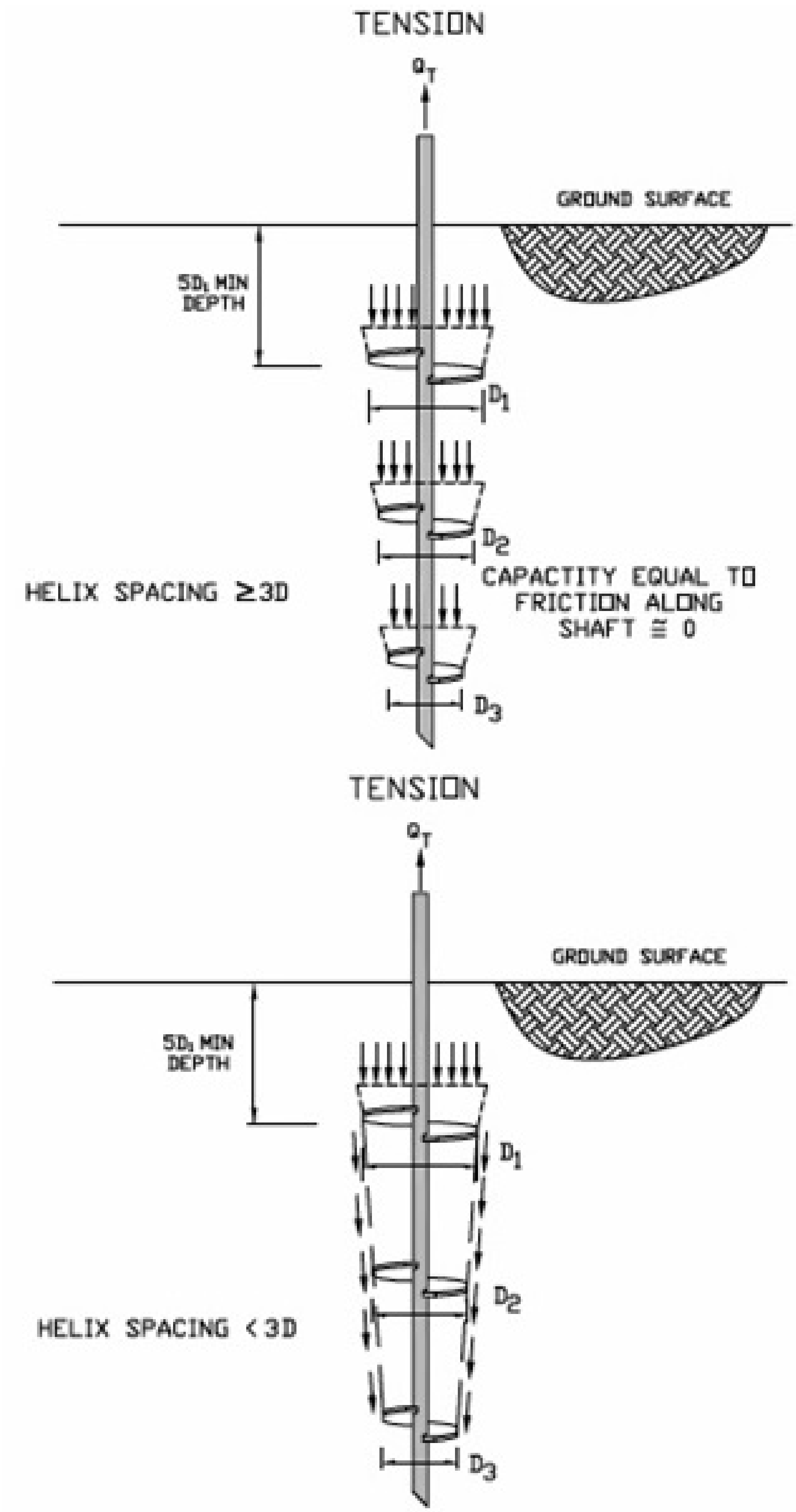

Figure 2.2 Individual Bearing and Perimeter Shear Models for Helical Piles with Slender Shafts (Chance 2015).

The Individual Plate Bearing method determines helix capacity by calculating the unit bearing capacity of tl 2.2a INDIVIDUAL PLATE BEARING lying the result by t 2.2b PERIMETER SHEAR rea. For square shaft piles, shaft resistance is neglected due to the lack of a smooth interface that develops during installation. However, round shaft piles will develop side resistance during installation and over time, and therefore needs to be considered in the calculation of ultimate capacity for this type of geometry. The Perimeter Shear Method assumes that a prism of soil will develop between the helix plates due to the close helix spacing and fail along a plane shown in Figure 2.2b.

2.3.1 Uplift Capacity of Helical Anchors in Saturated Clays

The current approach for determining ultimate capacity of a helical anchor in axial uplift is to consider the problem as an inverse bearing capacity problem with the concern of failure reaching the surface and producing a “breakout” of the helical plate. To avoid this, CHANCE® suggests not installing helical anchors at vertical depths less than 5 ft. for tension loading. Instead of a Bearing Capacity Factor, N_C, that is typically used for analysis of a helical anchor under compression loading, a Breakout Factor, F_C, is used. Das (1990) related the breakout factor to the ratio of depth of embedment and plate diameter, referred to as relative embedment of the plate (D/B), expressing a linear relationship for D/B ≤ 9 to be $F_C = 1.2(D/B)$. At D/B ≥ 7.5, which is considered to be the transition from shallow to deep behavior under tension in saturated clays, $F_C = 9$. This relationship, shown in Figure 2.3, shows a steady increase in the breakout factor with increasing relative embedment.

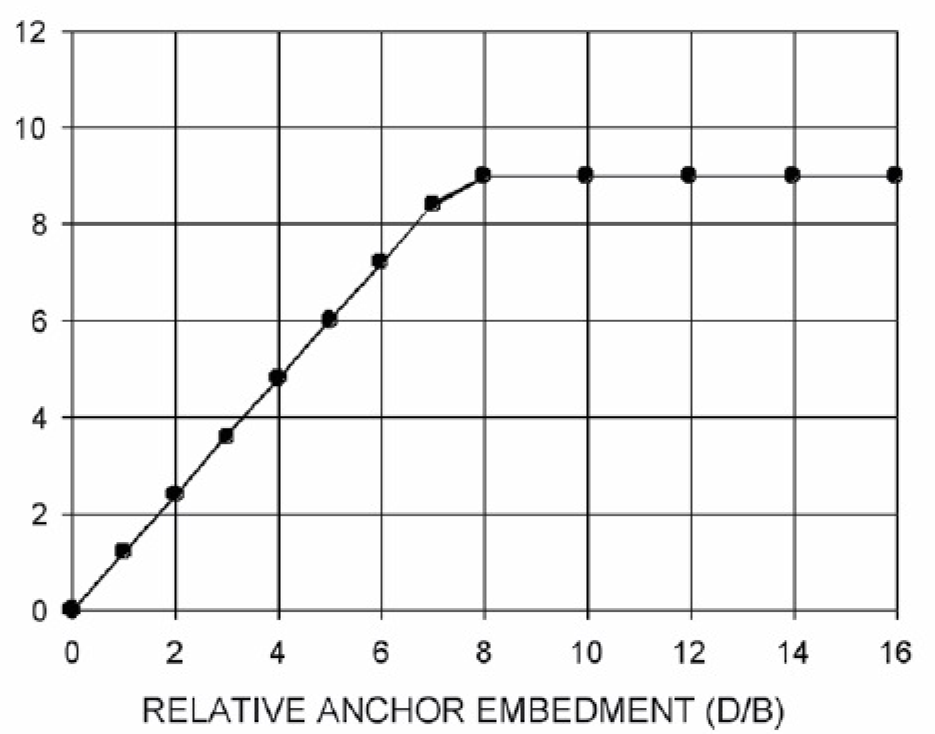

Figure 2.3 Breakout Factor vs. Relative Helix Embedment (D/B) (Chance 2015).

The uplift capacity of the helix is presented in Equation 2.1 (Chance 2015).

$$Q_{HU} = A_H(cF_C + \gamma' D) \qquad [2.1]$$

where:

Q_{HU} = Ultimate Uplift Capacity

c = "cohesion"; for φ' = 0 c = undrained shear strength = s_u

F_C = Breakout Factor for φ' = 0; $F_C = 1.2(D/B) \leq 9$

γ' = effective unit weight of soil above helical anchor plate

D = Depth of Embedment

At lower Breakout Factors, the ultimate uplift capacity decreases due to the failure plane propagating to the ground surface, creating a heave in the ground surface. Figure 2.4 displays both the shallow "global" failure mode and the deep "local" failure mode. For deep installations i.e., (D/B > 7.5), the Breakout Factor has a default value of 9 and Equation 2.1 is simplified to Equation 2.2.

$$Q_{HU} = A_H(9S_u + \gamma' D) \qquad [2.2]$$

Depending on the number of helices and quality of installation, sometimes undrained shear strength is reduced to a value closer to the remolded value. High disturbance factors coupled with multiple helices passing through the soil will remold the soil which will be mobilized during tension loading, lowering the undrained shear strength of the soil, especially in soft clays.

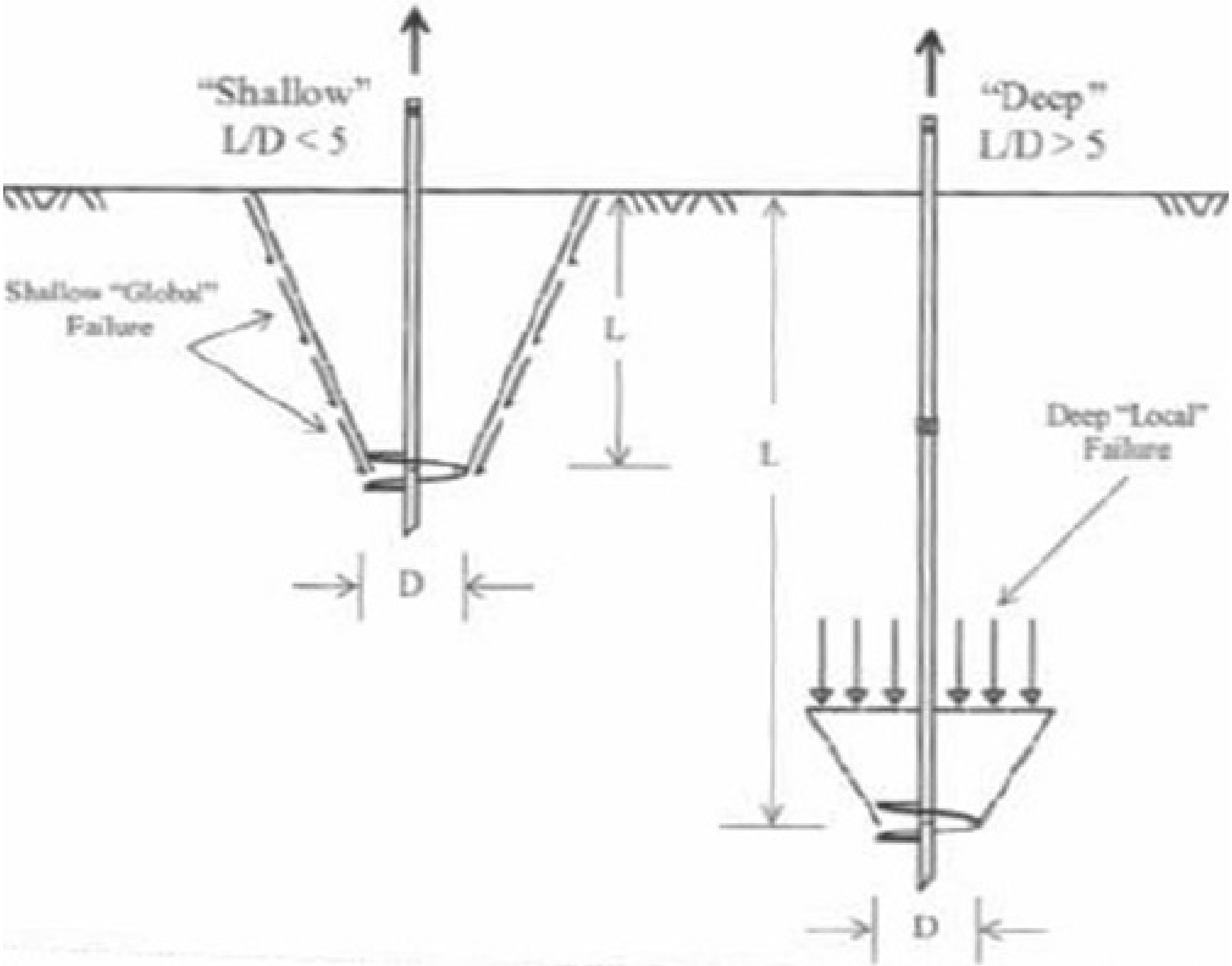

Figure 2.4 Uplift Failure Modes of Helical Screw Anchors (Toombs 2011).

For multiple helix anchors, the capacity can be taken as the summation of the capacity of the individual plates.

Round Shaft (RS) helical piles or anchors exhibit some shaft side resistance which is a function of the shaft geometry and the style of shaft couplings. In clays, an adhesion factor used in the "Alpha" method available in most textbooks is the available adhesion between the shaft and the clay which is merely a percentage of the undrained strength that is available for resistance along the shaft. Equation 2.3 shows this relationship.

$$\alpha = \frac{f_s}{s_u} \qquad [2.3]$$

where:

α = Adhesion Factor

f_s = Unit Side Resistance

s_u = Undrained Shear Strength of the Clay

The relationship between the undrained adhesion factor and the undrained shear strength of clays is shown in both Figure 2.5 and 2.6.

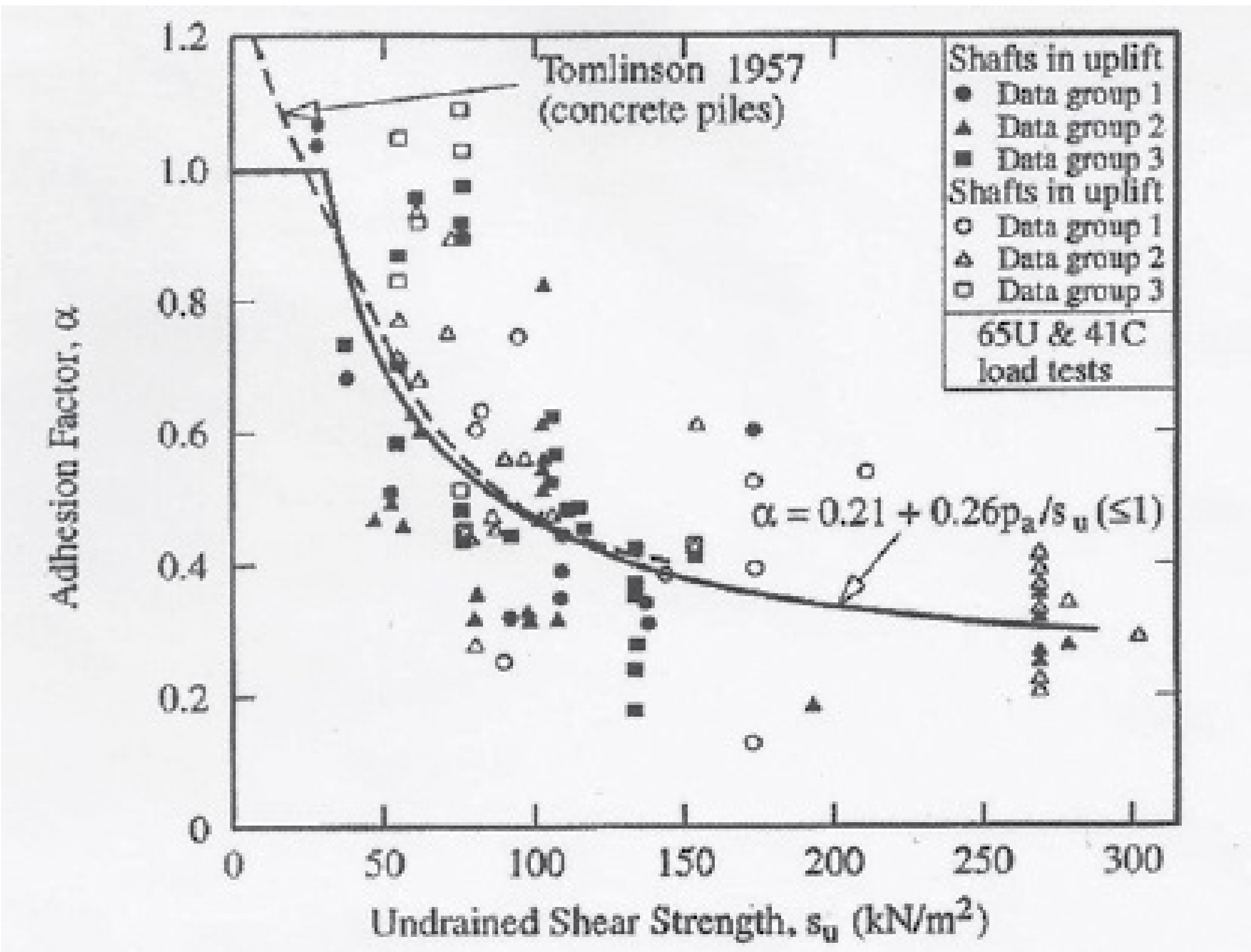

Figure 2.5 Adhesion Factor as a Function of s_u (Canadian Foundation Manual 2006).

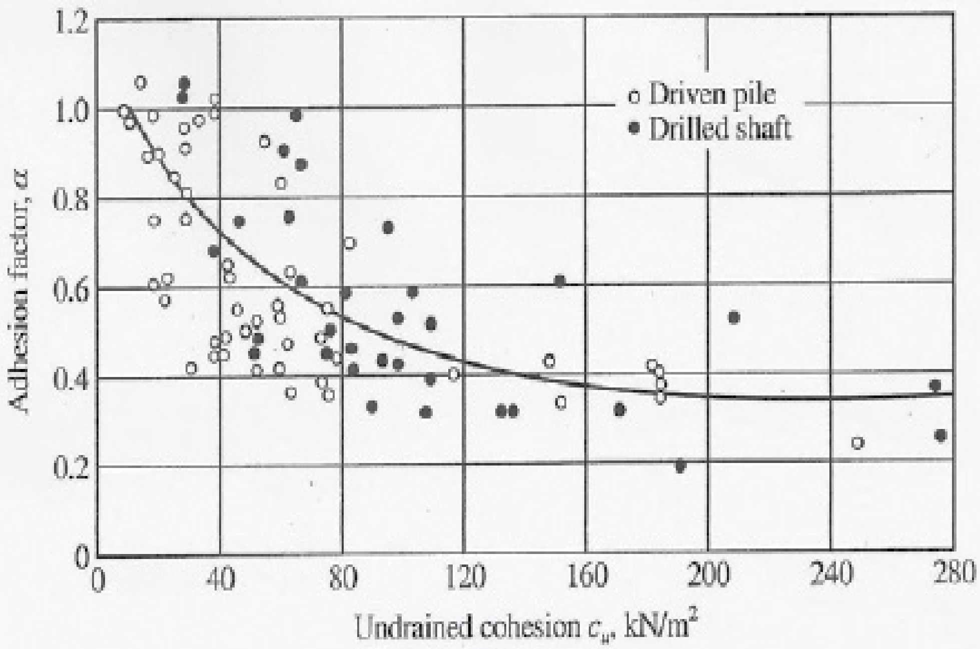

Figure 15.15 Adhesion factor α for piles with penetration lengths less than 50 m in clay. (Data from Dennis and Olson 1983 a & b; Stas and Kulhawy, 1984)

Figure 2.6 Variation in Adhesion Factor with Undrained Shear Strength of Clays (Stas & Kulhawy 1984)

The value of α is typically obtained from any of the numerous published charts in which f_s has been back calculated from actual pile load tests. Generally it is sufficient to select an average value of the adhesion factor for a given undrained shear strength to use for design. The total shaft resistance of the pile can then be obtained from Equation 2.4:

$$Q_S = (f_S)(\pi)(d)(L) \quad [2.4]$$

where:

Q_S = Total Shaft Resistance

d = Diameter of Central Shaft

L = Length of Round Shaft in Contact with Soil

2.3.2 Uplift Capacity of Helical Anchors in Sands

In sands, the tensile capacity of a helical anchor is typically assumed to be equal to the compression capacity given that the soil above the helix is the same as the soil below the helix in a zone of about 3 helix diameters (Chance 2015). Since in clean, saturated sands the cohesion factor is taken as zero and because the net helix area, which accounts for the contribution of the "width" term to ultimate capacity, is relatively small, the uplift capacity equation is reduced to:

$$Q_H = A_H(q'N_q) \quad [2.5]$$

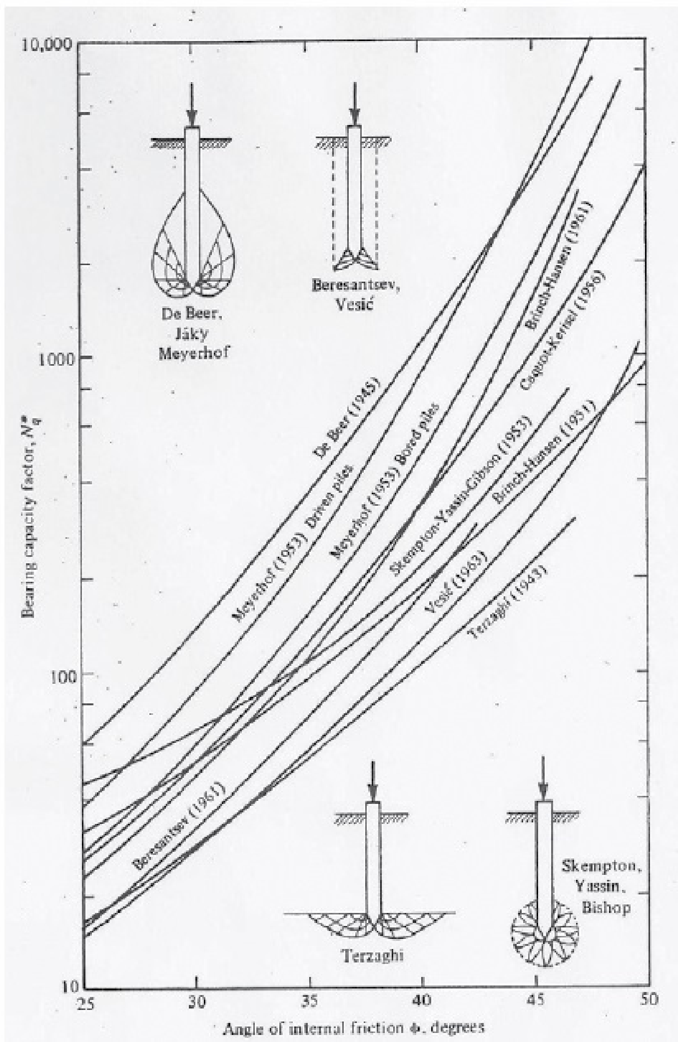

Figure 2.7 Reported Values of N_q for Deep Foundations in Sands (Winkerkorn & Fang 1983)

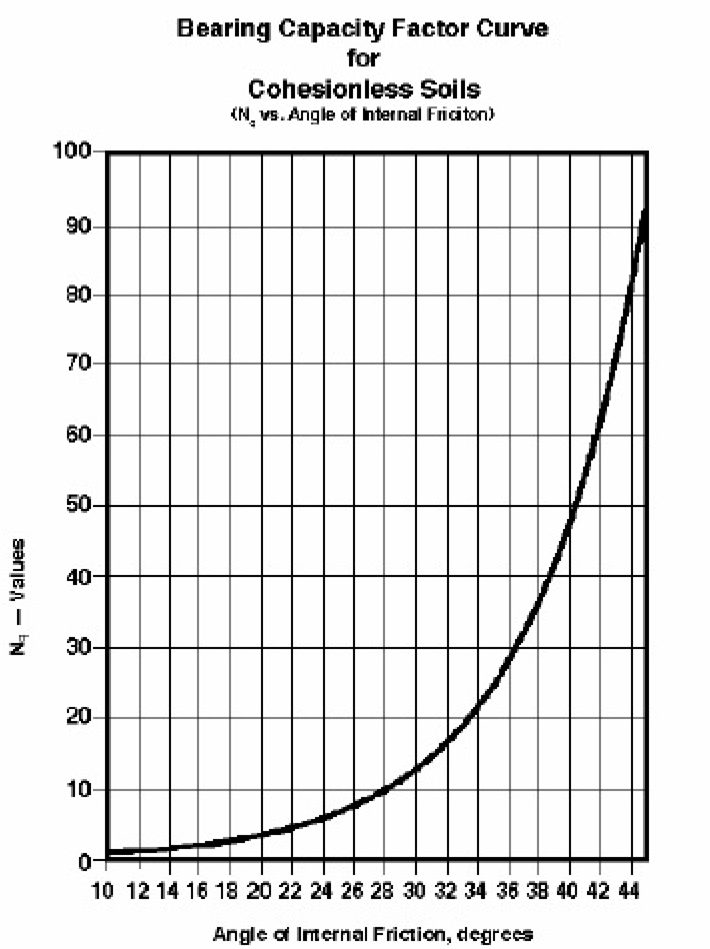

Figure 2.8 Recommended Bearing Capacity Factor, N_q, for Deep Screw-Piles and Helical Anchors in Sand (Chance 2015).

Figure 2.7 presents values of N_q from the literature based on the angle of internal friction, while Figure 2.8 includes recommended values from the Chance Design Manual (2015).

2.4 FACTORS INFLUENCING TORQUE-TO-CAPACITY FACTOR, K_T

Lutenegger (2013) explained the logic behind torque-to-capacity relationships, asserting that it stems from the inherent factors influencing both measurements. The ultimate capacity of a Screw-Pile or Helical Anchor is a function of the specific geometry of the pile/anchor, i.e. net helix area, shaft shape and surface area and soil properties, i.e., soil strength:

Q_{ult} = f(pile/anchor geometry; soil strength)

In parallel, the installation torque is generally assumed to also be a function of the pile/anchor specific geometry and soil properties:

T = f(pile/anchor geometry; soil strength)

Therefore, a sensible conclusion is an expected relationship between ultimate capacity and installation torque. A common equation seen in the literature is Equation 2.6.

$$Q_u = K_T * T \quad [2.6]$$

where:

Q_u = ultimate capacity of the helical anchor in uplift

K_T = empirical factor

T = average installation torque

Hoyt & Clemence (1989) performed an analysis of 91 square and round shaft single and multi helical anchors in uplift in a variety of soils using three methods: the individual plate bearing method, the cylindrical shear method, and the torque correlation method. Individual bearing and cylindrical shear methods are traditional geotechnical design methods used to predict helical pile capacity (Perko 2009). The torque correlation method proved to provide the least amount of scatter of the three methods. A histogram comparing calculated to measured capacity presented by Hoyt & Clemence is provided in Figure 2.10, showing a large amount of scatter above and below.

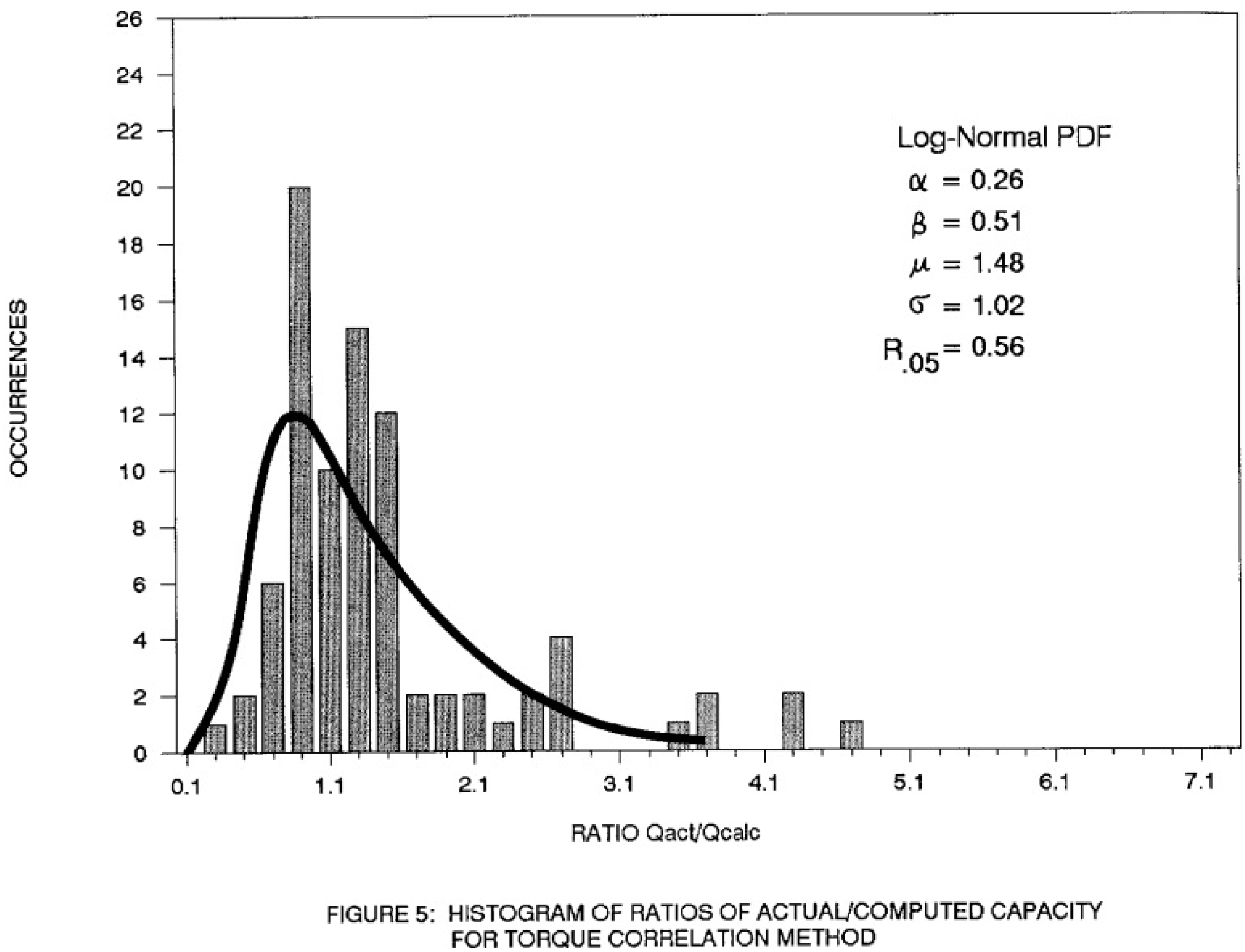

Figure 2.10 Histogram of Results from Torque Correlation Analysis (Hoyt & Clemence 1989)

The ratio of actual uplift capacity to calculated uplift capacity ranged from about 0.3 to 4.5. The conclusion from the analysis was that this torque-to-capacity relationship "…is more suited to on-site production control than design in the office." Many in the literature ignore this conclusion and still use their K_T values, provided in Table 2.1, for design.

Table 2.1 Suggested Values of K_T by Hoyt & Clemence (1989)

Shaft Type	Shaft Outer Diameter (in.)	K_T (ft^{-1})
Square & Round	<3.5	10
Round	3.5	7
Round Extensions	8.63	3

AC358, a paper by the International Code Council entitled Acceptance Criteria for Helical Foundation Systems and Devices, has a similar table of K_T values that are provided in Table 2.2.

Table 2.2 Suggest Values of K_T by AC358 (2007)

Shaft Type	Shaft Outer Diameter (in.)	K_T (ft^{-1})
Square	1.5	10
Square	1.75	10
Round	2.875	9
Round	3	8
Round	3.5	7

These proposed correlations only consider one variable, difference in shaft geometry, in selecting K_T values, but there are many other factors influencing K_T. Lutenegger (2013) presented factors affecting K_T and splits them up into appropriate categories, factors affecting installation torque and factors affecting ultimate capacity, included in Table 2.3.

Table 2.3 Summary Table of Factors Influencing K_T

Factors Affecting Installation Torque			Factors Affecting Ultimate Capacity		
Pile/Anchor Factors	Soil Factors	Contractor Factors	Pile/Anchor Factors	Soil Factors	Load Test Factors
Plate Diameter Number of Plates Plate Thickness Plate Pitch Shaft Shape Connection Style Surface Texture (Roughness)	Soil Type Soil Strength Soil Stiffness Sensitivity Water Table	Rotation Rate Advance Rate Down Force Inclination	Plate Diameter Number of Plates Plate Spacing Shaft Shape Connection Style	Soil Type Soil Strength Soil Stiffness Sensitivity Changes in Water Table	Loading Rate (Increment Duration & No. of Increments) Loading Direction Waiting Time Between Installation & Testing (Aging) Load Test Interpretation

The majority of these factors that are a function of pile/anchor geometry and soil properties overlap the two categories. The two sub-categories that stand alone on each side of the torque-to-capacity relationship are contractor factors and load test factors. For the installation side of the project, the contractor factors that were varied included rotation rate and advance rate, while the other factors were held constant for each site. Down force, or sometimes referred to as crowd, is the amount of downward force applied to the pile during installation. At the current time, there is no efficient way to measure this in a quantifiable way and therefore it cannot be monitored or controlled to any precise extent. Inclination, or the plumbness of the anchor being installed, was monitored by both the operator and inspector during installation.

For the current installation study, an RS2875 8/10/12 triple helix anchor was selected to eliminate any variability from the pile geometry. For piles being load tested, contractor factors were held constant along with load test factors. The test procedure was conducted in the same direction, with the same loading rate, the same waiting time between piles, and the results were all interpreted the same way.

An initial set of trial installations with varying speed were conducted at both the UMass DOE Site and the UMass AF-GT Site using an SS5 single-helix anchor. A single 12” helical anchor was installed at the UMass DOE Site at slow and regular throttle, and a single 14” helical anchor was installed at the UMass AF-GT Site at similar variations in speed. The same contractor, using the same excavator and torque head configuration was used to install the anchors at both sites. The results are shown in Figures 2.11-2.13 and indicate installation speed affects measured torque during installation of helical anchors. Figure 2.11 shows that a decrease in installation speed of about 5 RPMs, a difference shown in Figure 5.12, results in an average decrease in installation torque of about 100 ft-lbs in each anchor. The installation disturbance factor of the four trials is plotted versus depth in Figure 2.13 and indicates no significant difference with a change in speed. These results necessitated further investigation and therefore trial investigations using a round shaft triple-helix anchor were conducted to determine rate of installation effects.

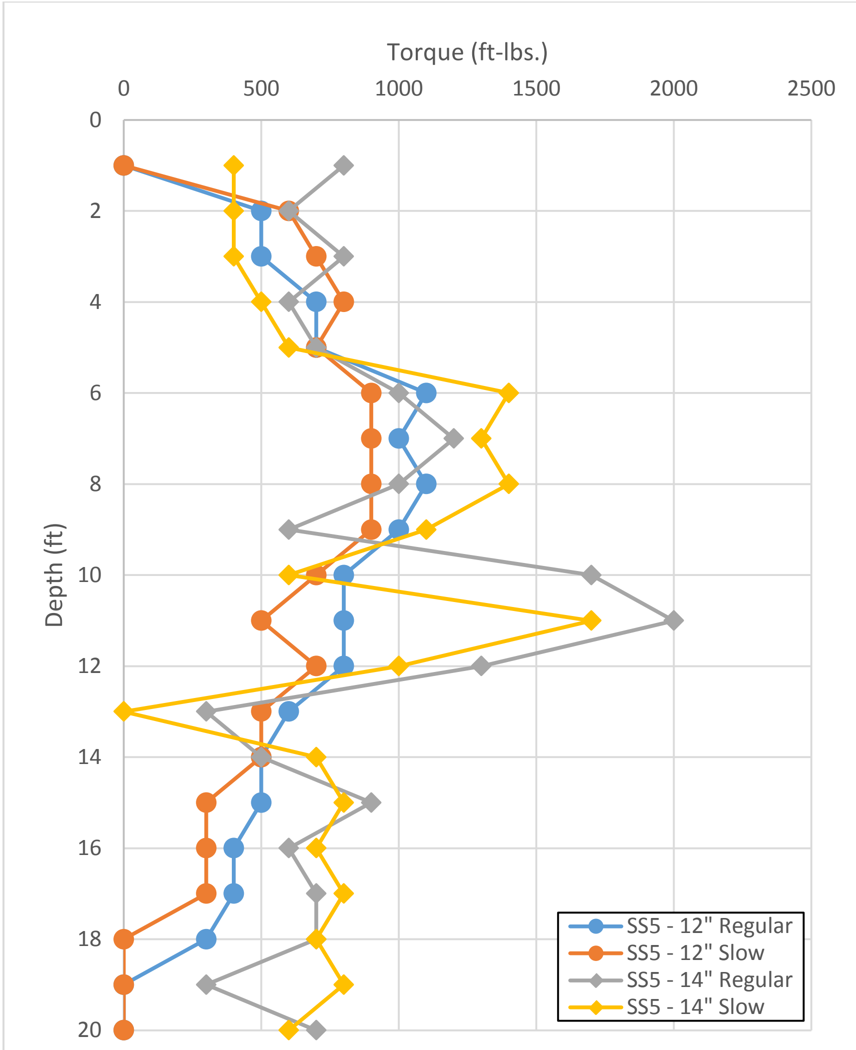

Figure 2.11 Effects of Speed Variation on Torque Profile at the UMass DOE Site and UMass AF-GT Site

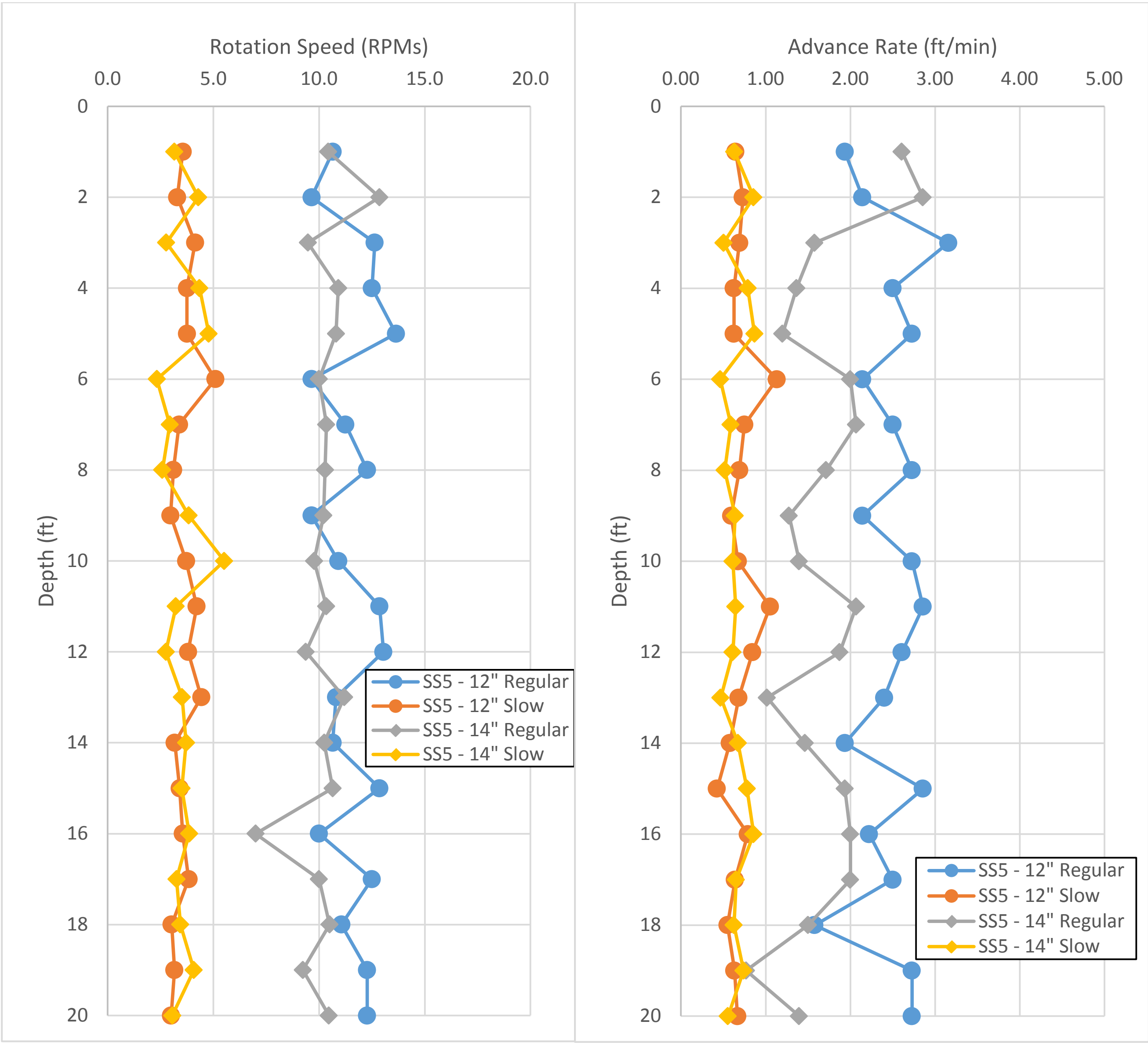

Figure 2.12 Effects of Speed Variation on Rotation Speed and Advance Rate at the UMass DOE Site and UMass AF-GT Site

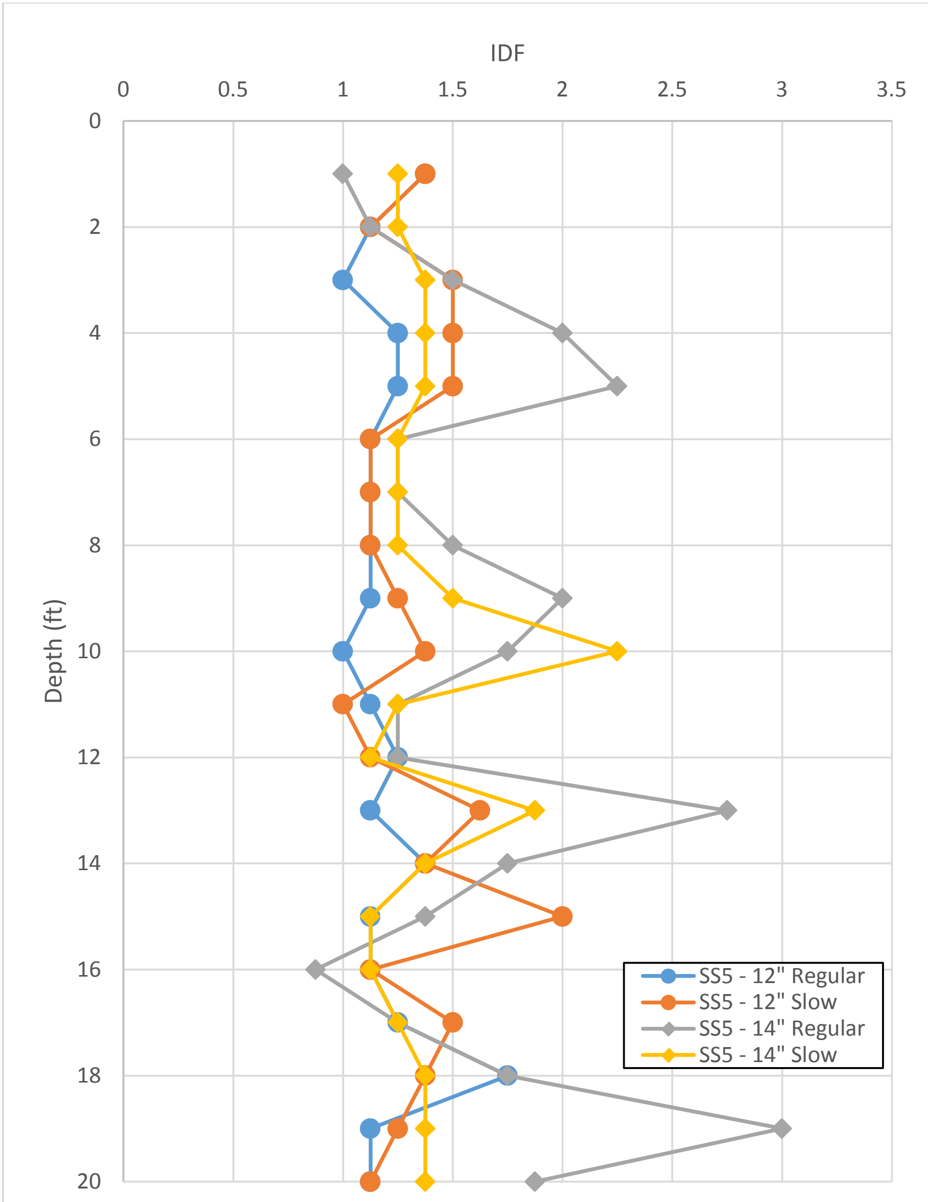

Figure 2.13 Effects of Speed Variation on Advance at the UMass DOE Site and UMass AF-GT Site

2.5 VARIATIONS IN K_T FROM THE RECENT LITERATURE

Many axial uplift tests on helical anchors of varying shaft geometries and helical configurations have been performed and published in the recent literature. The focus of this section will be on six papers from the last seven years that report results from a wide range of soil types, shaft diameters, and helix geometries.

Beim & Luna (2012) from Pile Dynamics performed installations and load tests at the National Geotechnical Experimentation Site of the University of Massachusetts (UMass DOE Site of this

Report) on eight RS2875 8/10/12 triple helix anchors at 3D spacing. The nomenclature refers to the helix diameter in inches from the lead to the trailing helix, i.e. an 8/10/12 helical anchor has an 8 in. plate which leads to pile into the soil, followed by a 10 in. plate and finally a 12 in. plate. 3 piles were installed to a depth of 12 ft. and 5 piles were installed to a depth of 18 ft., all in the local Connecticut Valley Varved Clay by the same contractors. Both dynamic load tests (DLTs) and static load tests (SLTs) were performed on these piles. The DLTs were performed approximately 2.5 months after installation, and the SLTs were conducted 20-30 days after the DLTs. The method for choosing the appropriate installation torque for each pile to calculate an appropriate K_T value was not discussed in this paper. Uplift capacity was calculated using the Davisson method (1972). This method defines the failure load as the load necessary to produce displacement exceeding the elastic deformation of the pile by a value of 0.15 in. Elastic deformation of the pile is calculated using Equation 2.7.

$$S = \frac{PL}{AE} + \frac{d}{120} + 4(mm) \quad [2.7]$$

where:

S = the displacement in mm

P = applied load to the pile

L = length of the pile in mm

A = cross-sectional area of the pile material

E = Young’s modulus of the pile material

d = pile diameter in mm

The results from Beim & Luna (2012), displayed in Table 2.4, produced significant scatter in K_T. This may be due to waiting to test the piles much longer than the typical 7 days, testing the piles at energies that produced different sets per blow prior to performing static load tests, and choosing inappropriate values for installation torque. Although it was not discussed, the tabulated values for installation torque seemed to correspond to the final value of torque measured during installation, which was a lower bound value and generally drove the K_T values up. Values of K_T closer to the suggested values might have been determined if the method of averaging the torque values equal to the final penetration distance of 3 average helix diameters.

The Davisson method of interpreting load tests was originally developed for driven steel piles with small diameters up to 12 in. Sakr (2011) described the main problem with applying Davisson’s criteria to helical piles. The offset criteria was initially developed to satisfy movements necessary to mobilize toe resistance of driven steel piles with small toe diameters. Since helical piles derive most of their uplift resistance from plate bearing capacity, up to 90% in cohesionless soils (Mathias et al. 2014), the use of the Davisson criterion yields significantly lower capacities than traditional 10% methods suggested by AC358 and do not reflect the actual capacities of helical piles.

Sakr tested large diameter, high capacity helical piles in both cohesionless (2011) and cohesive (2012) soils in Alberta, Canada. Shaft diameters of 12.75 in. and 16 in. were tested in both studies with helix diameters ranging from 30 to 36 in. Torque was measured at the end of installation and axial capacity was determined using the 5% displacement method, i.e. the load necessary to produce a displacement of 5% of the average helix diameter. Sakr (2011) noted that torque-to-capacity relationships reported in the literature are for small-diameter anchors resisting uplift loads and therefore the correlations should be used with caution to estimate uplift capacity of larger diameter piles. Low K_T values are expected for such large diameter piles (Deardorff 2007), and the results confirmed this assumption. Less scatter was observed in the cohesive soil tests than the cohesionless soil tests. Size (scale) effects, shape of the shaft, and the probable large amount of crowd associated with the installation of these massive piles would certainly affect this torque-to-capacity relationship. In addition, some of the pilot holes for the cohesionless soil site were predrilled to facilitate pile installation through frozen and hard soils. Still other piles necessitated the trimming of the leading edge of the helices to help installation through cobbles. During installation in the dense sands, dilation occurs which show particularly higher torque values which do not necessarily represent long-term soil conditions. With such large diameter shafts and no data regarding quality of installation, i.e. rotations per foot, it is hard to accept the correlation factors presented in this paper. Geometry, soil type, and range of K_T values are provided in Table 2.4.

Gavin et al. (2014) installed a single helix anchor with a 4.33 in. shaft diameter and 16 in. helix in dense fine sand located at the University College Dublin. Both compression and tension load tests were performed to determine the capacity of the anchor. An army of strain gauges were placed along the shaft and helix of the anchor to meticulously monitor any movement during the tests. Shaft resistance increased during the uplift tension test and plateaued around displacement equal to 5% of the average helix. From the strain gauges, it was observed that the majority of the resistance was occurring at the portion of the shaft immediately above the helix until displacements of about 1% of the average helix diameter, where resistance at this point spiked to zero. Torque was taken as the final measurement before advance was terminated and the uplift capacity was computed as the load necessary to produce displacement equal to 10% of the helix diameter. The K_T value of 3.9 is consistent with a decrease with an increase in shaft diameter. However, tests were performed on the same day of installation and therefore no time was given for the pile to set itself in the soil, possibly resulting in a lower capacity and consequently a lower value of K_T. More tests of a similar shaft diameter and differing helix diameters at this site is recommended to evaluate scatter associated with single helix anchors is very dense sands.

El Naggar et al. (2008) conducted a full-scale testing program on the Environmental site at the University of Western Ontario, London to evaluate the axial performance of square shaft helical anchors. 11 square shaft helical anchors with an 8/10/12 helix configuration were installed and tested in a variety of soils, from cohesive to intermediate to cohesionless soils to evaluate their performance in each soil type. Installation torque was averaged over the final 3 ft. of penetration in order to calculate a torque-to-capacity relationship. El Naggar et al. (2008) observed that generally, the near-linear failure region occurred at net displacements greater than 8% of the largest helical diameter and therefore developed their own method for determining ultimate capacity. The criterion is again related to the elastic displacement of the pile, and the equation is provided in Equation 2.8:

$$S = \frac{PL}{AE} + 0.08D \qquad [2.8]$$

where:

S = the displacement

P = applied load to the pile

L = length of the pile

A = cross-sectional area of the pile material

E = Young's modulus of the pile material

D = pile diameter

The values of K_T calculated in this study are presented in Table 2.4 and show that the torque-to-capacity relationship is dependent on soil type, with the lowest values observed in the clayey silt and the highest values in the sand.

El Naggar (2014) performed another set of axial uplift tests in Ponoka, Canada on round shaft helical anchors. Helical anchors with large diameter shafts, 12.75 in., and large helix diameters, 24 in., with varying spacing were the focus of this study. Similar methods used in his previous paper for monitoring installation torque, but for determining ultimate capacity, 3.5% of the helix diameter was used and proposed for large-diameter helical piles since it identifies the failure load within the nonlinear region of the load-displacement curve. Again, a range of soil types were investigated and interhelical spacing of 1.5D, 3D, and 4.5D were used. All piles were close-ended with a flush closure steel plate to prevent plugging during installation. Two piles were tested 9 months after installation while the others were tested 2 weeks post-installation. The piles that were allowed to age showed much higher K_T values. Thixotropic properties of soil in parallel with increased shaft resistance over time due to the disturbed soil healing may lead to an increased shaft capacity. Shaft resistance contribution increased from about 20-40% to around 65% after the 9 month period.

A new approach to investigate torque-to-capacity relationships was undertaken by Mathias et al. (2014). Quadruple helical anchors with a RS2875 10/12/14/14 configuration were outfitted with strain gauges to measure the installation torque and uplift capacity of each individual helix and shaft in attempt to isolate the components of the anchor that contribute to the torque correlation factor. In addition, extensions 4 inches in diameter were coupled to the lead sections to evaluate the efficiency of larger diameter extensions in shaft resistance. The results of this study show that the K_T factor is greater when the shaft resistance contributes 50% of pullout capacity compared to the anchor which resulted in very low shaft resistance. It also indicates that the addition of the fourth helix contributes more to the installation torque than to pullout capacity.

Table 2.4 presents a summary table of the repute of K_T from the reviewed literature (since 2008).

Table 2.4 Summary Table of Reported K_T Values from Recent Literature

Shaft Geometry	Shaft ϕ (in.)	Diameter of Helix (in.)	Pitch (in.)	D/P	Soil Type	K_t (ft^{-1})	Source	Tension or Compression
RS	4.33	16	4	4.0	Dense Fine Sand	3.9	Gavin et al. (2014)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	6.5	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	8.1	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	7.5	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	7.3	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	9.0	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Clayey Silt	7.6	El Naggar et al. (2008)	Tension

SS	1.75	8/10/12	3	3.3	Dense Silt	9.5	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Dense Silt	6.6	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Dense Silt	11.1	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Sand	7.4	El Naggar et al. (2008)	Tension
SS	1.75	8/10/12	3	3.3	Sand	10.0	El Naggar et al. (2008)	Tension
RS	12.75	30/30	3*	10.0	Very Hard Clay	1.7	Sakr (2012)	Tension
RS	16	36	3*	12	Very Hard Clay	1.5	Sakr (2012)	Tension
RS	16	32/32	3*	10.7	Very Dense Sand	1.5	Sakr (2012)	Tension
RS	16	32/32	3*	10.7	Very Stiff Till	1.9	Sakr (2012)	Tension
RS	12.75	30/30	3*	10	Very Dense Sand	2.9	Sakr (2011)	Tension
RS	16	36	3*	12	Very Dense Sand	1.3	Sakr (2011)	Tension
RS	16	32/32	3*	10.7	Very Dense Sand	2.6	Sakr (2011)	Tension
RS	16	32/32	3*	10.7	Very Dense Sand	1.7	Sakr (2011)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	16.2	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	14.3	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	13.5	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	10.1	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	9.9	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	12.6	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	13.1	Beim et al. (2012)	Tension
RS	2.875	8/10/12	3	3.3	CVVC	11.6	Beim et al. (2012)	Tension
RS	12.75	24	6	4	Very Stiff Silty Clay	10.2	El Naggar et al. (2014)	Tension
RS	12.75	24	6	4	Clay Till	20.5	El Naggar et al. (2014)	Tension
RS	12.75	24/24	6	4	Clay Till	26.5	El Naggar et al. (2014)	Tension

RS	12.75	24/24	6	4	Silty Sand	11.6	El Naggar et al. (2014)	Tension
RS	12.75	24/24	6	4	Stiff Clay	10.0	El Naggar et al. (2014)	Tension
RS	12.75	24/24	6	4	Stiff Clay	11.3	El Naggar et al. (2014)	Tension
Combo	2.875	10/12/14/14	3	4.2	Sandy Silt	4.8	Mathias et al. (2014)	Tension
Combo	2.875	10/12/14/14	3	4.2	Sandy Silt	3.3	Mathias et al. (2014)	Tension
RS	8.62	14/14/14	3*	4.7	Stiff Silty Clay	8.9	Tappenden & Sego (2007)	Compression
RS	8.62	14/14/14	3*	4.7	Stiff Silty Clay	10.3	Tappenden & Sego (2007)	Compression
RS	8.62	14/14	3*	4.7	Stiff Silty Clay	10.8	Tappenden & Sego (2007)	Compression
RS	8.62	14/14/14	3*	4.7	Stiff Silty Clay	9.5	Tappenden & Sego (2007)	Tension
RS	8.62	14/14/14	3*	4.7	Stiff Silty Clay	6.9	Tappenden & Sego (2007)	Tension
RS	8.62	14/14	3*	4.7	Stiff Silty Clay	9.2	Tappenden & Sego (2007)	Tension
RS	8.62	14/14/14	3*	4.7	Loose to Compact Silty Sand	10.5	Tappenden & Sego (2007)	Compression
RS	8.62	14/14/14	3*	4.7	Loose to Compact Silty Sand	10.3	Tappenden & Sego (2007)	Compression
RS	8.62	14/14	3*	4.7	Loose to Compact Silty Sand	8.5	Tappenden & Sego (2007)	Compression
RS	8.62	14/14/14	3*	4.7	Loose to Compact Silty Sand	7.1	Tappenden & Sego (2007)	Tension
RS	8.62	14/14/14	3*	4.7	Loose to Compact Silty Sand	4.4	Tappenden & Sego (2007)	Tension
RS	8.62	14/14	3*	4.7	Loose to Compact Silty Sand	7.5	Tappenden & Sego (2007)	Tension

RS	7	18	3*	6	Stiff Silty Clay	8.3	Tappenden & Sego (2007)	Compression
RS	8.62	18	3*	6	Stiff Silty Clay	7.7	Tappenden & Sego (2007)	Compression
RS	7	18/20	3*	6.33	Stiff Silty Clay	11.8	Tappenden & Sego (2007)	Compression
RS	9.6	18/20	3*	6.33	Hard Clay	9.9	Tappenden & Sego (2007)	Compression
RS	10.75	30	3*	4.2	Hard Clay Till	12.8	Tappenden & Sego (2007)	Compression
RS	10.75	30/30	3*	10	Hard Clay Till	14.1	Tappenden & Sego (2007)	Compression
RS	10.75	30	3*	10	Hard Clay Till	9.8	Tappenden & Sego (2007)	Tension
RS	10.75	30/30	3*	10	Hard Clay Till	10.9	Tappenden & Sego (2007)	Tension
RS	16	30	3*	10	Very Dense Sand Till	7.9	Tappenden & Sego (2007)	Tension
RS	8.62	15.75	3*	5.25	Stiff Clay Till	8.9	Tappenden & Sego (2007)	Compression
RS	12.75	36/36	3*	12	Stiff Silty Clay	8.0	Tappenden & Sego (2007)	Compression
RS	5.5	20/20/20	3*	6.67	Stiff Silty Clay	13.7	Tappenden & Sego (2007)	Compression
RS	4.5	18/18	3*	6	Stiff Silty Clay	18.1	Tappenden & Sego (2007)	Compression
RS	4.5	18	3*	6	Stiff Silty Clay	21.1	Tappenden & Sego (2007)	Compression
RS	8.625	24	3*	8	Clay	3.5	Hawkins and Thorsten (2009)	Compression
RS	8.625	24	3*	8	Clay Over Sand	4.3	Hawkins and Thorsten	Compression

							(2009)	
RS	8.625	24/30	3*	9	Clay Over Sand	5.0	Hawkins and Thorsten (2009)	Compression
RS	8.625	8/16/16/16/16	3*	4.8	Clay Over Sand	4.6	Hawkins and Thorsten (2009)	Compression
RS	8.625	8/24	3*	5.3	Clay Over Sand	5.1	Hawkins and Thorsten (2009)	Compression
RS	8.625	16/16/16/16	3*	5.3	Clay Over Sand	5.6	Hawkins and Thorsten (2009)	Compression
RS	8.625	24	3*	8	Clay Over Sand	5.8	Hawkins and Thorsten (2009)	Compression
RS	12.75	30	3*	10	Stiff to Very Stiff Clay Till	1.7	Padros et al. (2012)	Compression
RS	16	36	3*	12	Stiff to Very Stiff Clay Till	1.7	Padros et al. (2012)	Compression
RS	20	40	3*	13.3	Stiff to Very Stiff Clay Till	1.3	Padros et al. (2012)	Compression
RS	20	40	3*	13.3	Stiff to Very Stiff Clay Till	1.3	Padros et al. (2012)	Compression
RS	20	40/40	3*	13.3	Stiff to Very Stiff Clay Till	1.6	Padros et al. (2012)	Compression
RS	20	40/40/40	3*	13.3	Stiff to Very Stiff Clay Till	1.8	Padros et al. (2012)	Compression
RS	12.75	30/30	3*	10	Stiff to Very Stiff Clay Till	2.5	Padros et al. (2012)	Compression
RS	16	36/36	3*	12	Stiff to Very Stiff Clay Till	2.2	Padros et al. (2012)	Compression
RS	8.62	20/20	3*	6.7	Stiff to Very Stiff Clay Till	3.4	Padros et al. (2012)	Compression
RS	12.75	30	3*	10	Stiff to Very Stiff Clay Till	1.9	Padros et al. (2012)	Compression
RS	8.62	30/30	3*	10	Stiff to Very Stiff Clay Till	3.6	Padros et al. (2012)	Compression
**Note: Pitch values not mentioned, assumed traditional pitch of 3"*								

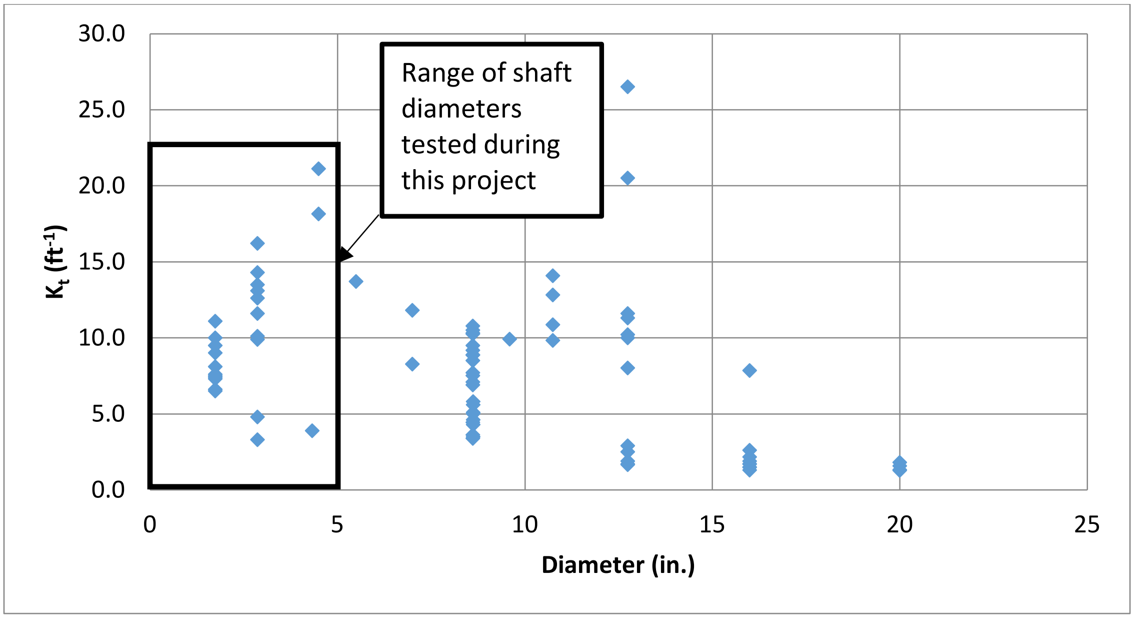

Figure 2.11 Variation of Reported K_T from the Recent Literature as a Function of Shaft Diameter (All Data)

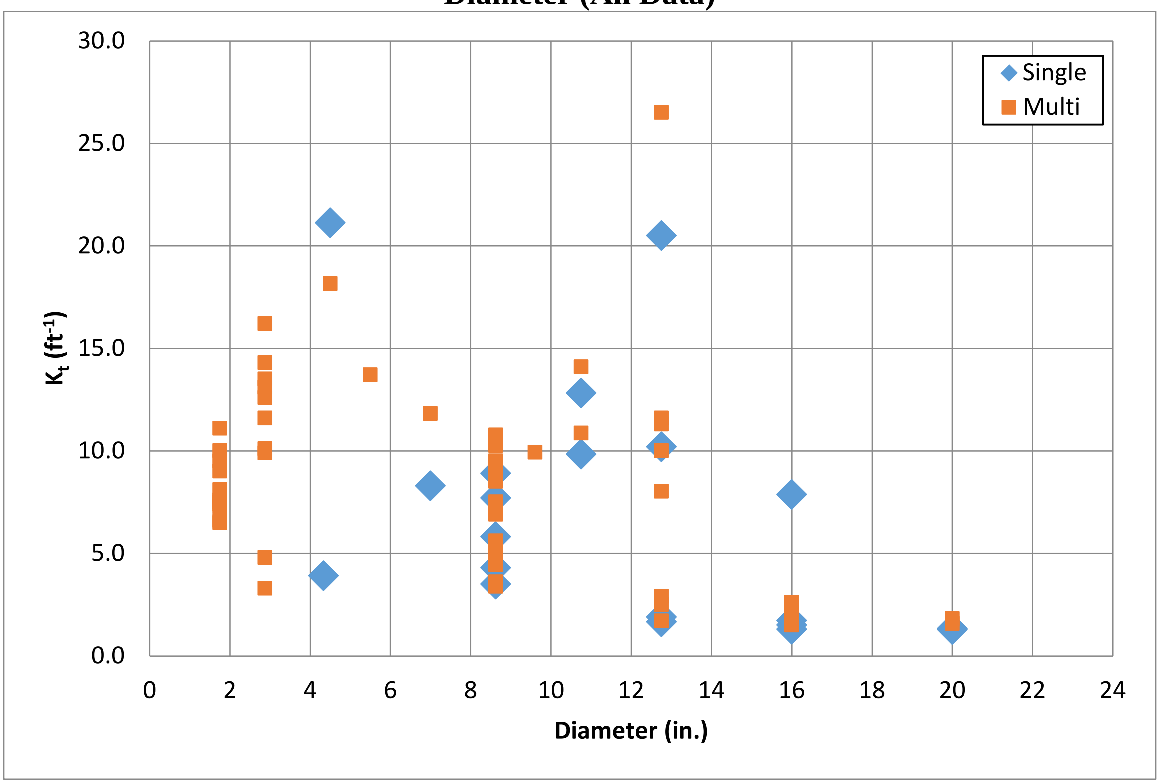

Figure 2.12 Variation of Reported K_T from the Recent Literature as a Function of Shaft Diameter (Single vs. Multi-Helix)

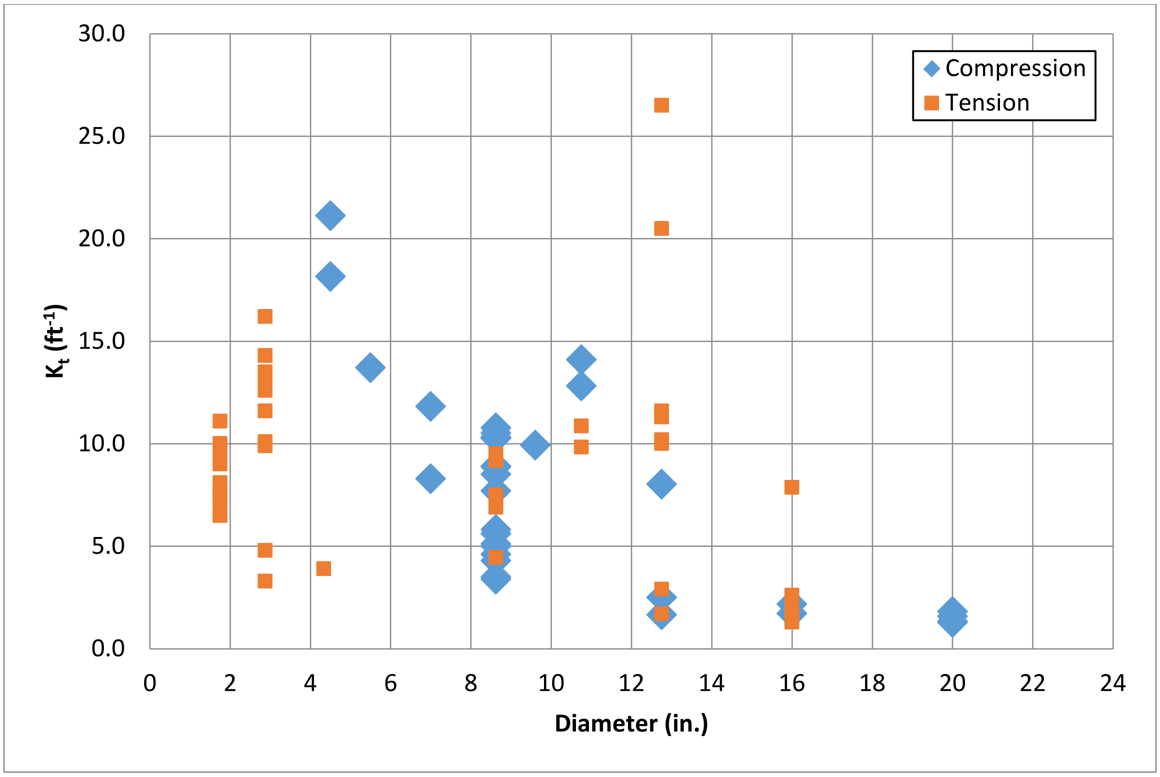

Figure 2.13 Variation of Reported K_T from the Recent Literature as a Function of Shaft Diameter (Compression vs. Tension Tests)

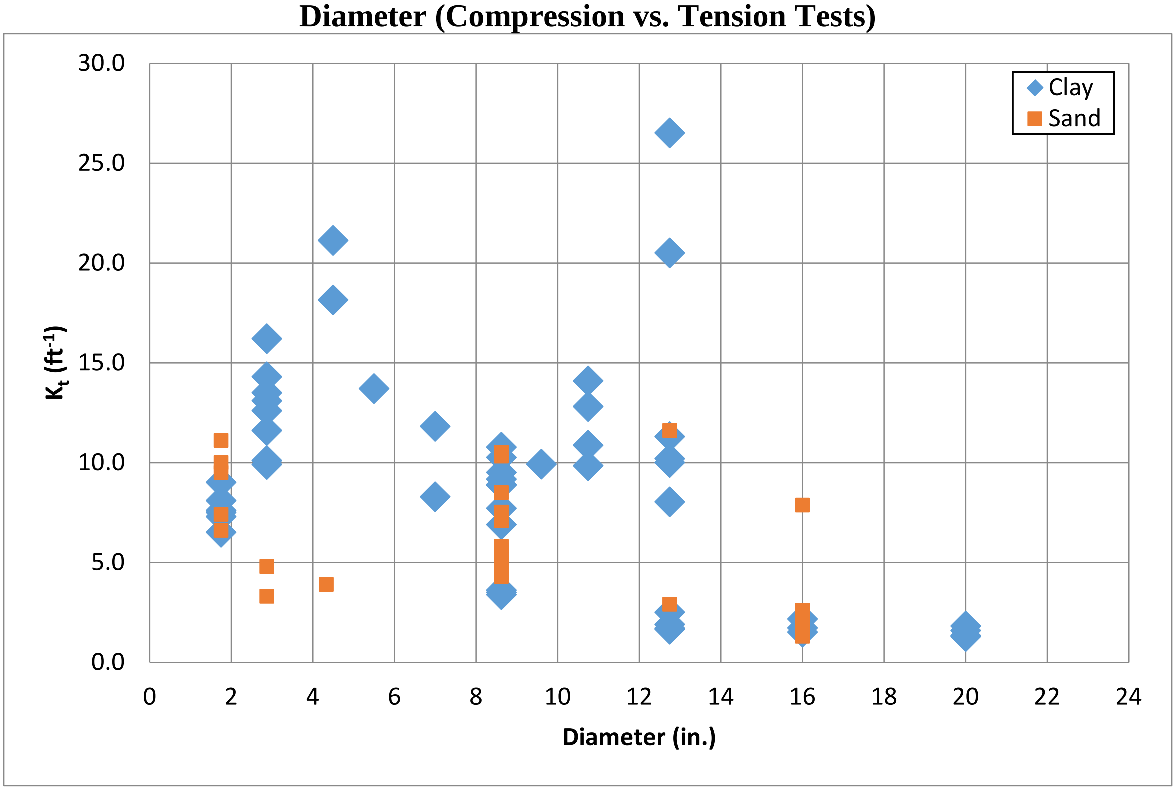

Figure 2.14 Variation of Reported K_T from the Recent Literature as a Function of Shaft Diameter (Clay vs. Sand)

Figure 2.11 further illustrates the scatter found in the literature for results of reported K_T. The majority of this scatter can be attributed to the variability in how K_T is calculated, e.g. definition of Q_{ult} and zone of measurement of torque. The definition of the appropriate installation torque to use when computing K_T is still not agreed upon i.e., which measurement to use. Similarly, a variety of methods for determining ultimate uplift capacity are being used, without one standing out as the most popular. The results from the reported literature were further delineated into groups in an attempt to develop reasonable trends based on factors affecting K_T. Figures 2.12-2.14 show the data broken up into single vs. multi-helix anchors, compression vs. tension tests, and clay vs. sand sites, none of which provide much insight on relevant trends. A summary table of the different methods for determining components that comprise K_T from Table 2.4 is provided in Table 2.5.

Table 2.5 Summary Table of Methods for Determining K_T in the Recent Literature

Installation Torque Used	Method to Determine Q_{ult}	Source
Final Value	10%	Gavin et al. (2014)
Average of Final 3 ft.	8%	Naggar et al. (2008)
Final Value	5%	Sakr (2012)
Final Value	5%	Sakr (2011)
Final Value	Davisson	Beim et al. (2012)
Average of Final 3 ft.	3.50%	El Naggar et al. (2014)
Average of Final Penetration = 3D	10%	Mathias et al. (2014)
Final Value	5%	Padros et al. (2012)
Average of Final 3 ft.	Davisson	Hawkins and Thorsten (2009)
Average of Final 3 ft.	Brinch-Hansen 80% Failure Criterion	Tappenden and Sego (2007)

Given all this disagreement for the most appropriate method for determining both installation torque and ultimate uplift capacity to obtain a relevant value of K_T, a necessity to standardize this process is obvious. AC358 provides specific criteria that should be followed if a torque-to-capacity relationship is to be used to predict capacity. The majority of the criteria, provided in Table 2.6, refer to the geometry of the helical anchor, but 11 and 12 are installation guidelines that deal with quality assurance and quality control for which both the contractor and inspector are responsible for. This list does not apply to large diameter piles because they are not used nearly as much as the typical anchors that are referred to by AC358. If the industry adopts this criteria, values of correlation factors can be easily compared since the process to arrive at them is identical. Standardization for using torque-to-capacity relationships would narrow the path to a more accurate explanation for the specific mechanisms affecting the correlation.

Table 2.6 Torque Correlation Conformance Criteria (AC358 2007).

	Criteria
1	Square shafts with dimensions between 1.5 inches by 1.5 inches and 1.75 inches and 1.75 inches, or round shafts with outside diameters between 2.875 inches and 3.5 inches.
2	True helix shaped plates that are normal with the shaft such that the leading and trailing edges that are within ¼ inch of parallel.
3	Capacity is within normal capacity limits.
4	Helix plate diameters between 8 inches and 14 inches with thickness between 3/8 inch and ½ inch.
5	Helix plates and shafts are smooth and absent of irregularities that extend more than 1/16 inch from the surface excluding connecting hardware and fittings.
6	Helix spacing along the shaft shall be between 2.4 and 3.6 times helix diameter.
7	Helix pitch is 3 inches ± ¼ inch.
8	All helix plates have the same pitch.
9	Helical plates are arranged such that they theoretically track the same path as the leading helix.
10	For shafts with multiple helices, the smallest diameter helix shall be mounted to the leading end of the shaft with progressively larger diameter helices above.
11	Helical pile shaft advancement equals or exceeds 85% of helix pitch per revolution at time of final torque measurement.
12	Helical piers shall be installed at a rate less than 25 revolutions per minute.
13	Helix plates have generally circular edge geometry.

CHAPTER 3: SITE DESCRIPTIONS

3.1 INTRODUCTION

Two sites with varying stratigraphy within the Pioneer Valley region were used to conduct this research. This chapter presents a description of each location, the site geology, and the general site characteristics.

Table 3.1 Summary Table of Site Location Use.

Site	Activity	Company	Machine	Drive Head
UMass AF-GT	Load Tests, Torque Installation Monitoring, Pitch Series Tests	UMass	Bobcat T190	Eskridge 50K (Small Head)
				Eskridge 77BD (Large Head)
UMass DOE Site 1	Load Tests, Field Vanes	Diversified	Bobcat 435 G-Series	Eskridgre 77BD (Large Head)
UMass DOE Site 2	Load Tests, Torque Installation Monitoring	Sea & Shore Construction, Inc.	Mustang ME8003	Pengo 12K
		Diversified Construction, Inc.	Bobcat 435 G-Series	Eskridge 50K (Small Head)
				Eskridge 77BD (Large Head)

3.2 UMASS GEOTECHNICAL EXPERIMENTATION SITE: (DOE)

3.2.1 Site Location and Description

The UMass Geotechnical Experimentation Site is located towards the south end of campus at the University of Massachusetts Amherst, as seen in Figure 3.1.

Figure 3.1 UMass-DOE Test Site Locations

This site, colloquially referred to as the Department of Energy (DOE), is located in the Connecticut River Valley in Western Massachusetts, east of MA-116 on the corner of N Hadley Rd and Mullins Way, just south of the Amherst Wastewater Treatment Facility. The site has gated access along with a gravel road that leads into both sites. The first site is located immediately to the right of the entrance off the gravel road and the other is beyond the set of four test bridge piers to the left of the access road. Site 1 was used to determine values from reload tests on multiple piles with the same shaft geometry, lead section geometry, and installation procedure to evaluate any scatter due to operator effects. Mini Field Vane Tests over helical anchors were also run in parallel with load tests on a SS5 12- series (SS5 12, SS5 12/12, and SS5 12/12/12) to determine aging effects on peak undrained shear strength and ultimate uplift capacity. Site 2 was used for torque installation monitoring and load testing helical piles of varying shaft geometries and lead section geometries to evaluate effects on ultimate uplift capacity.

3.2.2 Site Geology

The test site is located within the boundary of glacial Lake Hitchcock. The depositional environment of the UMass DOE Site is a product of the ancient Laurentide Ice Sheet melting, retreating, and forming a large ice dam near Rocky Hill, Connecticut (Lutenegger 2000). The resulting lacustrine deposits consist of seasonal depositions of varved clay and silt, locally known as Connecticut Valley Varved Clay (CVVC). During the summer, layers of silt and sand were deposited due to the high flow rate of the melt water, and during the winter the clay settled out due to the decrease in flow rate.

At present, a surface layer of loosely compacted fill comprised of fine-grained soils deposited as a result of the construction of the Amherst Wastewater Treatment Facility extends to about 5 ft. The natural lacustrine deposits below reach depths of approximately 100 ft. A stiff, overconsolidated upper crust of CVVC has developed that extends to about 15 to 20 ft. which transitions to a soft, nearly normally consolidated layer of CVVC.

3.2.3 Site Characterization

Connecticut Valley Varved Clay is a low plasticity silty clay that was deposited in generally horizontal alternating layers of silt and clay of varying thicknesses on the order of 2 to 8mm thick. This site has been characterized through numerous subsurface investigations and in-situ tests as part of research and development and academic purposes (Lutenegger 2000). Subsurface investigations at each site consisting of continuous sampling with a 4.25 inch Hollow-Stem Auger and a 2 inch Split Spoon sampler driven with a 140 pound Safety Hammer using a 30 inch drop height were conducted in general accordance with ASTM D6151 *Using Hollow-Stem Augers for Geotechnical Exploration and Soil Sampling*. SPT blow counts ranged from N_{60} = 5 to N_{60} = 16 blows per foot which would classify the consistency of the clay to be medium to stiff (Terzaghi et. al. 1996).

Unit skin friction values obtained from SPT-Torque measurements confirm these assertions of consistency, ranging from f_s = 30 kPa to f_s = 87 kPa in the upper 10 feet of the site. Figures 3.3 to 3.7 show the results from various in situ tests performed at the UMass DOE Site by Khalili (2013). A plot of sensitivity versus depth from mini field vane tests performed by the Author is provided in Figure 3.8 which shows the sensitivity of the CVVC to range on average from about 4 to 6. From 10 to 20 feet, the crust transitions to a soft clay overlying a very soft, nearly normally consolidated deposit of the CVVC. Groundwater levels at this site fluctuate seasonally from about 7 feet below ground surface to at the ground surface based on piezometer readings taken on site over 20 years. The subsurface profile of the site is provided in Figure 3.2.

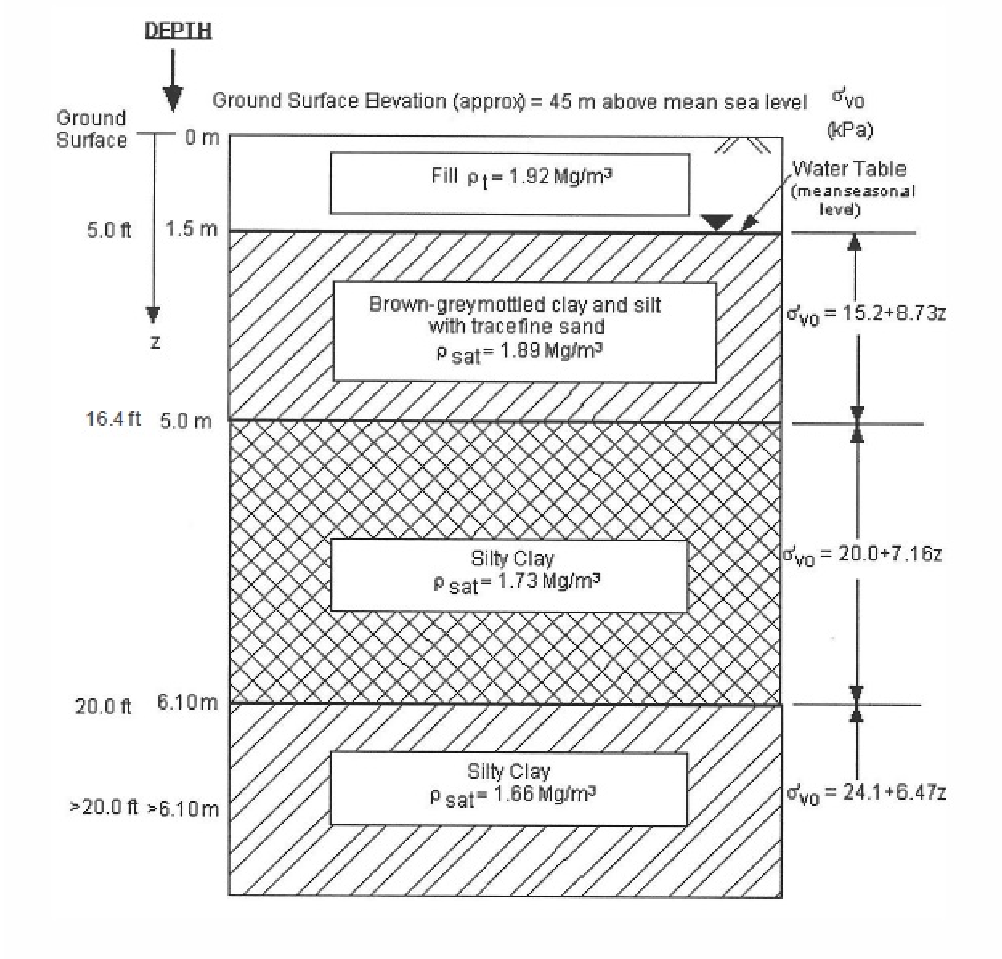

Figure 3.2 Generalized Subsurface Profile at the UMass DOE Site (Ball 2002).

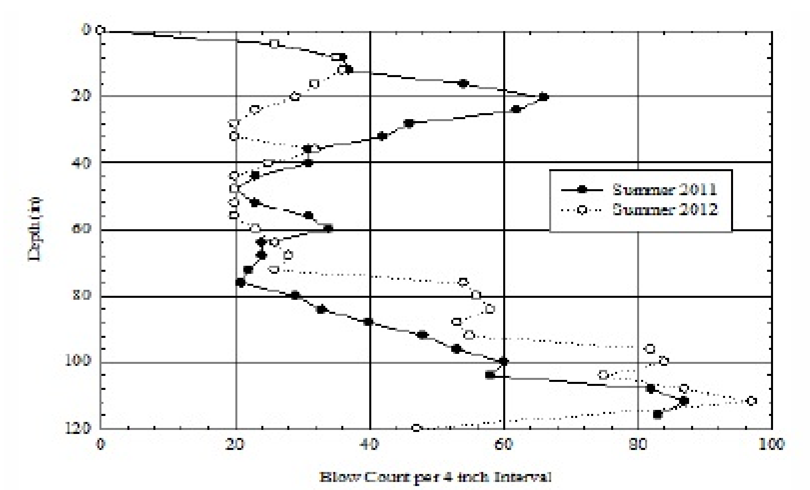

Figure 3.3 Results of DCP Tests from the UMass DOE Site (Khalili 2013).

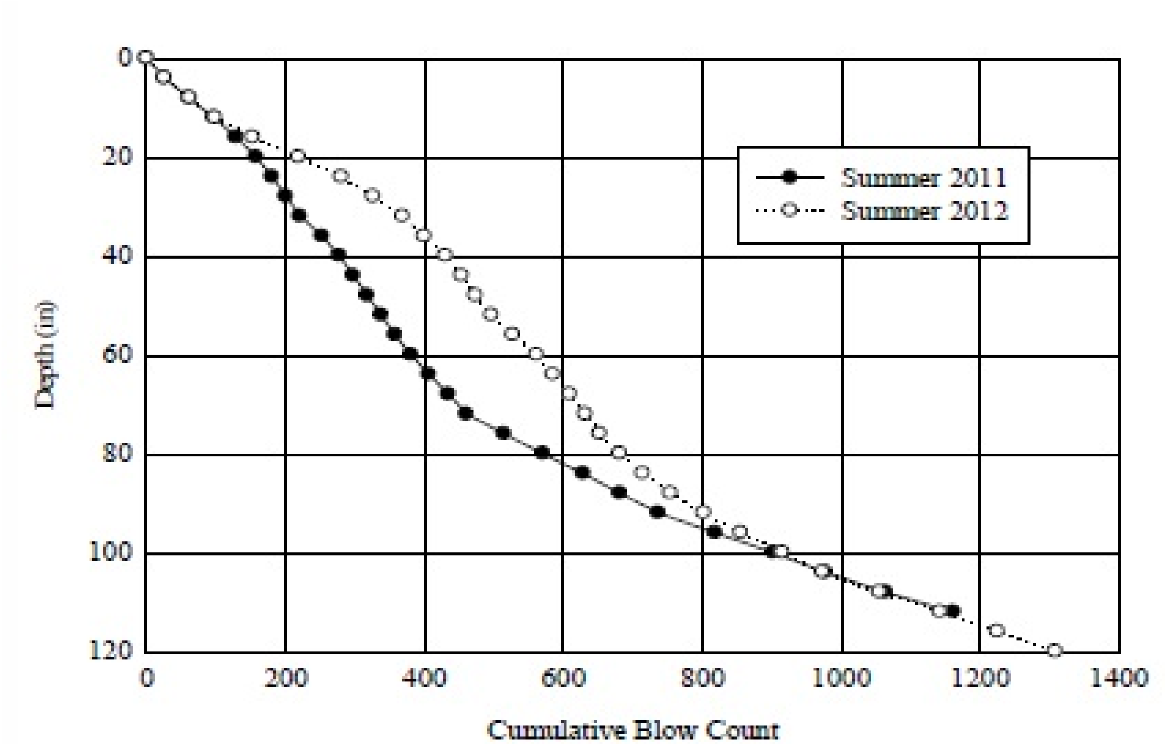

Figure 3.4 Analysis of DCP Tests at the UMass DOE Site (Khalili 2013).

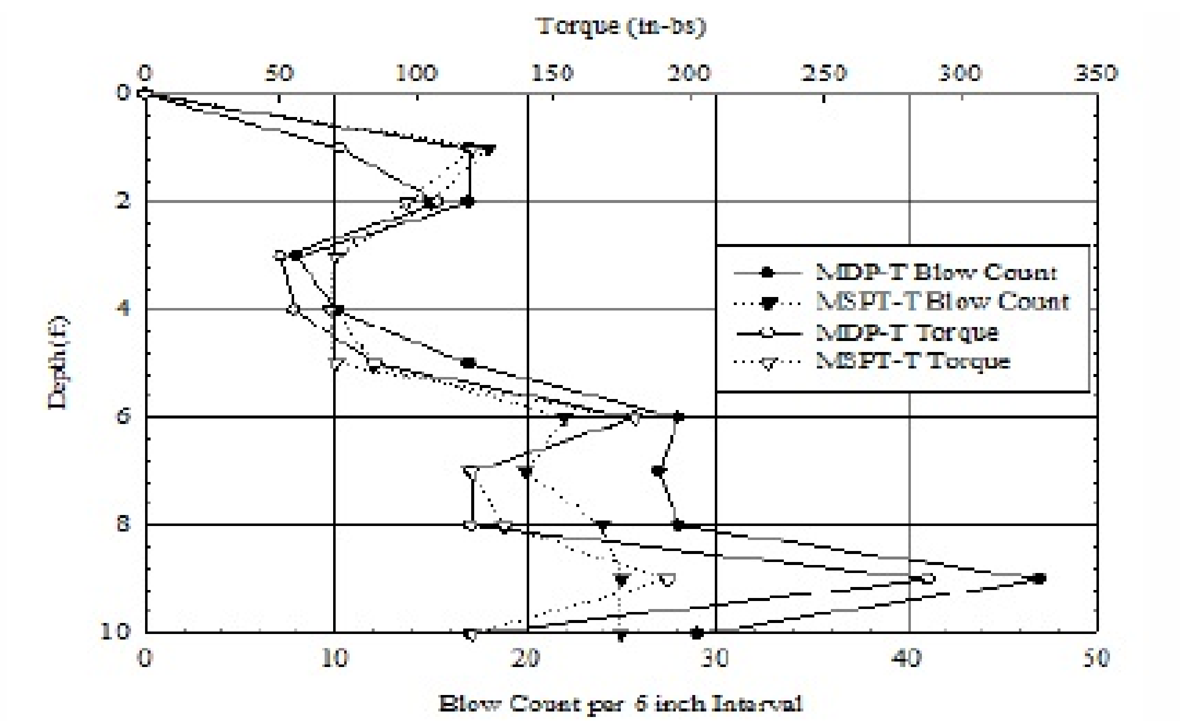

Figure 3.5 Results of MDP-T and MSP-T Tests at the UMass DOE Site (Khalili 2013).

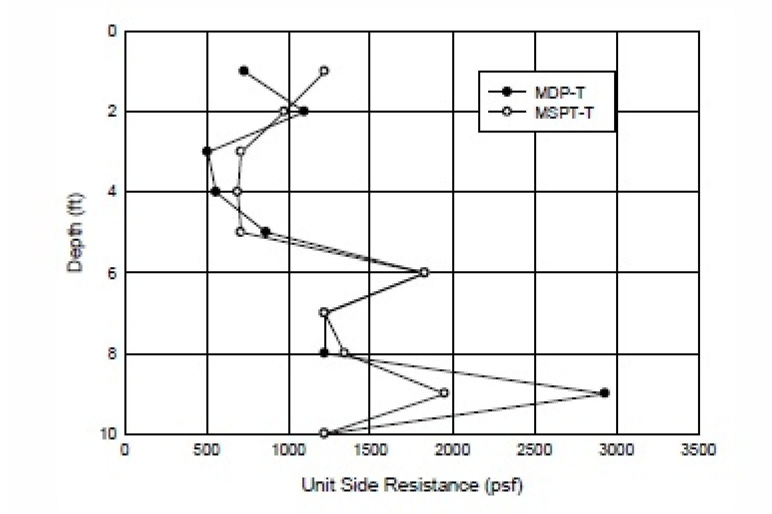

Figure 3.6 Unit Side Resistance Results of MSP-T and MDP-T at the UMass DOE Site (Khalili 2013).

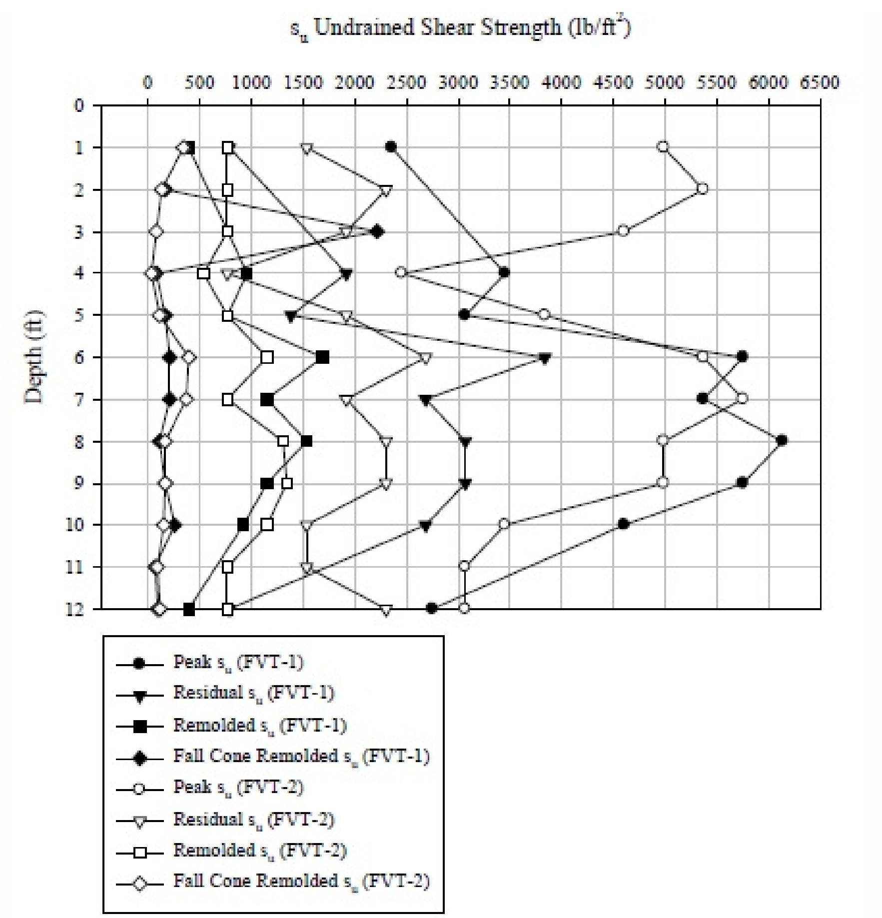

Figure 3.7 Undrained Shear Strength Plot Derived From Field Vane and Fall Cone Tests at the UMass DOE Site (Khalili 2013).

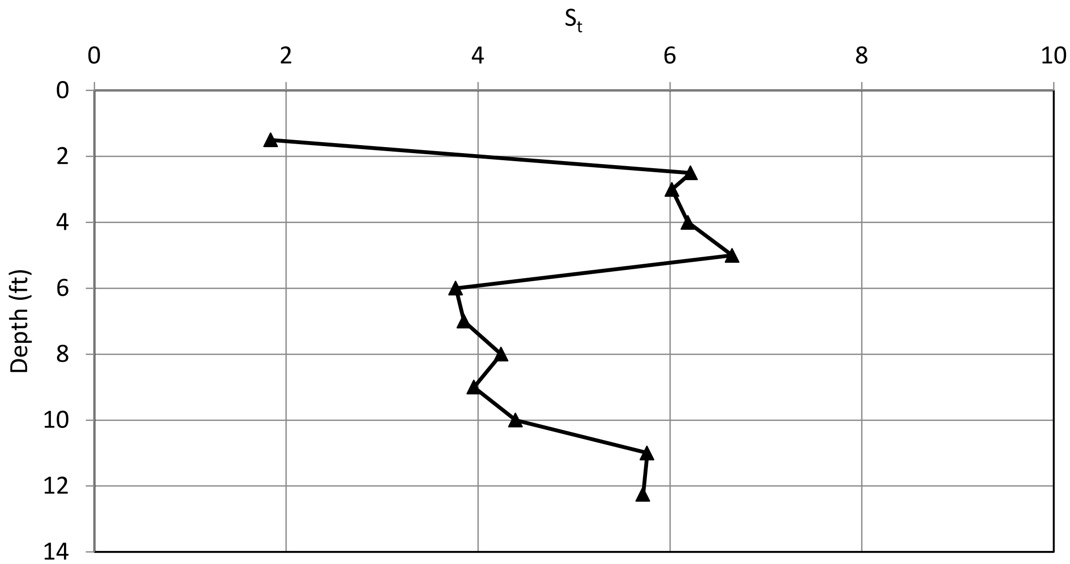

Figure 3.8 Sensitivity Plot from Field Vane Tests at the UMass DOE Site.

This site provides a good range of consistencies, from high OCR to near normally consolidated clay. The high OCR layer is expected to exhibit equal contribution from shaft resistance and plate bearing to ultimate capacity. As the pile is advanced into the softer clay, less of the capacity developed from the plate will contribute to capacity, leaving shaft resistance as the majority contributor to ultimate capacity of the pile.

3.3 UMASS AGRONOMY FARM: GEOTECHNICAL SITE (AF-GT)

3.3.1 Site Location and Description

The UMass Agronomy Farm located at 89-91 River Rd. west of the Connecticut River in South Deerfield, MA was the site of a test location referred to as UMass Ag-Farm GT Site. The Agronomy Farm is primarily used for agricultural purposes, but the sections outlined in Figure 3.9 have been reserved for geotechnical investigations such as in situ testing and load testing of pipe piles, H-piles, Screw-Piles and helical anchors, and finned pipe piles. The topographic map of the site is shown below in Figure 3.10.

Figure 3.9 UMass-Ag-Farm Test Site Locations

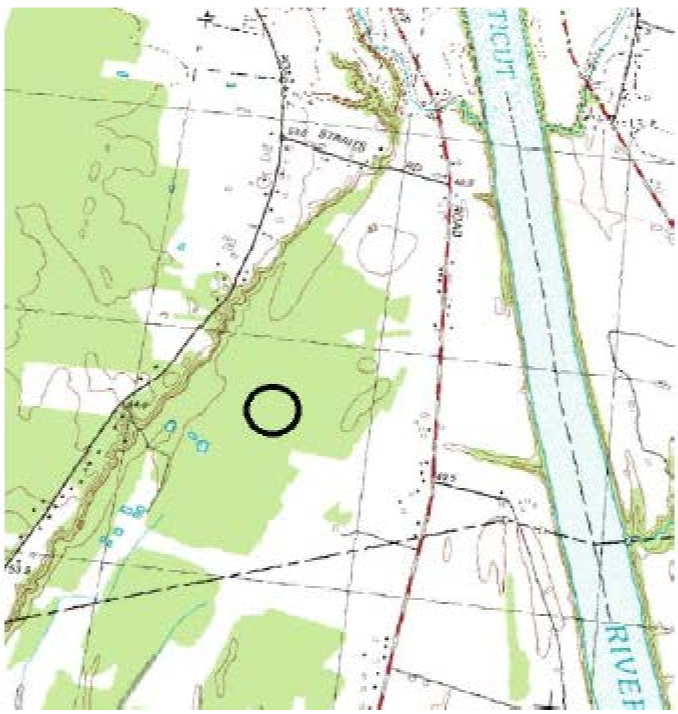

Figure 3.10 UMass-AF-GT Site Location and Topography

3.3.2 Site Geology

The Agronomy Farm is located at the site of the former Glacial Lake Hitchcock. The site is indicative of the lake slowly receding, as river terraces can clearly be seen along the site grading towards the Connecticut River. The site is on an alluvial floodplain at the base of Mt. Sugarloaf where thick lake bed deposits of CVVC can be found overlain by silty sand grading to medium to coarse sand.

3.3.3 Site Characterization

The UMass Ag-Farm GT Site has a fine to medium sand in the upper 13 feet that overlays a thick clay deposit of low plasticity CVVC from about 13 to 40 feet. The subsurface profile is provided below in Figure 3.11.

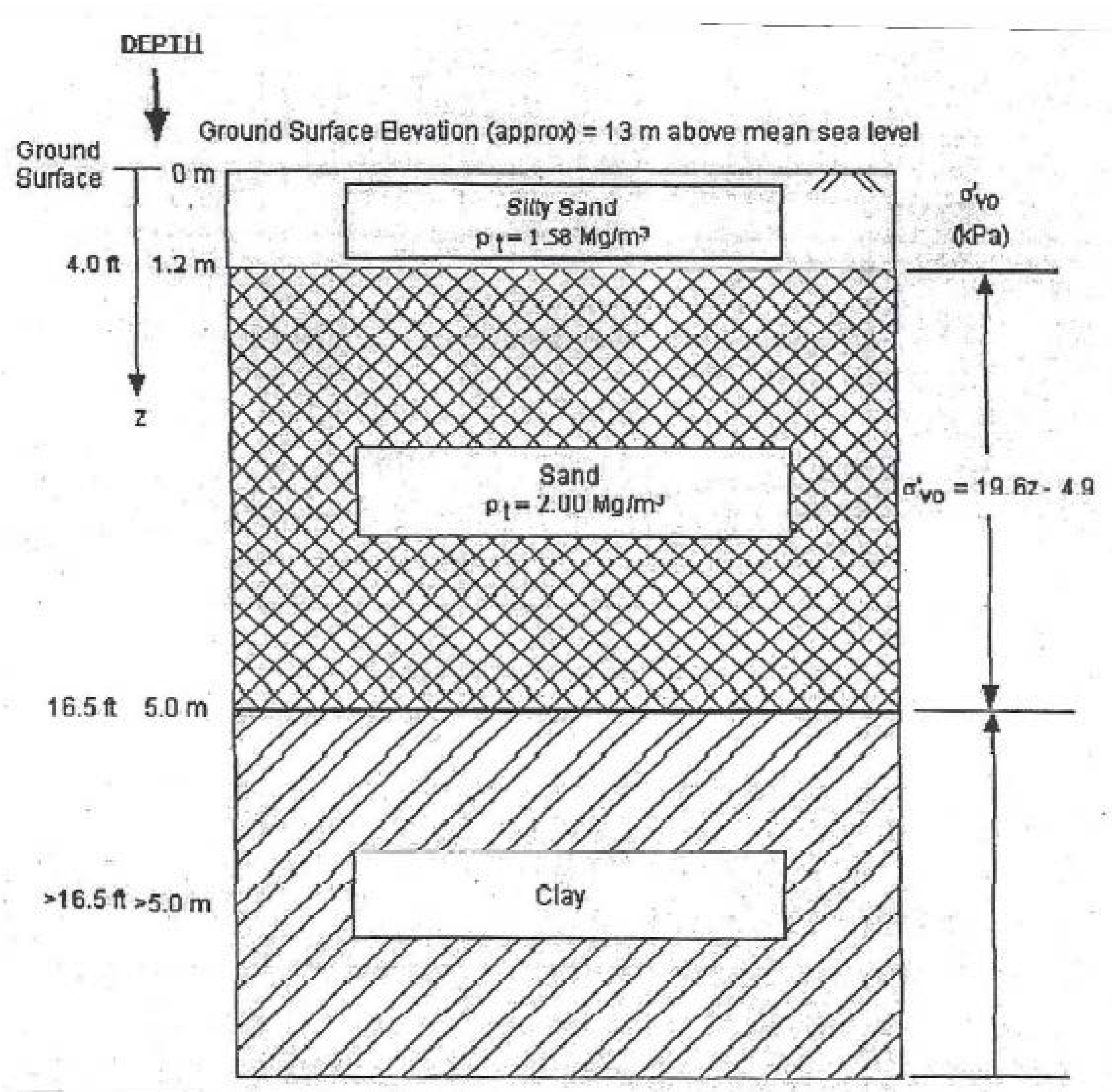

Figure 3.11 Generalized Subsurface Profile at the UMass AF-GT Site (Howey 2004).

SPT blow counts range from N = 6 to N = 24 blows per foot in the sandy layer and from N = 3 to N = 7 blows per foot in the clay layer. Figure 3.6 shows data for both a 2.5 inch and 3 inch diameter SPT Hammer driven to 40 feet. This data is consistent with a loose to medium dense layer of sand that transitions to soft clay at about 13 feet. Figure 3.13 and Table 3.1 show that the upper meter or so is dominated by silty sand, which transitions to a medium to coarse sand until about 13 feet. This site will be useful for analyzing helical anchors with lead sections embedded in different soil types than the shaft extensions above the helices.

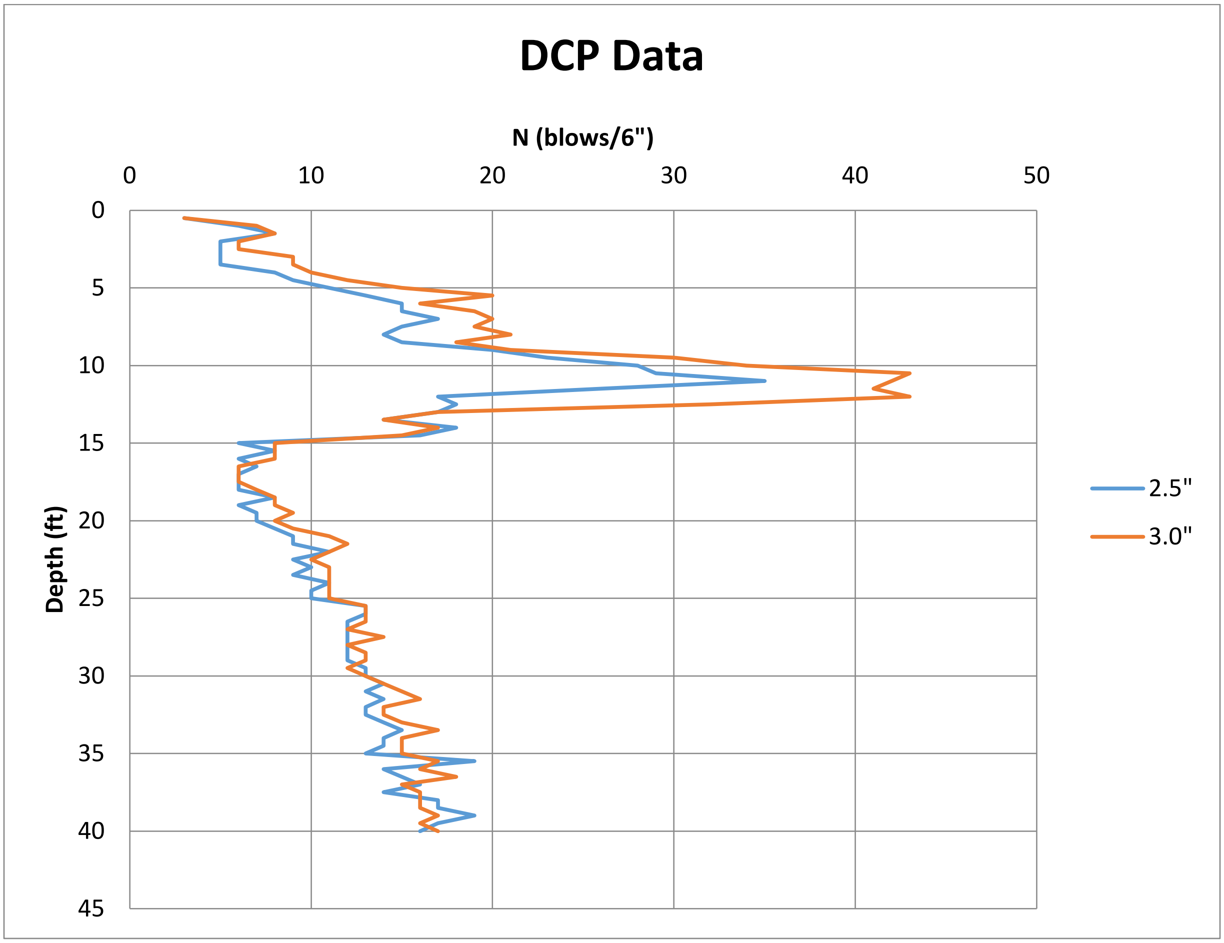

Figure 3.12 Large Drive Cone Penetration Data for the UMass AF-GT Site

Table 3.2 Grain-Size Analysis of the UMass AF-GT Site (Orszulak 2012).

Sample #	Depth (ft)			Depth (m)			% Sand	% silt	% clay	% fines	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c
S1	0	-	1	#	-	0	40.8	54.5	4.7	59.2	0.007	0.02	0.04	0.08	11.4	0.7
S2	1	-	2	0	-	1	24.0	70.1	5.8	76.0	0.006	0.02	0.030	0.04	6.7	1.7
S3	2	-	3	1	-	1	32.4	63.5	4.1	67.6	0.01	0.03	0.045	0.06	6.0	1.5
S4	3	-	4	1	-	1	46.4	50.8	2.8	53.6	0.015	0.035	0.065	0.09	6.0	0.9
S5	4	-	5	1	-	2	71.6	28.4	0.0	28.4	0.03	0.08	0.1	0.15	5.0	1.4
S6	5	-	6	2	-	2	91.3	8.7	0.0	8.7	0.085	0.2	0.45	0.5	5.9	0.9
S7	6	-	7	2	-	2	90.0	10.0	0.0	10.0	0.07	0.2	0.45	0.5	7.1	1.1
S8	7	-	8	2	-	2	94.2	ND	ND	4.4	0.2	0.45	0.6	0.7	3.5	1.4
S9	8	-	9	2	-	3	93.2	ND	ND	5.0	0.2	0.45	0.6	0.7	3.5	1.4
S10	9	-	10	3	-	#	89.1	ND	ND	3.7	0.2	0.4	0.7	0.9	4.5	0.9

CHAPTER 4: METHODS:

4.1 INTRODUCTION

The following chapter presents the methods of investigation used to obtain site characteristics of the UMass DOE Site, the procedures used to conduct uplift load tests, and the methods used to monitor installation of helical anchors. Each test or procedure is described in detail followed by an explanation of the main objective. The laboratory testing program consisted of water (moisture) content determinations and Fall Cone on remolded samples of the Connecticut Valley Varved Clay. The in situ test performed at the UMass DOE Site was the Miniature Field Vane Test in the upper 12 ft of the subsurface to look at s_u over 3 square shaft anchors. In situ monitoring consisted of ground water level measurements taken at the beginning of every testing and installation day. Figures 4.1 and 4.2 provide the Site Plans of the UMass DOE Site and the UMass AF-GT Site indicating the location of each foundation.

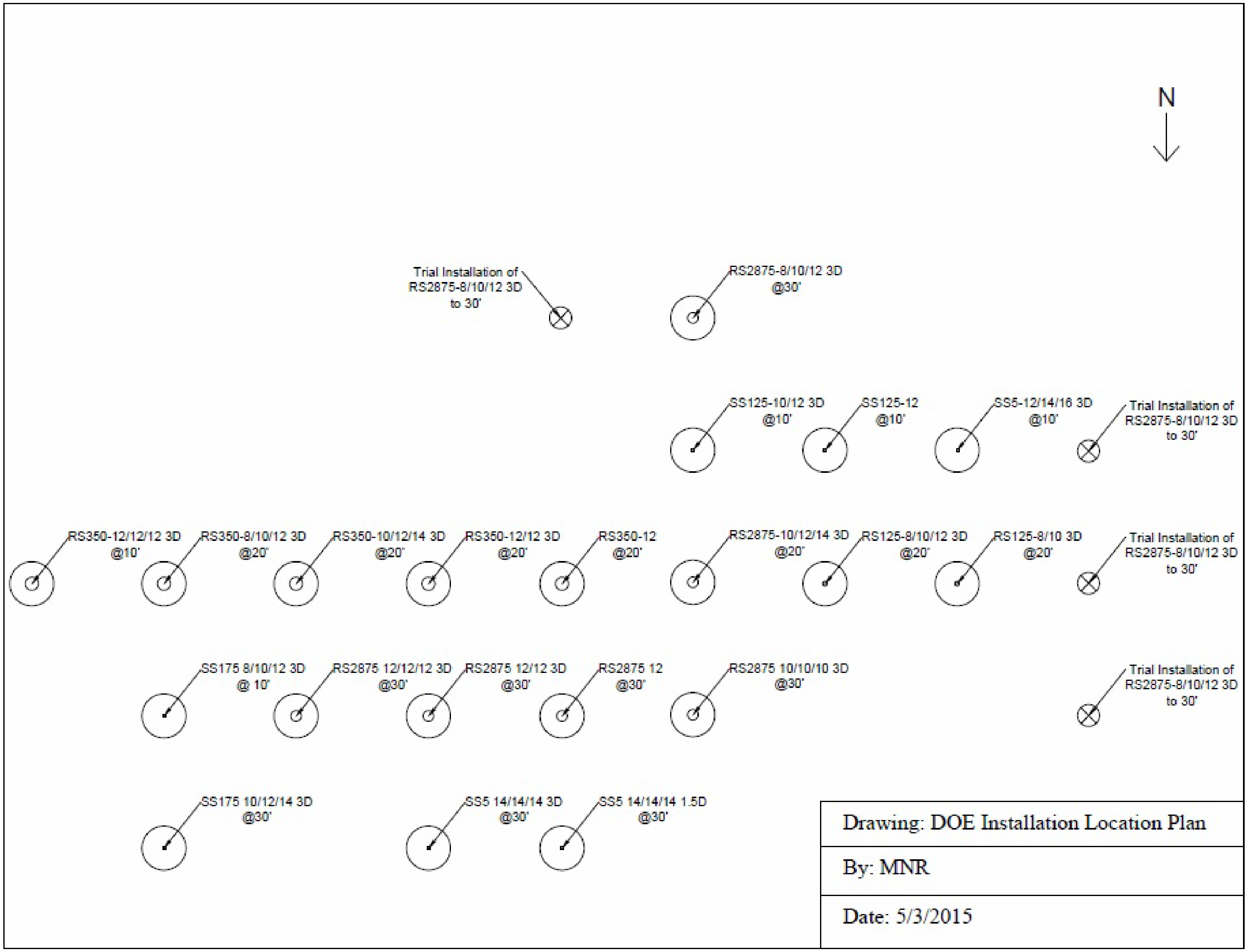

Figure 4.1 UMass-DOE Site Plan

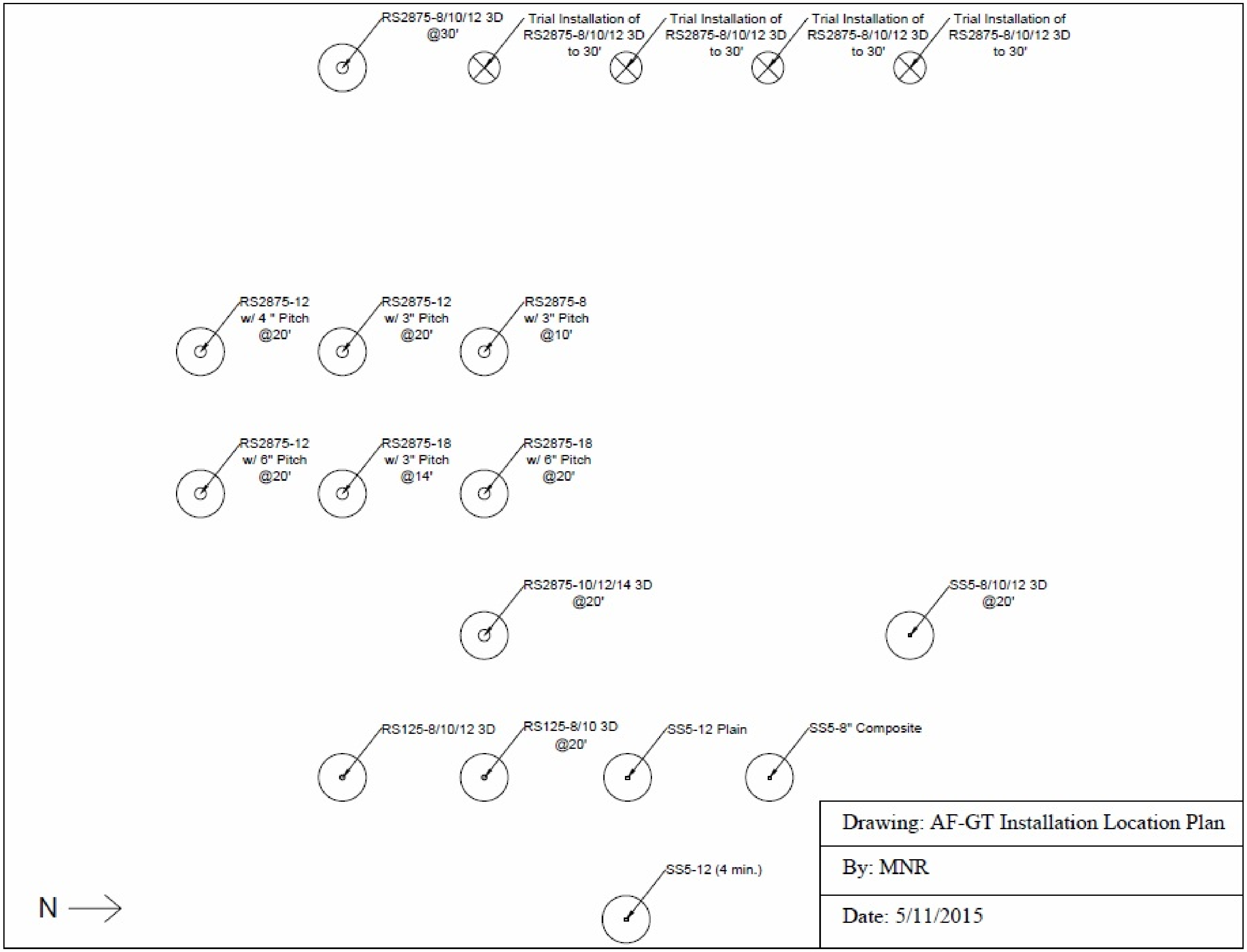

Figure 4.2 UMass-AF-GT Site Plan

4.2 IN SITU TESTS

4.2.1 Groundwater Monitoring

Ground water levels were monitored using an open-standpipe piezometer installed at the eastern side of the UMass DOE Site (Ball 2002). The piezometer was installed in a 2 in. hand auger hole. The piezometer consists of a 1.0 ft. section of 1.0 in. inner diameter machine slotted PVC connected to a solid-wall PVC riser pipe approximately 9.4 ft. long. The auger hole space outside the well screen was backfilled with filter sand and a bentonite seal was used to backfill the remaining length of the hole adjacent the riser pipe (Ball 2002). Ground water level readings were taken prior to each day of load testing and foundation installation conducted at the site using a Slope Indicator Co., Model 51453 Water Level Indicator.

4.2.2 Miniature Field Vane Testing

In order to determine the undrained shear strength over helical anchors & any effect of installation, miniature field vanes were performed in general accordance to ASTM D2573-08 *Standard Test Method for Field Vane Shear Test in Cohesive Soil*. Tests were conducted at the DOE site over the SS5 12 series, which consisted of single 12, 12/12, and 12/12/12 helical anchors on a 1.5 in. by 1.5 inch square shaft, in the Spring of 2013 and again in 2015 to evaluate any aging effects that may influence uplift capacity. In order to compare the disturbed values with undisturbed values, a control field vane test was performed in soil in which no pile had been installed. A 2 in. diameter hand auger was used to advance the borehole 8 in. so that when the vane was pushed the standard 6 inches, the test could be conducted at a depth of 1 ft. below ground surface. Tests were run at 1 ft. intervals, approximately 3.5 in. from the pile in order to evaluate the influence of installation disturbance of single and multi helix anchors, to a depth of 12 ft. below ground surface. A vane with a length of 2 in. and a diameter of 1 in., H/D = 2, was used in this test along with a CDI Multitorq Torque Data Acquisition system that measured the torque during rotation. Peak torque, and subsequently peak undrained shear strength, was focused on for this project because it is the main constituent for determining uplift capacity for helical anchors in clay. Torque was converted to undrained shear strength using Equation 4.1:

$$s_u = \frac{6T}{7D^3} \qquad [4.1]$$

where:

s_u = undrained shear strength

T = torque

D = Diameter of Vane

4.2.3 Sowers Dynamic Cone Penetrometer (SDCP)

As part of an independent study conducted at the UMass DOE Site, the Sowers Dynamic Cone Penetrometer (SDCP) was used to determine the resistance of the soil. The SDCP, illustrated in Figure 4.3, consisted of a 15-lb steel mass that is raised against a stainless steel stopper to a height of 20in. and released to strike an anvil, the force of which drives a 1.5in diameter 45 degree cone that has been seated in the bottom of a hand augured hole. The blows for the first 2” are recorded, and then blows for two more increments of 1.75in. each are recorded for a total drive of 5.5in. This process was performed in 1 foot intervals at the UMass DOE Site to a depth of 12 feet. Samples were collected at each interval for moisture content determinations.

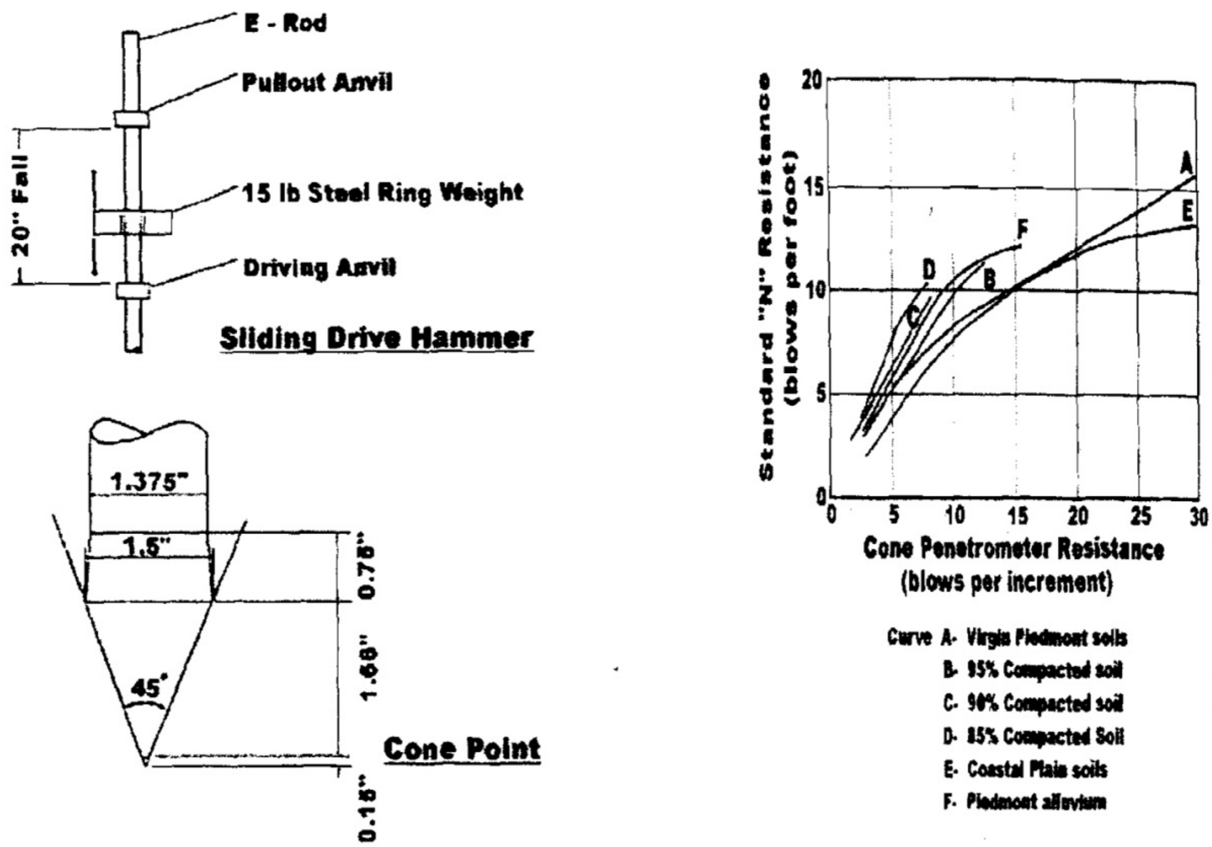

Figure 4.3 SDCP Setup and Resistance Curve

4.2.4 Mini Drive Probe Torque Tests (MDPT-T)

Mini Drive Probe Torque Tests (MDPT-Ts) were conducted in parallel with the SDCP. 60° cones with varying diameters were driven using a 22lb hammer dropped from a height of 19.625” into an anvil. Three straight probes with diameters of 2”, 1.5”, and 1” along with two tapered probes, one with a 1° taper and one with a 2° taper, were driven along with a mini cone and mini SPT at 3in intervals, with blows recorded for each interval. Dimensions of each probe are included in Figure 4.4. After the final 3in of penetration, a torque meter in series with a socket wrench was attached to the top of the probe using an adapter the probe was rotated in order to measure both the peak and residual torque of the soil. Skin friction was calculated from the values of torque using the specific geometry of each probe.

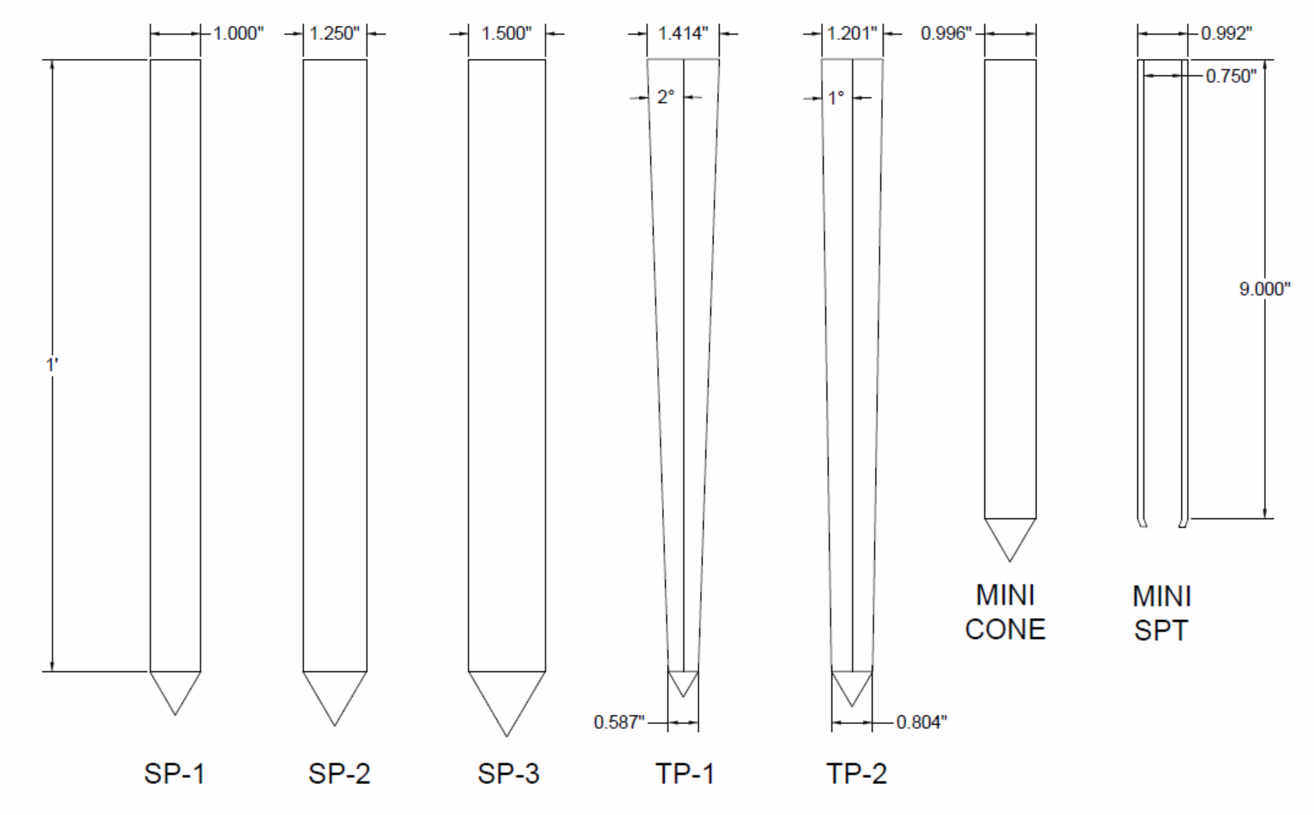

Figure 4.4 Probe Dimensions

4.3 LABORATORY TESTS

Fall Cone Tests were performed on remolded samples of the Connecticut Valley Varved Clay obtained during Sowers Cone Tests. These tests were performed according to the BS1377:1975, Test 2(A) standard. A sample of the soil was placed in a 55mm diameter and 40mm deep brass cup and rid of any voids using a spatula to carefully compact the soil in the container. A stainless steel cone of 100g was positioned so that the tip barely touched the sample and released from the device. Penetration was measured after 5 seconds of contact with the soil. The remolded undrained shear strength was calculated using Equation 4.2:

$$s_{ur} = \frac{KW}{h^2} \quad [4.2]$$

where:

s_{ur} = remolded undrained shear strength

K = cone factor, 0.8 for 30° cone (Hansbo 1957)

W = weight of the cone

The water content of the soil at the UMass DOE Site was obtained from these samples and samples collected from Miniature Field Vane Tests for depths of 1.5 ft. to 12.5 ft. at 1 ft. intervals in the Fall of 2013 and again for depths of 1 to 12 ft. at 1 ft. intervals in April of 2015. Water contents were determined in general accordance with American Society for Testing and Materials (ASTM) D2216-92 *Standard Test Method for Laboratory Determination of Moisture Content of Soil and Rock*. Samples were collected using a 2 in. diameter hand auger and were immediately placed into sealed Ziploc® bags that were kept out of the sun and labeled for site, borehole, and depth and transported to the Geotechnical Engineering Laboratories in Marston Hall at the University of Massachusetts Amherst. Specimens with a total mass of approximately 20 to 30 grams were taken from each sample and oven-dried at 110°C for 24 hours to determine the in situ moisture content of the soil.

4.4 INSTALLATION OF HELICAL ANCHORS

Each helical pile was installed with an excavator or skid steer with an adapter to attach a hydraulic drive torque head that provide the necessary torque to screw the helical anchor plumb into the soil at a consistent rate, which was generally about 30 seconds per foot. For single helix anchors, measurements of progressive advance were measured from the center of the helical plate. For double and triple helix installations, measurements were taken in the middle of the two plates and at the central plate respectively in order to embed the pile to the desired depth.

Helical piles were installed using a variety of machines and torque heads to determine the variability between different setups. The different combinations of machines and torque heads are provided in Tables 4.1 and 4.2. Variability between machine hydraulics and the torque head gearing lead were investigated to evaluate effects on installation torque.

4.4.1 Trial Installations

A single RS2875 tapered 8/10/12 triple helix was used in various trial installations at both the UMass AF-GT Site and the UMass DOE Site to determine the variability in results from using different machinery, torque heads, installation rates, soil types and operators. Only one configuration of helical anchor was chosen to hold the pile geometry factors that influence installation torque constant throughout the trials so that other factors could be isolated and evaluated.

4.4.2 Installations for Load Tests

Many Screw-Piles were installed to perform load tests to determine torque-to-capacity relationships. These anchors were monitored with the same equipment as the trial installations, but installation rate was kept as constant as possible to maintain uniformity. Consistency during installations for load tests was important so that torque-to-capacity relationships could be developed by isolating as many variables as possible to determine the most important factors that influence K_T.

Table 4.1 UMass-AF-GT Site Equipment List

Machine	**Hydraulic Flow Rate (GPM)**
Bobcat T190	16.9 (Standard Flow)
	26.4 (High Flow)
Drive Head	**Torque Capacity (ft-lbs.)**
Eskridge 50K (Small Head)	7000
Eskridge 77BD (Large Head)	6500

Table 4.2 UMass-DOE Site Equipment List

Day 1		*Day 2*	
Machine	**Hydraulic Flow Rate (GPM)**	**Machine**	**Hydraulic Flow Rate (GPM)**
Mustang ME8003	9.7 (Low Flow)	Bobcat 435 G-Series	19.81 (Standard Flow)
	21.8 (Standard Flow)	**Drive Head**	**Torque Capacity (ft-lbs.)**
Drive Head	**Torque Capacity (ft-lbs.)**	Eskridge 50K (Small Head)	7000
Pengo MDT-12K	12000	Eskridge 77BD (Large Head)	6500

Measured hydraulic pressure under zero torque was unique for each head. In order to determine this pressure, each head was engaged in the air, under no load, at both normal and full throttle. The results of these calibrations are provided in Table 4.3. For the large head mounted on the Bobcat T190, it was measured to be 120 psi and 130 psi for normal and full throttle respectively, which means there is not much variation in the differential pressure necessary for the large head to engage under no load at the different speeds. For the small head, a larger amount of differential pressure, 230 psi, was necessary to engage the drive head at normal throttle, and a substantial amount more pressure, 640 psi, was necessary at full throttle. This differential pressure at zero torque is something that must be considered when developing a relationship between torque and differential pressure for each unique setup.

Table 4.3 Drive Head Differential Pressure Calibration

Machine	Drive Head	Throttle	Differential Pressure (psi)
Bobcat T190	Eskridge 50K (Small)	Normal	230
		Full	640
	Eskridge 77BD (Large)	Normal	120
		Full	130
Bobcat 435 G-Series	Eskridge 50K (Small)	Normal	N/A
		Full	N/A
	Eskridge 77BD (Large)	Normal	N/A
		Full	N/A
Mustang ME8003	Pengo MDT-12K	Normal	N/A
		Full	N/A

4.5 PARAMETERS MEASURED DURING INSTALLATION:

At each foot of advance the torque, revolutions per foot, time (seconds) per foot, and differential hydraulic pressure at each foot were recorded. Two direct and one indirect method of measuring torque were implemented in this project. A Chance© digital torque indicator in series with a TORQ-PIN© torque transducer and hydraulic hoses complete with two pressure gages to measure differential pressure, a setup shown in Figure 4.5, were used to monitor installation torque.

Figure 4.5 Torque Monitoring During Helical Pile Installation at UMass-DOE Site Using Bobcat 435 and Large Eskridge Hydraulic Head.

The number of revolutions per foot is an indication of the quality of installation. Based on the pitch of the helical plate, an ideal installation can be quantified. The pitch of a helix is measured vertically from the start of the helix to the end as shown in Figure 4.6, which depicts a typical helical anchor.

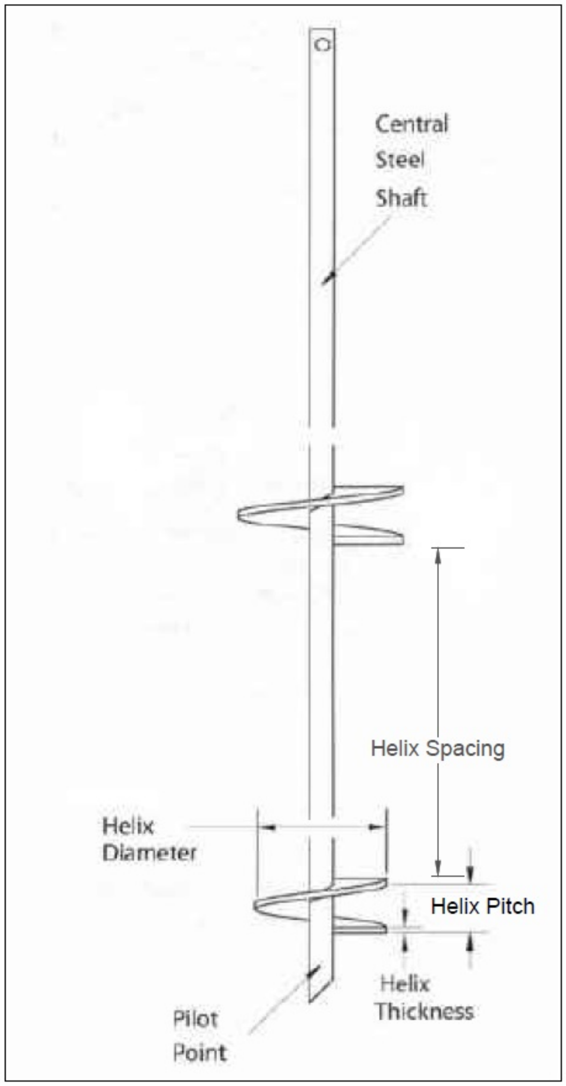

Figure 4.6 Typcial Helical Anchor.

A typical pitch of 3” for a helix would advance exactly 1 foot for every four rotations if it followed the path created by the plate, effectively screwing into the soil, yielding a perfect installation. However, soil conditions and installation technique often lead to a higher number of revolutions per ft. giving “imperfect” installations. “Imperfect” installations can lead to remolding of the soil which lowers the undrained shear strength in clay mobilized by the helical anchor to achieve its capacity. This may not have a major impact on soils in which sand is the main constituent because they are free draining and remolding them has little to no effect on the strength. The severity of this drop in strength is most likely related to the sensitivity of fine-grained soils. Therefore, monitoring the number of revolutions during installation can give the engineer insight on the quality of the installation. The spacing between the helices is also important. Typically multi-helix anchors are spaced at 3D, a length equal to 3 times the diameter of the helix plate, starting with the lead helix. In order to minimize the disturbance to the soil during installation, the helical plate should be advanced into the ground at a rate of one pitch distance per revolution, and multiple helices should be spaced along the shaft in multiples of the pitch, such that the successive helices follow the same path as the leading helix when penetration the soil (Ghaly et al. 1991).

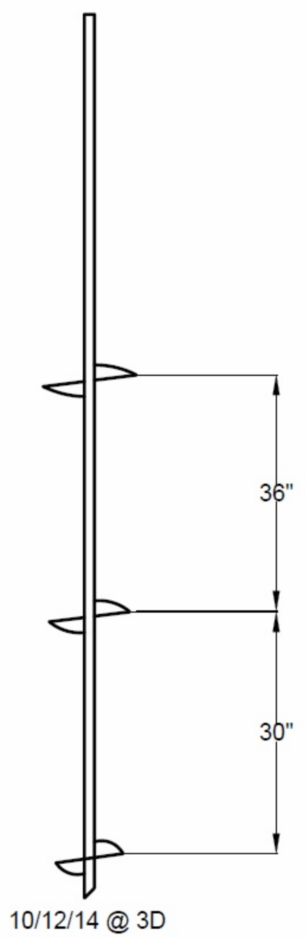

Figure 4.7 Typical Spacing for Helical Anchor

One way to quantify this metric has been proposed (Lutenegger et al. 2014) as defining an Installation Disturbance Factor to be equal to:

$$IDF = R/I \quad [4.3]$$

where:

IDF = Installation Disturbance Factor

R = measured revolutions per unit of advance

I = ideal revolutions per unit of advance = advance/pitch

Values of IDF should be as close to 1 as possible for an ideal installation to give the least disturbed soil conditions behind the helices. Figure 4.8 provided below shows two identical round shaft helical anchors installed to the same depth. As depth increased, the P anchor required more revolutions to advance to the same depth as the SCG anchor, resulting in a higher IDF.

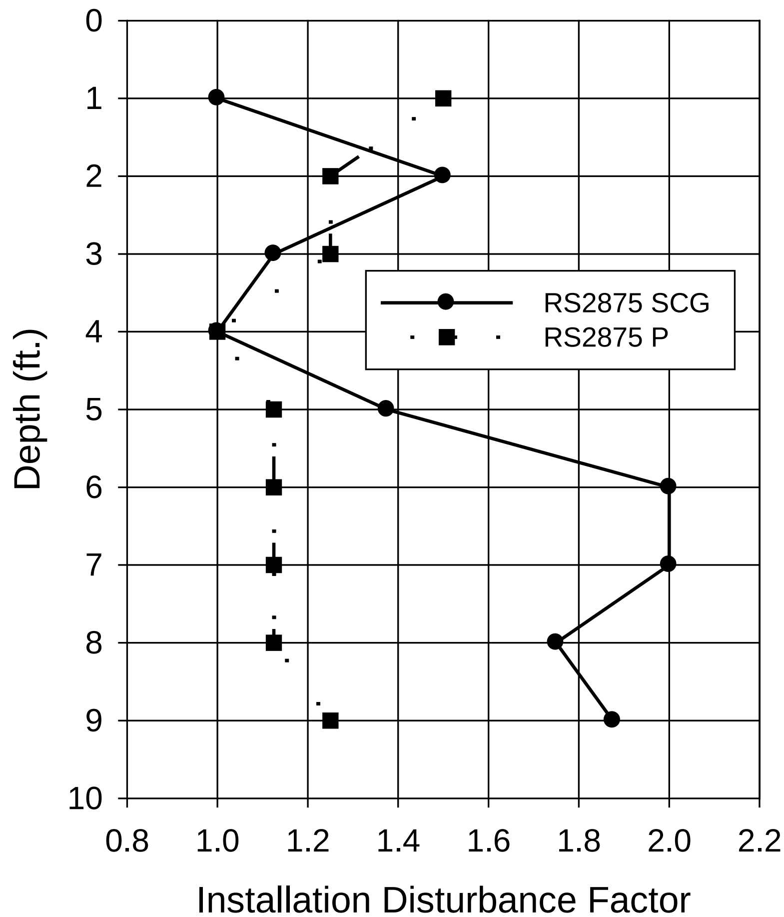

Figure 4.8 Installation Disturbance Factors for Two Round Shaft Helical Anchors (Lutenegger et al. 2014).

IDF plays a role in ultimate uplift capacity because as the number of rotations increase to advance a certain depth, the soil is disturbed more during advance. This is especially important for final installation depths that represent 1 to 2 diameters above the final embedment of the helix which is considered in traditional bearing capacity theory to be the zone of influence contributing to the load capacity in clays. This effect of a “poor” installation is illustrated in Figure 4.9.

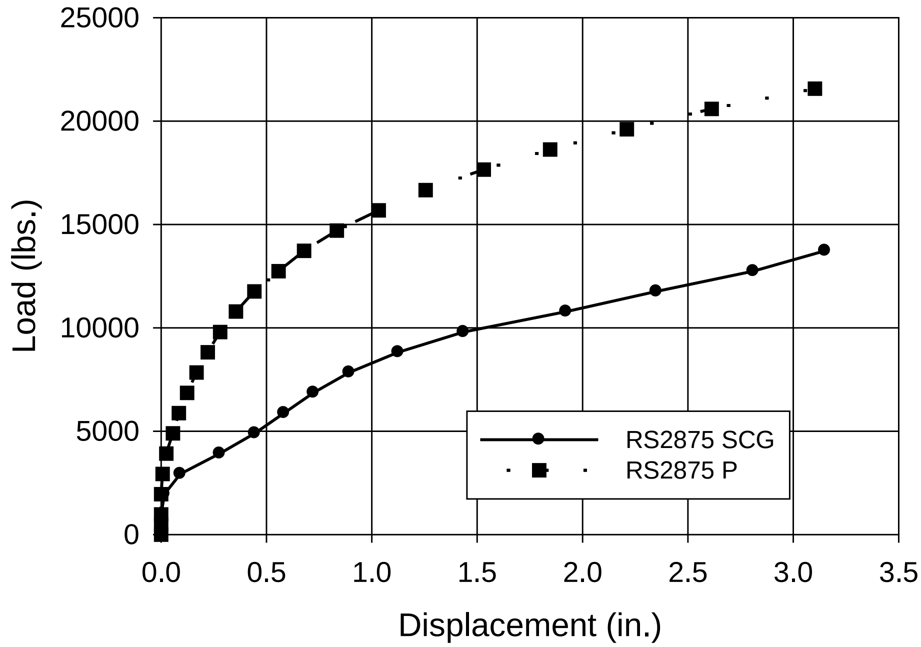

Figure 4.9 Comparison of Load-Displacement Curves for Two Round Shaft Helical Anchors & Influence of IDF (Lutenegger et al. 2014).

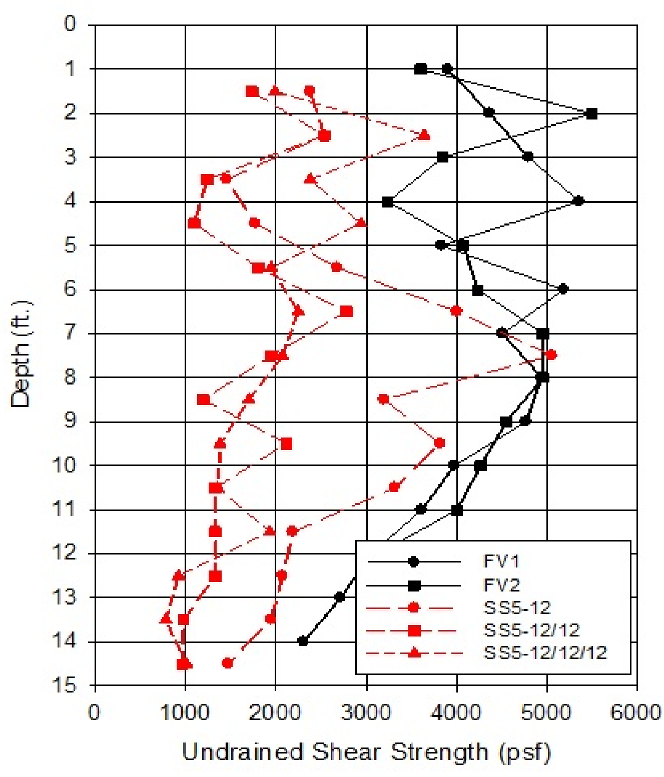

Figure 4.10 Effects of Helices on Undrained Shear Strength in Clays (Lutenegger et al. 2014).

It can be seen that soil disturbance due to a high IDF greatly impacts the uplift capacity of the round shaft helical anchors, diverging by as much as 8000 lbs. of capacity at large displacements. Even with perfect installation, there is still a reduction in strength that occurs due to the helix slicing into the soil. A plot of depth versus undrained shear strength is shown in Figure 4.10 which shows the reduction in strength with each addition of a helix. The greatest reduction in strength occurs after installation of the triple-helix anchor, which lowers the strength by 3000psf at some depths.

4.5.1 Indirect Methods of Measuring Torque

Torque is monitored during installation for a number of reasons. If the torque during installation exceeds the capacity of the equipment used to install the helical anchor, damage to the equipment will occur, and more seriously, someone may be injured. Another reason is that when there is a significant change in instantaneous torque, a new soil stratum may have been penetrated. Therefore, torque can be used to indicate changes in stratigraphy. It can also be used to indicate variability of stratigraphy across a job site. Torque will decrease if there is no advance and soil strength will decrease due to the plate effectively remolding the soil. When designing helical anchors, a certain capacity is required and this calculated available capacity considers the measured parameters of a known soil type present at the site. A sudden change in torque can be indicative that this desired layer has been reached and therefore termination criteria can be met within the target layer.

There are two indirect methods of measuring torque during installation of Screw-Piles: using hydraulic pressure and differential hydraulic pressure. Figure 4.11 provides examples of each indirect method.

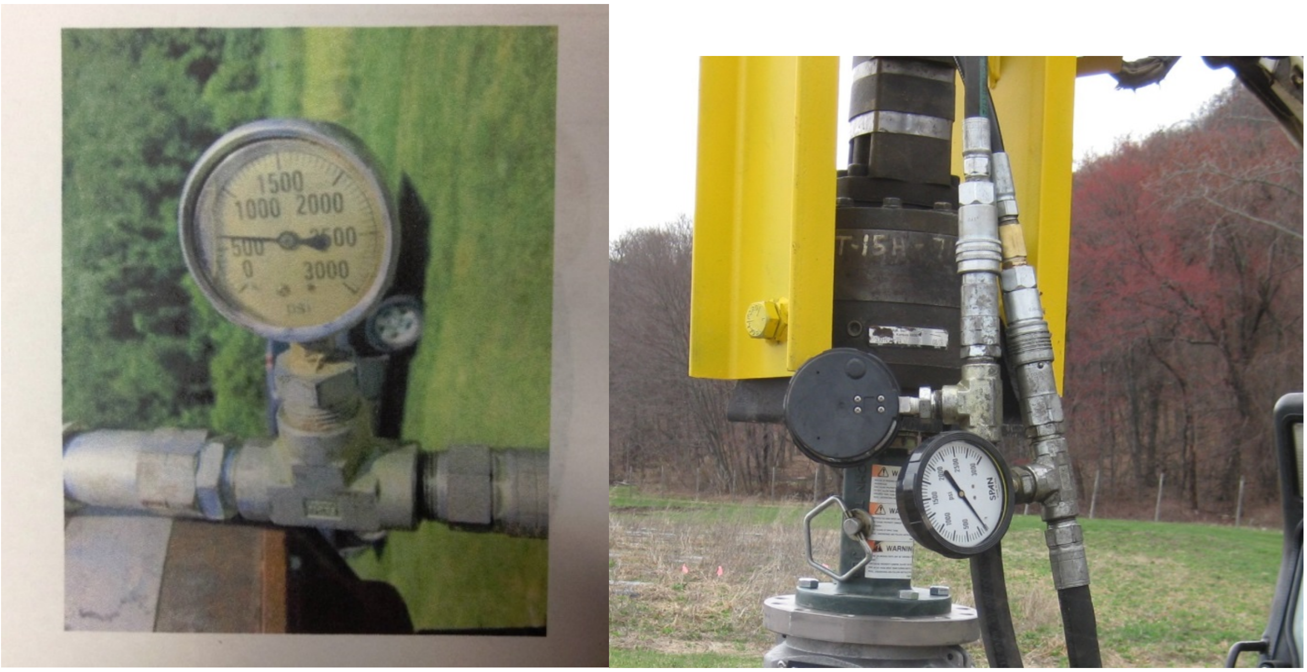

Figure 4.11 Indirect Methods of Measuring Torque (Hydraulic Pressure and Differential Pressure from left to right).

Contractors like the use of hydraulic pressure because it is simple inexpensive, but measuring hydraulic pressure or differential hydraulic pressure is an unreliable method to determine torque unless a proper, site specific correlation is made. When measuring hydraulic pressure, the value measured is the inflow pressure. When a gauge for the back pressure is available, differential pressure can be calculated by taking the difference of the two values. Deardorff (2011) discovered through many tests that each combination of torque head and machine has a unique torque versus differential pressure curve. He attributed the variability to the installation flow rate of the torque head and equipment flow capacity of the machine. When attempting to convert differential pressure to torque using the manufacturer’s published efficiency, the calculated value will generally be underpredicted, leading to conservative designs if using torque-to-capacity relationships for termination criteria. The equation for the conversion is provided in Equation 4.4:

$$\text{Torque} = \frac{DP^{*}CID^{*}PGR^{*}\eta}{2^{*}\pi^{*}(12in/1ft)} \qquad [4.4]$$

where:

DP = differential pressure across the hydraulic motor (psi)

CID = cubic inch displacement of the hydraulic motor (in^3)

PGR = planetary gear ratio of the planetary drive system

η = the drive head efficiency

Deardorff determined that manufacturer's almost always over-predict their torque head efficiencies leading to conservatively lower values of torque.

4.5.2 Direct Methods for Installing Torque

4.5.2.1 Chance Wireless Torque Indicator

Methods of measuring torque directly during installation of helical anchors include using a digital indicator, a torque transducer and a shear pin torque limiter. For this project, a CHANCE® digital indicator was used. Figure 4.12 shows the indicator mounted in-line between the Kelly bar adapter and pile adapter and measures torque using strain gauges.

Figure 4.12 CHANCE® Digital Indicator with Wireless Torque Display

The indicator sends the torque measurement wirelessly to an LED readout so the engineer can be constantly monitoring torque at distances of up to 50ft. The device from CHANCE® used in this project had the capacity for measuring torque of up to 30,000 ft-lbs., a value almost triple the value of the maximum capacity of the largest torque head used in the study. Torque can also be monitored using a torque transducer.

4.5.2.2 TORQ-PIN by Concept Torque Solutions, Inc.

A TORQ-PIN by Concept Torque Solutions, Inc. was utilized in this study. It replaces the dummy pin that connects the torque head to the excavator and also measures torque using strain gauges. The pin, seen in Figure 4.13, is connected using a series of wires to a 4.3” LED display that is able to monitor the torque, depth of installation, angle of installation, and also plumbness to the selected angle.

Figure 4.13 TORQ-PIN, 4.3” LED TORQ-PIN Display, TORQ-PIN Installation (from left to right).

These data can be downloaded onto a computer in the form of an excel file using a USB drive and easily manipulated. The third way of directly measuring torque involves the use of a shear pin torque limiter. This method requires multiple shear pins, each able to withstand a torsional force of 500 ft.-lbs. The appropriate amount of pins are placed into the slots located where the limiter connects to the Kelly bar and torque is indicated when the pins shear. This method limits the user to only one measurement and therefore is not an efficient way to monitor installation torque. A shear pin torque limiter should only be used as a calibration tool for other devices that directly measure torque.

4.6 LOAD TESTING

In order to determine the ultimate capacity of helical anchors in uplift, static load tests were performed in general accordance with the American Society for Testing and Materials (ASTM) D3689 *Standard Test Methods for Individual Piles Under Static Axial Tensile Load* using the incremental load method. Only tension tests were performed in this study. The tests utilized an Enerpac hollow ram 60 ton (500 kN) RCH 606 hydraulic jack. Cribbing in the form of wooden 6x6s were stacked one on top of the other as shown in Figure 4.14, to provide a platform for steel I-beams. The cribbing not only carried the load from the beams produced by the hydraulic pump and cylinder but also provided enough vertical clearance for the test to be performed. Once the cribbing was stacked to the appropriate height two 14 ft. aluminum I-beams were placed perpendicularly to the final row of 6x6s. A circular steel plate with a hole in the center was placed on the beams and centered over the anchor to be tested. The hydraulic cylinder was connected to the pump by a hose, was placed on this leveled off plate. The hole in both the center of the plate and through the center of the cylinder allowed a DYWIDAG rod to be run through the center and connected to the pile using a threaded adapter.

Figure 4.14 Typical Setup for Uplift Test of Helical Anchor at UMass-DOE Site

A 300 kip (1350 kN) Geokon load cell, sandwiched between two steel plates and connected to a Vishay Measurements Group P-3500 digital readout box shown in Figure 4.15, was then placed over the DYWIDAG rod so that the incremental load produced by the piston could be measured accurately.

Figure 4.15 Vishay Measurements Group P-3500 Strain Indicator

Once this part of the test was secured with a nut that thread onto the DYWIDAG rod, a small reference beam with two threaded rods each run through a U-bolt and secured tightly to the beam was driven into the ground. This reference beam was leveled and a digital displacement gauge with a precision of 0.0005 in. was secured to the reference beam to measure the displacement of the pile. A schematized view of the setup is provided in Figure 4.16.

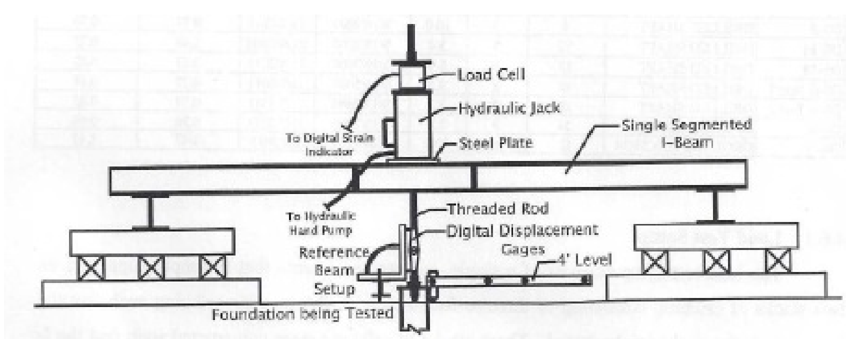

Figure 4.16 Uplift Load Test Schematic (Toombs 2011).

Constant load was applied using the hydraulic jack to the helical anchor and displacement was measured at increments of 0.5, 1, and 2.5 minutes for a pile-specific load schedule determined from calculations based on known capacities of helical anchors in similar soils. The load schedule typically represented increments of approximately 5% of the predicted ultimate capacity. Capacity of helical anchors was estimated using the empirical correlation factor K_T. The load was increased until a minimum displacement of approximately 20% of the average helix diameter of the anchor was achieved or until load could no longer be maintained. Rapid increase in displacement and constant pumping resulting in decreasing load application shown on the readout box were characteristic of a Screw-Pile failure. Once either failure or maximum necessary displacement was reached, final displacement was recorded and the anchor was allowed to “relax” for 5 minutes at zero load. After 5 minutes relaxation, the final displacement of the anchor was recorded and the test was complete.

CHAPTER 5: PRESENTATION OF RESULTS

5.1 INTRODUCTION

This chapter presents and discusses the results of the laboratory tests and in situ tests that were conducted as part of this research project. It also includes the results from the trial installations and load tests that were performed at both the UMass AF-GT site and the UMass DOE Site from Fall 2014-Spring 2015.

5.2 IN SITU TESTS

5.2.1 Miniature Field Vane Tests

Miniature Field Vane Tests (MFVTs) were performed at the UMass DOE Site over the blades of three SS5 anchors to determine changes in peak undrained shear strength over time. A 12, 12/12, and 12/12/12 were chosen to perform the tests over to compare data previously collected in the Fall of 2013. Figure 5.1 shows the results from the in situ tests. In general, the multi helix anchors disturbed the soil the most and therefore the corresponding peak undrained shear strengths measured over these anchors were less than the single and control by approximately 10 psi on average. As was expected, the disturbance from the triple helical anchor was the most severe and resulted in the lowest values of undrained shear strength and did not increase over time. There is a transition period at about 6 ft. below ground surface where the aged retests of the single and double anchor begin to converge toward the control values. The single and double helical anchors showed an increase in undrained shear strength over time of about 15 psi beneath the transition period of 6 ft. This may be a result of water table fluctuating, but never dropping for long below 6 ft., keeping the clay beneath 6 ft. completely saturated. Saturated clays lose strength in response to disturbance more readily than unsaturated clays. Tabulated results from the MFVTs are provided in Appendix B.

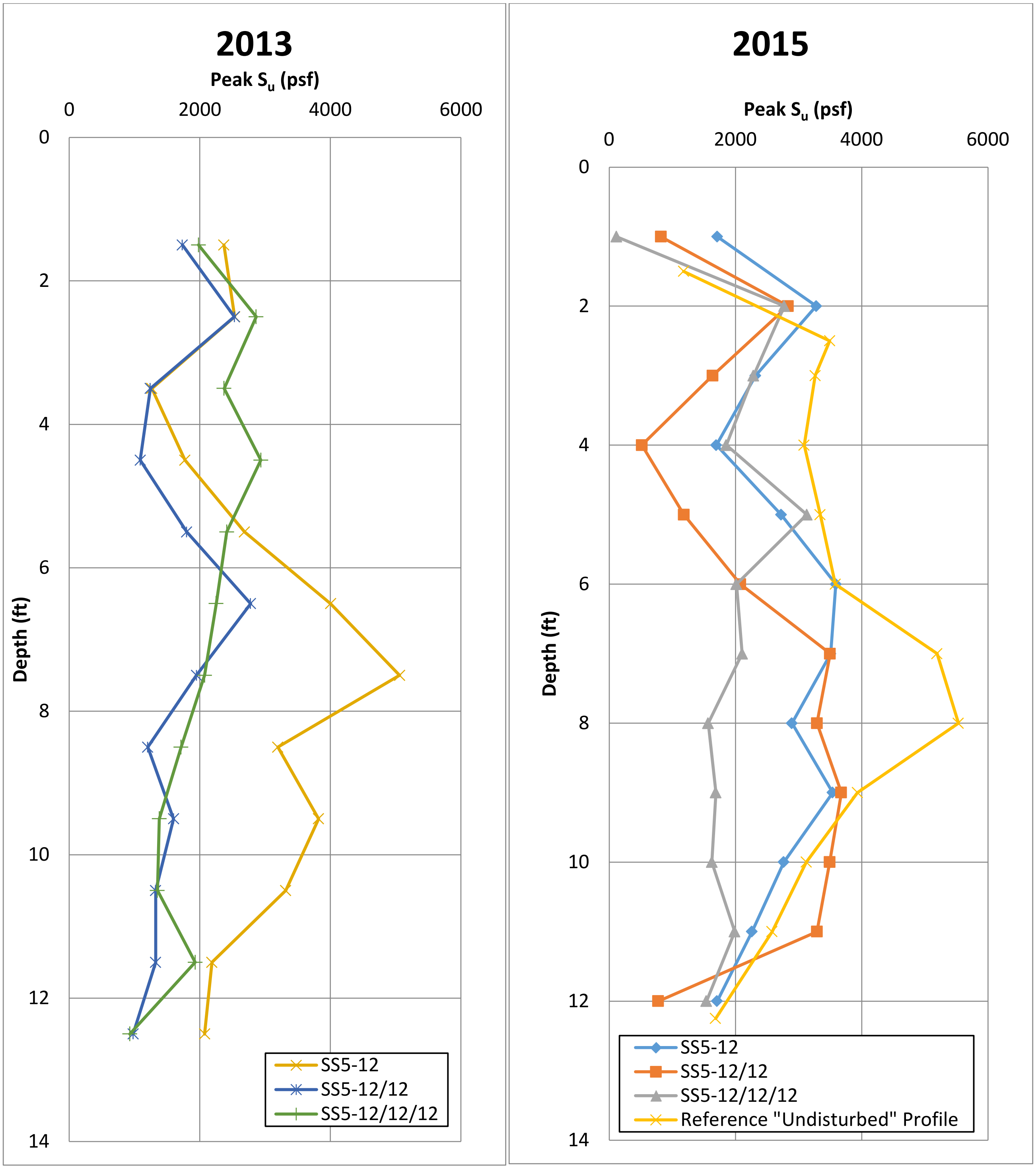

Figure 5.1 Results from MFVTs at the UMass DOE Site

5.2.2 Sowers Drive Cone Penetrometer

The results from the SDCP tests at the UMass DOE Site are provided in Figure 5.2 and show the transition from the stiff overconsolidated crust to the softer more normally consolidated clay at about 8ft.

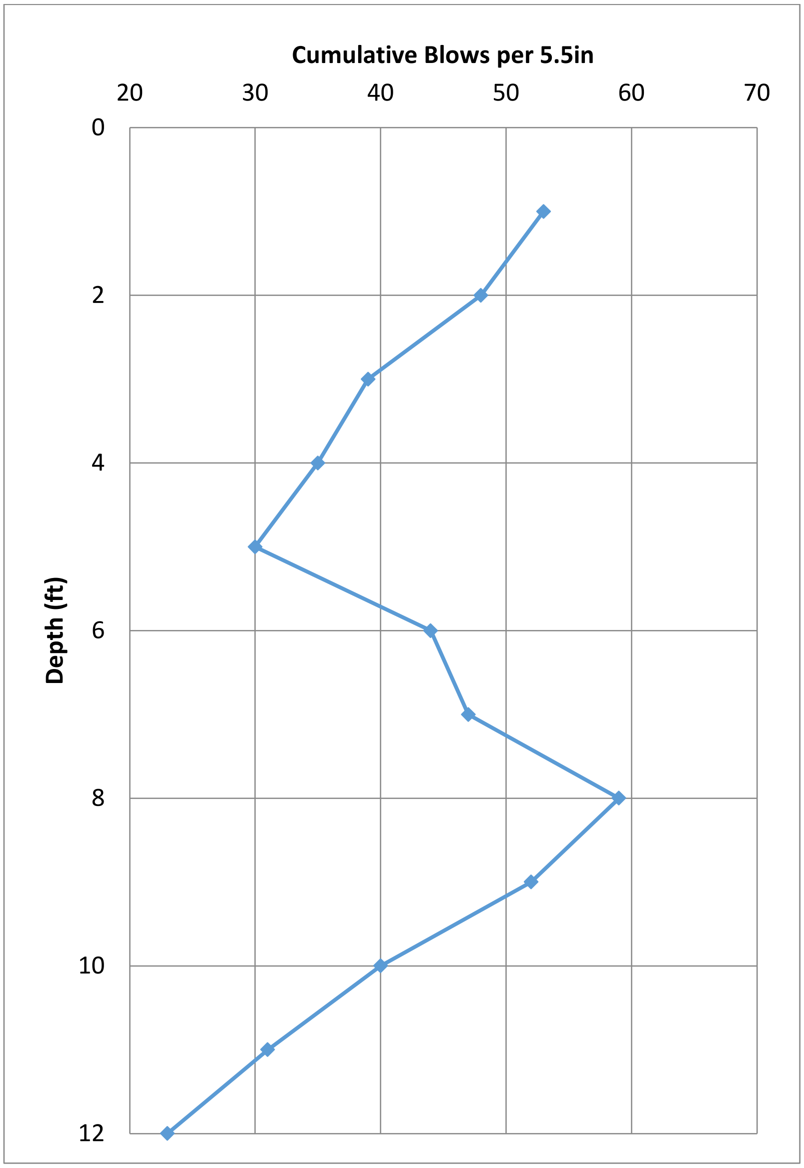

Figure 5.2 Results from SDCP at the UMass DOE Site

5.2.3 Mini Drive Probe Torque Tests (MDPT-T)

Figure 5.3 provides the results from the MDPT tests of the cumulative blow counts per foot at each interval. As expected, the larger the probe, the more blows it took to penetrate the soil. This plot confirms the transition interface at approximately 8ft. between the stiff crust and soft normally consolidated clay that was illustrated in Figure 5.2.

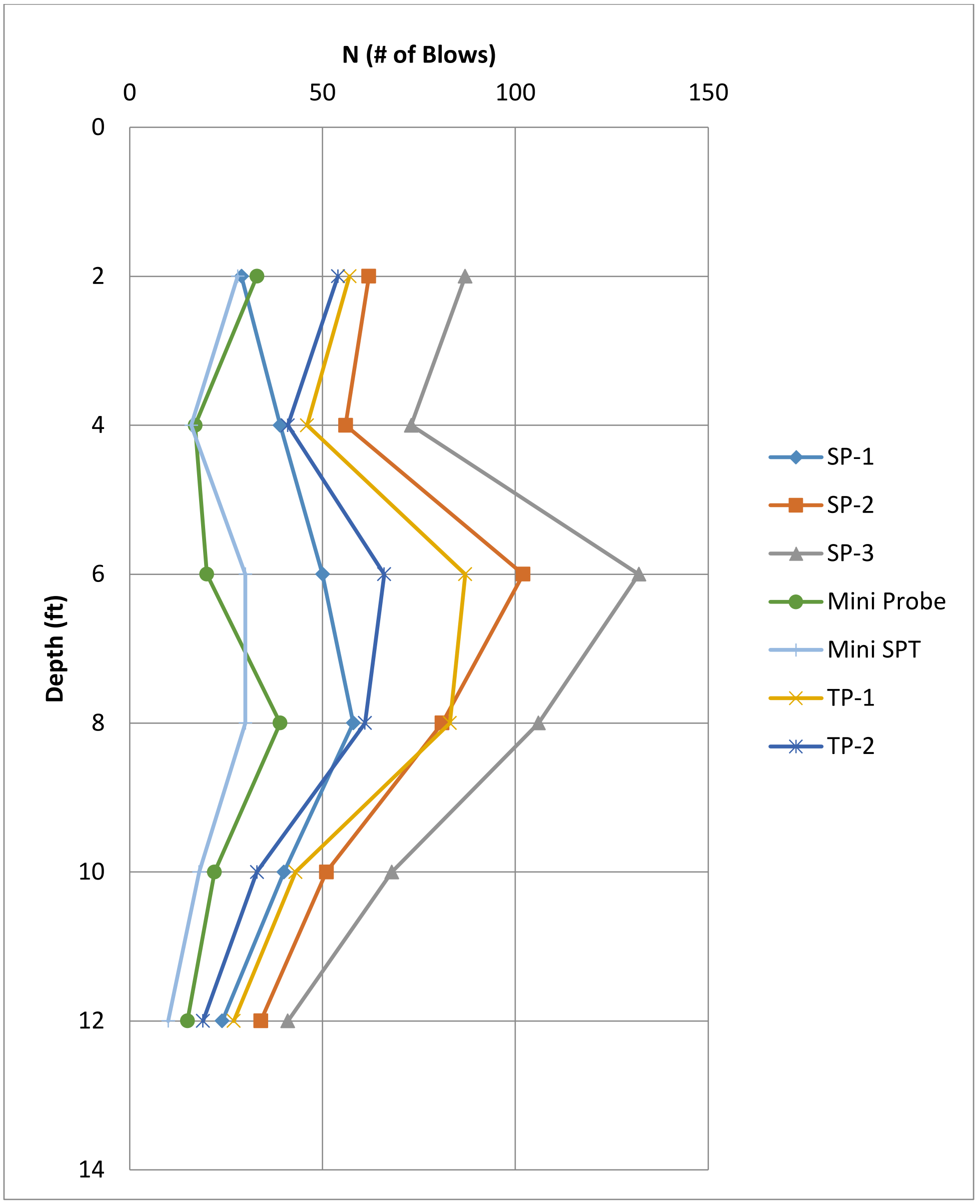

Figure 5.3 Results from MDPT-T at the UMass DOE Site

5.3 LABORATORY TESTS

5.3.1 Moisture Content

Water content determinations were performed on samples collected from the seven MFVTs conducted at the UMass DOE Site. Figure 5.4 presents the moisture content data from the Fall 2013, Fall 2014, and Spring 2015. Water contents at 2 ft. range 25-37% and increase linearly with depth to moisture contents ranging from 47-55% at the 12 ft. interval. The variation in the upper 6 ft. is caused by the sensitivity to water table fluctuations from rainfall. Overall, it is observed that moisture content is for the most part constant over time and between the different seasons. Tabulated results from water content determinations are included in Appendix B with the results from the MFVTs.

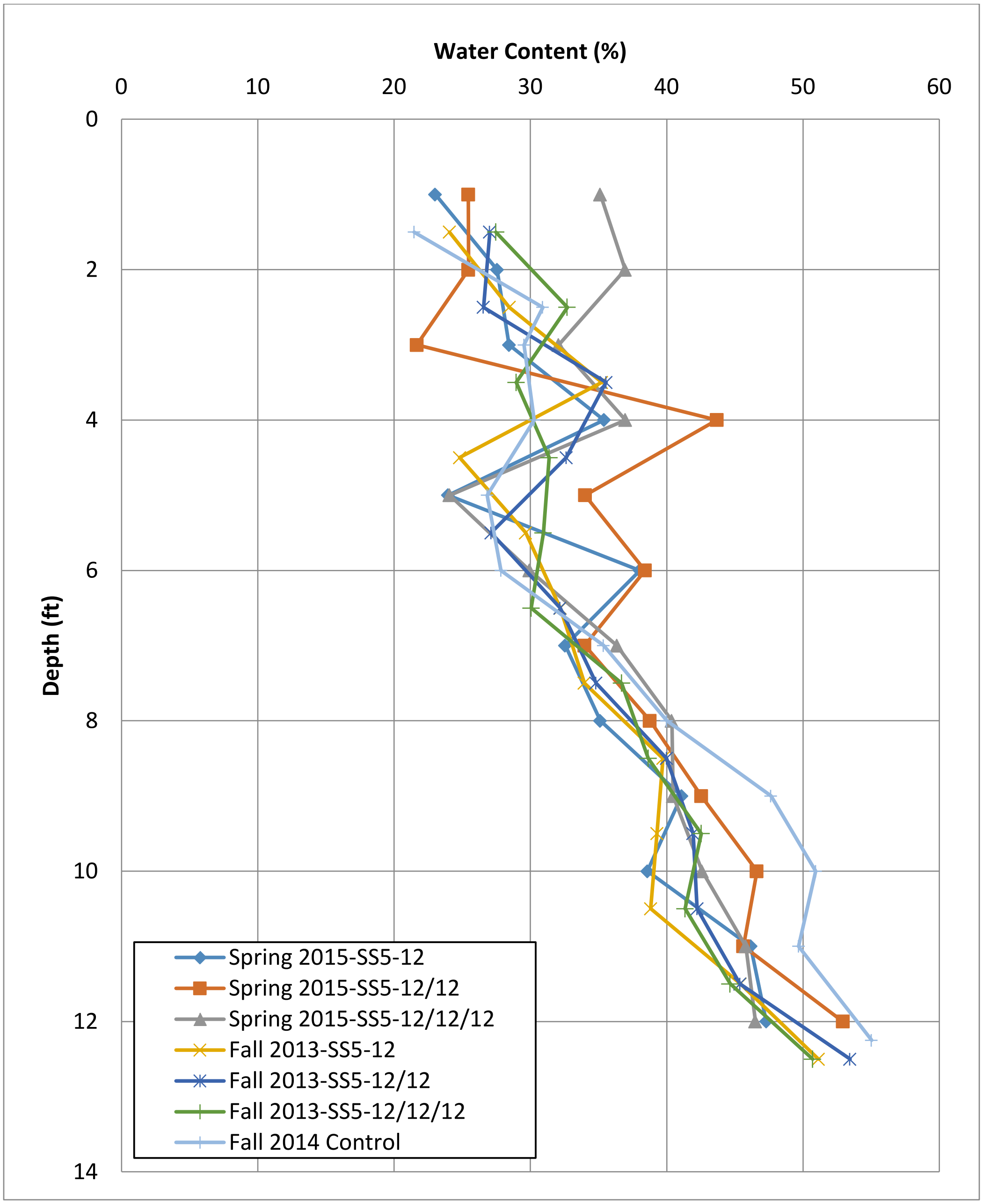

Figure 5.4 Moisture Content Profile at the UMass-DOE Site.

5.3.2 Fall Cone Tests

Fall cone tests were performed on samples obtained from the MDPT-T and results are provided in Figure 5.5. The remolded strength is noticeably much higher in the upper crust, with values ranging from 4000psf to 8500psf, and loses a considerable amount of strength starting at a depth of about 7 feet, dropping below 300psf in the normally consolidated clay below 8ft.

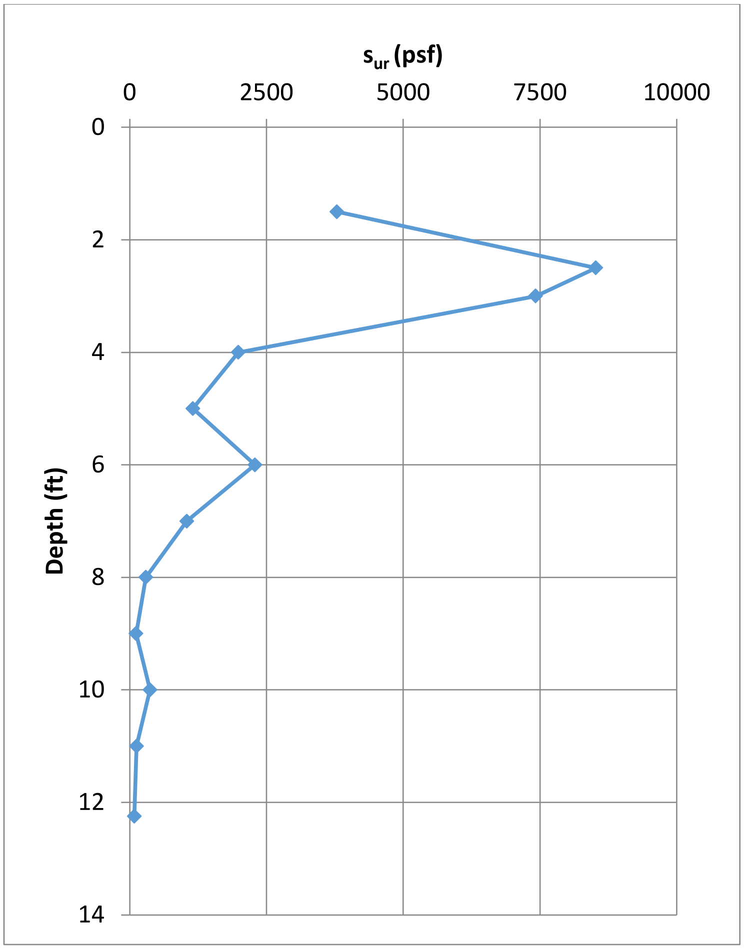

Figure 5.5 Remolded Fall Cone Results from the UMass DOE Site

5.4 TEST FOUNDATIONS

For this project, four different types of pipe piles and Screw-Piles and Helical Anchors were installed and tested at the various sites. These included plain pipe piles, helical pipe piles, round shaft helical anchors, and square shaft helical anchors.

5.4.1 Plain Pipe and Helical Pipe Piles

Plain pipe piles and similar geometry helical pipe piles were re-tested from a former Master of Science Project by Orszulak (2012) to determine aging effects on shallow helical foundations. Each plain pipe pile had a corresponding helical pipe pile installed with the same shaft geometry to the same depth but with a single 12 in. helix in order to separate the components of aging into shaft and helix dependency. A summary table of the pile characteristics is provided in Table 5.1.

Table 5.1 Summary Table of Shallow Foundations Evaluated.

Pile Number	Shaft Diameter (in.)	Pitch (in.)	Depth (ft.)	Helix Diameter (in.)
PP 1	2.875	N/A	4	N/A
PP 2	2.875	N/A	8	N/A
PP 3	4.5	N/A	4	N/A
PP 4	4.5	N/A	8	N/A
PP 5	6.625	N/A	4	N/A
PP 6	6.625	N/A	8	N/A
PP 7	8.625	N/A	4	N/A
HP 1	2.875	3	4	12
HP 2	2.875	3	8	12
HP 3	4.5	3	4	12
HP 4	4.5	3	8	12
HP 5	6.625	3	4	12
HP 6	6.625	3	8	12
HP 7	8.625	3	4	12

5.4.2 Round Shaft (RS) and Square Shaft (SS) Helical Anchors

Numerous RS and SS helical anchors were installed and tested and some retested for this project. All RS extensions had an upset end so only lead section was in contact with the soil along the shaft. In addition to piles that were installed, existing piles were re-tested and then screwed into the ground to be tested at greater depths. Both single-helix and multi-helix anchors were analyzed in this project to evaluate the influence of number of helices on torque-to-capacity relationships. For triple-helix anchors, both tapered and cylindrical configurations were installed and tested to evaluate disturbance factors. A tapered helical anchor has progressively larger helices after the lead helix to improve uplift capacity while limiting the disturbance felt by the upper helices. A cylindrical anchor has uniform diameter helices. The idea behind this design is to maximize bearing capacity contribution from the helix if disturbance in the soil is less of a factor, mainly in cohesionless soils. A schematic of the two configurations and the zone of disturbance they create during installation is illustrated in Figure 5.6. Types of SS piles and RS piles are presented in Tables 5.2 and 5.3 respectively.

Table 5.2 Summary Table of SS Helical Anchors Evaluated.

Square Shaft Helical Anchors					
Shaft Size (in.)	**Pitch (in.)**	**Helix Spacing**	**Helix Diameter (in.)**	**Site Tested**	**Test Depths (ft.)**
1.25	3	N/A	12	UMass DOE Site 2	10
1.25	3	3D	10/12	UMass DOE Site 2	10
1.5	3	N/A	12	UMass DOE Site 2	15
1.5	3	3D	12/12	UMass DOE Site 2	15
1.5	3	3D	12/12/12	UMass DOE Site 2	10, 15, 20
1.5	3	3D	8/10/12	UMass AF-GT	10, 20
1.5	3	3D	10/12/14	UMass DOE Site 2	10, 20, 30, 40
1.5	3	3D	12/14/16	UMass DOE Site 2	10
1.5	3	1.5D	14/14/14	UMass DOE Site 2	10, 20, 30
1.5	3	3D	14/14/14	UMass DOE Site 2	10, 20, 30
1.5	3	N/A	12	UMass AF-GT	20
1.75	3	3D	8/10/12	UMass DOE Site 2	10
1.75	3	3D	10/12/14	UMass DOE Site 2	10, 20, 30

Table 5.3 Summary Table of RS Screw-Piles.

Round Shaft Helical Anchors						
Coating	**Shaft Diameter (in.)**	**Pitch (in.)**	**Helix Spacing**	**Helix Diameter (in.)**	**Site Tested**	**Test Depths (ft.)**
Galvanized	1.25	3	3D	8/10	UMass DOE Site 2	20
Galvanized	1.25	3	3D	8/10/12	UMass DOE Site 2	10, 20
Galvanized	1.9	3	N/A	14	UMass DOE Site 1	9
Galvanized	2.875	3	N/A	10	UMass DOE Site 2	10, 20
Galvanized	2.875	3	N/A	12	UMass DOE Site 2	10, 20, 30
SCG	2.875	3	N/A	14	UMass DOE Site 1	9
Galvanized	2.875	3	N/A	14	UMass DOE Site 1	9
Plain	2.875	3	N/A	14	UMass DOE Site 1	9
SCBP	2.875	3	N/A	14	UMass DOE Site 1	9
SCBP-HCO	2.875	3	N/A	14	UMass DOE Site 1	9
SCBP-NCH	2.875	3	N/A	14	UMass DOE Site 1	9
Galvanized	2.875	3	3D	10/10	UMass DOE Site 2	10, 20
Galvanized	2.875	3	3D	12/12	UMass DOE Site 2	10, 20, 30
Galvanized	2.875	3	3D	10/10/10	UMass DOE Site 2	10, 20, 30
Galvanized	2.875	3	3D	12/12/12	UMass DOE Site 2	10, 20, 30
Galvanized	2.875	3	3D	8/10/12	UMass DOE Site 2	10, 20, 30
Galvanized	2.875	3	3D	10/12/14	UMass DOE Site 2	10, 20
Galvanized	2.875	3	3D	8/10/12	UMass AF-GT	10, 20, 30
Plain	2.875	3	N/A	8	UMass AF-GT	10
Plain	2.875	3	N/A	12	UMass AF-GT	10, 20
Plain	2.875	4	N/A	12	UMass AF-GT	10, 20
Plain	2.875	6	N/A	12	UMass AF-GT	10, 20
Plain	2.875	3	N/A	18	UMass AF-GT	10
Plain	2.875	6	N/A	18	UMass AF-GT	10, 20
Galvanized	3.5	3	N/A	12	UMass DOE Site 2	10, 20
Galvanized	3.5	3	3D	12/12	UMass DOE Site 2	10, 20
Galvanized	3.5	3	3D	12/12/12	UMass DOE Site 2	10
Galvanized	3.5	3	3D	8/10/12	UMass DOE Site 2	10, 20
Galvanized	3.5	3	3D	10/12/14	UMass DOE Site 2	10, 20
Plain	4.5	3	N/A	14	UMass DOE Site 2	9
SCBP-HCO	4.5	3	N/A	14	UMass DOE Site 2	9
Galvanized	4.5	3	N/A	14	UMass DOE Site 2	9
SCG	4.5	3	N/A	14	UMass DOE Site 2	9
SCBP-NCH	4.5	3	N/A	14	UMass DOE Site 2	9
SCBP	4.5	3	N/A	14	UMass DOE Site 2	9

** Note: SCG - Slick Coated Galvinized pile, SCBP - Slick Coated Black Pile,*
SCBP-HCO - Slick Coated Helix Only Black Pile, SCBP-NCH - Slick Coated Shaft Black Pile

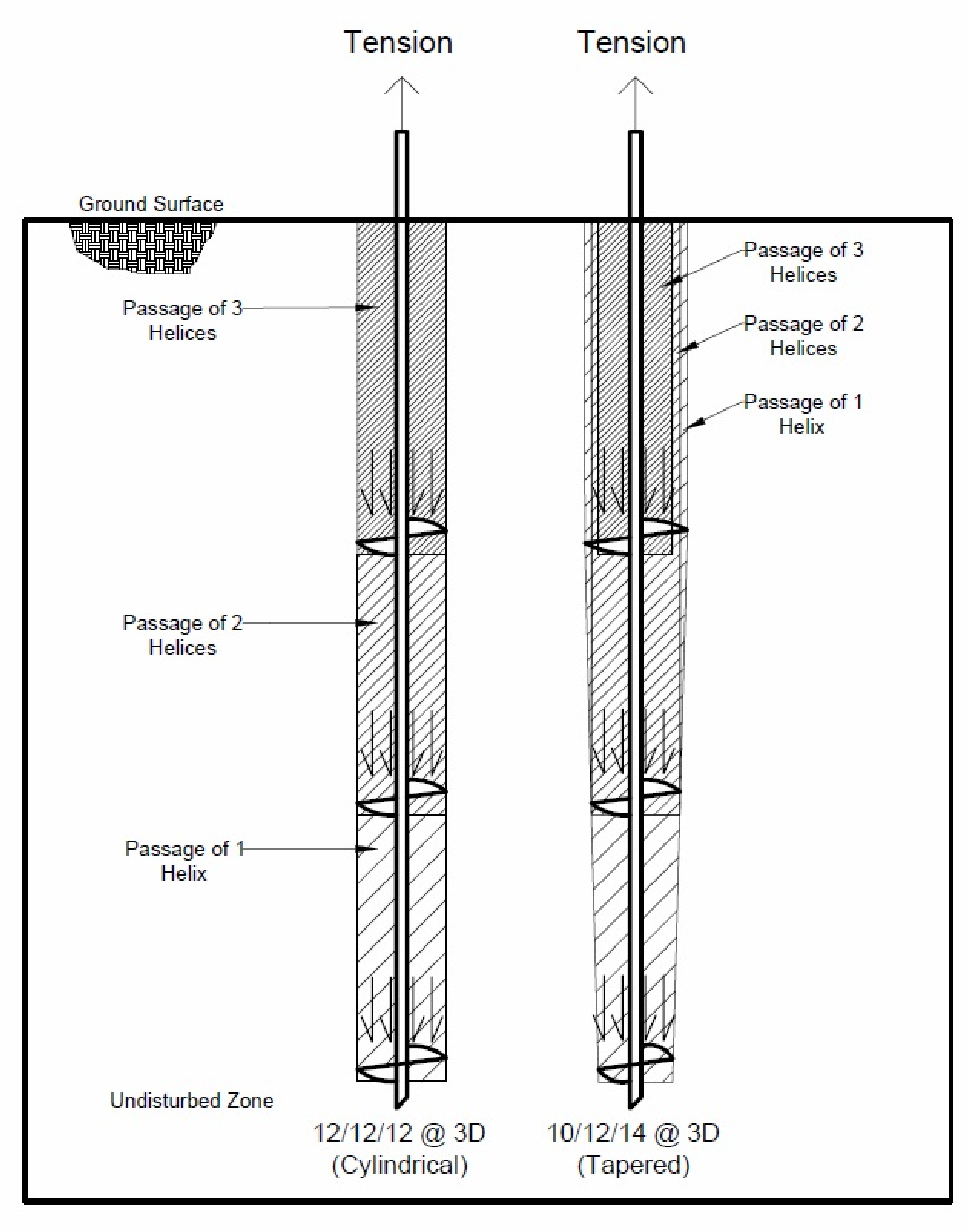

Figure 5.6 Disturbance Effects of Tapered vs. Cylindrical Helical Anchors.

5.5 TRIAL INSTALLATIONS- INVESTIGATION OF INSTALLATION TORQUE

5.5.1 UMass-AF-GT Site

Various trial installations were performed at the Agronomy Farm located in South Deerfield, MA just west of the Connecticut River across River Rd. All trial installations were performed with a Bobcat T190 compact track loader equipped with the necessary 1 1/8 in. diameter hydraulic lines to provide power to the torque head. Two torque heads were tested at the Agronomy Farm to determine the variability in performance given the same machine. Capacity for the two torque heads along with the hydraulic flow rate and standard and high flow for the T190 are provided in Table 5.4.

Table 5.4 Machine and Torque Head Specifications Used at UMass-AF-GT Site

Machine	Hydraulic Flow Rate (GPM)
Bobcat T190	16.9 (Standard Flow)
	26.4 (High Flow)
Drive Head	**Torque Capacity (ft-lbs)**
Eskridge 50K (Small Head)	7000
Eskridge 77BD (Large Head)	6500

An RS2875 8/10/12 was installed to a depth of 30 ft. using different combinations of rotation speed and torque head configuration. During every trial installation, differential hydraulic pressure, torque, rotations per foot, and time per foot of advance were recorded. The Eskridge 50K is referred to as the small head because it is about half the size of the larger Eskridge 77BD torque head. They have similar torque capacities but are geared differently to produce similar torque at different gear ratios. A trial installation using the small head operating at normal throttle was conducted along with 4 trials using the larger head; one at low throttle, one at normal throttle, one at full throttle, and the last at normal throttle but with measurements of torque recorded at 0.5 ft. intervals.

Figure 5.7 presents the results of the installations. Although the operator intentionally slowed the machine down to an idle in an attempt to advance the anchor as slowly as possible, the resulting rotation speed was only about 1 or 2 RPMs slower on average than the normal rate of installation. In contrast, the full throttle installation was almost 3 times faster, jumping from an average of around 6 RPMs to about 15.

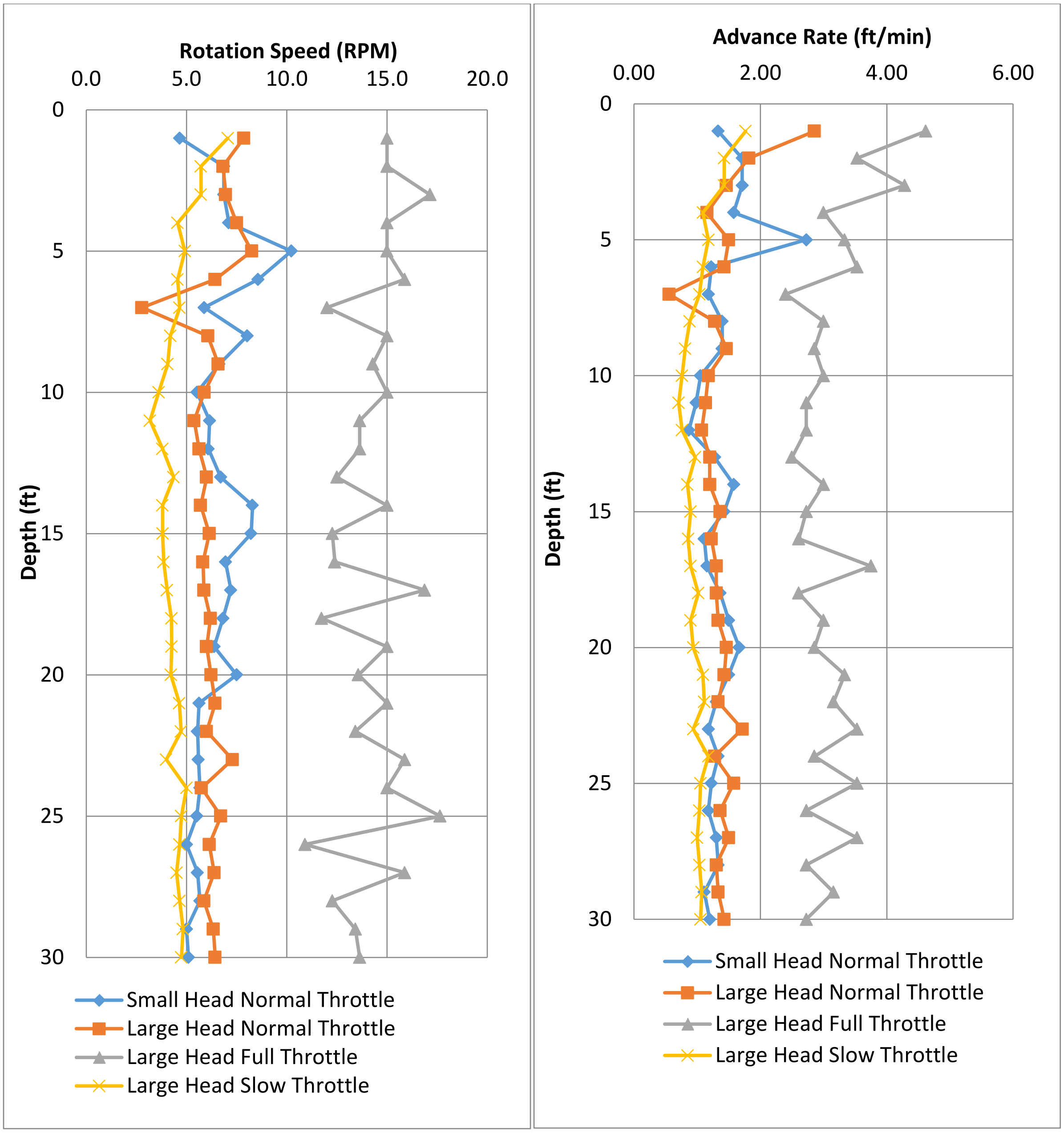

Figure 5.7 Installation Rate Effects at the UMass-AF-GT Site.

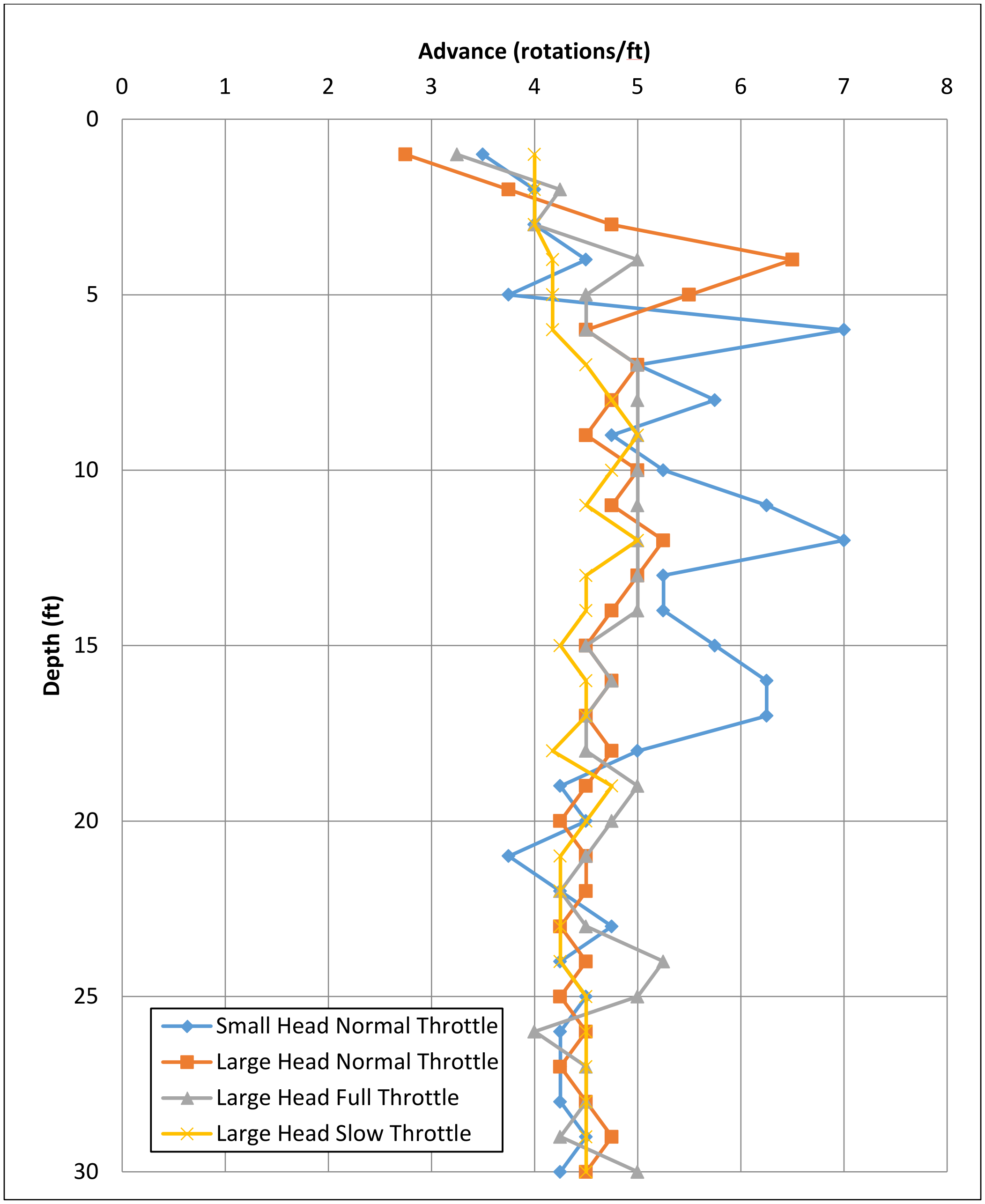

Figure 5.8 Installation Rate Effects on Advance at the UMass-AF-GT Site.

Figure 5.9 illustrates that, despite the different installation rates, the number of revolutions per foot remained consistent. Therefore, full throttle installation does not contribute to disturbance due to a high installation disturbance factor. Figures 5.9 and 5.10 show the installation rate effects on the torque and differential pressure profiles. On average, the torque and differential pressure for the full throttle installation was about 50% greater than the normal throttle installation. This indicates that increased speed does have an effect on the installation torque, but since the geometry of the pile is identical when installed at a normal rate, the capacities should be the same, implying that increasing the installation rate will decrease the correlation factor K_T. Tests need to be performed on helical anchors installed at high rates to verify this assertion.

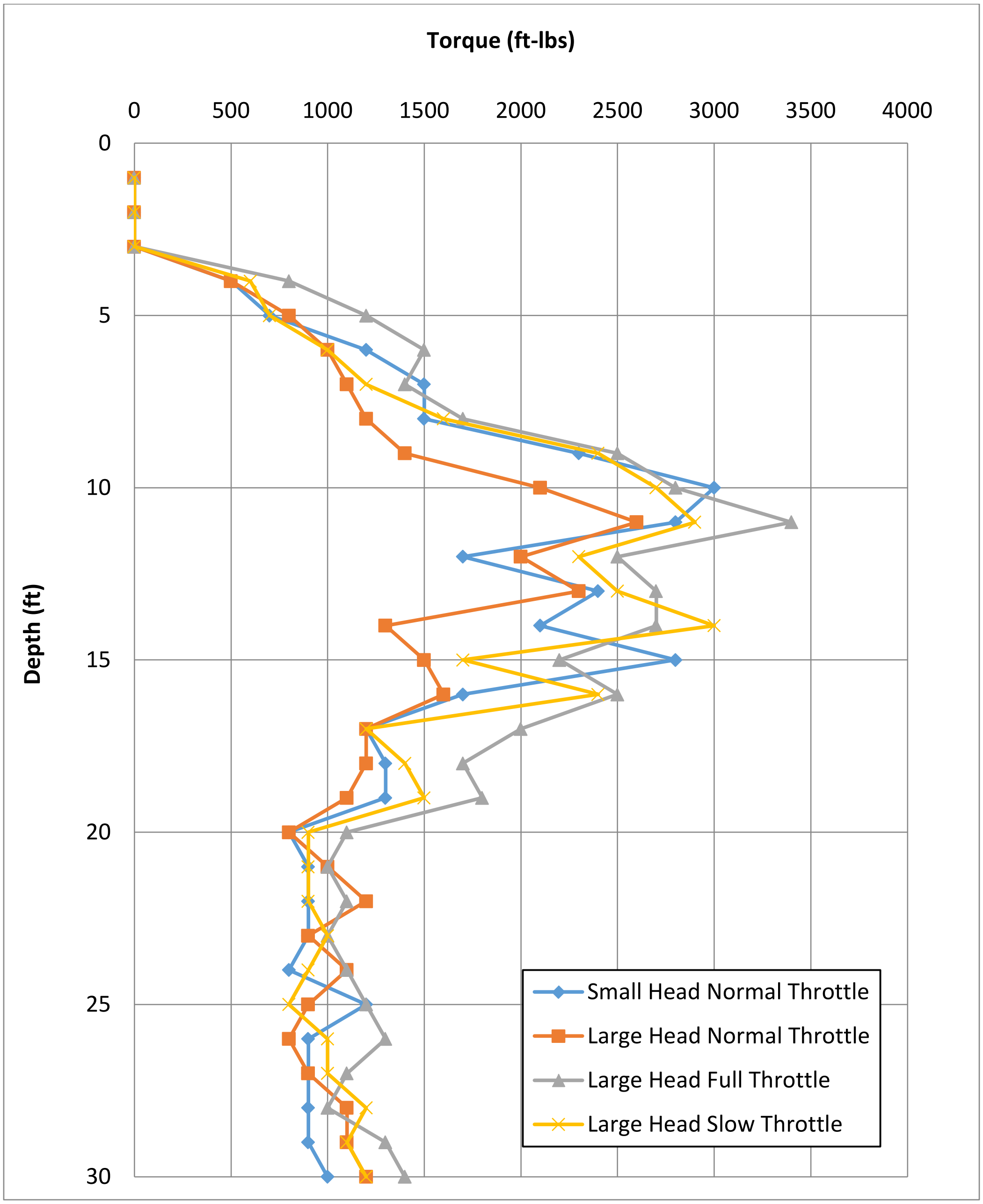

Figure 5.9 Torque Profile at the UMass-AF-GT Site for Different Torque Heads and Speeds.

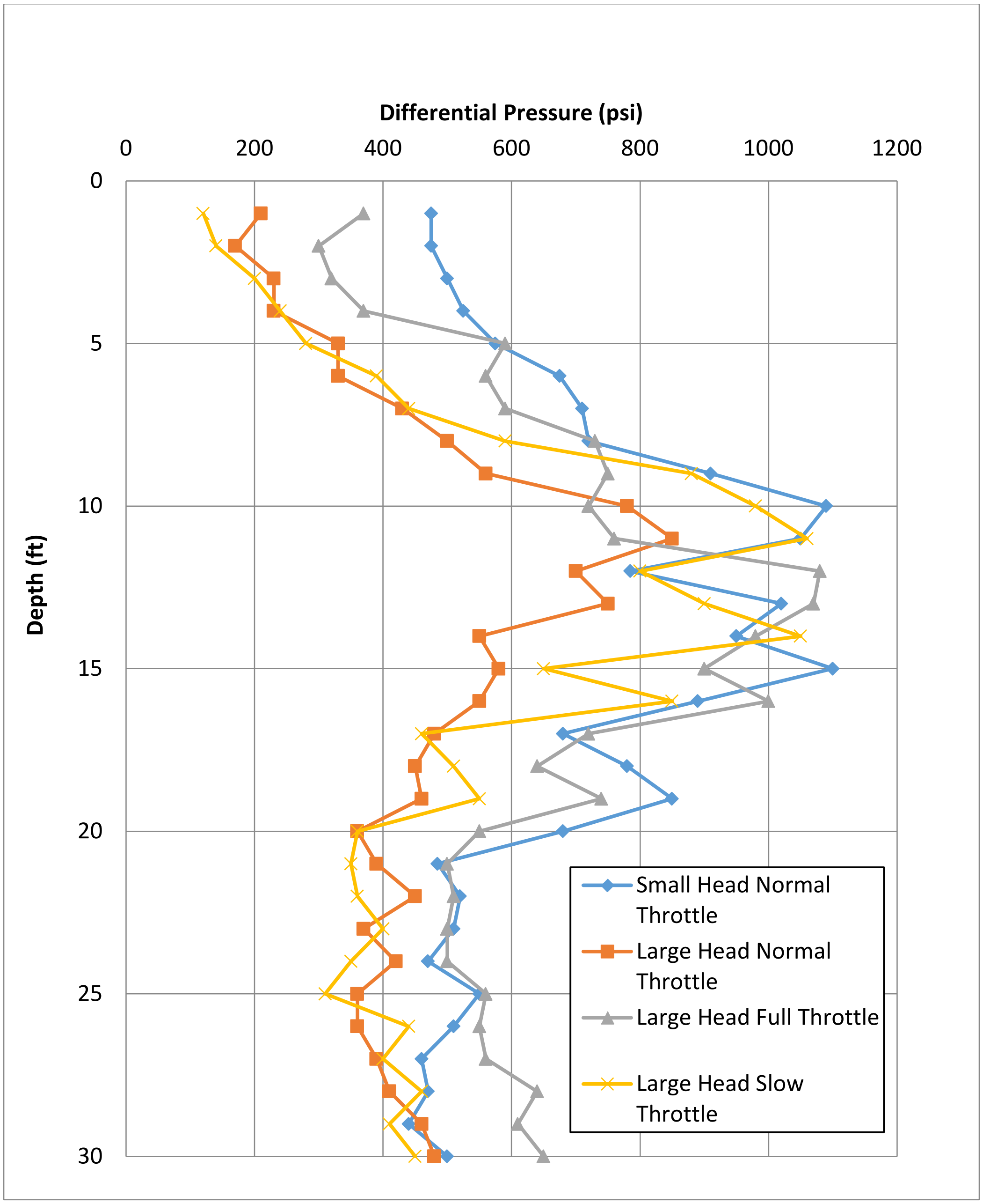

Figure 5.10 Differential Pressure Profile at the UMass-AF-GT Site for Different Torque Heads and Speeds.

Figure 5.11 shows the comparison of the two torque heads at the UMass AF-GT Site. The small head at normal throttle displays higher torque consistently through the granular soils, but then converges towards the values of the larger head once it transitions into the CVVC at about 17 ft. Values from the smaller head exceed those of the larger head by 1300 ft-lbs at a depth of 15 ft.

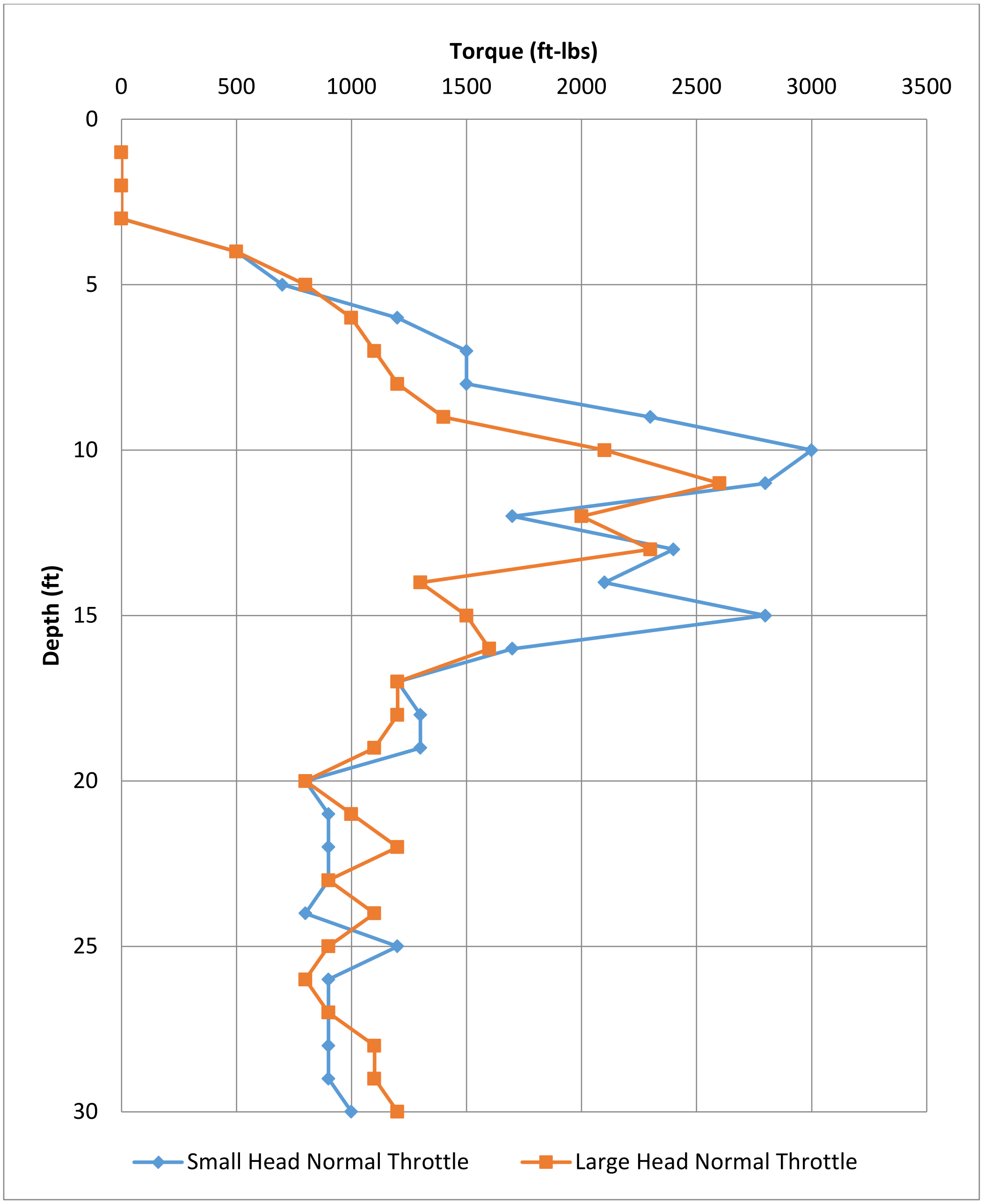

Figure 5.11 Small Head versus Large Head Comparison at the UMass-AF-GT Site at Normal Throttle.

A unique relationship between differential hydraulic pressure and torque exhists for every torque head. This is illustrated in Figure 5.12 which shows Torque vs. Differential Pressure for both the small and the large head. Although they show minimal differences in slope, the offset is significantly different. The linear trendline through the data from the small head shows a considerable offset at zero torque of about 240 psi, while the trendline for the large head is only off by about 20 psi. This may have to due with a certain pressure requirement to initiate movement in the torque head for the Eskridge 50K. Figures 5.13 and 5.14 show the variation due to slow and fast installation. The slow curve shows a tight linear relationship while the full throttle installation exhibits a lot more scatter. This indicates that differential pressure is not a good indicator of installation torque during full throttle installation because the correlation has an R-squared value of about 0.66.

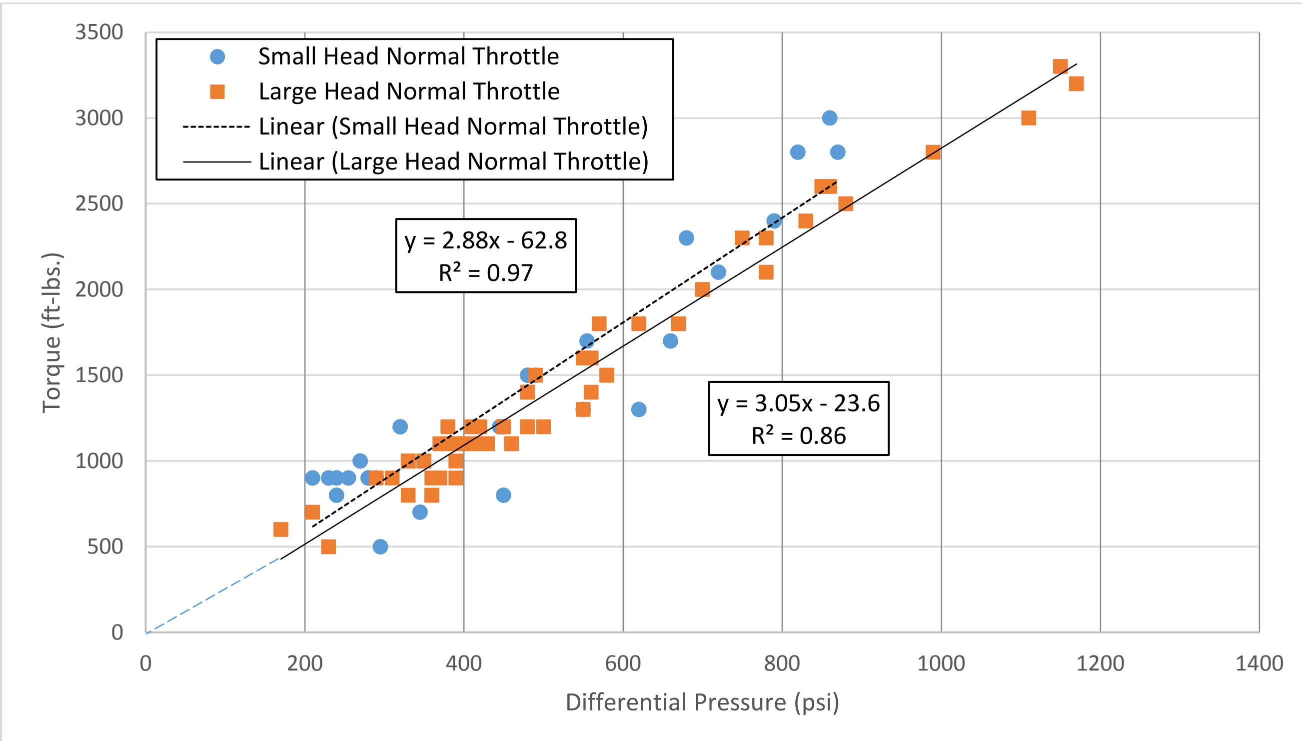

Figure 5.12 Normal Throttle Installation Results at the UMass AF-GT Site.

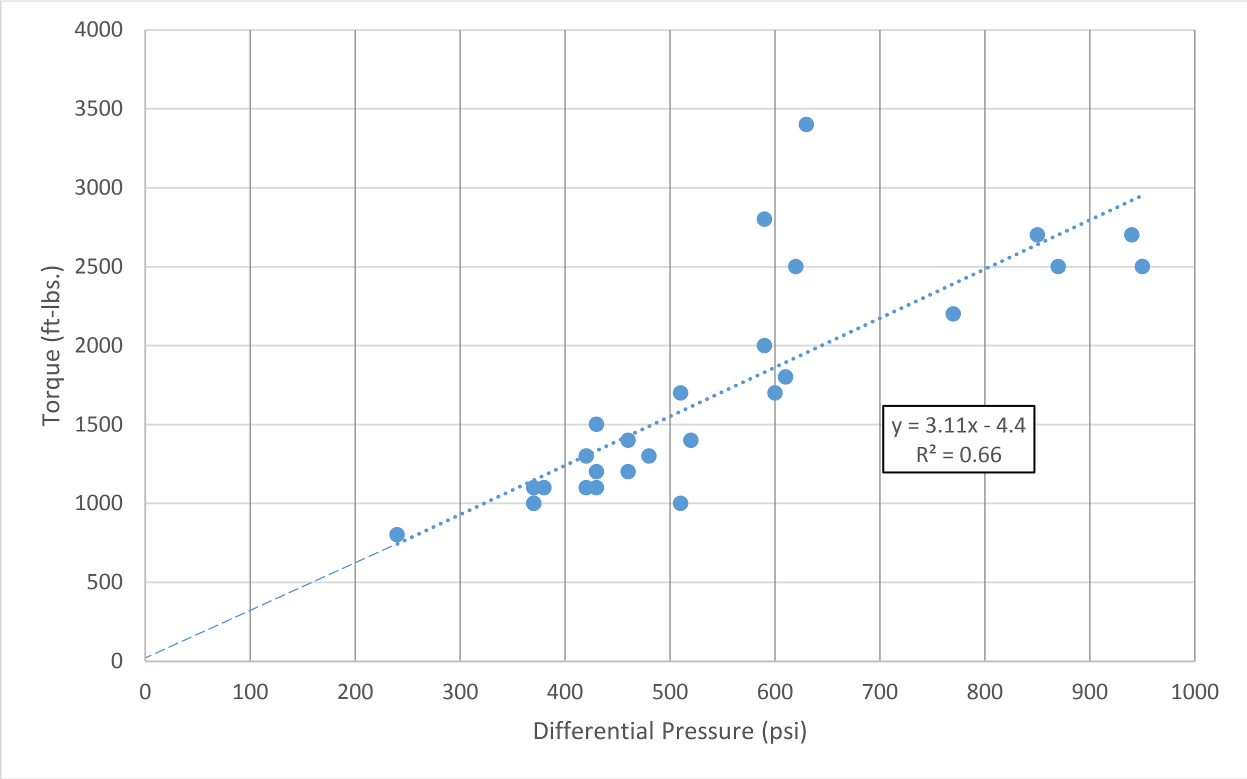

Figure 5.13 Large Head, Full Throttle Installation Results at the UMass AF-GT Site

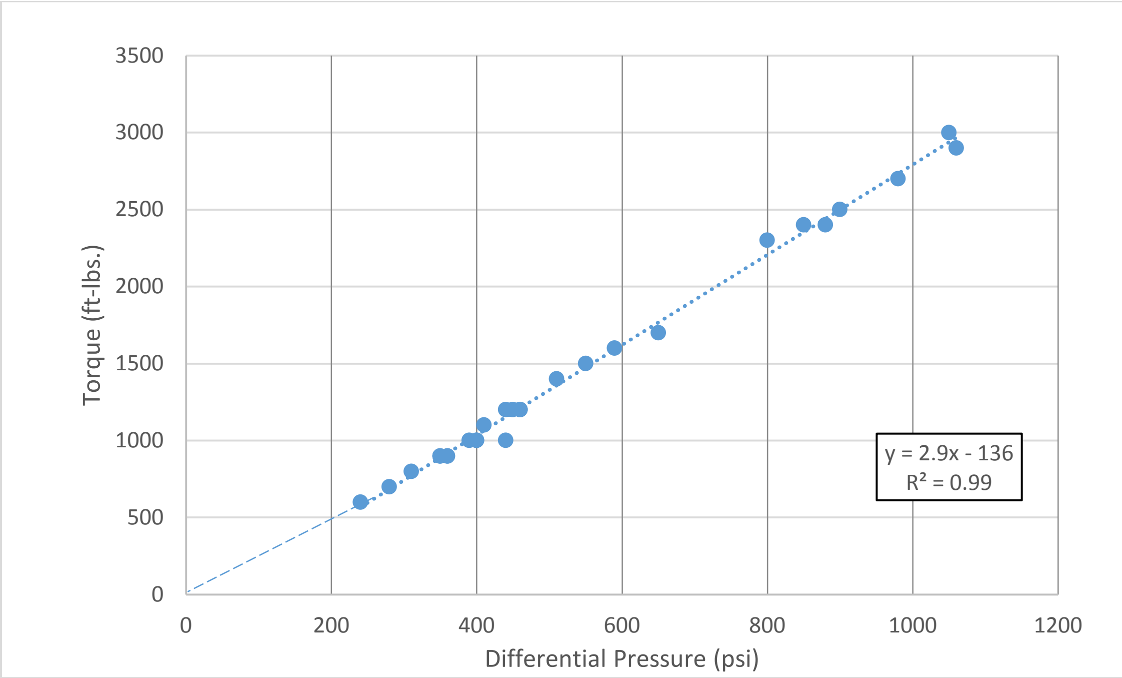

Figure 5.14 Large Head, Slow Throttle Installation Results at the UMass AF-GT Site

The final trial installation was performed with the large head at normal throttle and measurements of torque were measured at 0.5 ft. intervals in order to evaluate the resolution that is possible to achieve with the proper monitoring process and any refinement in stratigraphy. Figure 5.14 illustrates the importance of having good resolution in data collection. At the 15 ft. interval, the value that would be interpreted if the engineer was monitoring every 2 ft. would be about 2450 ft-lbs. Using the data from the 1 ft. intervals, the value at 15 ft. is actually 1800 ft-lbs. This is a drastic difference, espeically when using torque-to-capacity relationships to verify capacity. With 10 ft-1 being a standard K_T value, that equates to an overestimation of capacity by about 6500 lbs, which is about 25-33% of the ultimate uplift capacity of the anchor in this soil. This confirms the need to monitor installation torque at the very least every foot. At 0.5 ft. increments the gap shrinks between readings, but is still on the order of 200-500 ft-lbs. different.

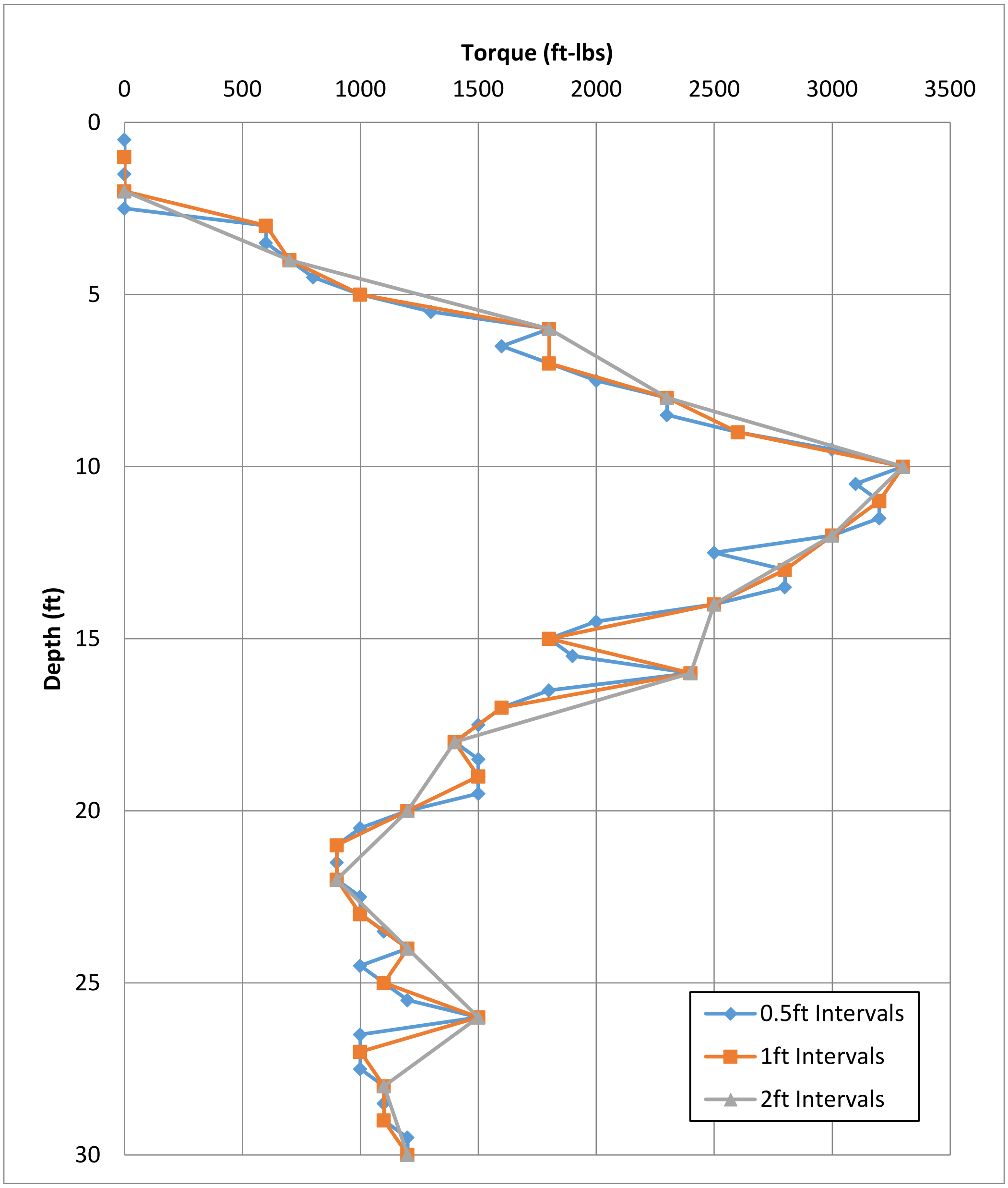

Figure 5.14 Large Head, Normal Throttle Installation Results – Umass AF-GT Site

Figure 5.15 shows an overlay of the original normal throttle trial with the second normal throttle trial to show the difference in torque readings when the lead section is plugged. After the first 4 trials, the RS2875 lead section was plugged for about 4 ft. up the hollow pipe. The plug was cleaned out before the final trial to determine resolution effects was conducted. It is observed that the plugged trial had significantly lower torque readings, by as much as 1200 ft-lbs at times.

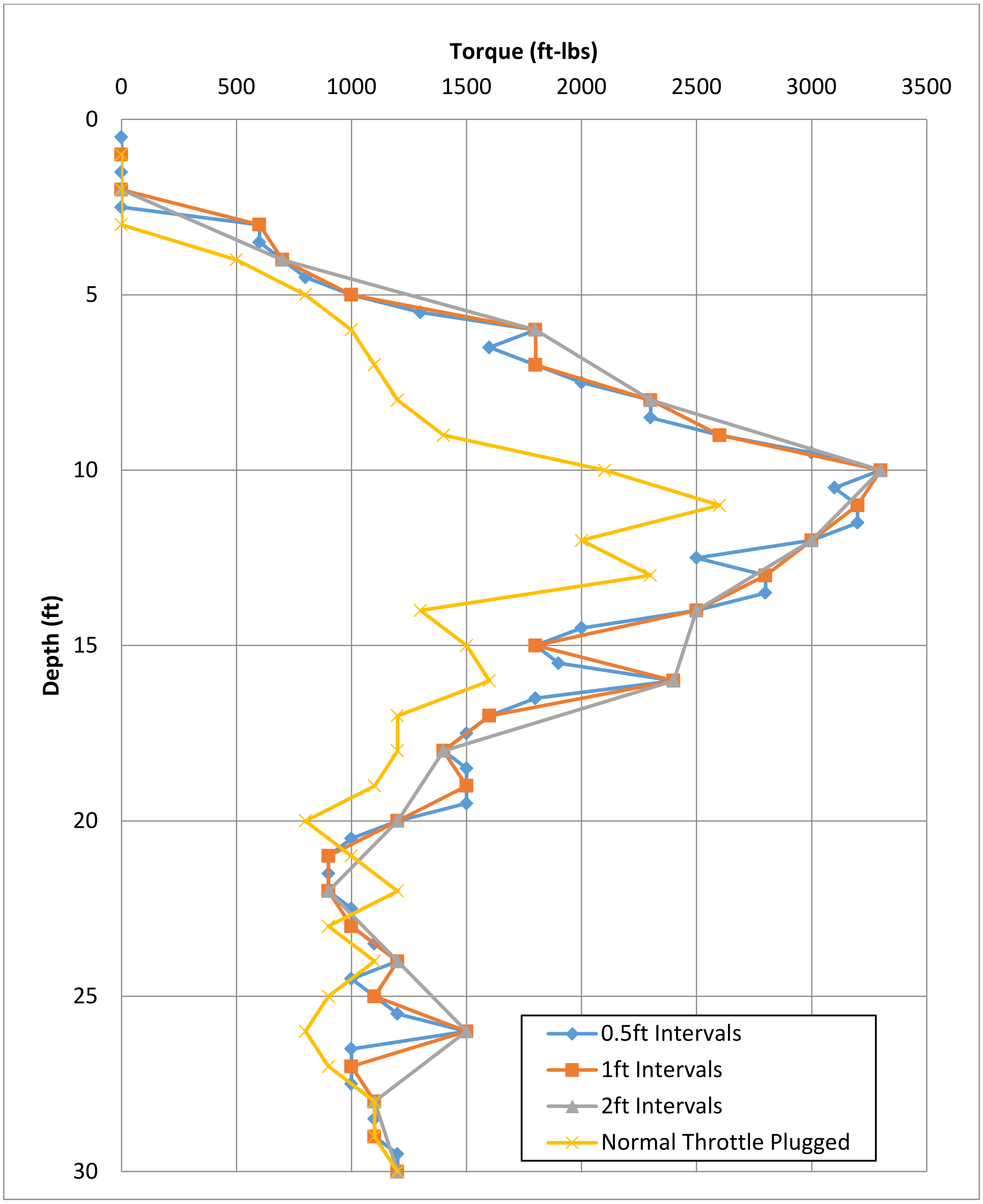

Figure 5.15 Large Head, Normal Throttle, Plugged vs. Not Plugged Comparison UMass – AF-GT Site.

5.5.2 UMass DOE Site

Three days of installations were conducted at the UMass DOE Site with two different excavators and three different torque heads. Day 1 and 3 were with Sea & Shore Contracting, Inc. and their Mustang ME8003 compact excavator and Day 2 was with Diversified Construction Services, LLC and their Bobcat mini-excavator. A summary table showing the machine and torque head specifications is included in Table 5.5.

Table 5.5 Machine and Torque Head Specifications for the UMass DOE Site

Day 1+3		*Day 2*	
Machine	**Hydraulic Flow Rate (GPM)**	**Machine**	**Hydraulic Flow Rate (GPM)**
Mustang ME8003	9.7 (Low Flow)	Bobcat 435 G-Series	19.81 (Standard Flow)
	21.8 (Standard Flow)	**Drive Head**	**Torque Capacity (ft-lbs)**
Drive Head	**Torque Capacity (ft-lbs)**	Eskridge 50K(Small)	7000
Pengo MDT-12K	12000	Eskridge 77BD (Large)	6500

The same RS2875 8/10/12 triple helix anchor was used in these trial installations in order to keep the pile geometry constant. Day 1 consisted of three identical trials with the same machine, same Pengo MDT-12K torque head, and same installation rate to evaluate repeatability. On Day 3, a single installation at full throttle was conducted to determine its effect on the results measured both during installation and during a load test performed on the anchor that was allowed to rest for 10 days. Figure 5.16 presents the results from the four trials, showing consistent installation rates via rotation speed and advance rate with the only outlier being the installation performed at full throttle as expected. The spike at approximately 11 feet during Trial 3 represents the operator accidentally hitting the throttle and increasing the rate before returning it to normal throttle for the next interval. Figure 5.17 shows the advance of the pile also staying consistent with each trial, despite increasing speed during the full throttle installation.

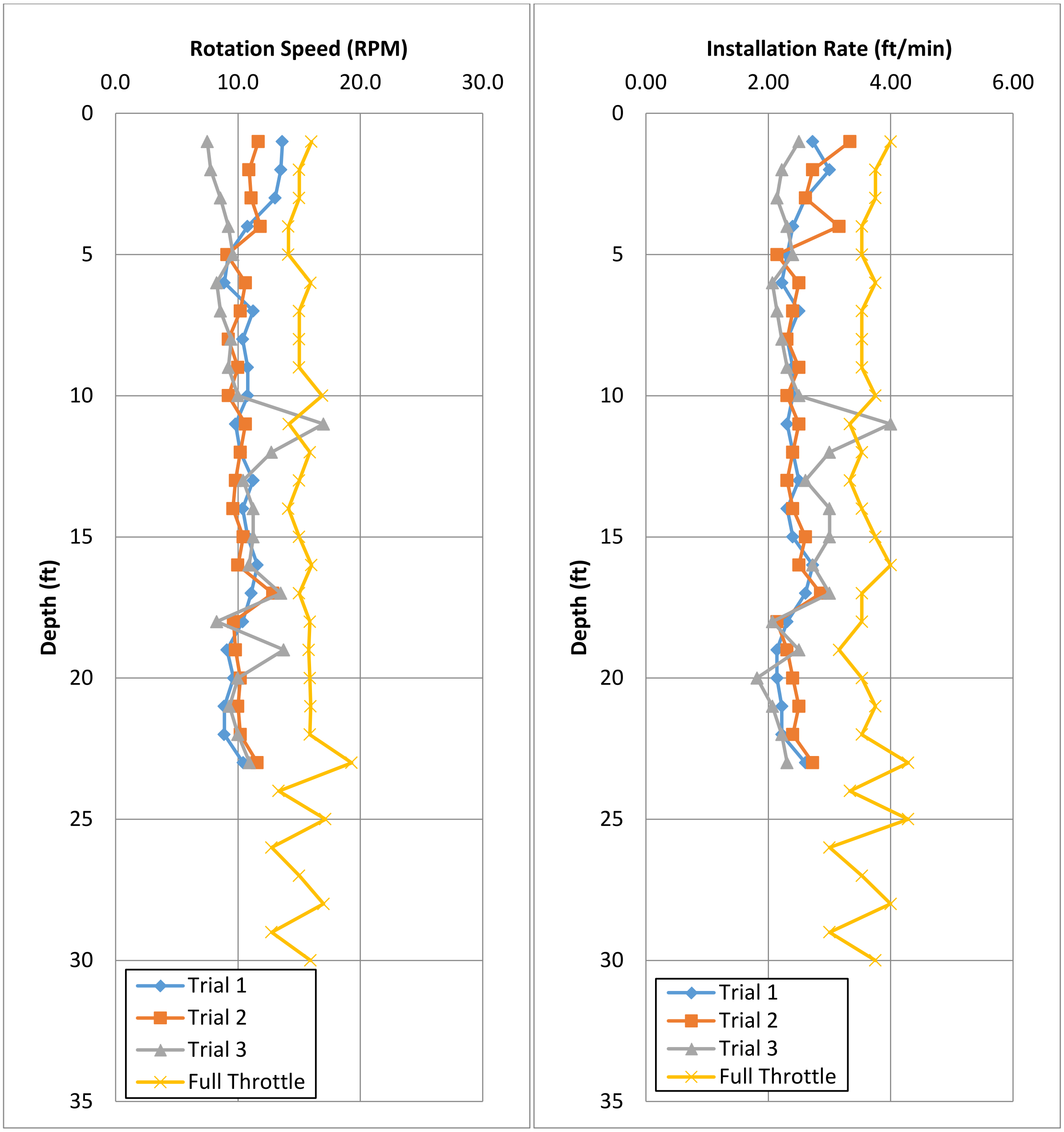

Figure 5.16 Repeatability for Mustang ME8003 at the UMass-DOE Site

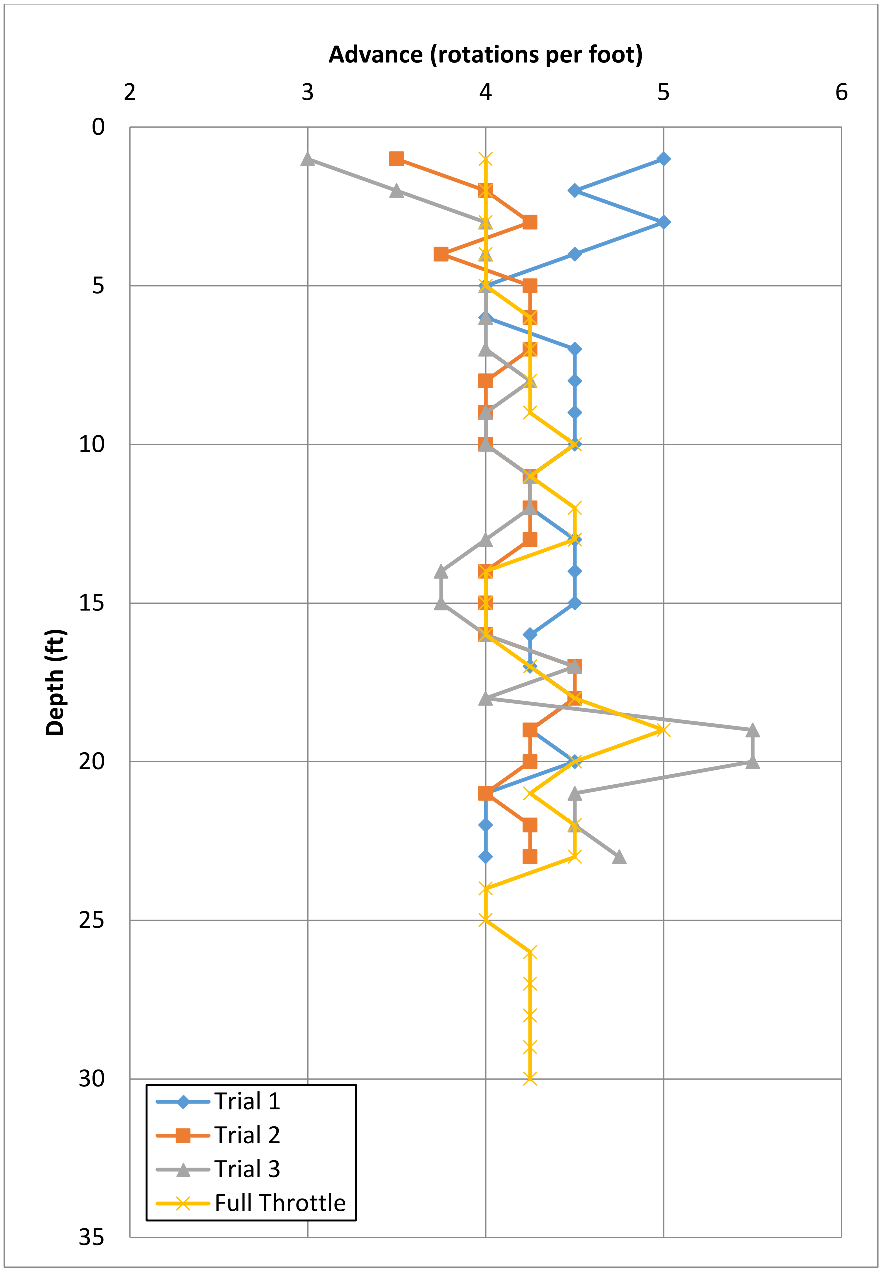

Figure 5.17 Advance Comparison for Mustang ME8003 at the UMass-DOE Site

Day 2 at the UMass DOE Site was used to compare two torque heads using the same machine to show variability between the heads. At the same throttle, Figure 5.18 shows the smaller head producing a slower rotation speed and advance rate, with a generally consistent difference of about 2.5 RPMs and about 0.6 ft/ min. Figure 5.19 reiterates the uniformity of advance regardless of machine, installation rate and soil type and proves it is only a function of pile geometry, specifically shape and pitch of the helices.

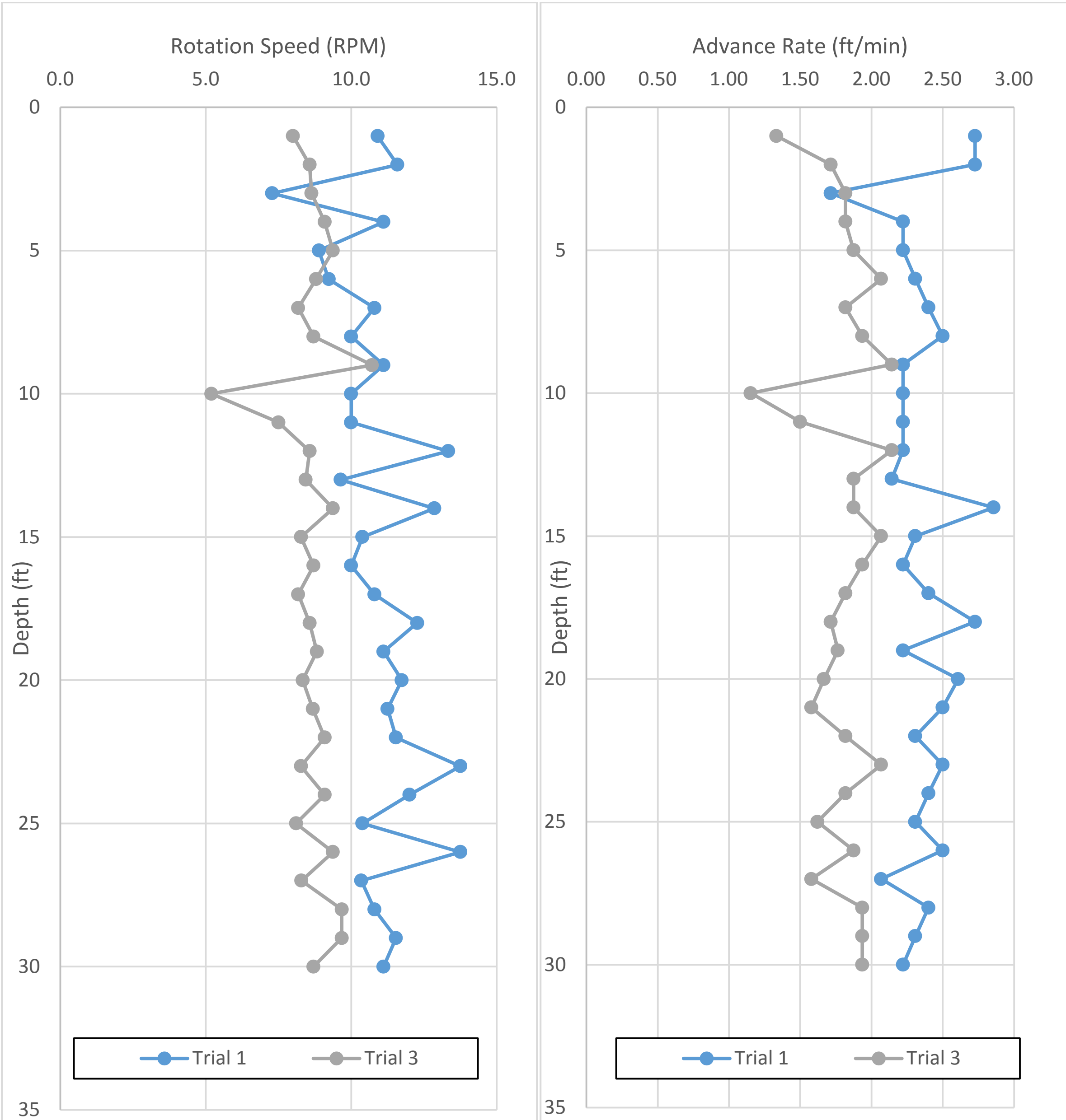

Figure 5.18 Comparison of Installation Rate of Eskridge 50K (Small) and Eskridge 77BD (Large) Torque Heads at the UMass-DOE Site

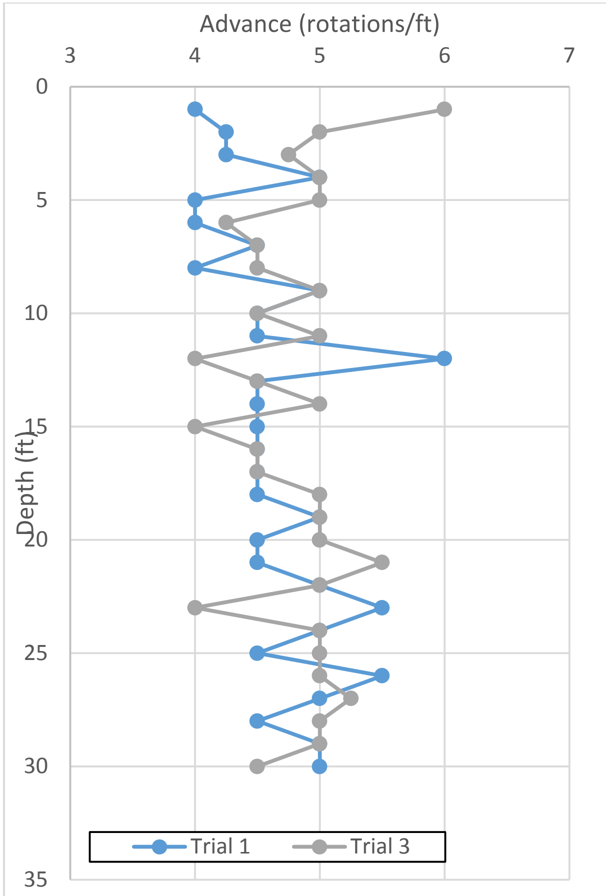

Figure 5.19 Comparison of Advance of Small and Large Torque Heads at the UMass DOE Site

Figure 5.20 shows a consistent torque profile from Day 1. This indicates that repeatability for the same setup regarding machine and torque head can be achieved. The slight variation in readings is attributed to the slight variation is subsurface stratigraphy spatially. The torque profile for the two torque heads is shown in Figure 5.21, which illustrates higher torque from about 4 ft. below ground surface to around 9 ft., but is consistent throughout the rest of the profile, within 100 ft-lbs, which is the precision at which the Chance Digital Indicator reads at. Figure 5.22 shows all the trial installation torque profiles obtained from the UMass DOE Site. This figure shows a general trend in the data with not much variation in the profile besides the upper crust where there is a gap of about 400 ft-lbs of torque from the lower to the upper bound.

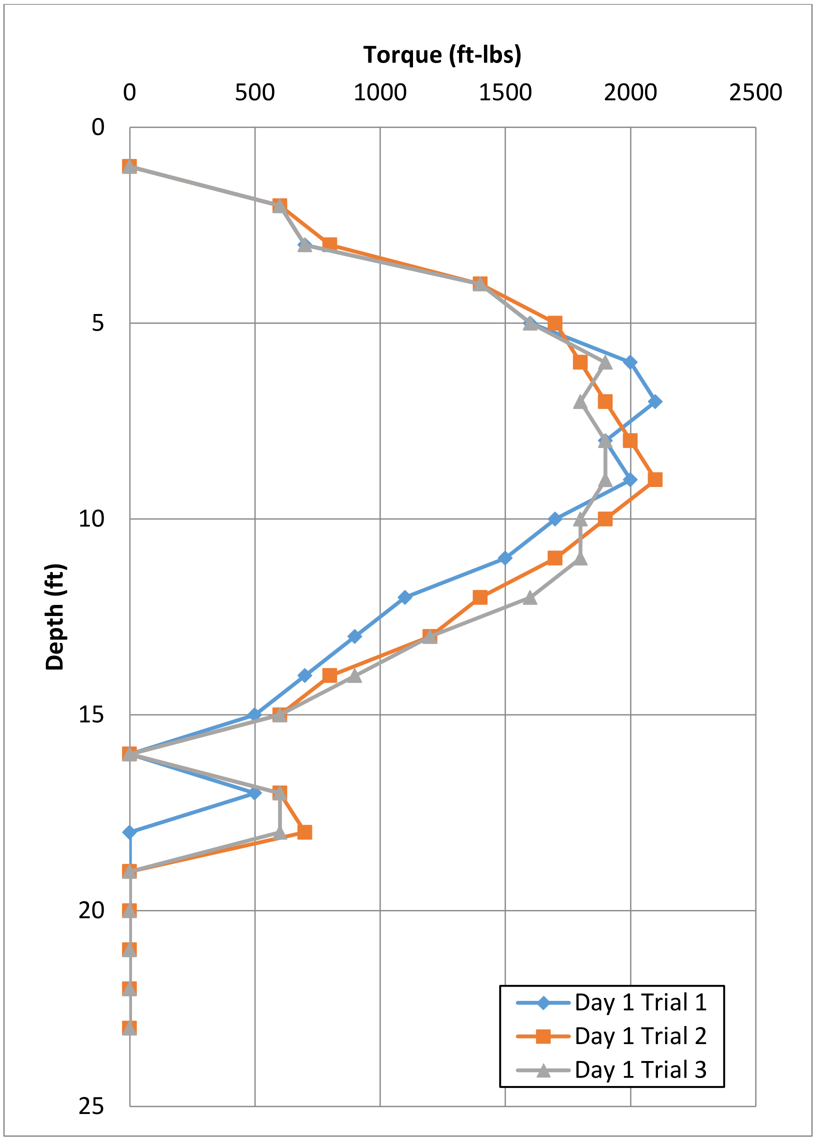

Figure 5.20 Torque Profiles from Pengo & Chance Digital Readout Day 1 at the UMass-DOE Site

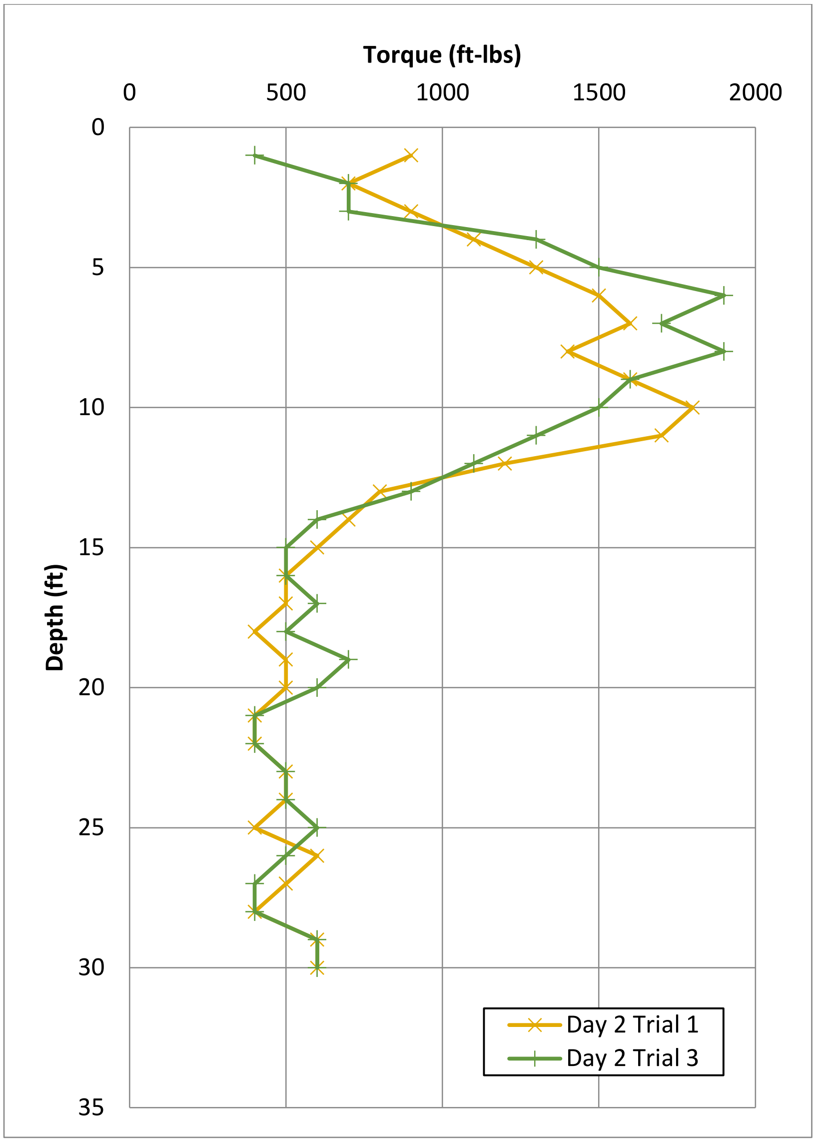

Figure 5.21 Torque Profiles from Day 2, Eskridge Small Head versus Eskridge Large Head at the UMass-DOE Site

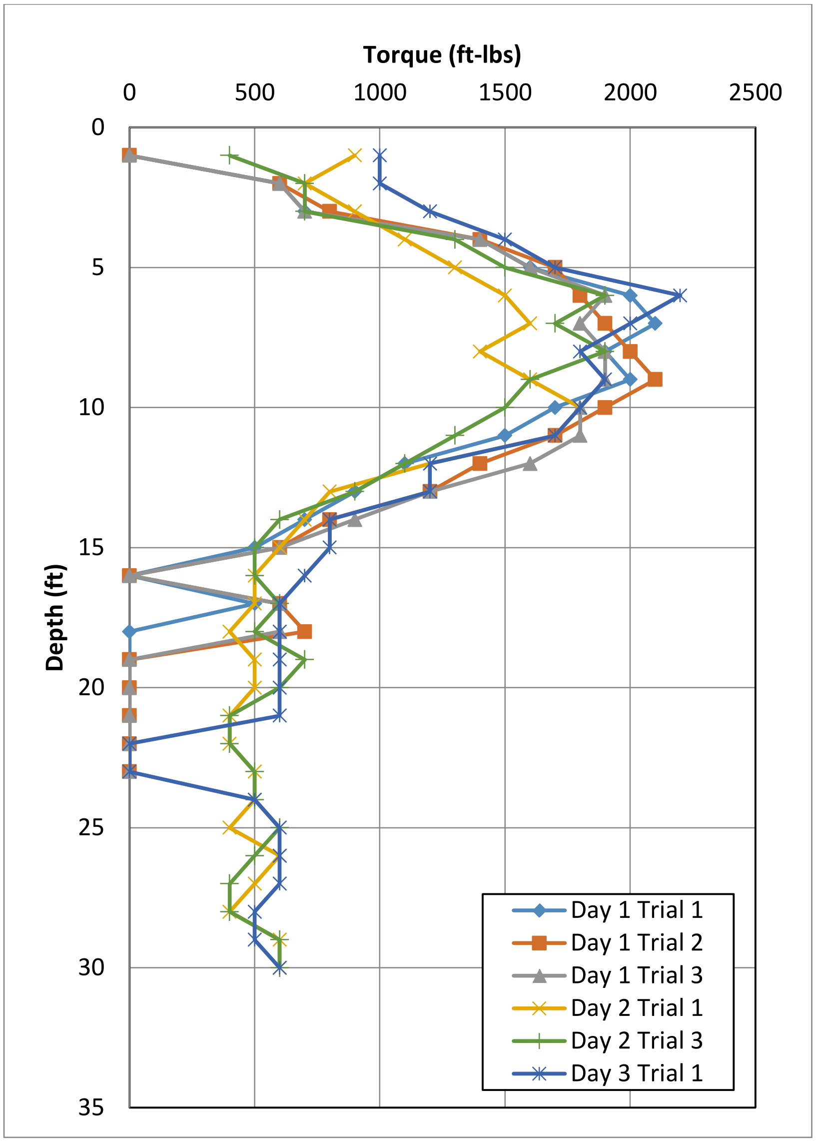

Figure 5.22 Trial Installation Torque Profiles from the UMass DOE Site

The Eskridge Large Head used by Diversified, Inc. shows another unique torque vs. differential pressure relationship, displayed in Figure 5.23. It has a good correlation, with an R squared of 0.94, but also shows an offset of the linear trendline through the x-axis. This implies the necessity to build up an initial pressure in order to rotate the torque head, or possibly an initial idling pressure of approximately 150 psi is normal for the Eskridge Large Head. All installation data is provided in tables located in Appendix A.

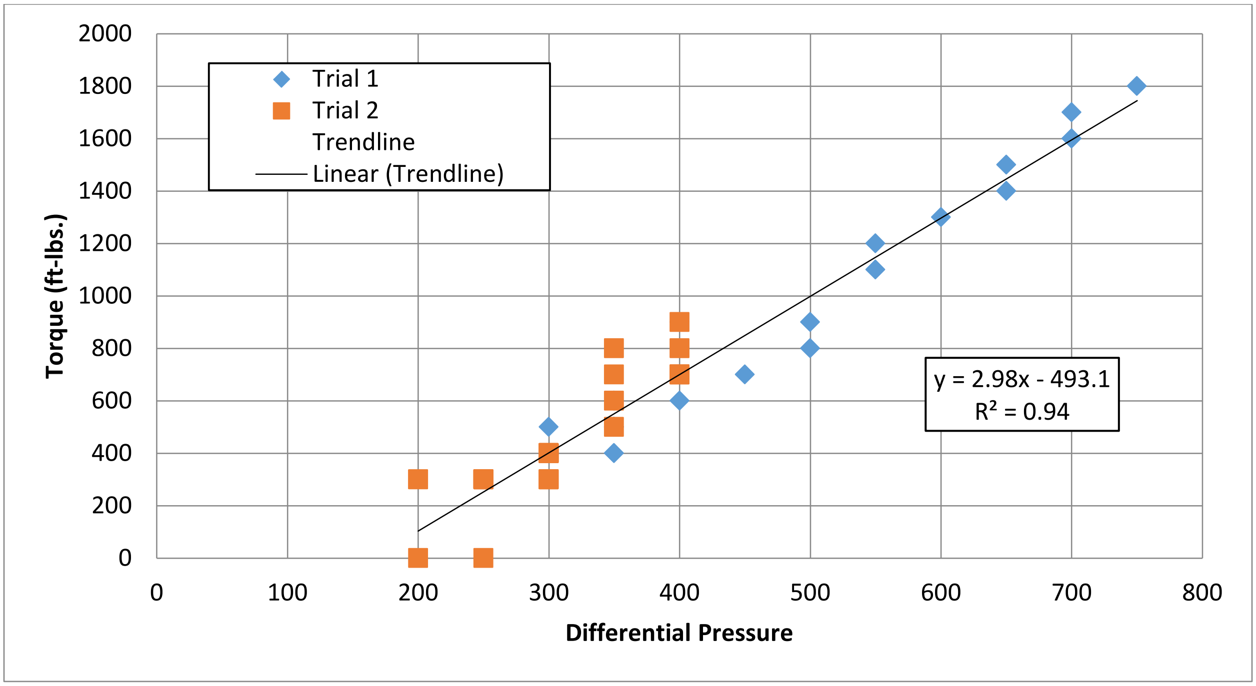

Figure 5.23 Torque vs. Differential Pressure for Eskridge Large Head at the UMass-DOE Site

5.6 UPLIFT LOAD TEST RESULTS

5.6.1 Determination of Ultimate Uplift Capacities

Criteria for determining ultimate uplift capacities of the tested screw-piles and helical anchors are loads corresponding to 5%, 10%, and 20% displacements of the average helix diameter. The load representing these displacements is defined as Q_5, Q_{10}, and Q_{20}. Additionally, displacement at a safety factor of 2 for each load test is denoted as $\Delta Q_{10/2}$ and $\Delta Q_{20/2}$. A typical load test on a SS125 helical anchor is included in Figure 5.24, presenting the relevant criteria on the plot. For the pipe piles, the load at which plunging failure initiates is taken as the ultimate uplift capacity of the pile. For comparative purposes, Q_{10} is used as the ultimate uplift capacity. Q_5 is determined to provide a ratio of the FHWA definition of ultimate capacity, 5% method, to the AC358 10% method. Since the full capacity of the helical anchor is typically not achieved at Q_{10}, Q_{20} is used to illustrate the amount of additional capacity the helical anchor possesses.

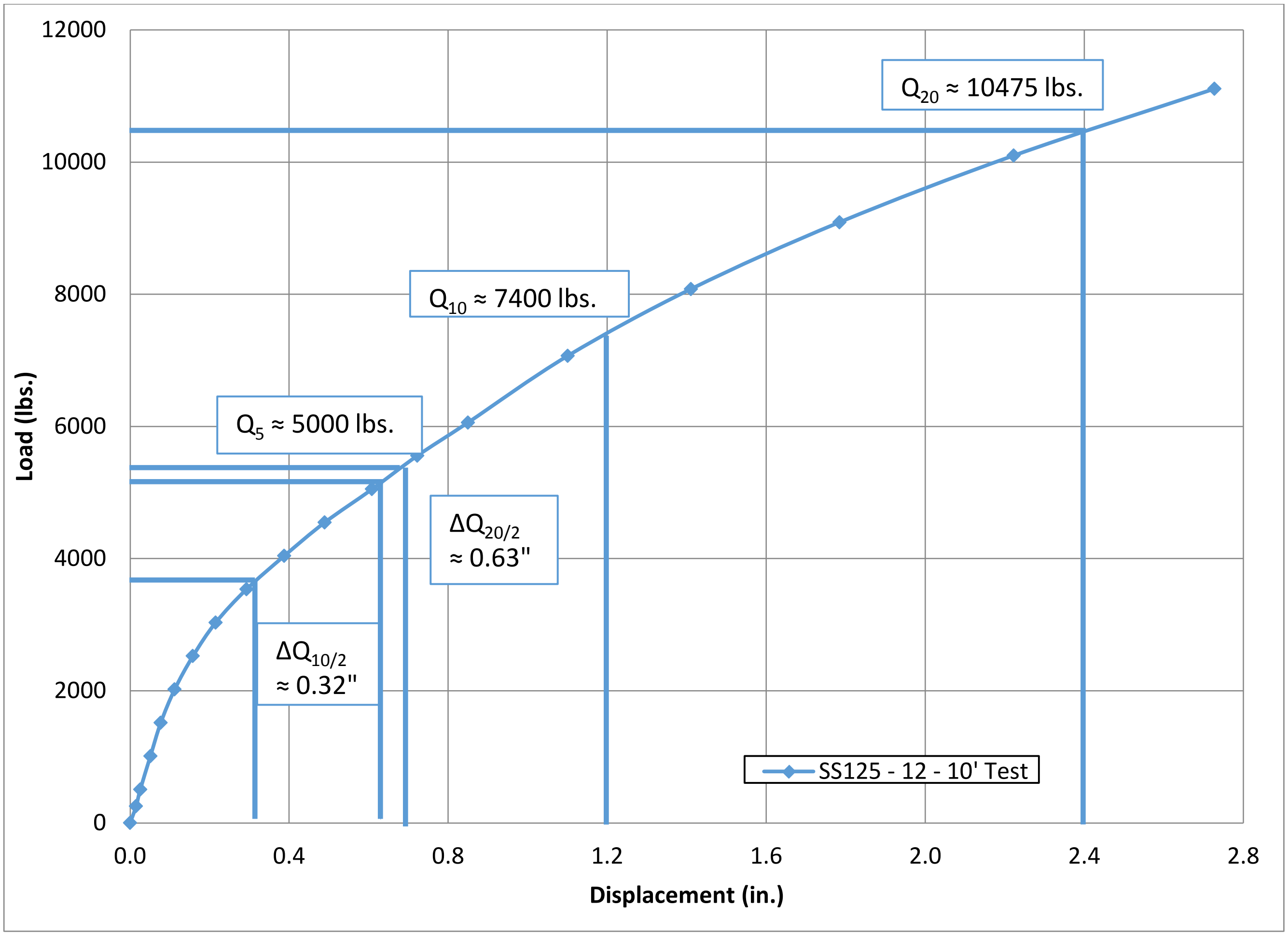

Figure 5.24 Typical Load Test Results

5.6.2 Uplift Reload Tests on Shallow Foundations

Reload tests were performed on shallow pipe piles and helical pipe piles at the UMass DOE Site 1 location to determine aging effects on shallow foundations and to separate aging effects by shaft and helical contributions. Results of the tests are tabulated in Appendix B. Table 5.5 shows the ratio of "aged" ultimate capacity to initial ultimate capacity. Figures 5.25 and 5.26 show this ratio versus aging period and versus diameter respectively. The majority of the helical pipe piles and pipe piles lose strength over time after an initial load test. This is due to the global failure that is occurring during testing of shallow foundations. The failure surface extends to the surface and therefore there is no soil above the failed soil to help with the healing process to improve strength like there is with deep foundations that exhibit a more localized failure. Figure 5.26 shows a general trend of decreasing ratio of aged capacity to initial capacity. Generally, the pipe piles show a lower ratio of aged capacity to initial capacity, which implies that the helix contributes to increased strength over time. Load test results are included in Appendix B.

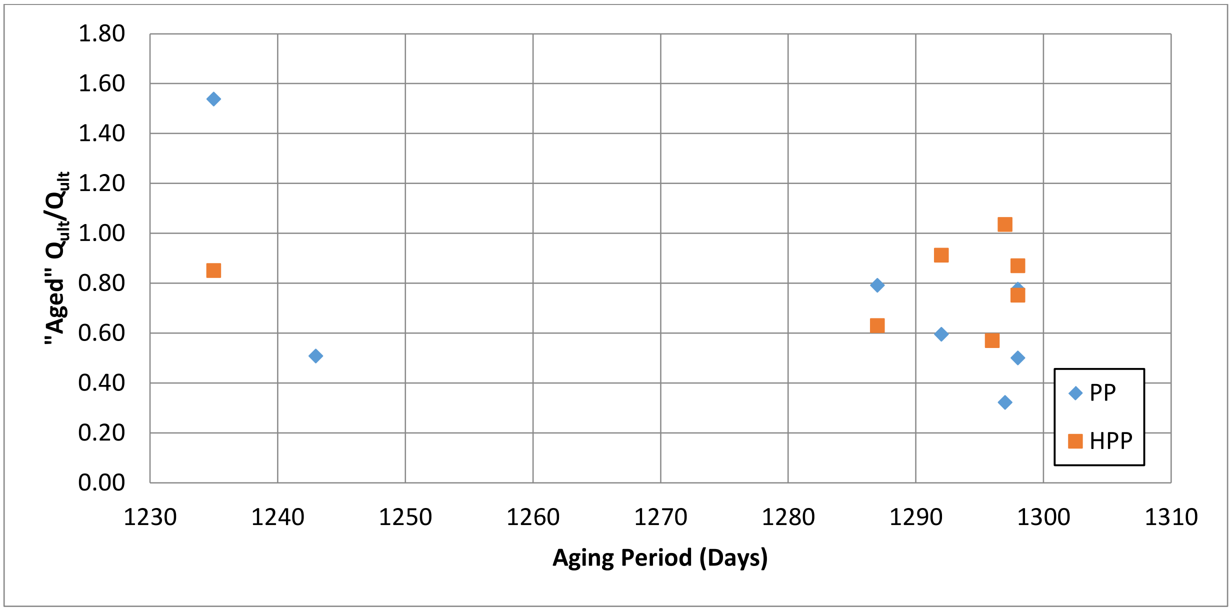

Figure 5.25 Aged Uplift Capacity versus Aging Period – UMass DOE Site

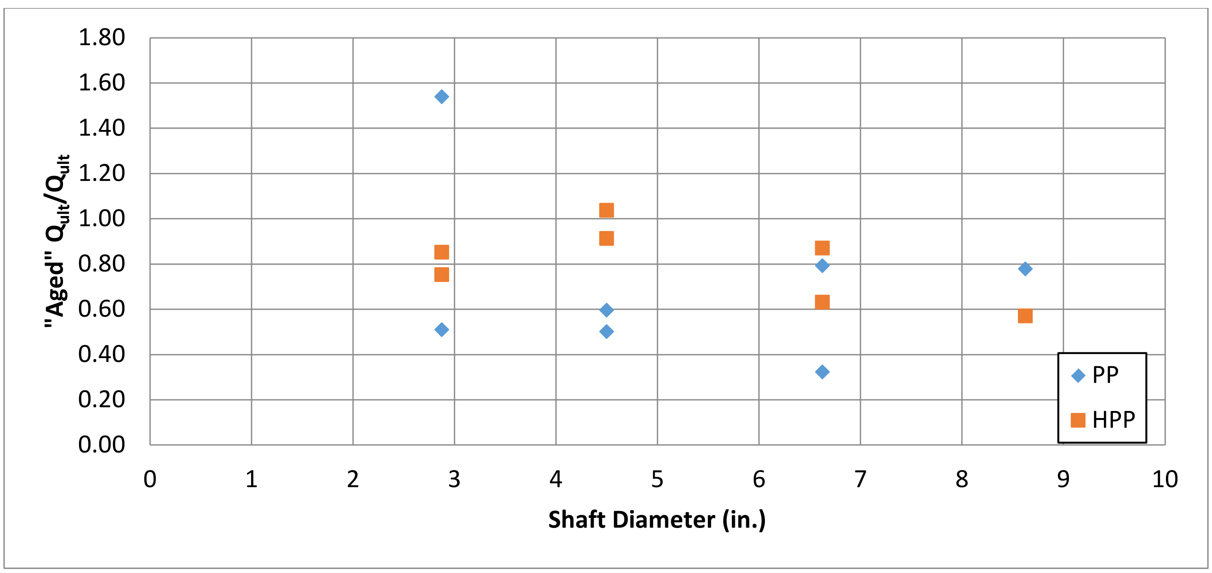

Figure 5.26 Aged Uplift Capacity versus Shaft Diameter – UMass DOE Site

Table 5.5 Results from Aged Shallow Foundation Uplift Tests – UMass DOE Site

Shaft	Helix	Depth	Days	Initial	Aged	Ratio of

Diameter (in)	Diameters (in)	(ft)	Rest	Q_{ult}	Q_{ult}	Q_{ult}
2.875	PP	4	1243	2950	1500	0.51
2.875	PP	8	1235	4550	7000	1.54
2.875	12	4	1235	7400	6300	0.85
2.875	12	8	1298	13300	10000	0.75
4.5	PP	4	1298	2500	1250	0.50
4.5	PP	8	1292	8400	5000	0.60
4.5	12	4	1292	8000	7300	0.91
4.5	12	8	1297	15250	15800	1.04
6.625	PP	4	1297	6200	2000	0.32
6.625	PP	8	1287	11500	9100	0.79
6.625	12	4	1287	9200	5800	0.63
6.625	12	8	1298	20000	17400	0.87
8.625	PP	4	1298	7400	5750	0.78
8.625	12	4	1296	15800	9000	0.57

5.6.3 Uplift Retests on Round and Square Shaft Helical Anchors

Reload tests were performed on 68 round shaft and square shaft helical anchors at both the UMass DOE Site 1 and 2 to determine if capacity increased with time. Figures 5.27 and 5.28 show the results from these tests. Figure 5.27 shows an increase in the aged capacity with an increase in diameter for the round shaft anchors. A significant amount of scatter is displayed in Figure 5.27 by the square shaft anchors. Square shaft anchors develop very little side resistance in comparison to round shaft anchors, and this attributes to the scatter shown in the plot. Figure 5.28 shows a general increasing trend in Aged capacity with increasing time. Load test results are provided in Appendix B.

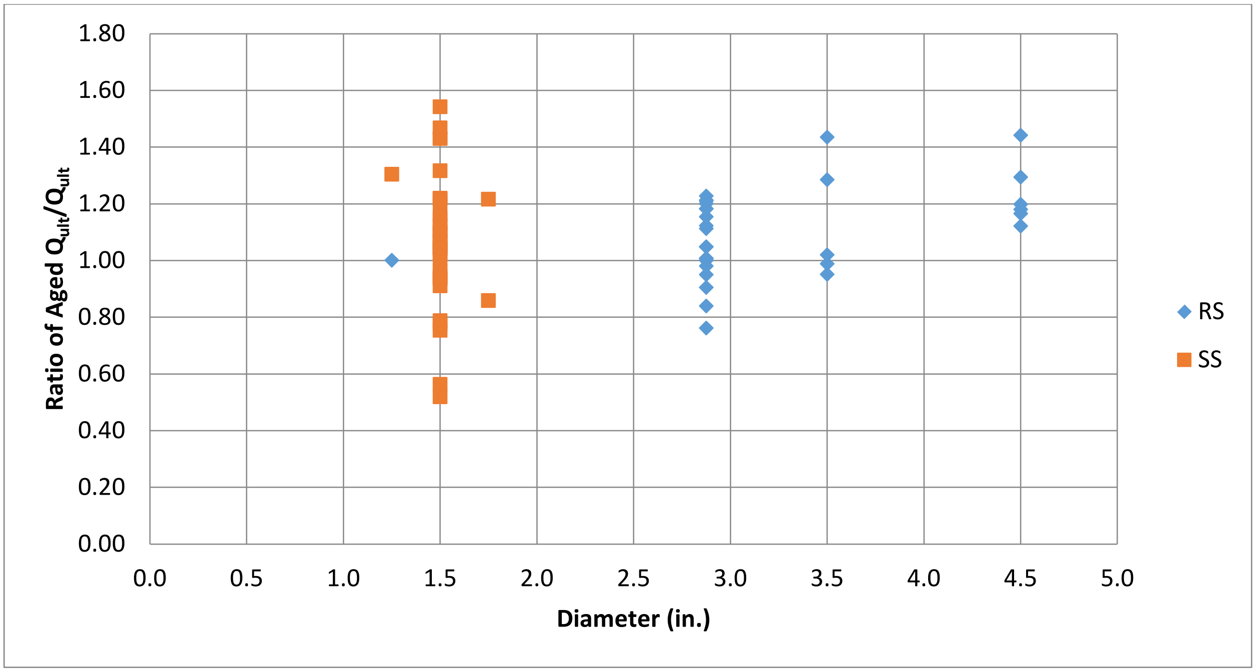

Figure 5.27 Ratio of Uplift Capacity vs. Shaft Diameter – UMass DOE Site

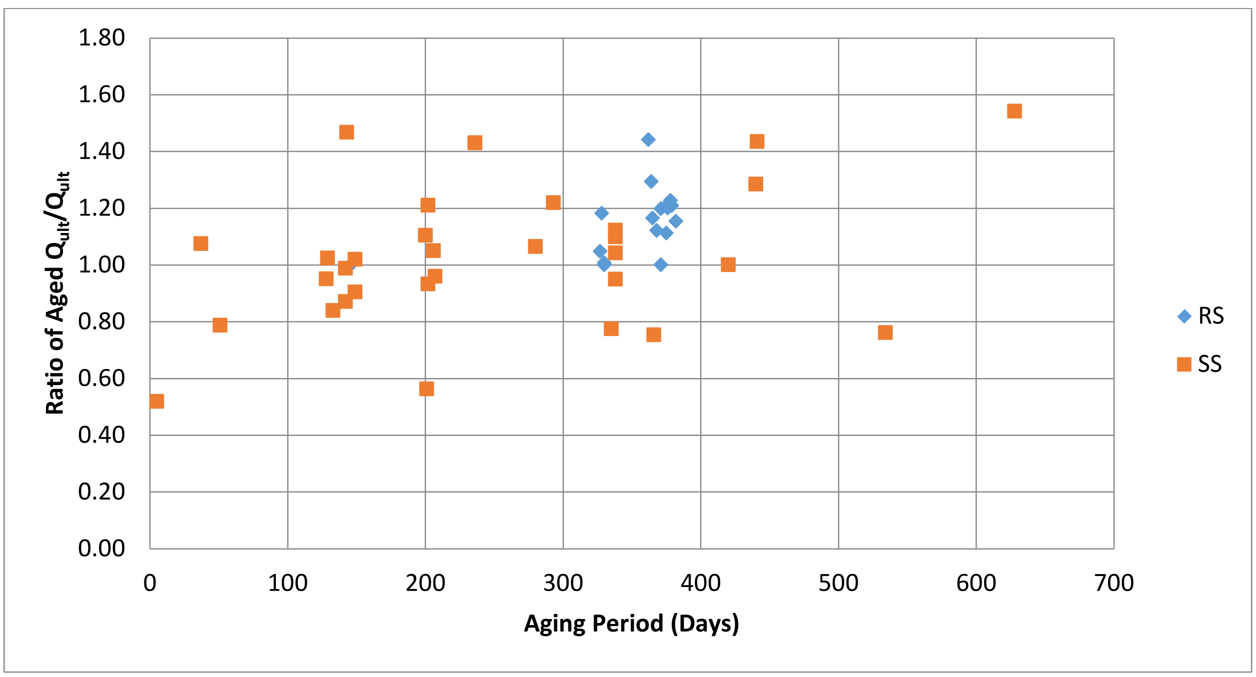

Figure 5.28 Ratio of Uplift Capacity vs. Aging Period – UMass DOE Site

5.6.6 Torque-to-Capacity Relationships

A total of 91 uplift load tests were performed on round and square shaft Screw-Piles and helical anchors at the UMass DOE Site 1 and 2 and at the UMass AF-GT Site. Installation torque was taken as the average value of the final penetration distance equal to three times the average helix diameter. Q_{ult} was determined as the load necessary to produce a displacement of 10% of the average helix diameter. Figures 5.29 and 5.30 show how K_T varies with shaft size for round shaft and square shaft anchors respectively. In agreement with the results found by Hoyt and Clemence (1989), the correlation factor decreases with increasing shaft size for round shaft anchors. Square shaft anchors, however, appear to follow the opposite trend as shown in Figure 5.30. Generally, the values obtained during the project are much higher than the proposed AC358 values. This may be because the values chosen for the paper were on the conservative side.

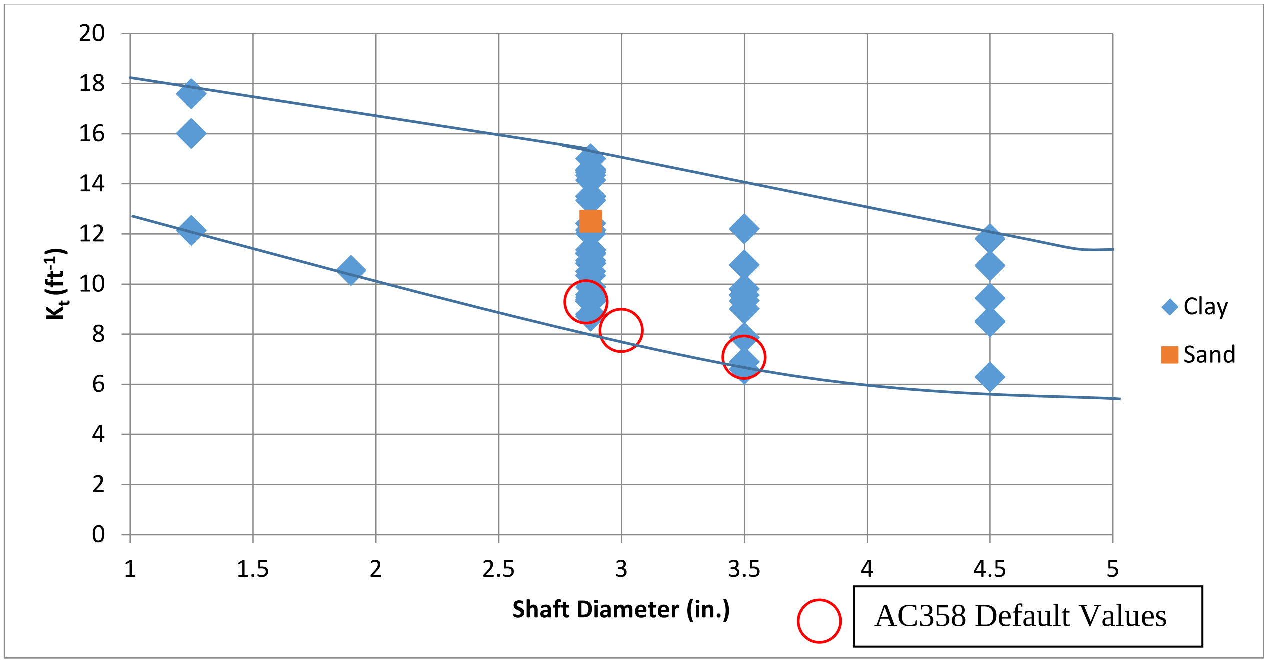

Figure 5.29 Round Shaft Correlation Factors – All Tests - Both Test Sites

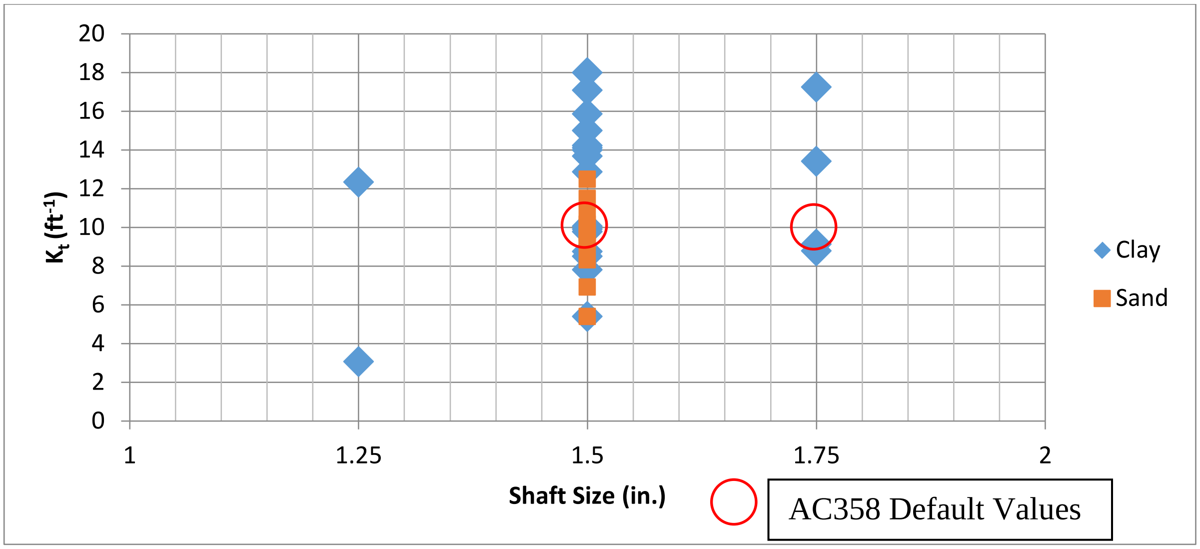

Figure 5.30 Square Shaft Correlation Factors – All Tests- Both Test Sites

An attempt to distinguish factors that had the most influence on the correlation factor was made by generating histograms of the correlation factor and grouping different combinations of the various factors that are known to influence K_T. Figure 5.31 presents the overall histogram for all piles tested in this study, before any separation was applied. A significant amount of scatter resulted, with the arithmetic mean resulting in a range of 9-11 ft^{-1}. A complete summary table containing all the Q_{ult} and K_T values for each test can be found in Appendix B-3.

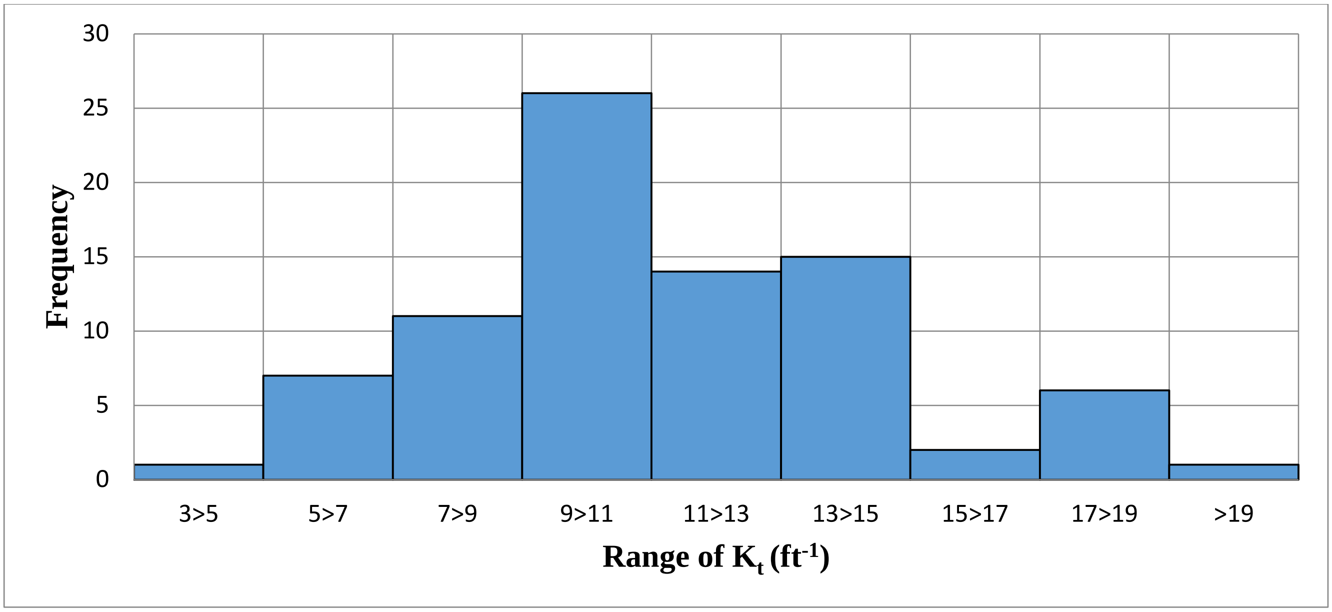

Figure 5.31 Histogram Showing Range of KT for all Piles

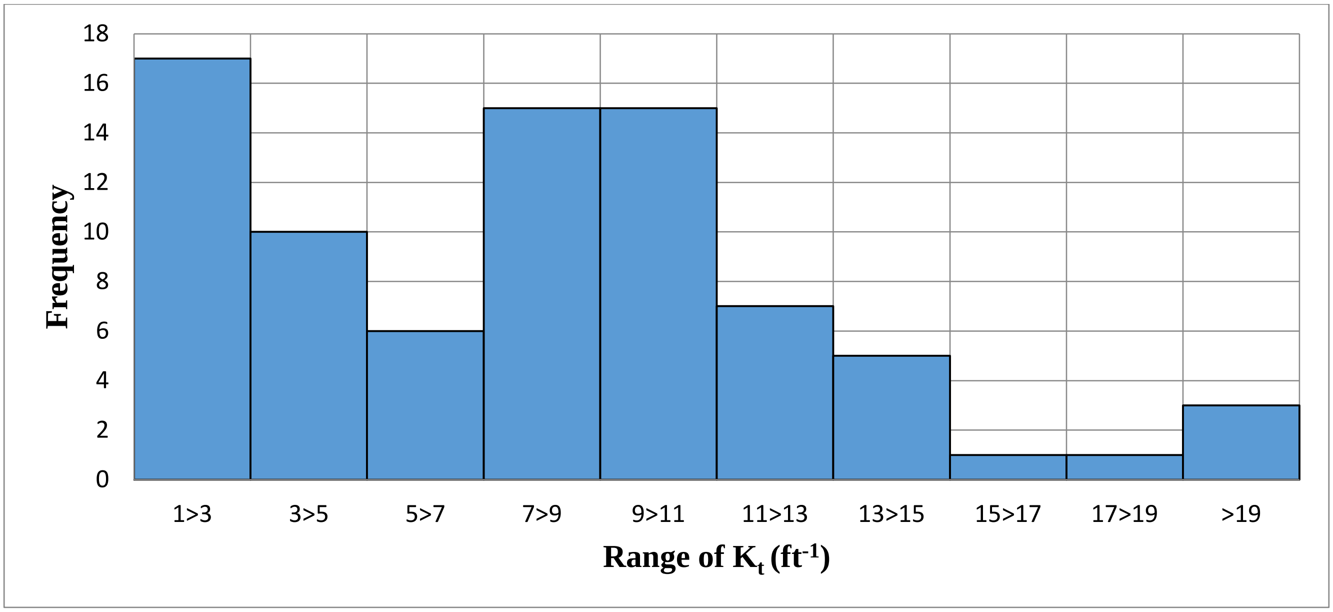

Figure 5.32 Histogram Showing Range of K_T for Piles Reported in Literature

Figures 5.33 and 5.34 present the first round of separation. Single versus multi helical anchors show in Figure 5.33 that as you add helices to the helical anchor, the correlation between torque and capacity weakens. This may have to do with disturbance factors affecting the capacity more than the installation torque. Figure 5.34 illustrates the difference in the measured K_T values. Sand show much less scatter with a range of 5 to 13 ft^{-1}, while the values in Clay range from 3 to 19+ft^{-1}. This may be due to the complexity introduced by clay with sensitivity factors or simply might stem from the larger volume of data available from the clay site compared to the sand site.

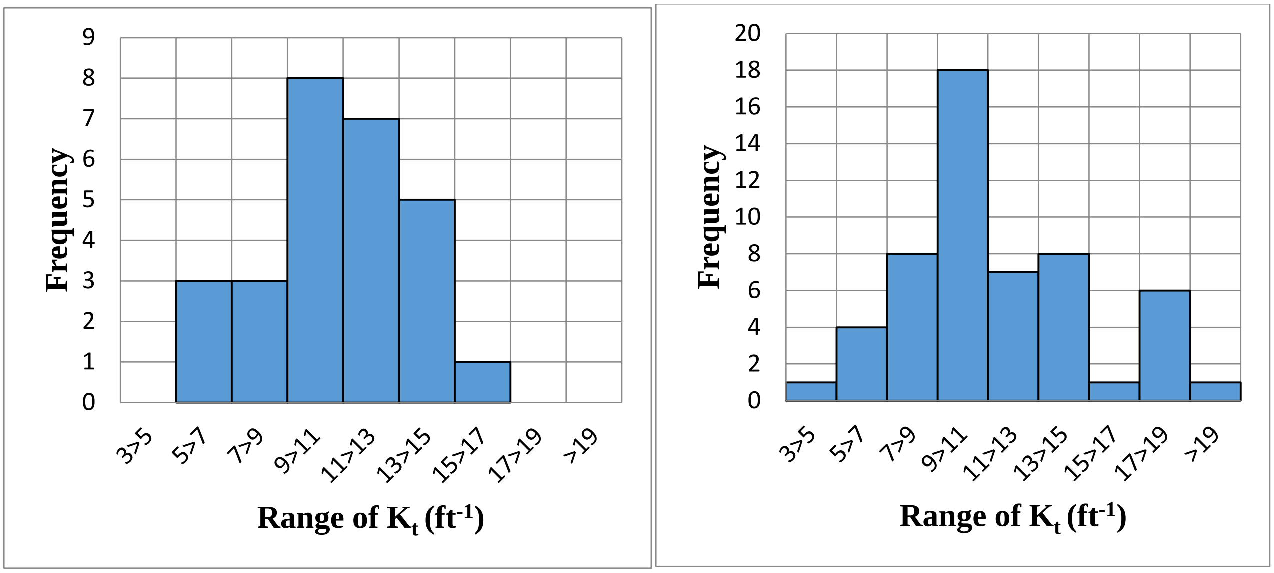

Figure 5.33 Single versus Multi Helical Anchors (from left to right).

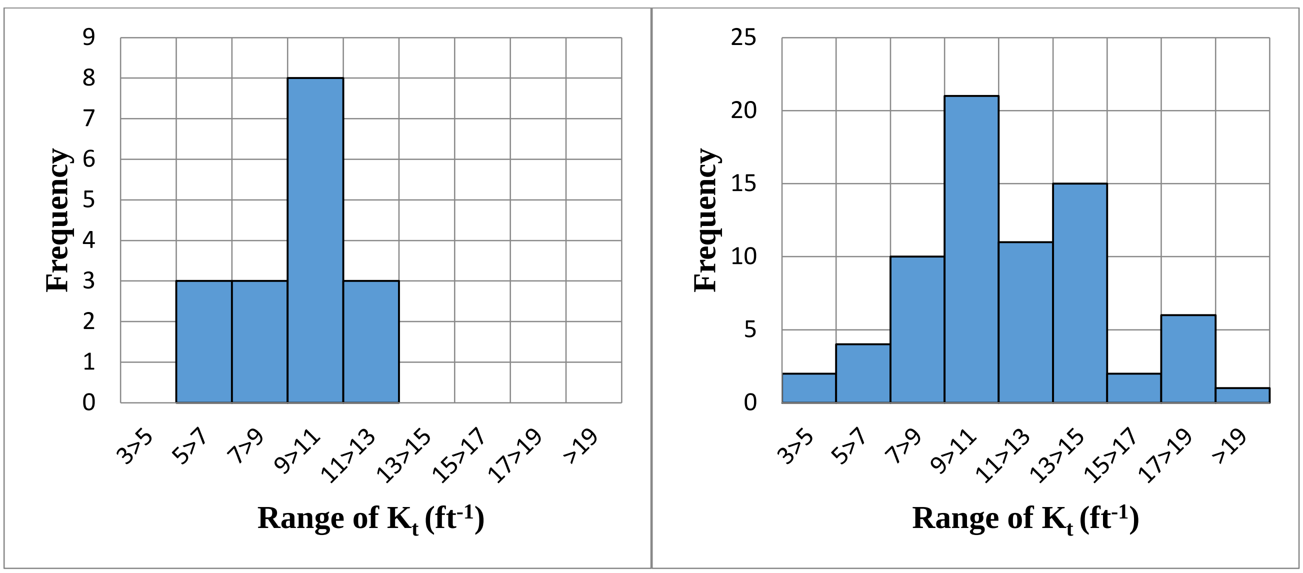

Figure 5.34 Helical Anchors in Sand versus Clay (from left to right)

Figures 5.33 and 5.34 represent the second round of attempts to separate the test results to determine an explanation for the variability of values obtained for K_T. Single versus multi helical anchors in clay were examined to account for the added disturbance when additional helices are added onto the shaft. Mathias et al. (2014) concluded that each additional helix contributes more to installation torque than it does to capacity. The single helical anchors do in fact show less scatter than the multi helical anchors, illustrated in Figure 5.35. Figure 5.36 show results in stiff and soft clay which represent the upper 10 ft. of the UMass DOE Site and below the 10 ft. transition for stiff to soft clay respectively. The histogram show relatively lower values for anchors seated in the stiff clay compared to those in the soft clay.

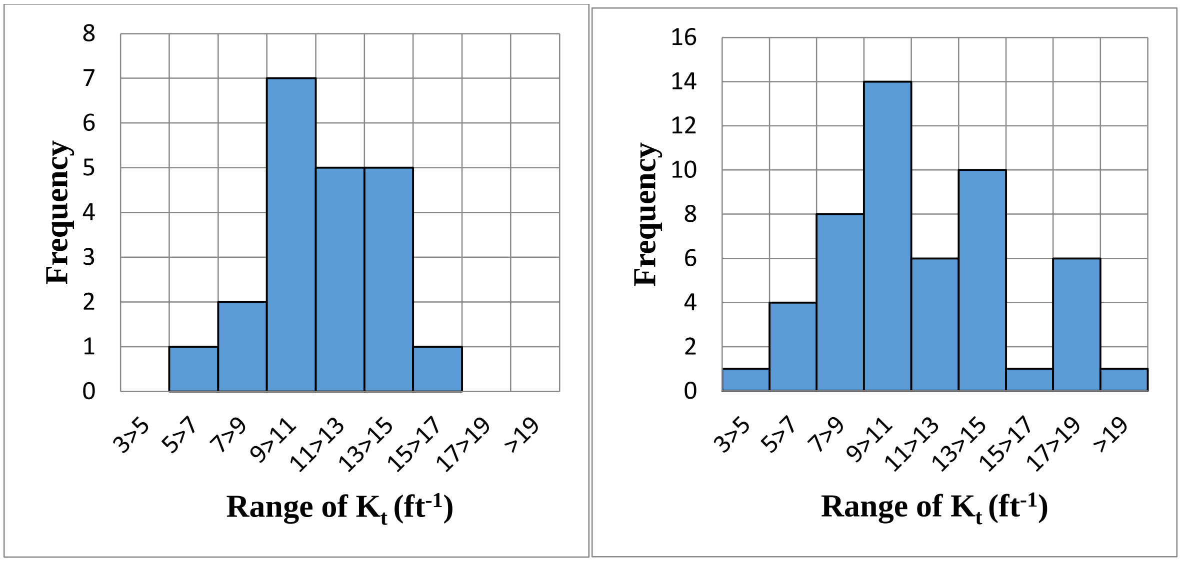

Figure 5.35 Single vs. Multi Helical Anchors in Clay

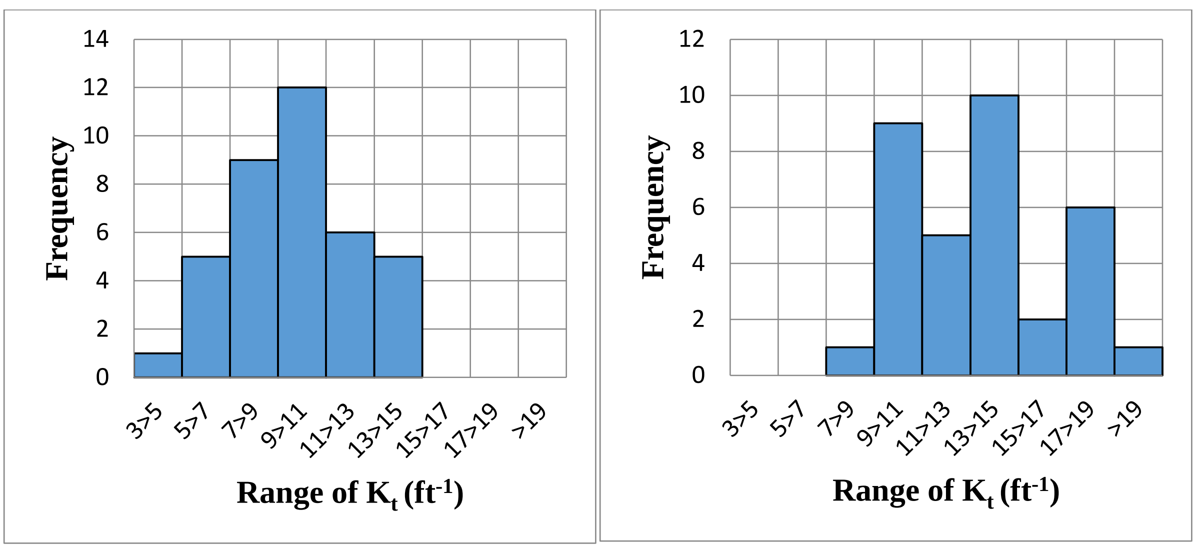

Figure 5.36 Helical Anchors in Stiff vs. Soft Clay

5.6.7 Single-Helix Round Shaft Series

At the UMass DOE Site, a series of RS2875 and RS350 10, 12, 14, and 16" single-helix anchors were installed and subjected to uplift axial load tests in an attempt to determine the effects of increasing helix diameter on similar shaft diameter piles. Figure 3.37 shows a decreasing trend in K_T as the helix diameter increases. This is in agreement with the assertion that K_T also decreases with an increase in shaft diameter, which leads to the conclusion that the bigger the helical anchor, shaft diameter or helix diameter, the more effort is needed to install (higher torque), but the increase in capacity is not proportional to the increase in necessary installation torque.

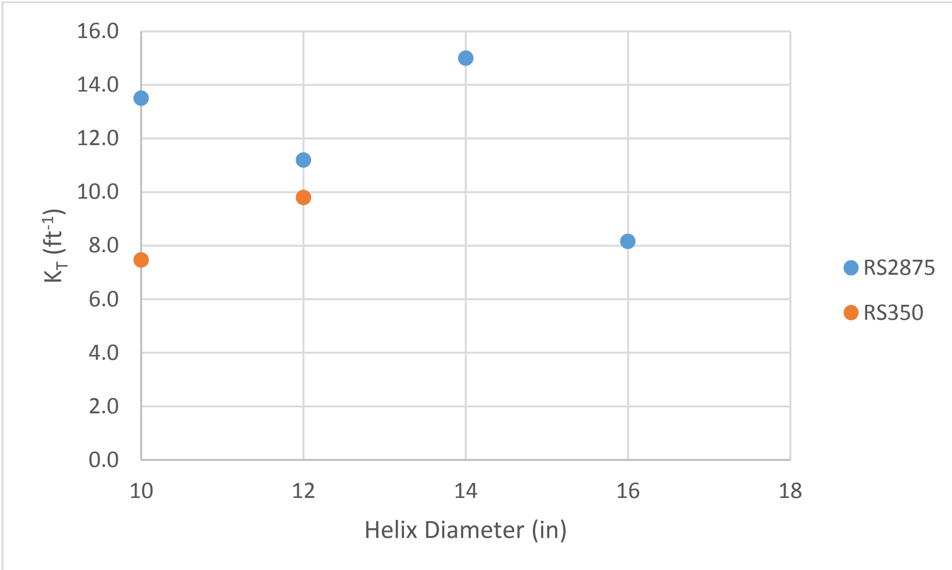

Figure 5.37 Variation in K_T for RS Single Helix Anchors at the UMass DOE Site

5.6.8 Pitch Series Results

A series of six single helix 2.875 in. diameter round shaft Screw-Piles were tested at the UMass AF-GT Site to determine the effects of pitch on installation torque and torque-to-capacity relationships. Table 5.6 provides a list of the different geometries of the piles in the pitch series.

Table 5.6 Pitch Series Configurations

Shaft Diameter (in.)	Helix Diameter (in.)	Pitch (in.)
2.875	8	3
2.875	12	3
2.875	12	4
2.875	12	6
2.875	18	3
2.875	18	6

Figure 5.38 shows the torque profiles for the pitch series and indicates that as pitch increases the installation torque increases. This seems to be more exaggerated in the granular soils in the upper 14 feet, but is not as pronounced once the Screw-Piles enter the fine-grained CVVC at a depth of 14 ft.

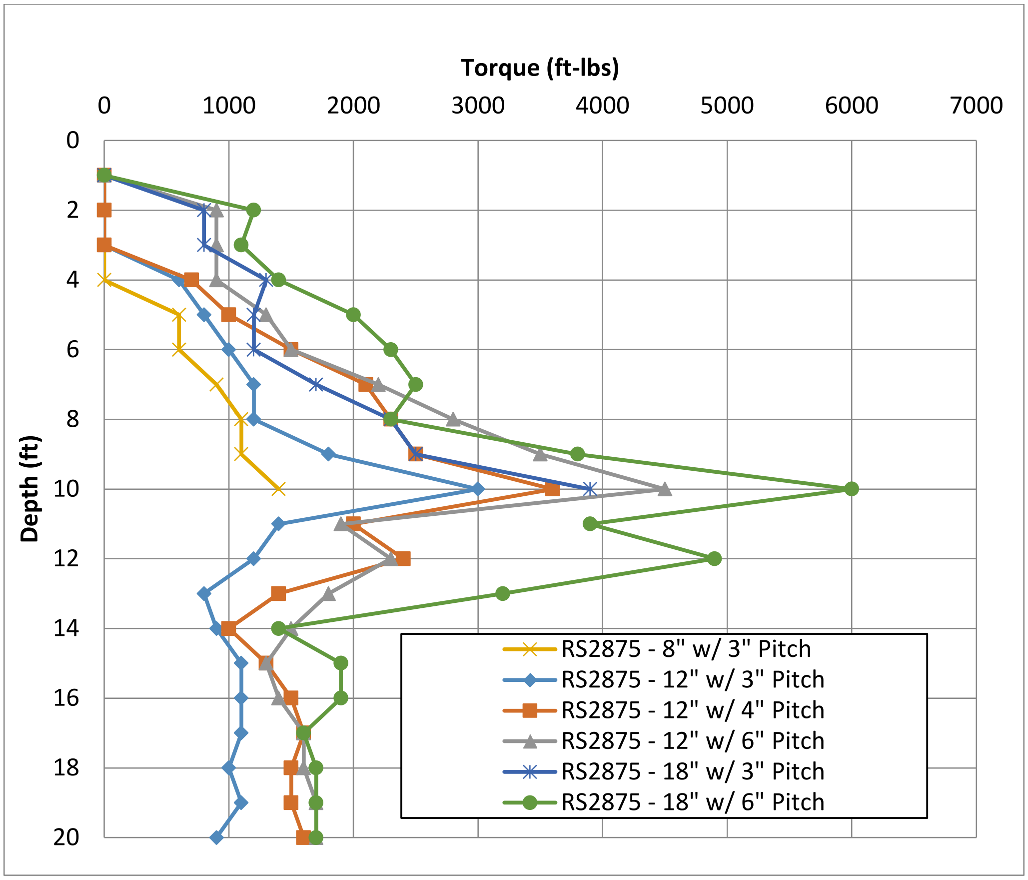

Figure 5.38 Torque Profile for Pitch Series at the UMass AF-GT Site

The Torque versus Differential pressure relationship relative to the pitch series is shown in Figure 5.39 and agrees with the relationship discovered at the UMass DOE Site. The best fit line for the smaller head has an offset of about 250 psi, while the trendline for the larger head appears to go through zero. The Chance Digital indicator only reads values starting at 500 ft-lbs. and therefore the zero values that are plotted do not actually represent installation torque of 0 ft-lbs.

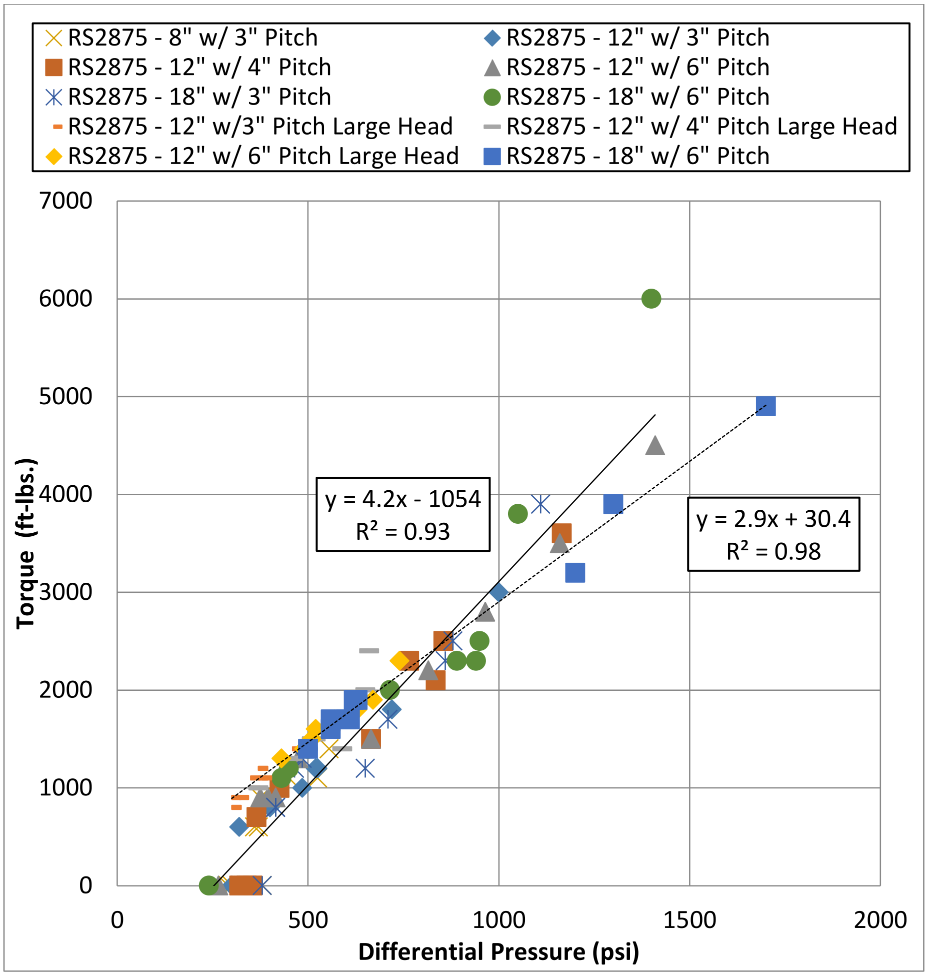

Figure 5.39 Torque vs. Differential Pressure for Pitch Series at the UMass AF-GT Site

Figure 5.40 shows the rotation speed of the pitch series during installation. Generally, the speed was held fairly constant with the exception of a few areas where the operator sped it up slightly without knowing. Installation results from the pitch series show a decrease in advance with an increase in pitch. The upper 10 ft. of installation show a near perfect Installation Disturbance Factor in Figure 5.41, but then it increases afterwards. This must be from being damaged during load testing. The large load applied to each pile during uplift tests must have damaged the blades in such a way that advancing is no longer fluent and therefore more revolutions than ideal are being recorded.

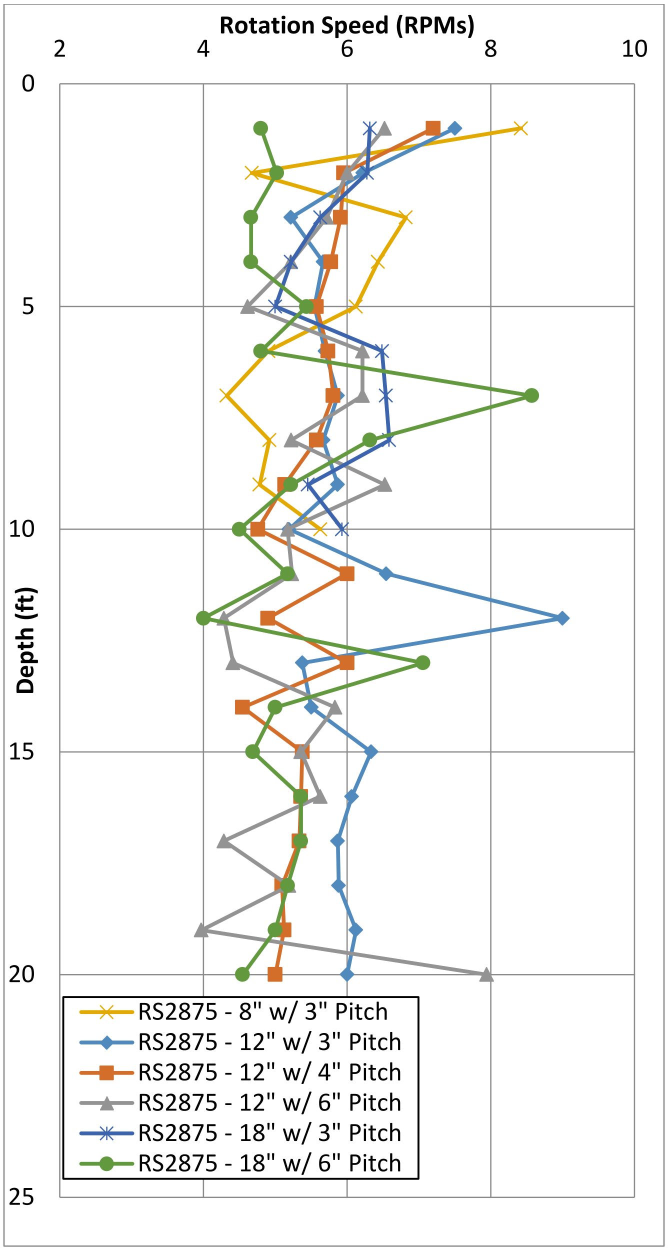

Figure 5.40 Rotation Speed of the Pitch Series at the UMass AF-GT Site

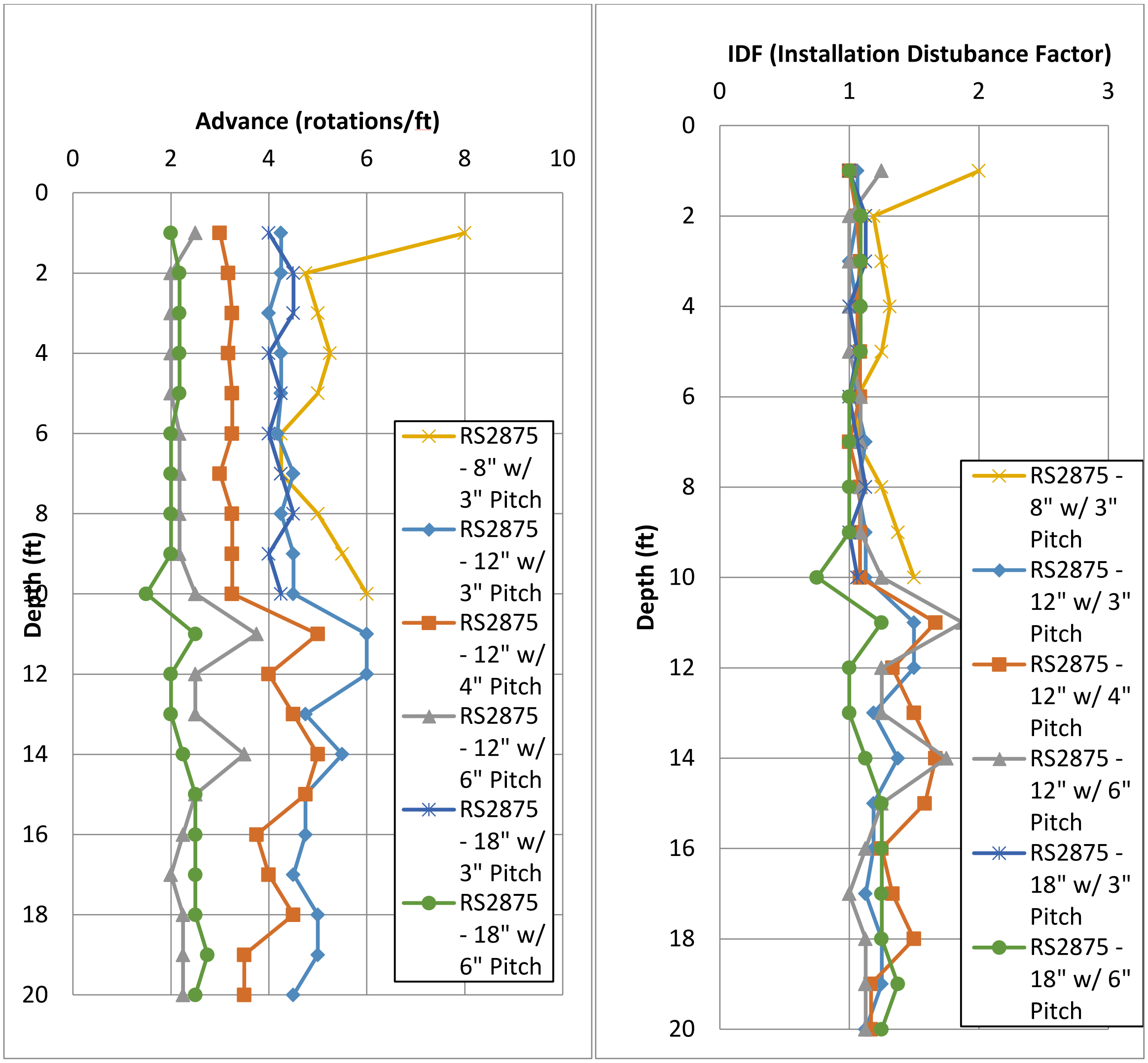

Figure 5.41 Pitch Series Installation Results – UMass AF-GT Site

Figure 5.42 presents the results from the load tests performed at the AF-GT. As expected, with increasing helix diameter, uplift capacity increases. The helical anchor with a 12 in. helix and 4 in. pitch produced the highest uplift capacity of the three 12 in. anchors tested by approximately 4000 lbs. The 12 in. helix with a 6 in. pitch did show a higher capacity than the 3” pitch anchor, but only by about 1500lbs. Figure 5.43 provides the results from the load tests performed on the same anchors at a depth of 20 feet. The capacities of the 12 in. anchors are consistent with one another. The 18 in. anchor produced a linear load-displacement plot which is indicative of a damaged plate. It did not behave like a typical anchor. A summary table of the load tests performed on the pitch series is included in Table 5.7 and shows a decrease in K_T from the 10’ depth to the 20’ depth.

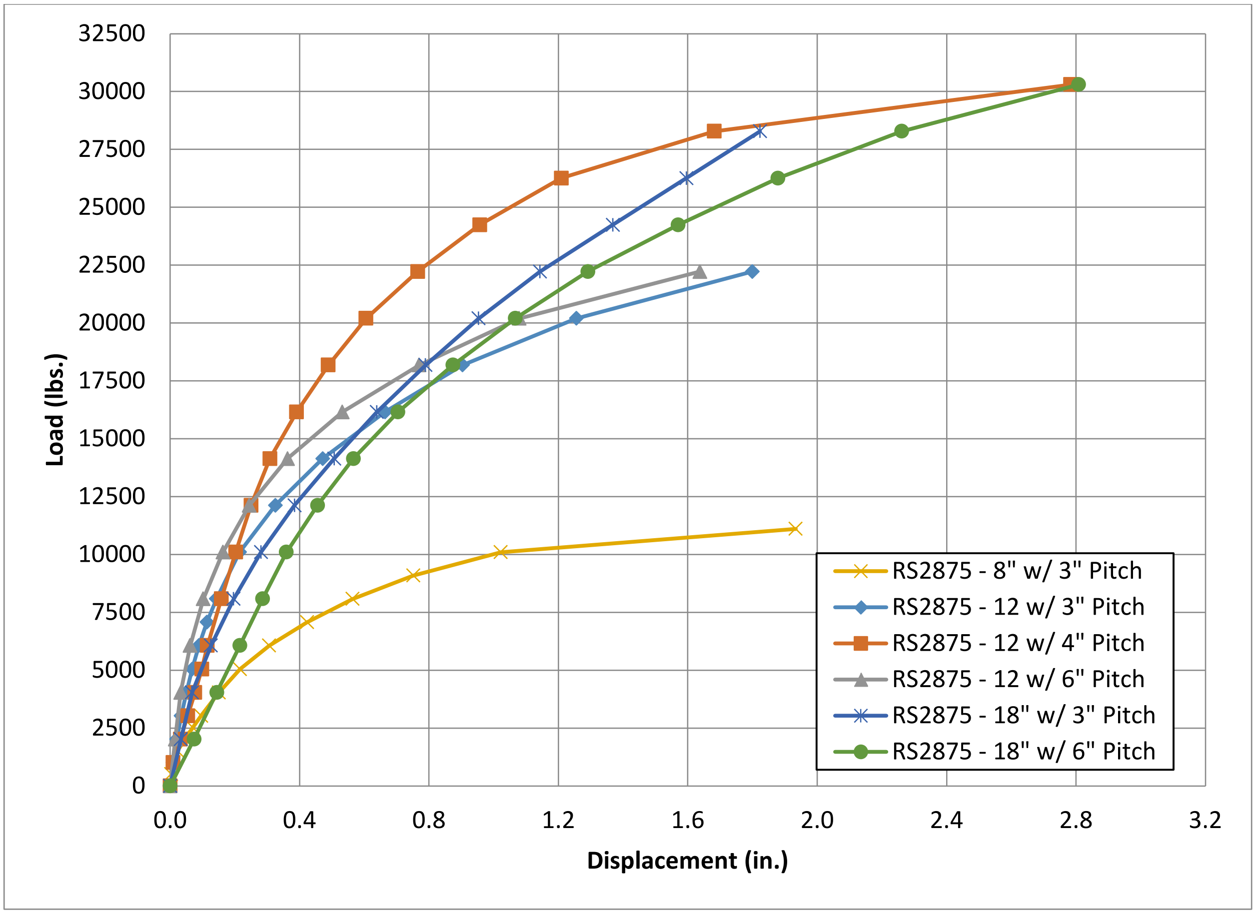

Figure 5.42 Load Test Results for the Pitch Series at the UMass AF-GT Site – 10' Depth

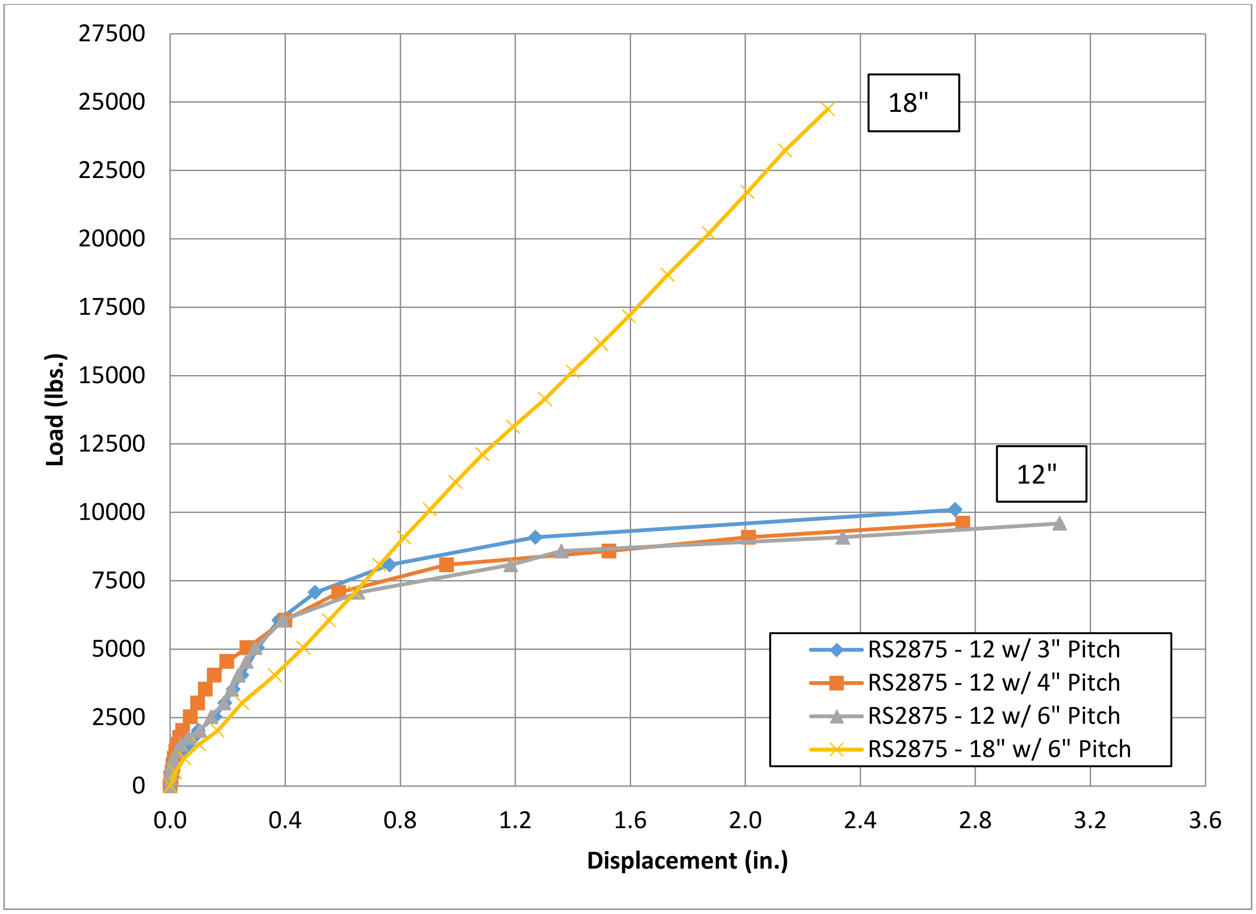

Figure 5.43 Load Test Results for the Pitch Series at the UMass AF-GT Site – 20' Depth

Table 5.7 Summary Table of Pitch Series

Site	Geometry	Average Diameter (in.)	Depth (ft)	Q_{ult} (lbs.)	Installation Torque (ft-lbs)	K_t (ft^{-1})
UMass AF-GT	RS2875-8" w/ 3" Pitch	8	10	9300	1250	7.4
	RS2875-12" w/ 3" Pitch	12	10	19000	2000	9.5
	RS2875-12" w/ 3" Pitch	12	20	8950	1000	9.0
	RS2875-12" w/ 4" Pitch	12	10	26200	2800	9.4
	RS2875-12" w/ 4" Pitch	12	20	8300	1533	5.4
	RS2875-12" w/ 6" Pitch	12	10	20600	3600	5.7
	RS2875-12" w/ 6" Pitch	12	20	8100	1667	4.9
	RS2875-18" w/ 3" Pitch	18	10	28100	2600	10.8
	RS2875-18" w/ 6" Pitch	18	10	25750	3650	7.1
	RS2875-18" w/ 6" Pitch	18	20	19400	1700	11.4

After installation of the pitch series, the plug, measured as the amount of soil that filled the end of the anchor, of each anchor was measured using a tape measure. The data shows that once the pipe has about 18” of soil it will not take on any more plug when advanced an additional 10 ft, effectively acting like a closed-end pipe pile. If more soil entered the hollow anchor, friction would develop, driving torque values to install the anchor higher, but not proportionally adding to capacity and therefore lowering measured K_T. The plug length ratio, PLR, remained fairly constant from the clay site to the sand site at a depth of 10 ft, indicating that once the helical anchor was plugged, no more soil entered the pipe during advance. The PLR decreased at depths of 20 feet which means the amount of plug remained the same despite advancing the pipe another 10 feet.

Table 5.8 Summary Table of Plugging Data

Pile Geometry	Depth (ft.)	Plug (in.)	PLR
UMass - AF-GT Site			
RS2875 8" w/ 3" Pitch	10	19	0.16
RS2875 12" w/ 3" Pitch	10	19	0.16
RS2875 12" w/ 3" Pitch	20	20	0.08
RS2875 12" w/ 4" Pitch	10	18.5	0.15
RS2875 12" w/ 4" Pitch	20	19	0.08
RS2875 12" w/ 6" Pitch	10	18.5	0.15
RS2875 12" w/ 6" Pitch	20	25	0.10
RS2875 18" w/ 3" Pitch	10	13.5	0.11
RS2875 18" w/ 6" Pitch	10	18	0.15
RS2875 18" w/ 6" Pitch	20	21	0.09
UMass - DOE Site			
RS2875 - 12"	10	10.5	0.09
RS2875 - 12"	10	8	0.07
RS2875 - 12"	10	7.5	0.06
RS2875 - 12"	10	11.5	0.10
RS2875 - 12"	10	16.5	0.14
RS2875 - 12"	10	20	0.17
RS2875 - 14"	10	17.5	0.15
RS2875 - 14"	10	17	0.14
RS2875 - 14"	10	15.5	0.13
RS2875 - 14"	10	16	0.13
RS2875 - 14"	10	15.5	0.13
RS2875 - 16"	10	16.5	0.14
RS350 - 10"	10	20	0.17
RS350 - 14"	10	18	0.15
RS350 - 16"	10	20.5	0.17

CHAPTER 6 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSTIONS

The following conclusions are based on the trial installations and load tests on both shallow and deep helical anchors performed at both the UMass AF-GT Site in South Deerfield, MA and the UMass DOE Site at the University of Massachusetts Amherst in Hadley, MA.

6.1.1 Installation Torque

- Helical anchors develop higher installation torque with increasing pitch of helical plates.
- Increased rotation rate leads to higher measured torque.
- Each torque head has a unique relationship between differential pressure and torque. Torque to differential pressure relationships must be calibrated for each combination of machine and torque head.
- Smaller torque head produces slower rotation rate than larger head at the same throttle on the same machine.
- Installation rate does not affect advance, i.e. IDF.

6.1.2 Torque-to-Capacity Relationships

- Tapered and cylindrical Screw-Piles with the same shaft diameter and net helix area develop the similar installation torque, but tapered piles have a higher capacity, therefore a higher value of K_T.
- K_T is dependent upon precision of measurements of installation torque. Only direct methods of monitoring installation should be used to determine torque correlation factors.
- K_T increases in soft clay compared to stiff clay.
- K_T is highly dependent upon the failure criterion selected.
- K_T is dependent upon the definition of installation torque.

6.2 RECOMMENDATIONS FOR FUTURE RESEARCH

6.2.1 Installation Torque

- Evaluate the offset of the torque vs. pressure curve.

- Monitor installation and perform uplift load tests on different pitched single helical anchors in clay.
- Monitor installation and perform uplift load tests on different pitched multi helical anchors in sand and clay.
- Measure crowd during installation to determine effects on installation torque.
- Test same machine and torque head at different sites to determine if soil type has effect on unique torque-to-pressure relationship.

6.2.2 Torque-to-Capacity Relationships

- Evaluate tapered vs. cylindrical torque to capacity relationships of multi helical anchors in sand.
- Test capacity of anchors installed with full throttle installation speed.
- Determine the effects of load testing on helical anchors by installing trial piles to depths where tests have been already been conducted. Anchors may be damaged during uplift load tests, affecting installation quality and reducing uplift load capacity when advanced and tested at subsequent depths.

CHAPTER 7 REFERENCES

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APPENDIX A: AF-GEOTECH

A-1 INSTALLTION LOGS

Pitch Series

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	8" Helix w/ 3" Pitch		
Extensions	1-5'		**Plug (in):**	19		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	*Time (s)*	*Rotation Speed (RPMs)*
1	0	290	8	1.05	57	8.4
2	0	300	4.75	0.98	61	4.7
3	0	330	5	1.36	44	6.8
4	0	380	5.25	1.22	49	6.4
5	600	360	5	1.22	49	6.1
6	600	370	4.25	1.15	52	4.9
7	900	375	4.25	1.02	59	4.3
8	1100	450	5	0.98	61	4.9
9	1100	525	5.5	0.87	69	4.8
10	1400	555	6	0.94	64	5.6

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	12" Helix w/ 3" Pitch		
Extensions	N/A		**Plug (in):**	N/A		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	*Time (s)*	*Rotation Speed (RPMs)*
1	0	315	4.25	1.76	34	7.5
2	0	320	4.25	1.46	41	6.2
3	0	300	4	1.30	46	5.2
4	600	320	4.25	1.33	45	5.7
5	800	400	4.25	1.30	46	5.5
6	1000	485	4.175	1.36	44	5.7
7	1200	525	4.5	1.30	46	5.9
8	1200	520	4.25	1.33	45	5.7
9	1800	720	4.5	1.30	46	5.9
10	3000	1000	4.5	1.15	52	5.2
11	1400	460	6	1.09	55	6.5
12	1200	370	6	1.50	40	9.0
13	800	300	4.75	1.13	53	5.4
14	900	320	5.5	1.00	60	5.5
15	1100	350	4.75	1.33	45	6.3
16	1100	380	4.75	1.28	47	6.1
17	1100	370	4.5	1.30	46	5.9
18	1000	350	5	1.18	51	5.9
19	1100	370	5	1.22	49	6.1
20	900	300	4.5	1.33	45	6.0

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	12" Helix w/ 4" Pitch		
Extensions	N/A		**Plug (in):**	N/A		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	320	3	2.40	25	7.2
2	0	355	3.175	1.88	32	6.0
3	0	340	3.25	1.82	33	5.9
4	700	365	3.175	1.82	33	5.8
5	1000	425	3.25	1.71	35	5.6
6	1500	665	3.25	1.76	34	5.7
7	2100	835	3	1.94	31	5.8
8	2300	765	3.25	1.71	35	5.6
9	2500	855	3.25	1.58	38	5.1
10	3600	1165	3.25	1.46	41	4.8
11	2000	650	5	1.20	50	6.0
12	2400	660	4	1.22	49	4.9
13	1400	590	4.5	1.33	45	6.0
14	1000	370	5	0.91	66	4.5
15	1300	460	4.75	1.13	53	5.4
16	1500	510	3.75	1.43	42	5.4
17	1600	540	4	1.33	45	5.3
18	1500	510	4.5	1.13	53	5.1
19	1500	520	3.5	1.46	41	5.1
20	1600	560	3.5	1.43	42	5.0

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	12" Helix w/ 6" Pitch		
Extensions	N/A		**Plug (in):**	N/A		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	265	2.5	2.61	23	6.5
2	900	415	2	3.00	20	6.0
3	900	395	2	2.86	21	5.7
4	900	375	2	2.61	23	5.2
5	1300	475	2	2.31	26	4.6
6	1500	665	2.175	2.86	21	6.2
7	2200	815	2.175	2.86	21	6.2
8	2800	965	2.175	2.40	25	5.2
9	3500	1160	2.175	3.00	20	6.5
10	4500	1410	2.5	2.07	29	5.2
11	1900	670	3.75	1.40	43	5.2
12	2300	740	2.5	1.71	35	4.3
13	1800	630	2.5	1.76	34	4.4
14	1500	510	3.5	1.67	36	5.8
15	1300	430	2.5	2.14	28	5.4
16	1400	490	2.25	2.50	24	5.6
17	1600	560	2	2.14	28	4.3
18	1600	520	2.25	2.31	26	5.2
19	1700	600	2.25	1.76	34	4.0
20	1700	570	2.25	3.53	17	7.9

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	18" Helix w/ 3" Pitch		
Extensions	N/A		**Plug (in):**	N/A		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	380	4	1.58	38	6.3
2	800	415	4.5	1.40	43	6.3
3	800	415	4.5	1.25	48	5.6
4	1300	485	4	1.30	46	5.2
5	1200	465	4.25	1.18	51	5.0
6	1200	650	4	1.62	37	6.5
7	1700	710	4.25	1.54	39	6.5
8	2300	860	4.5	1.46	41	6.6
9	2500	880	4	1.36	44	5.5
10	3900	1110	4.25	1.40	43	5.9

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	18" Helix w/ 6" Pitch		
Extensions	N/A		**Plug (in):**	N/A		
Rig Type	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Small Torque Head		**Technicians**	MNR, AJL, MC		
Depth (ft):	*Torque (ft-lbs)*	*Differential Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	240	2	2.40	25	4.8
2	1200	450	2.175	2.31	26	5.0
3	1100	430	2.175	2.14	28	4.7
4	1400	500	2.175	2.14	28	4.7
5	2000	715	2.175	2.50	24	5.4
6	2300	940	2	2.40	25	4.8
7	2500	950	2	4.29	14	8.6
8	2300	890	2	3.16	19	6.3
9	3800	1050	2	2.61	23	5.2
10	6000	1400	1.5	3.00	20	4.5
11	3900	1300	2.5	2.07	29	5.2
12	4900	1700	2	2.00	30	4.0
13	3200	1200	2	3.53	17	7.1
14	1400	500	2.25	2.22	27	5.0
15	1900	630	2.5	1.88	32	4.7
16	1900	620	2.5	2.14	28	5.4
17	1600	560	2.5	2.14	28	5.4
18	1700	600	2.5	2.07	29	5.2
19	1700	610	2.75	1.82	33	5.0
20	1700	560	2.5	1.82	33	4.5

Trial Installations

HELICAL ANCHOR INSTALLATION LOG							
Date:	4/23/2015		**Location:**	AF-GT			
Pile Geometry:	RS2875		**Lead Section:**	8/10/12			
Extensions:	4-7'		**Trial:**	Normal Throttle			
Rig Type:	Bobcat T190		**Torque Indicator**	Chance Digital Indicator			
Torque Head:	Eskridge 50K		**Technicians**	MNR + AJL			
Depth (ft):	*TORQ-PIN (ft-lbs.)*	*Torque (ft-lbs)*	*Pressure Differential(psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	N/A	0	475	3.5	1.33	45	4.7
2	155	0	475	4	1.71	35	6.9
3	355	0	500	4	1.71	35	6.9
4	459	500	525	4.5	1.58	38	7.1
5	721	700	575	3.75	2.73	22	10.2
6	1123	1200	675	7	1.22	49	8.6
7	1330	1500	710	5	1.18	51	5.9
8	1403	1500	720	5.75	1.40	43	8.0
9	2199	2300	910	4.75	1.40	43	6.6
10	2634	3000	1090	5.25	1.05	57	5.5
11	2368	2800	1050	6.25	0.98	61	6.1
12	1361	1700	785	7	0.87	69	6.1
13	2142	2400	1020	5.25	1.28	47	6.7
14	1797	2100	950	5.25	1.58	38	8.3
15	2345	2800	1100	5.75	1.43	42	8.2
16	1367	1700	890	6.25	1.11	54	6.9
17	990	1200	680	6.25	1.15	52	7.2
18	1297	1300	780	5	1.36	44	6.8
19	1193	1300	850	4.25	1.50	40	6.4
20	777	800	680	4.5	1.67	36	7.5
21	800	900	485	3.75	1.50	40	5.6
22	908	900	520	4.25	1.30	46	5.5
23	855	900	510	4.75	1.18	51	5.6
24	729	800	470	4.25	1.33	45	5.7
25	1080	1200	550	4.5	1.22	49	5.5
26	800	900	510	4.25	1.18	51	5.0
27	810	900	460	4.25	1.30	46	5.5
28	822	900	470	4.25	1.33	45	5.7
29	905	900	440	4.5	1.11	54	5.0

30	1015	1000	500	4.25	1.20	50	5.1
Notes: 1) Installed at 1/2 throttle, normal speed. 2) Total drive of 30' in 22.9 minutes.							

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/29/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12		
Extensions:	2-7', 3-5'		**Trial:**	Normal Throttle		
Rig Type:	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Torque Head:	Eskridge 77BD		**Technicians**	MNR + AJL		
Depth (ft):	*Torque (ft-lbs)*	*Pressure Differential(psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	210	2.75	2.86	21	7.9
2	0	170	3.75	1.82	33	6.8
3	0	230	4.75	1.46	41	7.0
4	500	230	6.5	1.15	52	7.5
5	800	330	5.5	1.50	40	8.3
6	1000	330	4.5	1.43	42	6.4
7	1100	430	5	0.56	108	2.8
8	1200	500	4.75	1.28	47	6.1
9	1400	560	4.5	1.46	41	6.6
10	2100	780	5	1.18	51	5.9
11	2600	850	4.75	1.13	53	5.4
12	2000	700	5.25	1.07	56	5.6
13	2300	750	5	1.20	50	6.0
14	1300	550	4.75	1.20	50	5.7
15	1500	580	4.5	1.36	44	6.1
16	1600	550	4.75	1.22	49	5.8
17	1200	480	4.5	1.30	46	5.9
18	1200	450	4.75	1.30	46	6.2
19	1100	460	4.5	1.33	45	6.0
20	800	360	4.25	1.46	41	6.2
21	1000	390	4.5	1.43	42	6.4
22	1200	450	4.5	1.33	45	6.0
23	900	370	4.25	1.71	35	7.3
24	1100	420	4.5	1.28	47	5.7
25	900	360	4.25	1.58	38	6.7
26	800	360	4.5	1.36	44	6.1
27	900	390	4.25	1.50	40	6.4
28	1100	410	4.5	1.30	46	5.9

29	1100	460	4.75	1.33	45	6.3
30	1200	480	4.5	1.43	42	6.4
Notes: 1) Installed at 1/2 throttle, normal speed. 2) Total drive of 30' in 23.2 minutes.						

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/29/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12		
Extensions:	2-7', 3-5'		**Trial:**	Full Throttle		
Rig Type:	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Torque Head:	Eskridge 77BD		**Technicians**	MNR + AJL		
Depth (ft):	*Torque (ft-lbs)*	*Pressure Differential(psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	370	3.25	4.62	13	15.0
2	0	300	4.25	3.53	17	15.0
3	0	320	4	4.29	14	17.1
4	800	370	5	3.00	20	15.0
5	1200	590	4.5	3.33	18	15.0
6	1500	560	4.5	3.53	17	15.9
7	1400	590	5	2.40	25	12.0
8	1700	730	5	3.00	20	15.0
9	2500	750	5	2.86	21	14.3
10	2800	720	5	3.00	20	15.0
11	3400	760	5	2.73	22	13.6
12	2500	1080	5	2.73	22	13.6
13	2700	1070	5	2.50	24	12.5
14	2700	980	5	3.00	20	15.0
15	2200	900	4.5	2.73	22	12.3
16	2500	1000	4.75	2.61	23	12.4
17	2000	720	4.5	3.75	16	16.9
18	1700	640	4.5	2.61	23	11.7
19	1800	740	5	3.00	20	15.0
20	1100	550	4.75	2.86	21	13.6
21	1000	500	4.5	3.33	18	15.0
22	1100	510	4.25	3.16	19	13.4
23	1000	500	4.5	3.53	17	15.9
24	1100	500	5.25	2.86	21	15.0
25	1200	560	5	3.53	17	17.6
26	1300	550	4	2.73	22	10.9
27	1100	560	4.5	3.53	17	15.9

28	1000	640	4.5	2.73	22	12.3
29	1300	610	4.25	3.16	19	13.4
30	1400	650	5	2.73	22	13.6

Notes: 1) Installed at full throttle, faster than normal speed.
2) Total drive of 30' in 9.9 minutes.

HELICAL ANCHOR INSTALLATION LOG			
Date:	4/30/2015	**Location:**	AF-GT
Pile Geometry:	RS2875	**Lead Section:**	8/10/12
Extensions:	2-7', 3-5'	**Trial:**	Slow Throttle
Rig Type:	Bobcat T190	**Torque Indicator**	Chance Digital Indicator
Torque Head:	Eskridge 77BD	**Technicians**	MNR + AJL

Depth (ft):	*Torque (ft-lbs)*	*Pressure Differential(psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	0	120	4	1.76	34	7.1
2	0	140	4	1.43	42	5.7
3	0	200	4	1.43	42	5.7
4	600	240	4.175	1.09	55	4.6
5	700	280	4.175	1.18	51	4.9
6	1000	390	4.175	1.09	55	4.6
7	1200	440	4.5	1.03	58	4.7
8	1600	590	4.75	0.88	68	4.2
9	2400	880	5	0.81	74	4.1
10	2700	980	4.75	0.76	79	3.6
11	2900	1060	4.5	0.71	85	3.2
12	2300	800	5	0.76	79	3.8
13	2500	900	4.5	0.97	62	4.4
14	3000	1050	4.5	0.85	71	3.8
15	1700	650	4.25	0.90	67	3.8
16	2400	850	4.5	0.86	70	3.9
17	1200	460	4.5	0.90	67	4.0
18	1400	510	4.175	1.02	59	4.2
19	1500	550	4.75	0.90	67	4.3
20	900	360	4.5	0.94	64	4.2
21	900	350	4.25	1.09	55	4.6
22	900	360	4.25	1.11	54	4.7
23	1000	400	4.25	0.94	64	4.0
24	900	350	4.25	1.18	51	5.0
25	800	310	4.5	1.05	57	4.7
26	1000	440	4.5	1.03	58	4.7

27	1000	400	4.5	1.00	60	4.5
28	1200	460	4.5	1.03	58	4.7
29	1100	410	4.5	1.07	56	4.8
30	1200	450	4.5	1.05	57	4.7

Notes: 1) Installed at low throttle, slower than normal speed.
2) Total drive of 30' in 30.3 minutes.

HELICAL ANCHOR INSTALLATION LOG						
Date:	4/30/2015		**Location:**	AF-GT		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12		
Extensions:	2-7', 3-5'		**Trial:**	Normal Throttle		
Rig Type:	Bobcat T190		**Torque Indicator**	Chance Digital Indicator		
Torque Head:	Eskridge 77BD		**Technicians**	MNR + AJL		
Depth (ft):	*Torque (ft-lbs)*	*Pressure Differential(psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
0.5	0	-	-	-	-	-
1	0	100	4	2.50	24	10.0
1.5	0	-	-	-	-	-
2	0	160	4	1.76	34	7.1
2.5	0	-	-	-	-	-
3	600	170	4	1.67	36	6.7
3.5	600	-	-	-	-	-
4	700	210	4	1.46	41	5.9
4.5	800	-	-	-	-	-
5	1000	330	4.25	1.36	44	5.8
5.5	1300	-	-	-	-	-
6	1800	570	4.75	1.15	52	5.5
6.5	1600	-	-	-	-	-
7	1800	620	4.25	1.30	46	5.5
7.5	2000	-	-	-	-	-
8	2300	780	5	1.07	56	5.4
8.5	2300	-	-	-	-	-
9	2600	860	4.75	1.15	52	5.5
9.5	3000	-	-	-	-	-
10	3300	1150	4.75	0.88	68	4.2
10.5	3100	-	-	-	-	-
11	3200	1170	4.75	0.97	62	4.6
11.5	3200	-	-	-	-	-
12	3000	1110	5	1.05	57	5.3
12.5	2500	-	-	-	-	-

13	2800	990	5	1.09	55	5.5
13.5	2800	-	-	-	-	-
14	2500	880	5	1.11	54	5.6
14.5	2000	-	-	-	-	-
15	1800	670	4.5	1.20	50	5.4
15.5	1900	-	-	-	-	-
16	2400	830	4.5	1.20	50	5.4
16.5	1800	-	-	-	-	-
17	1600	560	4.25	1.22	49	5.2
17.5	1500	-	-	-	-	-
18	1400	480	4.5	1.20	50	5.4
18.5	1500	-	-	-	-	-
19	1500	580	4.25	1.33	45	5.7
19.5	1500	-	-	-	-	-
20	1200	380	4.5	1.43	42	6.4
20.5	1000	-	-	-	-	-
21	900	290	4.5	1.40	43	6.3
21.5	900	-	-	-	-	-
22	900	310	4.5	1.50	40	6.8
22.5	1000	-	-	-	-	-
23	1000	350	4.75	1.20	50	5.7
23.5	1100	-	-	-	-	-
24	1200	420	4.5	1.54	39	6.9
24.5	1000	-	-	-	-	-
25	1100	390	4.5	1.46	41	6.6
25.5	1200	-	-	-	-	-
26	1500	490	4.5	1.36	44	6.1
26.5	1000	-	-	-	-	-
27	1000	350	4.5	1.33	45	6.0
27.5	1000	-	-	-	-	-
28	1100	400	4.5	1.46	41	6.6
28.5	1100	-	-	-	-	-
29	1100	370	4	1.54	39	6.2
29.5	1200	-	-	-	-	-
30	1200	410	4.5	1.30	46	5.9
30.5	1200	-	-	-	-	-
31	1100	380	4.25	1.43	42	6.1
31.5	1200	-	-	-	-	-
32	1400	480	4.25	1.40	43	5.9

Notes: 1) Installed at normal throttle, normal speed.
2) Total drive of 30' in 24.8 minutes.

Installations for Load Tests

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#1	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	560	*N/A*	*N/A*	*N/A*
9	*N/A*	600	*N/A*	*N/A*	*N/A*
10	*N/A*	1160	*N/A*	*N/A*	*N/A*
11	1200	1325	5	1.7	35
12	1100	1350	5	1.9	32
13	500	1260	5	1.9	31
14	400	1300	5	2.1	29
15	600	1175	5.5	2.2	27
16	500	1140	5	2.1	28
17	500	1060	6	1.7	36
18	600	1200	6.5	1.6	37
19	800	1010	6.5	1.8	33
20	600	1160	5	2.4	25

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#2	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	480	*N/A*	*N/A*	*N/A*
9	*N/A*	1000	*N/A*	*N/A*	*N/A*
10	*N/A*	1040	*N/A*	*N/A*	*N/A*
11	1000	N/A	5.5	1.9	32
12	800	N/A	5.5	1.9	32
13	500	N/A	5.75	1.8	33
14	500	N/A	6.25	2.0	30
15	600	N/A	6.5	1.8	33
16	500	N/A	5	2.4	25
17	600	N/A	56	1.8	34
18	600	N/A	8	1.6	38
19	400	N/A	5.5	1.7	35
20	600	N/A	5	2.7	22

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#3	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	760	*N/A*	*N/A*	*N/A*
9	*N/A*	920	*N/A*	*N/A*	*N/A*
10	*N/A*	880	*N/A*	*N/A*	*N/A*
11	800	N/A	6.5	2.1	28
12	1200	N/A	6.25	2.0	30
13	600	N/A	5	2.3	26
14	600	N/A	5.5	1.9	31
15	400	N/A	9	1.6	38
16	300	N/A	10	0.6	94
17	500	N/A	8.5	1.0	59
18	600	N/A	10	1.3	47
19	500	N/A	15	0.8	77
20	500	N/A	7	1.5	40

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#4	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	480	*N/A*	*N/A*	*N/A*
9	*N/A*	1000	*N/A*	*N/A*	*N/A*
10	*N/A*	1040	*N/A*	*N/A*	*N/A*
11	*N/A*	N/A	*N/A*	*N/A*	*N/A*
12	*N/A*	N/A	*N/A*	*N/A*	*N/A*
13	*N/A*	N/A	*N/A*	*N/A*	*N/A*
14	*N/A*	N/A	*N/A*	*N/A*	*N/A*
15	*N/A*	N/A	*N/A*	*N/A*	*N/A*
16	*N/A*	N/A	*N/A*	*N/A*	*N/A*
17	*N/A*	N/A	*N/A*	*N/A*	*N/A*
18	*N/A*	N/A	*N/A*	*N/A*	*N/A*
19	*N/A*	N/A	*N/A*	*N/A*	*N/A*
20	*N/A*	N/A	*N/A*	*N/A*	*N/A*

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#4	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	480	*N/A*	*N/A*	*N/A*
9	*N/A*	1000	*N/A*	*N/A*	*N/A*
10	*N/A*	1040	*N/A*	*N/A*	*N/A*
11	*N/A*	N/A	*N/A*	*N/A*	*N/A*
12	*N/A*	N/A	*N/A*	*N/A*	*N/A*
13	*N/A*	N/A	*N/A*	*N/A*	*N/A*
14	*N/A*	N/A	*N/A*	*N/A*	*N/A*
15	*N/A*	N/A	*N/A*	*N/A*	*N/A*
16	*N/A*	N/A	*N/A*	*N/A*	*N/A*
17	*N/A*	N/A	*N/A*	*N/A*	*N/A*
18	*N/A*	N/A	*N/A*	*N/A*	*N/A*
19	*N/A*	N/A	*N/A*	*N/A*	*N/A*
20	*N/A*	N/A	*N/A*	*N/A*	*N/A*

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	SS5 - 12 - TS#6	
Extensions	N/A		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	320	*N/A*	*N/A*	*N/A*
2	*N/A*	400	*N/A*	*N/A*	*N/A*
3	*N/A*	400	*N/A*	*N/A*	*N/A*
4	*N/A*	440	*N/A*	*N/A*	*N/A*
5	*N/A*	560	*N/A*	*N/A*	*N/A*
6	*N/A*	660	*N/A*	*N/A*	*N/A*
7	*N/A*	680	*N/A*	*N/A*	*N/A*
8	*N/A*	640	*N/A*	*N/A*	*N/A*
9	*N/A*	760	*N/A*	*N/A*	*N/A*
10	*N/A*	1000	*N/A*	*N/A*	*N/A*
11	700	N/A	7	1.6	37
12	700	N/A	6	2.3	26
13	600	N/A	6.75	1.8	34
14	400	N/A	7	2.1	29
15	500	N/A	4.5	2.5	24
16	400	N/A	4.5	2.9	21
17	700	N/A	4.5	2.9	21
18	800	N/A	5.5	2.4	25
19	700	N/A	5.75	2.2	27
20	800	N/A	5.5	2.3	26

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013, 11/15/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	Combo 8/10/12 @3D	
Extensions	5', 7'		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	400	N/A	4.5	2.2	27
2	400	N/A	5	1.3	48
3	900	N/A	4.5	2.5	24
4	1400	N/A	4.5	2.3	26
5	1600	N/A	5	2.1	28
6	2100	N/A	5	2.5	24
7	1900	N/A	5	2.1	29
8	2800	N/A	4.5	1.9	32
9	3000	N/A	4.25	2.1	29
10	3300	N/A	4.25	2.0	30
11	1700	950	5	#VALUE!	N/A
12	1500	900	5	#VALUE!	N/A
13	1500	900	5	#VALUE!	N/A
14	1400	850	4.5	#VALUE!	N/A
15	1100	740	5	#VALUE!	N/A
16	800	750	4.5	#VALUE!	N/A
17	1400	800	4.5	#VALUE!	N/A
18	1000	720	4.5	#VALUE!	N/A
19	800	675	4.5	#VALUE!	N/A
20	600	660	4.5	#VALUE!	N/A

HELICAL ANCHOR INSTALLATION LOG					
Date:	7/2/2013, 11/15/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	8/10/12 @3D	
Extensions	5', 7'		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	400	N/A	5.5	2.2	27
2	500	N/A	5	2.7	22
3	800	N/A	6	2.0	30
4	1100	N/A	5	2.7	22
5	1200	N/A	5	2.1	28
6	1400	N/A	5	2.1	28
7	1700	N/A	5	1.9	31
8	1900	N/A	5.5	2.1	29
9	2300	N/A	5	1.8	33
10	1400	N/A	4.5	1.9	31
11	800	650	5	#VALUE!	N/A
12	900	675	5	#VALUE!	N/A
13	1100	750	5.5	#VALUE!	N/A
14	800	650	5.5	#VALUE!	N/A
15	900	675	5	#VALUE!	N/A
16	700	640	5	#VALUE!	N/A
17	800	670	5	#VALUE!	N/A
18	600	600	5	#VALUE!	N/A
19	700	610	4.5	#VALUE!	N/A
20	900	660	5	#VALUE!	N/A

HELICAL ANCHOR INSTALLATION LOG					
Date:	11/15/2013		**Location:**	AF-GT	
Pile Geometry:	SS5		**Lead Section:**	RS2875 8/10/12 @3D	
Extensions	5', 7'		**Plug (in):**	N/A	
Rig Type	Bobcat 435 G-Series		**Torque Indicator**	Chance Digital Indicator	
Hydraulic Head	Eskridge 77BD (Large Head)		**Technicians**	JAE + NVW	
Depth (ft):	*Torque (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
Initial:	*N/A*	200	*N/A*	*N/A*	*N/A*
1	*N/A*	N/A	*N/A*	*N/A*	*N/A*
2	*N/A*	N/A	*N/A*	*N/A*	*N/A*
3	*N/A*	N/A	*N/A*	*N/A*	*N/A*
4	*N/A*	N/A	*N/A*	*N/A*	*N/A*
5	*N/A*	N/A	*N/A*	*N/A*	*N/A*
6	*N/A*	N/A	*N/A*	*N/A*	*N/A*
7	*N/A*	N/A	*N/A*	*N/A*	*N/A*
8	*N/A*	N/A	*N/A*	*N/A*	*N/A*
9	*N/A*	N/A	*N/A*	*N/A*	*N/A*
10	*N/A*	N/A	*N/A*	*N/A*	*N/A*
11	2600	1100	4.5	*N/A*	N/A
12	3300	1450	4.5	*N/A*	N/A
13	3400	1475	4.5	*N/A*	N/A
14	2300	1200	4.5	*N/A*	112
15	2100	1050	4.5	*N/A*	N/A
16	1200	760	4.5	*N/A*	N/A
17	1000	740	4.5	*N/A*	N/A
18	700	650	4.5	*N/A*	N/A
19	900	700	4.5	*N/A*	N/A
20	1100	750	2	*N/A*	251

A-2 LOAD TEST DATA

Pitch Series

Anchor Geometry:	RS2875	Lead Section:	8" w/ 3" Pitch	Installation Torque (ft.-lbs.)	1250
Installation Date:	4/30/2015	Weather:	Sunny, 60s	Water Level (fbgs):	9
Date of Test:	5/2/2015	Site:	DOE	Depth of Installation (ft.):	10
Technician:	MNR	Test #:	1	Days Rest	2
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0030	0.0
2	200	1010	2.5	0.0095	0.1
3	300	1515	2.5	0.0220	0.3
4	400	2020	2.5	0.0465	0.6
5	500	2525	2.5	0.0695	0.9
6	600	3030	2.5	0.0955	1.2
7	800	4040	2.5	0.1505	1.9
8	1000	5050	2.5	0.2160	2.7
9	1200	6060	2.5	0.3060	3.8
10	1400	7070	2.5	0.4230	5.3
11	1600	8080	2.5	0.5640	7.1
12	1800	9090	2.5	0.7515	9.4
13	2000	10100	2.5	1.0220	12.8
14	2200	11110	2.5	1.9335	24.2
Notes: 1. Final displacement at 1.9420 inches, rebounded after 5 minutes to 1.8090 inches.					

Anchor Geometry:	RS2875	Lead Section:	12" w/ 3" Pitch	Installation Torque (ft.-lbs.)	2000
Installation Date:	4/30/2015	Weather:	Sunny, 60s	Water Level (fbgs):	9
Date of Test:	5/2/2015	Site:	AF-GT	Depth of Installation (ft.):	10
Technician:	MNR	Test #:	1	Days Rest	2
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	200	1010	2.5	0.0320	0.3
2	400	2020	2.5	0.0430	0.4
3	600	3030	2.5	0.0570	0.5
4	800	4040	2.5	0.0730	0.6
5	1000	5050	2.5	0.0910	0.8
6	1200	6060	2.5	0.1120	0.9
7	1400	7070	2.5	0.1365	1.1
8	1600	8080	2.5	0.1655	1.4
9	2000	10100	2.5	0.2375	2.0
10	2400	12120	2.5	0.3480	2.9
11	2800	14140	2.5	0.4945	4.1
12	3200	16160	2.5	0.6875	5.7
13	3600	18180	2.5	0.9265	7.7
14	4000	20200	2.5	1.2785	10.7
15	4400	22220	2.5	1.8230	15.2

Notes:
1. Final displacement at 2.5100 inches, rebounded after 5 minutes to 2.0680 inches.
2. Pile failed at 4700 on the digital readout box.

Anchor Geometry:	RS2875	**Lead Section:**	12" w/ 3" Pitch	**Installation Torque (ft-lbs.)**	1000
Installation Date:	5/4/2015	**Weather:**	N/A	**Water Level (fbgs):**	N/A
Date of Test:	5/18/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	20
Technician:	CZ	**Test #:**	1	**Days Rest**	14
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.0170	0.1
2	100	505	2.5	0.0175	0.1
3	150	757.5	2.5	0.0440	0.4
4	200	1010	2.5	0.0850	0.7
5	250	1262.5	2.5	0.1435	1.2
6	300	1515	2.5	0.1830	1.5
7	350	1767.5	2.5	0.2015	1.7
8	400	2020	2.5	0.2175	1.8
9	500	2525	2.5	0.2750	2.3
10	600	3030	2.5	0.3100	2.6
11	700	3535	2.5	0.3385	2.8
12	800	4040	2.5	0.3690	3.1
13	1000	5050	2.5	0.4235	3.5
14	1200	6060	2.5	0.4975	4.1
15	1400	7070	2.5	0.6240	5.2
16	1600	8080	2.5	0.8830	7.4
17	1800	9090	2.5	1.3900	11.6
18	2000	10100	2.5	2.8500	23.8

Notes:
1. Final displacement at 2.8685 inches, rebounded after 5 minutes to 2.4360 inches.

Anchor Geometry:	RS2875	**Lead Section:**	12" w/ 4" Pitch	**Installation Torque (ft.-lbs.)**	2800
Installation Date:	4/30/2015	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	9
Date of Test:	5/2/2015	**Site:**	AF-GT	**Depth of Installation (ft.):**	10
Technician:	MNR	**Test #:**	1	**Days Rest**	2
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	200	1010	2.5	0.0090	0.1
2	400	2020	2.5	0.0315	0.3
3	600	3030	2.5	0.0540	0.5
4	800	4040	2.5	0.0765	0.6
5	1000	5050	2.5	0.0975	0.8
6	1200	6060	2.5	0.1150	1.0
7	1600	8080	2.5	0.1580	1.3
8	2000	10100	2.5	0.2025	1.7
9	2400	12120	2.5	0.2500	2.1
10	2800	14140	2.5	0.3085	2.6
11	3200	16160	2.5	0.3910	3.3
12	3600	18180	2.5	0.4890	4.1
13	4000	20200	2.5	0.6055	5.0
14	4400	22220	2.5	0.7650	6.4
15	4800	24240	2.5	0.9570	8.0
16	5200	26260	2.5	1.2090	10.1
17	5600	28280	2.5	1.6820	14.0
18	6000	30300	2.5	2.7835	23.2

Notes:
1. Final displacement at 2.8245 inches, rebounded after 5 minutes to 2.5590 inches.

Anchor Geometry:	RS2875	**Lead Section:**	12" w/ 4" Pitch	**Installation Torque (ft-lbs.)**	1533
Installation Date:	5/4/2015	**Weather:**	N/A	**Water Level (fbgs):**	N/A
Date of Test:	5/18/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	20
Technician:	CZ	**Test #:**	1	**Days Rest**	14
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.0155	0.0
2	100	505	2.5	0.0330	0.1
3	150	757.5	2.5	0.0550	0.1
4	200	1010	2.5	0.0720	0.1
5	250	1262.5	2.5	0.0855	0.2
6	300	1515	2.5	0.0935	0.2
7	350	1767.5	2.5	0.0995	0.3
8	400	2020	2.5	0.1085	0.4
9	500	2525	2.5	0.1360	0.6
10	600	3030	2.5	0.1615	0.8
11	700	3535	2.5	0.1880	1.0
12	800	4040	2.5	0.2190	1.3
13	900	4545	2.5	0.2620	1.6
14	1000	5050	2.5	0.3515	2.2
15	1200	6060	2.5	0.4650	3.3
16	1400	7070	2.5	0.6515	4.9
17	1600	8080	2.5	1.0270	8.0
18	1700	8585	2.5	1.5915	12.7
19	1800	9090	2.5	2.0765	16.8
20	1900	9595	2.5	2.8220	23.0

Notes:
1. Final displacement at 2.8330 inches, rebounded after 5 minutes to 2.4330 inches.

Anchor Geometry:	RS2875	Lead Section:	12" w/ 6" Pitch	Installation Torque (ft.-lbs.)	3600
Installation Date:	4/30/2015	Weather:	Sunny, 60s	Water Level (fbgs):	9
Date of Test:	5/2/2015	Site:	AF-GT	Depth of Installation (ft.):	10
Technician:	MNR	Test #:	1	Days Rest	2
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	400	2020	2.5	0.0295	0.1
2	800	4040	2.5	0.0465	0.3
3	1200	6060	2.5	0.0755	0.5
4	1600	8080	2.5	0.1160	0.9
5	2000	10100	2.5	0.1770	1.4
6	2400	12120	2.5	0.2585	2.0
7	2800	14140	2.5	0.3765	3.0
8	3200	16160	2.5	0.5465	4.4
9	3600	18180	2.5	0.7835	6.4
10	4000	20200	2.5	1.0930	9.0
11	4400	22220	2.5	1.6520	13.7

Notes:
1. Final displacement at 2.3455 inches, rebounded after 5 minutes to 2.0425 inches.
2. Adapter was hitting I-Beam, slipped off at 5200, load relaxed to about 4200 on readout box. Re-Zeroed and reloaded to 4400, Failure at 4800.

Anchor Geometry:	RS2875	Lead Section:	12" w/ 6" Pitch	Installation Torque (ft-lbs.)	1667
Installation Date:	5/4/2015	Weather:	N/A	Water Level (fbgs):	N/A
Date of Test:	5/18/2015	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	CZ	Test #:	1	Days Rest	14
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0020	0.0
2	100	505	2.5	0.0020	0.0
3	150	757.5	2.5	0.0040	0.0
4	200	1010	2.5	0.0115	0.1
5	250	1262.5	2.5	0.0235	0.2
6	300	1515	2.5	0.0375	0.3
7	350	1767.5	2.5	0.0635	0.5
8	400	2020	2.5	0.1030	0.9
9	500	2525	2.5	0.1425	1.2
10	600	3030	2.5	0.1865	1.6
11	700	3535	2.5	0.2135	1.8
12	800	4040	2.5	0.2375	2.0
13	900	4545	2.5	0.2650	2.2
14	1000	5050	2.5	0.2965	2.5
15	1200	6060	2.5	0.3910	3.3
16	1400	7070	2.5	0.6535	5.4
17	1600	8080	2.5	1.1850	9.9
18	1700	8585	2.5	1.3605	11.3
19	1800	9090	2.5	2.3395	19.5
20	1900	9595	2.5	3.0935	25.8

Notes:
1. Final displacement at 3.0935 inches, rebounded after 5 minutes to 2.6915 inches.

Anchor Geometry:	RS2875	Lead Section:	18" w/ 3" Pitch	Installation Torque (ft-lbs.)	2900
Installation Date:	4/30/2015	Weather:	Sunny, 60s	Water Level (fbgs):	9
Date of Test:	5/2/2015	Site:	AF-GT	Depth of Installation (ft):	10
Technician:	MNR	Test #:	1	Days Rest	2
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	400	2020	2.5	0.0330	0.2
2	800	4040	2.5	0.0675	0.4
3	1200	6060	2.5	0.1260	0.7
4	1600	8080	2.5	0.1960	1.1
5	2000	10100	2.5	0.2805	1.6
6	2400	12120	2.5	0.3845	2.1
7	2800	14140	2.5	0.5070	2.8
8	3200	16160	2.5	0.6390	3.6
9	3600	18180	2.5	0.7895	4.4
10	4000	20200	2.5	0.9535	5.3
11	4400	22220	2.5	1.1435	6.4
12	4800	24240	2.5	1.3685	7.6
13	5200	26260	2.5	1.5960	8.9
14	5600	28280	2.5	1.8230	10.1

Notes:

1. Final displacement at 1.8230 inches, rebounded after 5 minutes to 1.1245 inches.

Anchor Geometry:	RS2875	**Lead Section:**	18" w/ 6" Pitch	**Installation Torque (ft-lbs.)**	4033
Installation Date:	4/30/2015	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	9
Date of Test:	5/2/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	10
Technician:	MNR	**Test #:**	1	**Days Rest**	2
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	400	2020	2.5	0.0740	0.4
2	800	4040	2.5	0.1440	0.8
3	1200	6060	2.5	0.2155	1.2
4	1600	8080	2.5	0.2855	1.6
5	2000	10100	2.5	0.3595	2.0
6	2400	12120	2.5	0.4555	2.5
7	2800	14140	2.5	0.5665	3.1
8	3200	16160	2.5	0.7045	3.9
9	3600	18180	2.5	0.8740	4.9
10	4000	20200	2.5	1.0670	5.9
11	4400	22220	2.5	1.2910	7.2
12	4800	24240	2.5	1.5705	8.7
13	5200	26260	2.5	1.8790	10.4
14	5600	28280	2.5	2.2615	12.6
15	6000	30300	2.5	2.8080	15.6

Notes:
1. Final displacement at 2.8110 inches, rebounded after 5 minutes to 2.2150 inches.

Anchor Geometry:	RS2875	**Lead Section:**	18" w/ 6" Pitch	**Installation Torque (ft-lbs.)**	1700
Installation Date:	5/4/2015	**Weather:**	N/A	**Water Level (fbgs):**	N/A
Date of Test:	5/18/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	20
Technician:	CZ	**Test #:**	1	**Days Rest**	14
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	100	505	2.5	0.2180	0.1
2	200	1010	2.5	0.4285	0.3
3	300	1515	2.5	0.5835	0.6
4	400	2020	2.5	0.6885	0.9
5	600	3030	2.5	0.8310	1.4
6	800	4040	2.5	0.9445	2.0
7	1000	5050	2.5	1.0435	2.6
8	1200	6060	2.5	1.1330	3.1
9	1400	7070	2.5	1.2235	3.6
10	1600	8080	2.5	1.3090	4.0
11	1800	9090	2.5	1.3945	4.5
12	2000	10100	2.5	1.4845	5.0
13	2200	11110	2.5	1.5735	5.5
14	2400	12120	2.5	1.6670	6.0
15	2600	13130	2.5	1.7735	6.6
16	2800	14140	2.5	1.8845	7.2
17	3000	15150	2.5	1.9800	7.8
18	3200	16160	2.5	2.0800	8.3
19	3400	17170	2.5	2.1760	8.9
20	3700	18685	2.5	2.3110	9.6
21	4000	20200	2.5	2.4545	10.4
22	4300	21715	2.5	2.5895	11.2
23	4600	23230	2.5	2.7190	11.9
24	4900	24745	2.5	2.8685	12.7

Notes:
1. Final displacement at 2.8110 inches, rebounded after 5 minutes to 2.2150 inches.

Other Load Tests

Anchor Geometry:	SS5	Lead Section:	12	Installation Torque (ft-lbs.)	600
Installation Date:	7/2/2013	Weather:	Cloudy, 60s	Water Level (fbgs):	
Date of Test:	9/16/2014	Site:	AF-GT	Depth of Installation (ft):	SS5-12" 20'
Technician:	MNR	Test #:	2	Days Rest	440
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.2030	1.7
2	100	505	2.5	0.2790	2.3
3	150	757.5	2.5	0.3015	2.5
4	200	1010	2.5	0.3240	2.7
5	250	1262.5	2.5	0.3380	2.8
6	300	1515	2.5	0.3555	3.0
7	350	1767.5	2.5	0.3800	3.2
8	400	2020	2.5	0.4015	3.3
9	500	2525	2.5	0.4675	3.9
10	600	3030	2.5	0.5330	4.4
11	700	3535	2.5	0.6105	5.1
12	800	4040	2.5	0.7015	5.8
13	900	4545	2.5	0.7900	6.6
14	1000	5050	2.5	0.9235	7.7
15	1100	5555	2.5	1.0570	8.8
16	1200	6060	2.5	1.1890	9.9
17	1300	6565	2.5	1.4035	11.7
18	1400	7070	2.5	1.5895	13.2
19	1500	7575	2.5	1.7375	14.5
20	1600	8080	2.5	1.8505	15.4
21	1700	8585	2.5	2.0410	17.0
22	1800	9090	2.5	2.7265	22.7

Notes:
1. Final displacement at 2.8130 inches, rebounded after 5 minutes to 2.3280 inches.
2. Continuous pumping occurred at a digital reading of 1200 or approximately 6060 pounds.
3. Heard two separate popping sounds during constant load of 9090 pounds. Displacement jumped ~.2" each time.
4. The pile seemed loose at the top. Had a decent amount of horizontal play, ~2" of give.

Anchor Geometry:	SS5	**Lead Section:**	12	**Installation Torque (ft-lbs.)**	666
Installation Date:	7/2/2013	**Weather:**	Sunny, 60s no wind	**Water Level (fbgs):**	
Date of Test:	7/3/2013	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5-12" 20'
Technician:	J.L	**Test #:**	1	**Days Rest**	1
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.0070	0.1
2	100	505	2.5	0.1380	1.2
3	150	757.5	2.5	0.1690	1.4
4	200	1010	2.5	0.1990	1.7
5	250	1262.5	2.5	0.2240	1.9
6	300	1515	2.5	0.2500	2.1
7	350	1767.5	2.5	0.2660	2.2
8	400	2020	2.5	0.2855	2.4
9	500	2525	2.5	0.3200	2.7
10	600	3030	2.5	0.3695	3.1
11	700	3535	2.5	0.4500	3.8
12	800	4040	2.5	0.5780	4.8
13	900	4545	2.5	0.7630	6.4
14	1000	5050	2.5	1.0200	8.5
15	1100	5555	2.5	1.3230	11.0
16	1200	6060	2.5	1.6910	14.1
17	1300	6565	2.5	2.1415	17.8
18	1400	7070	2.5	2.7810	23.2

Anchor Geometry:	SS5	Lead Section:	12	Pile Code:	#2
Installation Date:	7/2/2013	Weather:	Sunny, slightly windy	Water Level (fbgs):	
Date of Test:	9/12/2014	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	MNR	Test #:	2	Days Rest	437
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	75	378.75	2.5	0.0225	0.2
2	100	505	2.5	0.0250	0.2
3	150	757.5	2.5	0.0270	0.2
4	200	1010	2.5	0.0345	0.3
5	250	1262.5	2.5	0.0430	0.4
6	300	1515	2.5	0.0640	0.5
7	350	1767.5	2.5	0.0950	0.8
8	400	2020	2.5	0.1315	1.1
9	500	2525	2.5	0.2070	1.7
10	600	3030	2.5	0.2955	2.5
11	700	3535	2.5	0.3825	3.2
12	800	4040	2.5	0.4750	4.0
13	900	4545	2.5	0.5890	4.9
14	1000	5050	2.5	0.7035	5.9
15	1100	5555	2.5	0.8295	6.9
16	1200	6060	2.5	0.9870	8.2
17	1300	6565	2.5	1.1620	9.7
18	1400	7070	2.5	1.3565	11.3
19	1500	7575	2.5	1.6015	13.3
20	1600	8080	2.5	1.8670	15.6
21	1700	8585	2.5	2.1880	18.2
22	1800	9090	2.5	2.5295	21.1
23	1900	9595	2.5	2.9525	24.6

Notes:
1. Final displacement at 3.5180 inches, rebounded after 5 minutes to 2.9795 inches.
2. Continuous pumping occurred at a digital reading of 1200 or approximately 6060 pounds.

Anchor Geometry:	SS5	Lead Section:	12	Pile Code:	#2
Installation Date:	7/2/2013	Weather:	Sunny, slightly windy	Water Level (fbgs):	
Date of Test:	5/7/2014	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	HZ	Test #:	1	Days Rest	309
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0185	0.2
2	100	505	2.5	0.0380	0.3
3	150	757.5	2.5	0.0575	0.5
4	200	1010	2.5	0.0775	0.6
5	250	1262.5	2.5	0.0985	0.8
6	300	1515	2.5	0.1170	1.0
7	350	1767.5	2.5	0.1380	1.2
8	400	2020	2.5	0.1580	1.3
9	450	2272.5	2.5	0.1760	1.5
10	500	2525	2.5	0.1935	1.6
11	550	2777.5	2.5	0.2130	1.8
12	600	3030	2.5	0.2335	1.9
13	650	3282.5	2.5	0.2615	2.2
14	700	3535	2.5	0.2910	2.4
15	800	4040	2.5	0.3540	3.0
16	900	4545	2.5	0.4530	3.8
17	1000	5050	2.5	0.5935	4.9
18	1100	5555	2.5	0.8040	6.7
19	1200	6060	2.5	1.0445	8.7
20	1300	6565	2.5	1.3995	11.7
21	1400	7070	2.5	1.8540	15.5
22	1500	7575	2.5	2.4950	20.8
23	1600	8080	2.5	3.2250	26.9

Notes:
1. Final displacement at 3.3720 inches, rebounded after 5 minutes to 2.5540 inches.

Anchor Geometry:	SS5	Lead Section:	12	Pile Code:	#5
Installation Date:	7/2/2013	Weather:	Sunny, slightly windy	Water Level (fbgs):	N/A
Date of Test:	9/12/2014	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	MNR	Test #:	1	Days Rest	437
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0090	0.1
2	100	505	2.5	0.0190	0.2
3	150	757.5	2.5	0.0300	0.3
4	200	1010	2.5	0.0425	0.4
5	250	1262.5	2.5	0.0600	0.5
6	300	1515	2.5	0.0800	0.7
7	350	1767.5	2.5	0.1050	0.9
8	400	2020	2.5	0.1340	1.1
9	500	2525	2.5	0.1680	1.4
10	600	3030	2.5	0.2075	1.7
11	700	3535	2.5	0.2545	2.1
12	800	4040	2.5	0.3155	2.6
13	900	4545	2.5	0.4170	3.5
14	1000	5050	2.5	0.5775	4.8
15	1100	5555	2.5	0.8130	6.8
16	1200	6060	2.5	1.0900	9.1
17	1300	6565	2.5	2.1095	17.6
18	1400	7070	2.5	2.5080	20.9
19	1500	7575	2.5	2.9400	24.5
20	1600	8080	2.5	3.4035	28.4

Notes:

1. Final displacement at 3.8190 inches, rebounded after 5 minutes to 3.1730 inches.
2. Slipping occurred at three points. Slipping was characterized by a noticeable "popping" sound followed by a drop in the digital reading. It dropped from 200 to 175, from 300 to 200, and 500 to 350.
3. Continuous pumping occurred starting at a digital reading of around 900, meaning the jack had to be continuously pumped to maintain constant loading.

Anchor Geometry:	SS5	**Lead Section:**	12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	7/2/2013	**Weather:**	Cloudy, 60s	**Water Level (fbgs):**	
Date of Test:	9/16/2014	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5-12" 20'
Technician:	MNR	**Test #:**	2	**Days Rest**	441
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.2665	2.2
2	100	505	2.5	0.4400	3.7
3	150	757.5	2.5	0.5180	4.3
4	200	1010	2.5	0.5255	4.4
5	250	1262.5	2.5	0.5470	4.6
6	300	1515	2.5	0.5700	4.8
7	350	1767.5	2.5	0.6050	5.0
8	400	2020	2.5	0.6370	5.3
9	500	2525	2.5	0.7020	5.9
10	600	3030	2.5	0.7855	6.5
11	700	3535	2.5	0.8850	7.4
12	800	4040	2.5	0.9735	8.1
13	900	4545	2.5	1.0630	8.9
14	1000	5050	2.5	1.2120	10.1
15	1100	5555	2.5	1.3370	11.1
16	1200	6060	2.5	1.4630	12.2
17	1300	6565	2.5	1.6780	14.0
18	1400	7070	2.5	1.8330	15.3
19	1500	7575	2.5	1.9925	16.6
20	1600	8080	2.5	2.2405	18.7
21	1700	8585	2.5	2.4225	20.2
22	1800	9090	2.5	2.7265	22.7
23	1900	9595	2.5	2.9525	24.6

Notes:
1. Final displacement at 2.9565 inches, rebounded after 5 minutes to 2.4220 inches.
2. Continuous pumping occurred at a digital reading of 1200 or approximately 6060 pounds.

Anchor Geometry:	SS5	**Lead Section:**	12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	7/2/2013	**Weather:**	Cloudy, 60s	**Water Level (fbgs):**	
Date of Test:	7/2/2013	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5-12" 20'
Technician:	HZ	**Test #:**	1	**Days Rest**	0.1
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.2850	2.4
2	100	505	2.5	0.3015	2.5
3	150	757.5	2.5	0.3270	2.7
4	200	1010	2.5	0.3525	2.9
5	250	1262.5	2.5	0.3720	3.1
6	300	1515	2.5	0.3915	3.3
7	350	1767.5	2.5	0.4150	3.5
8	400	2020	2.5	0.4400	3.7
9	500	2525	2.5	0.4740	4.0
10	600	3030	2.5	0.5115	4.3
11	700	3535	2.5	0.5630	4.7
12	800	4040	2.5	0.6580	5.5
13	900	4545	2.5	0.8450	7.0
14	1000	5050	2.5	1.1065	9.2
15	1100	5555	2.5	1.5005	12.5
16	1200	6060	2.5	2.0605	17.2
17	1300	6565	2.5	2.6210	21.8
18	1400	7070	2.5	3.2095	26.7

Notes:

1. Final displacement at 3.1985 inches, rebounded after 5 minutes to 2.2240 inches.

Anchor Geometry:	SS5	**Lead Section:**	12	**Installation Torque (ft-lbs.)**	733
Installation Date:	7/2/2013	**Weather:**	Sunny, 60s no wind	**Water Level (fbgs):**	
Date of Test:	9/15/2014	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5-12" 20'
Technician:	MNR	**Test #:**	2	**Days Rest**	430
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.0300	0.3
2	100	505	2.5	0.0610	0.5
3	150	757.5	2.5	0.0925	0.8
4	200	1010	2.5	0.1250	1.0
5	250	1262.5	2.5	0.1595	1.3
6	300	1515	2.5	0.1930	1.6
7	350	1767.5	2.5	0.2295	1.9
8	400	2020	2.5	0.2860	2.4
9	500	2525	2.5	0.3655	3.0
10	600	3030	2.5	0.4590	3.8
11	700	3535	2.5	0.5650	4.7
12	800	4040	2.5	0.7135	5.9
13	900	4545	2.5	0.8970	7.5
14	1000	5050	2.5	1.1295	9.4
15	1100	5555	2.5	1.4105	11.8
16	1200	6060	2.5	1.7705	14.8
17	1300	6565	2.5	2.2835	19.0
18	1400	7070	2.5	2.8610	23.8

Notes:
1. Final displacement at 3.4735 inches, rebounded after 5 minutes to 2.9345 inches.
2. Continuous pumping occurred at a digital reading of 800 or approximately 4040 pounds.

Anchor Geometry:	SS5	Lead Section:	12	Installation Torque (ft-lbs.)	733
Installation Date:	7/2/2013	Weather:	Sunny, 60s no wind	Water Level (fbgs):	
Date of Test:	7/12/2013	Site:	AF-GT	Depth of Installation (ft):	SS5-12" 20'
Technician:	J.L	Test #:	1	Days Rest	10
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0380	0.3
2	100	505	2.5	0.0590	0.5
3	150	757.5	2.5	0.0830	0.7
4	200	1010	2.5	0.1265	1.1
5	250	1262.5	2.5	0.1470	1.2
6	300	1515	2.5	0.1690	1.4
7	350	1767.5	2.5	0.1925	1.6
8	400	2020	2.5	0.2180	1.8
9	500	2525	2.5	0.2755	2.3
10	600	3030	2.5	0.3975	3.3
11	700	3535	2.5	0.7020	5.9
12	750	3787.5	2.5	1.0105	8.4
13	800	4040	2.5	1.3265	11.1
14	850	4292.5	2.5	1.6200	13.5
15	900	4545	2.5	1.9295	16.1
16	950	4797.5	2.5	2.2665	18.9
17	1000	5050	2.5	2.5805	21.5

Anchor Geometry:	SS5	Lead Section:	12	Pile Code:	#6
Installation Date:	7/2/2013	Weather:	Sunny, 60s no wind	Water Level (fbgs):	
Date of Test:	9/15/2014	Site:	AF-GT	Depth of Installation (ft):	SS5-12" 20'
Technician:	MNR	Test #:	RT	Days Rest	404
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0275	0.2
2	100	505	2.5	0.0575	0.5
3	150	757.5	2.5	0.0900	0.8
4	200	1010	2.5	0.1265	1.1
5	250	1262.5	2.5	0.1520	1.3
6	300	1515	2.5	0.1820	1.5
7	350	1767.5	2.5	0.2175	1.8
8	400	2020	2.5	0.2500	2.1
9	500	2525	2.5	0.3135	2.6
10	600	3030	2.5	0.3850	3.2
11	700	3535	2.5	0.4690	3.9
12	800	4040	2.5	0.5500	4.6
13	900	4545	2.5	0.6630	5.5
14	1000	5050	2.5	0.7845	6.5
15	1100	5555	2.5	0.9265	7.7
16	1200	6060	2.5	1.1645	9.7
17	1300	6565	2.5	1.4110	11.8
18	1400	7070	2.5	1.7155	14.3
19	1500	7575	2.5	2.0750	17.3
20	1600	8080	2.5	2.5205	21.0

Notes:
1. Final displacement at 3.0890 inches, rebounded after 5 minutes to 2.1345 inches.

2. Continuous pumping occurred at a digital reading of 1400 or approximately 7070 pounds.

Anchor Geometry:	SS5	Lead Section:	12	Pile Code:	#6
Installation Date:	7/2/2013	Weather:	Sunny, 60s no wind	Water Level (fbgs):	
Date of Test:	8/3/2013	Site:	AF-GT	Depth of Installation (ft):	SS5-12" 20'
Technician:	J.L	Test #:	1	Days Rest	30
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0265	0.2
2	100	505	2.5	0.0685	0.6
3	150	757.5	2.5	0.0880	0.7
4	200	1010	2.5	0.1135	1.0
5	250	1262.5	2.5	0.1315	1.1
6	300	1515	2.5	0.1520	1.3
7	350	1767.5	2.5	0.1680	1.4
8	400	2020	2.5	0.1835	1.5
9	450	2272.5	2.5	0.2010	1.7
10	500	2525	2.5	0.2210	1.8
11	550	2777.5	2.5	0.2455	2.1
12	600	3030	2.5	0.2735	2.3
13	650	3282.5	2.5	0.3145	2.6
14	700	3535	2.5	0.3430	2.9
15	750	3787.5	2.5	0.4115	3.4
16	800	4040	2.5	0.5065	4.2
17	900	4545	2.5	0.7320	6.1
18	1000	5050	2.5	1.0205	8.5
19	1100	5555	2.5	1.4480	12.1
20	1200	6060	2.5	1.9740	16.5
21	1250	6312.5	2.5	2.4370	20.3

Anchor Geometry:	Combo RS2875 + SS5	**Lead Section:**	8/10/12	**Pile Code:**	
Installation Date:	11/15/2013	**Weather:**	Sunny, 50s	**Water Level (fbgs):**	
Date of Test:	11/9/2014	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5 RS2875 8/10/12 Combo @20'
Technician:	MNR	**Test #:**	1	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	100	505	2.5	0.0540	0.5
2	200	1010	2.5	0.0890	0.9
3	300	1515	2.5	0.1310	1.3
4	400	2020	2.5	0.1695	1.7
5	600	3030	2.5	0.2665	2.7
6	800	4040	2.5	0.3655	3.7
7	1000	5050	2.5	0.4275	4.3
8	1200	6060	2.5	0.4855	4.9
9	1400	7070	2.5	0.5590	5.6
10	1600	8080	2.5	0.6605	6.6
11	1800	9090	2.5	0.8015	8.0
12	2000	10100	2.5	1.0220	10.2
13	2400	12120	2.5	1.9070	19.1
14	2600	13130	2.5	3.0950	31.0

Notes:
1. Final displacement at 3.0950 inches, rebounded after 5 minutes to 2.6310 inches.
2. Continuous pumping occurred at a digital reading of 2600 or 13130 pounds. Failed at 2600 on read out box, could not sustain this load for the full 2.5 minutes.

Anchor Geometry:	Combo RS2875 + SS5	**Lead Section:**	8/10/12	**Pile Code:**	
Installation Date:	11/15/2013	**Weather:**	Sunny and Windy, 70s	**Water Level (fbgs):**	9.4
Date of Test:	4/13/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	SS5 RS2875 8/10/12 Combo @20'
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	100	505	2.5	0.1255	1.3
2	200	1010	2.5	0.1415	1.4
3	300	1515	2.5	0.1580	1.6
4	400	2020	2.5	0.1795	1.8
5	600	3030	2.5	0.2325	2.3
6	800	4040	2.5	0.3080	3.1
7	1000	5050	2.5	0.4005	4.0
8	1200	6060	2.5	0.5275	5.3
9	1400	7070	2.5	0.6775	6.8
10	1600	8080	2.5	0.8965	9.0
11	1800	9090	2.5	1.1685	11.7
12	2000	10100	2.5	1.5995	16.0
13	2200	11110	2.5	2.2355	22.4
14	2400	12120	2.5	3.1395	31.4

Notes:

1. Final displacement at 3.0950 inches, rebounded after 5 minutes to 2.6310 inches.
2. Continuous pumping occurred at a digital reading of 2600 or 13130 pounds. Failed at 2600 on read out box, could not sustain this load for the full 2.5 minutes.

Anchor Geometry:	SS5	Lead Section:	8/10/12	Installation Torque (ft-lbs.)	733
Installation Date:	11/15/2013	Weather:	Sunny, 50s	Water Level (fbgs):	N/A
Date of Test:	11/9/2014	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	MNR	Test #:	1	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0185	0.19
2	100	505	2.5	0.0435	0.44
3	200	1010	2.5	0.0710	0.71
4	300	1515	2.5	0.0995	1.00
5	400	2020	2.5	0.1220	1.22
6	500	2525	2.5	0.1435	1.44
7	600	3030	2.5	0.1675	1.68
8	700	3535	2.5	0.1975	1.98
9	800	4040	2.5	0.2335	2.34
10	900	4545	2.5	0.2790	2.79
11	1000	5050	2.5	0.3420	3.42
12	1200	6060	2.5	0.4990	4.99
13	1400	7070	2.5	0.8200	8.20
14	1600	8080	2.5	1.4275	14.28
15	1800	9090	2.5	2.8980	28.98
Notes:					

1. Final displacement at 3.2415 inches, rebounded after 5 minutes to 2.5510 inches.

Anchor Geometry:	SS5	**Lead Section:**	8/10/12	**Installation Torque (ft-lbs.)**	733
Installation Date:	11/15/2013	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	9.4
Date of Test:	4/13/2015	**Site:**	AF-GT	**Depth of Installation (ft):**	20
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	133	671.65	2.5	0.0015	0.0
2	200	1010	2.5	0.0090	0.1
3	300	1515	2.5	0.0265	0.3
4	400	2020	2.5	0.0575	0.6
5	600	3030	2.5	0.1395	1.4
6	800	4040	2.5	0.2530	2.5
7	1000	5050	2.5	0.3870	3.9
8	1200	6060	2.5	0.5445	5.4
9	1400	7070	2.5	0.7665	7.7
10	1600	8080	2.5	1.1155	11.2
11	1800	9090	2.5	1.5925	15.9
12	2000	10100	2.5	2.4055	24.1

Notes:
1. Final displacement at 2.6835 inches, rebounded after 5 minutes to 2.0190 inches.

Anchor Geometry:	RS2875	Lead Section:	8/10/12	Installation Torque (ft-lbs.)	900
Installation Date:	11/15/2013	Weather:	Sunny, 50s	Water Level (fbgs):	N/A
Date of Test:	11/9/2014	Site:	AF-GT	Depth of Installation (ft):	RS2875 8/10/12 @20'
Technician:	MNR	Test #:	1	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0465	0.5
2	200	1010	2.5	0.0800	0.8
3	300	1515	2.5	0.1180	1.2
4	400	2020	2.5	0.1505	1.5
5	600	3030	2.5	0.2385	2.4
6	800	4040	2.5	0.3180	3.2
7	1000	5050	2.5	0.3650	3.7
8	1200	6060	2.5	0.4585	4.6
9	1400	7070	2.5	0.5375	5.4
10	1600	8080	2.5	0.6585	6.6
11	1800	9090	2.5	0.8475	8.5
12	2000	10100	2.5	1.1785	11.8
13	2400	12120	2.5	2.2865	22.9
Notes:					

1. Final displacement at 3.2415 inches, rebounded after 5 minutes to 2.5510 inches.

Anchor Geometry:	RS2875	Lead Section:	8/10/12	Installation Torque (ft-lbs.)	900
Installation Date:	11/15/2013	Weather:	Sunny, 50s	Water Level (fbgs):	9.4
Date of Test:	4/13/2015	Site:	AF-GT	Depth of Installation (ft):	20
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0690	0.7
2	200	1010	2.5	0.0830	0.8
3	300	1515	2.5	0.0985	1.0
4	400	2020	2.5	0.1220	1.2
5	600	3030	2.5	0.1755	1.8
6	800	4040	2.5	0.2490	2.5
7	1000	5050	2.5	0.3445	3.4
8	1200	6060	2.5	0.4545	4.5
9	1400	7070	2.5	0.5755	5.8
10	1600	8080	2.5	0.7180	7.2
11	1800	9090	2.5	0.8955	9.0
12	2000	10100	2.5	1.1420	11.4
13	2200	11110	2.5	1.4780	14.8

14	2400	12120	2.5	1.9485	19.5
15	2600	13130	2.5	2.7600	27.6

Notes:
1. Final displacement at 2.6850 inches, rebounded after 5 minutes to 2.1925 inches.

A-3 SUMMARY TABLE OF LOAD TESTS

Geometry	Depth (ft)	Q_{ult} (lbs.)	Installation Torque (ft-lbs)	K_t (ft^{-1})
Aged Tests and Repeats on Single-Helix				
SS5-12 #1	20	5500	667	9.2
SS5-12 #1	20RT	6700	667	11.2
SS5-12 #2	20	6650	533	12.5
SS5-12 #2	20RT	6300	533	11.8
SS5-12 #3	20	6125	533	11.5
SS5-12 #4	20	5550	667	8.3
SS5-12 #4	20RT	6250	667	9.4
SS5-12 #5	20	3950	733	5.4
SS5-12 #5	20RT	5200	733	7.1
SS5-12 #6	20	5300	767	6.9
SS5-12 #6	20RT	6150	767	8.0
1st Time Tests				
SS5-8/10/12 3D	10	17500	1867	9.4
SS5-8/10/12 3D	20	7450	733	10.2
SS5-8/10/12 3D	20RT	7800	733	10.6
RS2875-8/10/12 3D	10	29000	N/A	-
RS2875-8/10/12 3D	20	10000	900	11.1

RS2875-8/10/12 3D	20RT	9800	900	10.9
RS2875-8/10/12 3D	30	12100	-	-
Combo-8/10/12 3D	10	29500	3033	9.7
Combo-8/10/12 3D	20	9600	800	12.0
Combo-8/10/12 3D	20RT	8950	800	11.2
Pitch Series				
RS2875-8" w/ 3" Pitch	10	9300	1250	7.4
RS2875-12" w/ 3" Pitch	10	19000	2000	9.5
RS2875-12" w/ 3" Pitch	20	8950	1000	9.0
RS2875-12" w/ 4" Pitch	10	26200	2800	9.4
RS2875-12" w/ 4" Pitch	20	8300	1533	5.4
RS2875-12" w/ 6" Pitch	10	20600	3600	5.7
RS2875-12" w/ 6" Pitch	20	8100	1667	4.9
RS2875-18" w/ 3" Pitch	10	28100	2600	10.8
RS2875-18" w/ 6" Pitch	10	25750	3650	7.1
RS2875-18" w/ 6" Pitch	20	19400	1700	11.4
Time Series				
SS5-12 #1	20	5500	666	9.2
SS5-12 #2	20	6650	533	12.5
SS5-12 #3	20	6125	533	11.5
SS5-12 #4	20	5550	667	8.3
SS5-12 #5	20	3950	733	5.4
SS5-12 #6	20	5300	767	6.9

A-4 FIELD TESTS

Boring No.: B-1	Project: AgFarm Solar Site		Casing:	Sampler:
Boring Company: Seaboard	Location: UMass Agronomy Farm	Type:	H.S.A.	SS (2 in. O.D. with plastic catcher)
Date Started: 8 June 2012	South Deerfield, MA	I.D.:	4.25 in.	1.38 in.
Date Completed: 8 June 2012		Hammer Wt.:	NA	140 lbs.
		Hammer Fall:	NA	30 in.
		Rig Type:	Mobile Drill B-53	
		Hammer/Rod Type:Safety with cable pulley - AWJ		

Depth (ft)	Sample Information									Sample Description	Peak τ (ft-lbs)	Residual τ (ft-lbs)
	Number	Type	Pen. (inches)	Rec. (inches)	Depth (ft)	Blows/6 Inch Interval 0 - 6	6 - 12	12 - 18	w (%)			
	S1	SS	18	16	1 - 2.5	10	11	10	22.5	Light brown dry very stiff silt	65	65
	S2	SS	18	17	3.5 - 5	4	4	4	17.4	Light brown dry medium stiff silt	25	25
5												
	S3	SS	18	17.5	6.5 - 8	5	4	6	14.7	Medium brown damp silty sand	50	40
10	S4	SS	18	18.5	9 - 10.5	4	5	8	26.8	Dark brown moist stiff silt with trace fine sand	35	35
15												
	S5	SS	18	16	15 - 16.5	3	6	11	6.5	Light brown damp medium dense uniform fine sand	60	60
20												
	S6	SS	18	18	20 - 21.5	4	7	8	19.3	Dark brown wet medium dense well graded medium sand	55	50
25												
	S7	SS	18	8 (Clay) 13 (Sand)	25 - 26.5	7	6	7	43.3 (Clay) 21.4 (Sand)	Dark gray wet medium stiff clay (Clay) Dark brown wet medium dense well graded sand (Sand)	160	160
30												

Boring No.: B-4	Project: AgFarm Solar Site		Casing:	Sampler:
Boring Company: Seaboard	Location: UMass Agronomy Farm	Type:	H.S.A.	SS (3 in. O.D. with plastic catcher)
Date Started: 8 June 2012	South Deerfield, MA	I.D.:	4.25 in.	2.38 in.
Date Completed: 8 June 2012		Hammer Wt.:	NA	140 lbs.
		Hammer Fall:	NA	30 in.
		Rig Type:	Mobile Drill B-53	
		Hammer/Rod Type: Safety with cable pulley - AWJ		

Depth (ft)	Sample Information											
	Number	Type	Pen. (inches)	Rec. (inches)	Depth (ft)	Blows/6 Inch Interval			w (%)	Sample Description	Peak *T* (ft-lbs)	Residual *T* (ft-lbs)
						0 - 6	6 - 12	12 - 18				
	S1	SS	18	17	1 - 2.5	15	14	13	22.6	Light brown dry very stiff silt	80	80
	S2	SS	18	12.5 (Silt) 9 (Sand)	3.5 - 5	6	10	8	13.1 (Silt) 3.3 (Sand)	Dark brown dry silt (Silt) Dark brown damp uniform medium dense sand (Sand)	55	55
5												
	S3	SS	18	19	6.5 - 8	7	7	7	18.5	Light to medium brown damp fine-sandy silt	60	60
10	S4	SS	18	20	9 - 10.5	10	10	11	16.1	Dark brown moist stiff silt with trace fine sand	60	60
15												
	S5	SS	18	19	15 - 16.5	7	8	10	5.4	Brown damp medium dense uniform fine sand	55	55
20												
	S6	SS	18	14	20 - 21.5	4	8	12	23.3	Dark brown wet medium dense well graded medium sand	60	60
25												
	S7	SS	18	14.5	25 - 26.5	9	18	17	13.3	Brown moist dense well graded sand	145	120
30												

APPENDIX B: DEPARTMENT OF ENERGY (DOE)

B-1 INSTALLATION LOGS

Trial Installations

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	3-7'		**Trial #**	1		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	N/A	0	N/A	5	2.73	22
2	N/A	600	N/A	4.5	3.00	20
3	N/A	700	N/A	5	2.61	23
4	N/A	1400	N/A	4.5	2.40	25
5	N/A	1600	N/A	4	2.31	26
6	N/A	2000	N/A	4	2.22	27
7	N/A	2100	N/A	4.5	2.50	24
8	N/A	1900	N/A	4.5	2.31	26
9	N/A	2000	N/A	4.5	2.40	25
10	N/A	1700	N/A	4.5	2.40	25
11	N/A	1500	N/A	4.25	2.31	26
12	N/A	1100	N/A	4.25	2.40	25
13	N/A	900	N/A	4.5	2.50	24
14	N/A	700	N/A	4.5	2.31	26
15	N/A	500	N/A	4.5	2.40	25
16	N/A	0	N/A	4.25	2.73	22
17	N/A	500	N/A	4.25	2.61	23
18	N/A	0	N/A	4.5	2.31	26
19	N/A	0	N/A	4.25	2.14	28
20	N/A	0	N/A	4.5	2.14	28
21	N/A	0	N/A	4	2.22	27
22	N/A	0	N/A	4	2.22	27
23	N/A	0	N/A	4	2.61	23
Notes: 1) Installed at 1/2 throttle, normal speed. 2) Total drive of 23' in 32 minutes.						

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	3-7'		**Trial #**	2		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	N/A	0	N/A	3.5	3.33	18
2	N/A	600	N/A	4	2.73	22
3	N/A	800	N/A	4.25	2.61	23
4	N/A	1400	N/A	3.75	3.16	19
5	N/A	1700	N/A	4.25	2.14	28
6	N/A	1800	N/A	4.25	2.50	24
7	N/A	1900	N/A	4.25	2.40	25
8	N/A	2000	N/A	4	2.31	26
9	N/A	2100	N/A	4	2.50	24
10	N/A	1900	N/A	4	2.31	26
11	N/A	1700	N/A	4.25	2.50	24
12	N/A	1400	N/A	4.25	2.40	25
13	N/A	1200	N/A	4.25	2.31	26
14	N/A	800	N/A	4	2.40	25
15	N/A	600	N/A	4	2.61	23
16	N/A	0	N/A	4	2.50	24
17	N/A	600	N/A	4.5	2.86	21
18	N/A	700	N/A	4.5	2.14	28
19	N/A	0	N/A	4.25	2.31	26
20	N/A	0	N/A	4.25	2.40	25
21	N/A	0	N/A	4	2.50	24
22	N/A	0	N/A	4.25	2.40	25
23	N/A	0	N/A	4.25	2.73	22

Notes: 1) Installed at 1/2 throttle, normal speed.
2) Total drive of 23' in 38.6 minutes.

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	3-7'		**Trial #**	3		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	N/A	0	N/A	3	2.50	24
2	N/A	600	N/A	3.5	2.22	27
3	N/A	700	N/A	4	2.14	28
4	N/A	1400	N/A	4	2.31	26
5	N/A	1600	N/A	4	2.40	25
6	N/A	1900	N/A	4	2.07	29
7	N/A	1800	N/A	4	2.14	28
8	N/A	1900	N/A	4.25	2.22	27
9	N/A	1900	N/A	4	2.31	26
10	N/A	1800	N/A	4	2.50	24
11	N/A	1800	N/A	4.25	4.00	15
12	N/A	1600	N/A	4.25	3.00	20
13	N/A	1200	N/A	4	2.61	23
14	N/A	900	N/A	3.75	3.00	20
15	N/A	600	N/A	3.75	3.00	20
16	N/A	0	N/A	4	2.73	22
17	N/A	600	N/A	4.5	3.00	20
18	N/A	600	N/A	4	2.07	29
19	N/A	0	N/A	5.5	2.50	24
20	N/A	0	N/A	5.5	1.82	33
21	N/A	0	N/A	4.5	2.07	29
22	N/A	0	N/A	4.5	2.22	27
23	N/A	0	N/A	4.75	2.31	26

Notes:
1) Installed at 1/2 throttle, normal speed.
2) Total drive of 23' in 18.6 minutes
3) Significantly faster because 7' extension was left on from previous trial and approximately 14' was intsalled at once.

HELICAL ANCHOR INSTALLATION LOG						
Date:	11/11/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	4-7'		**Trial #**	1		
Rig Type	Bobcat 435		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Eskridge 77BD		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	1780	900	600	4	2.73	22
2	1763	700	650	4.25	2.73	22
3	2316	900	700	4.25	1.71	35
4	2444	1100	750	5	2.22	27
5	2760	1300	800	4	2.22	27
6	3048	1500	850	4	2.31	26
7	3321	1600	900	4.5	2.40	25
8	3059	1400	850	4	2.50	24
9	3267	1600	900	5	2.22	27
10	3426	1800	950	4.5	2.22	27
11	3102	1700	900	4.5	2.22	27
12	2654	1200	750	6	2.22	27
13	1868	800	700	4.5	2.14	28
14	1810	700	600	4.5	2.86	21
15	1592	600	600	4.5	2.31	26
16	1400	500	550	4.5	2.22	27
17	1362	500	550	4.5	2.40	25
18	1092	400	500	4.5	2.73	22
19	1305	500	500	5	2.22	27
20	1319	500	550	4.5	2.61	23
21	1156	400	500	4.5	2.50	24
22	1274	400	500	5	2.31	26
23	1364	500	550	5.5	2.50	24
24	960	500	550	5	2.40	25
25	1182	400	550	4.5	2.31	26
26	1511	600	550	5.5	2.50	24
27	1435	500	550	5	2.07	29
28	1168	400	550	4.5	2.40	25
29	1336	600	550	5	2.31	26
30	1420	600	550	5	2.22	27

Notes: 1) Installed at 1/2 throttle, normal speed.
2) Total drive of 30' in 27.5 minutes.

HELICAL ANCHOR INSTALLATION LOG						
Date:	11/11/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	4-7'		**Trial #**	2		
Rig Type	Bobcat 435		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Eskridge 77BD		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	439	0	400	3.5	3.16	19
2	1912	800	550	4	2.73	22
3	1824	800	600	6	2.00	30
4	1549	700	550	6.5	1.58	38
5	2038	900	600	6	1.62	37
6	1842	700	600	7.5	1.30	46
7	1938	700	600	6.5	1.40	43
8	1733	700	600	8.5	1.15	52
9	1513	600	550	6.5	1.25	48
10	1290	500	550	6	1.43	42
11	1154	400	500	6.5	1.67	36
12	1054	400	500	6.5	1.54	39
13	967	300	500	6	1.82	33
14	881	300	500	6.5	1.94	31
15	891	300	450	5	2.14	28
16	1024	400	500	5.5	1.88	32
17	863	300	450	6	1.62	37
18	721	0	450	4.5	2.14	28
19	886	300	450	3	2.73	22
20	819	300	450	4	2.31	26
21	760	300	400	4	2.22	27
22	850	300	400	4	2.07	29
23	889	300	450	4	2.14	28
24	945	300	500	4.5	2.22	27
25	1016	400	500	5	2.07	29
26	1021	300	500	5.5	1.88	32
27	1071	400	500	6.5	1.58	38
28	1080	400	500	4.5	2.00	30

29	1179	400	500	4.5	2.31	26
Notes: 1) Installed at 1/2 throttle, normal speed. 2) Reinstalled pile into same hole as Trial 1						

HELICAL ANCHOR INSTALLATION LOG						
Date:	11/11/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	8/10/12 @ 3D		
Extensions	4-7'		**Trial #**	3		
Rig Type	Bobcat 435		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Eskridge 50K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
1	N/A	400	250	6	1.33	45
2	N/A	700	250	5	1.71	35
3	N/A	700	250	4.75	1.82	33
4	N/A	1300	250	5	1.82	33
5	N/A	1500	250	5	1.88	32
6	N/A	1900	250	4.25	2.07	29
7	N/A	1700	250	4.5	1.82	33
8	N/A	1900	250	4.5	1.94	31
9	N/A	1600	250	5	2.14	28
10	N/A	1500	250	4.5	1.15	52
11	N/A	1300	250	5	1.50	40
12	N/A	1100	250	4	2.14	28
13	N/A	900	250	4.5	1.88	32
14	N/A	600	250	5	1.88	32
15	N/A	500	250	4	2.07	29
16	N/A	500	250	4.5	1.94	31
17	N/A	600	250	4.5	1.82	33
18	N/A	500	250	5	1.71	35
19	N/A	700	250	5	1.76	34
20	N/A	600	250	5	1.67	36
21	N/A	400	250	5.5	1.58	38
22	N/A	400	250	5	1.82	33
23	N/A	500	250	4	2.07	29
24	N/A	500	250	5	1.82	33
25	N/A	600	250	5	1.62	37

26	N/A	500	250	5	1.88	32
27	N/A	400	250	5.25	1.58	38
28	N/A	400	250	5	1.94	31
29	N/A	600	250	5	1.94	31
30	N/A	600	250	4.5	1.94	31

Notes: 1) Installed at 1/2 throttle, normal speed.
2) Total drive of 30' in 34.7 minutes.

HELICAL ANCHOR INSTALLATION LOG					
Date:	6/10/2015	**Location:**	DOE Site 2		
Pile Geometry:	RS2875	**Lead Section:**	8/10/12 @ 3D		
Extensions	4-7', 1-3"	**Trial Speed**	Fast		
Rig Type	Mustang 8003	**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K	**Technicians**	MNR + AJL		
Depth (ft):	*Torque from Chance (ft-lbs)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)	*Rotation Speed (RPMs)*
1	1000	4	4.00	15	16.0
2	1000	4	3.75	16	15.0
3	1200	4	3.75	16	15.0
4	1500	4	3.53	17	14.1
5	1700	4	3.53	17	14.1
6	2200	4.25	3.75	16	15.9
7	2000	4.25	3.53	17	15.0
8	1800	4.25	3.53	17	15.0
9	1900	4.25	3.53	17	15.0
10	1800	4.5	3.75	16	16.9
11	1700	4.25	3.33	18	14.2
12	1200	4.5	3.53	17	15.9
13	1200	4.5	3.33	18	15.0
14	800	4	3.53	17	14.1
15	800	4	3.75	16	15.0
16	700	4	4.00	15	16.0
17	600	4.25	3.53	17	15.0
18	600	4.5	3.53	17	15.9
19	600	5	3.16	19	15.8
20	600	4.5	3.53	17	15.9
21	600	4.25	3.75	16	15.9
22	0	4.5	3.53	17	15.9
23	0	4.5	4.29	14	19.3
24	500	4	3.33	18	13.3
25	600	4	4.29	14	17.1

26	600	4.25	3.00	20	12.8
27	600	4.25	3.53	17	15.0
28	500	4.25	4.00	15	17.0
29	500	4.25	3.00	20	12.8
30	600	4.25	3.75	16	15.9
Notes: 1) Installed at 1/2 throttle, normal speed. 2) Total drive of 30' in 27.5 minutes.					

Installations for Load Tests

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	Single 12		
Extensions	2-5'		**Plug (in):**	N/A		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
21.5	N/A	0	N/A	4.5	3.2	19
22.5	N/A	0	N/A	4	4.3	14
23.5	N/A	0	N/A	3.5	4.0	15
24.5	N/A	0	N/A	3	3.5	17
25.5	N/A	0	N/A	4	3.8	16
26.5	N/A	0	N/A	3.75	4.3	14
27.5	N/A	0	N/A	3	4.6	13
28.5	N/A	0	N/A	3	5.5	11
Notes: 1) Installed at full throttle. 2) 18" measured from the bottom of first extension each time, lost 6" per extension 3) Total drive of ~9.5'						

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	12/12 @ 3D		
Extensions	2-5'		**Plug (in):**	N/A		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
21.5	N/A	0	N/A	6	2.31	26
22.5	N/A	0	N/A	4	3.53	17
23.5	N/A	0	N/A	3.5	4.00	15
24.5	N/A	0	N/A	3	5.00	12
25.5	N/A	0	N/A	5	2.50	24
26.5	N/A	0	N/A	4.5	3.16	19
27.5	N/A	0	N/A	5	3.53	17
28.5	N/A	0	N/A	4.75	3.53	17

Notes: 1) Installed at 1/2 throttle.
2) 18" measured from the bottom of first extension each time, lost 6" per extension
3) Total drive of ~9.5'

HELICAL ANCHOR INSTALLATION LOG						
Date:	10/17/2014		**Location:**	DOE Site 2		
Pile Geometry:	RS2875		**Lead Section:**	12/12/12 @ 3D		
Extensions	2-5'		**Plug (in):**	N/A		
Rig Type	Mustang ME8003		**Torque Indicator**	Chance Digital Indicator		
Hydraulic Head	Pengo 12K		**Technicians**	MNR + MAH		
Depth (ft):	*Torque from TORQPIN (ft-lbs)*	*Torque from Chance Indicator (ft-lbs)*	*Pressure (psi)*	*Revolutions per foot*	*Installation Rate (ft/min)*	Time (s)
21.5	N/A	0	N/A	7	1.40	43
22.5	N/A	0	N/A	5.5	1.88	32
23.5	N/A	0	N/A	5	2.00	30
24.5	N/A	0	N/A	5	2.07	29
25.5	N/A	0	N/A	4.5	2.00	30
26.5	N/A	0	N/A	5	2.31	26
27.5	N/A	0	N/A	5	2.14	28
28.5	N/A	0	N/A	5	2.00	30
29.5	N/A	0	N/A	5	2.22	27

Notes: 1) Installed at 1/2 throttle.
2) 18" measured from the bottom of first extension each time, lost 6" per extension
3) Total drive of ~9.5'

B-2 LOAD TEST DATA

Shallow Aged Reload Tests

Anchor Geometry:	RS2875	**Lead Section:**	PP	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	11/15/2011	**Weather:**	Sunny, 60s	**Water Level (fbgs):**	0.8
Date of Test:	4/18/2015	**Site:**	DOE	**Depth of Installation (ft):**	4
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	25	126.25	2.5	0.0000	0.0
2	50	252.5	2.5	0.0000	0.0
3	75	378.75	2.5	0.0000	0.0
4	100	505	2.5	0.0025	0.1
5	150	757.5	2.5	0.0060	0.2
6	200	1010	2.5	0.0210	0.7
7	250	1262.5	2.5	0.1650	5.7
8	300	1515	2.5	1.0605	36.9

Notes:
1. Final displacement at 2.2815 inches, rebounded after 5 minutes to 2.2520 inches.
2. Pile failed at 300 on the digital readout box.

Anchor Geometry:	RS2875	Lead Section:	PP	Installation Torque (ft-lbs.)	N/A
Installation Date:	9/21/2011	Weather:	Sunny, 60s	Water Level (fbgs):	1
Date of Test:	4/18/2015	Site:	DOE	Depth of Installation (ft):	8
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	50	252.5	2.5	0.0035	0.1
2	100	505	2.5	0.0055	0.2
3	150	757.5	2.5	0.0070	0.2
4	200	1010	2.5	0.0085	0.3
5	250	1262.5	2.5	0.0105	0.4
6	300	1515	2.5	0.0115	0.4
7	350	1767.5	2.5	0.0125	0.4
8	400	2020	2.5	0.0180	0.6
9	450	2272.5	2.5	0.0200	0.7
10	500	2525	2.5	0.0245	0.9
11	550	2777.5	2.5	0.0285	1.0
12	600	3030	2.5	0.0325	1.1
13	650	3282.5	2.5	0.0380	1.3
14	700	3535	2.5	0.0445	1.5
15	800	4040	2.5	0.0630	2.2
16	900	4545	2.5	0.0890	3.1
17	1000	5050	2.5	0.1315	4.6
18	1100	5555	2.5	0.2055	7.1
19	1200	6060	2.5	0.3140	10.9
20	1400	7070	2.5	0.9790	34.1

Notes:

1. Final displacement at 1.1445 inches, rebounded after 5 minutes to 1.0455 inches.
2. Pile failed at 1400 on the digital readout box.

Anchor Geometry:	RS2875	Lead Section:	Single 12	Installation Torque (ft-lbs.)	N/A
Installation Date:	9/19/2011	Weather:	Sunny, 70s	Water Level (fbgs):	0.8
Date of Test:	4/18/2015	Site:	DOE	Depth of Installation (ft):	4
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	-0.0095	0.0
2	200	1010	2.5	0.0105	0.2
3	300	1515	2.5	0.0395	0.4
4	400	2020	2.5	0.0830	0.8
5	500	2525	2.5	0.1410	1.3
6	600	3030	2.5	0.2165	1.9
7	700	3535	2.5	0.3025	2.6
8	800	4040	2.5	0.4025	3.4
9	900	4545	2.5	0.5200	4.4
10	1000	5050	2.5	0.6615	5.6
11	1100	5555	2.5	0.8250	7.0
12	1200	6060	2.5	1.0495	8.8
13	1400	7070	2.5	1.5675	13.1
14	1600	8080	2.5	2.6180	21.9

Notes:
1. Final displacement at 2.9285 inches, rebounded after 5 minutes to 2.5280 inches.
2. Pile failed at 1700 on the digital readout box.

Anchor Geometry:	RS2875	**Lead Section:**	Single 12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/19/2011	**Weather:**	Sunny, 60s	**Water Level (fbgs):**	1
Date of Test:	4/19/2015	**Site:**	DOE	**Depth of Installation (ft):**	8
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	200	1010	2.5	0.0055	0.0
2	400	2020	2.5	0.0270	0.2
3	600	3030	2.5	0.0780	0.7
4	800	4040	2.5	0.1670	1.4
5	1000	5050	2.5	0.2605	2.2
6	1200	6060	2.5	0.3895	3.2
7	1400	7070	2.5	0.5370	4.5
8	1600	8080	2.5	0.7195	6.0
9	1800	9090	2.5	0.9375	7.8
10	2000	10100	2.5	1.2390	10.3
11	2200	11110	2.5	1.5785	13.2
12	2400	12120	2.5	2.1335	17.8
13	2600	13130	2.5	2.8935	24.1

Notes:
1. Final displacement at 2.9045 inches, rebounded after 5 minutes to 2.5140 inches.

Anchor Geometry:	RS450	Lead Section:	PP	Installation Torque (ft-lbs.)	N/A
Installation Date:	10/28/2011	Weather:	Sunny, 60s	Water Level (fbgs):	1
Date of Test:	4/19/2015	Site:	DOE	Depth of Installation (ft):	4
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	25	126.25	2.5	0.0015	0.1
2	50	252.5	2.5	0.0080	0.3
3	75	378.75	2.5	0.0240	0.8
4	100	505	2.5	0.0550	1.9
5	125	631.25	2.5	0.0875	3.0
6	150	757.5	2.5	0.1240	4.3
7	175	883.75	2.5	0.1910	6.6
8	200	1010	2.5	0.3475	12.1
9	225	1136.25	2.5	0.9545	33.2

Notes:
1. Final displacement at 1.6265 inches, rebounded after 5 minutes to 1.5725 inches.
2. Pile failed at 250 on the digital readout box.

Anchor Geometry:	RS450	Lead Section:	PP	Installation Torque (ft-lbs.)	N/A
Installation Date:	9/21/2011	Weather:	Sunny, 70s	Water Level (fbgs):	0.8
Date of Test:	4/18/2015	Site:	DOE	Depth of Installation (ft):	8
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0000	0.0
2	200	1010	2.5	0.0000	0.0
3	300	1515	2.5	0.0000	0.0
4	400	2020	2.5	0.0000	0.0
5	500	2525	2.5	0.0000	0.0
6	600	3030	2.5	0.0000	0.0
7	700	3535	2.5	0.0010	0.0
8	800	4040	2.5	0.0215	0.7
9	900	4545	2.5	0.0915	3.2
10	1000	5050	2.5	1.9420	67.5

Notes:
1. Final displacement at 1.9420 inches, rebounded after 5 minutes to 1.9300 inches.

2. Pile failed at 1000 on the digital readout box.

Anchor Geometry:	RS450	**Lead Section:**	Single 12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/19/2011	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	1
Date of Test:	4/19/2015	**Site:**	DOE	**Depth of Installation (ft):**	4
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	100	505	2.5	0.0075	0.1
2	200	1010	2.5	0.0245	0.2
3	300	1515	2.5	0.0605	0.5
4	400	2020	2.5	0.0980	0.8
5	500	2525	2.5	0.1465	1.2
6	600	3030	2.5	0.1955	1.6
7	700	3535	2.5	0.2510	2.1
8	800	4040	2.5	0.3195	2.7
9	900	4545	2.5	0.4025	3.4

10	1000	5050	2.5	0.4995	4.2
11	1200	6060	2.5	0.7415	6.2
12	1400	7070	2.5	0.7285	9.1
13	1600	8080	2.5	1.1905	13.0
14	1800	9090	2.5	2.0450	20.1

Notes:
1. Final displacement at 2.3800 inches, rebounded after 5 minutes to 2.0725 inches.
2. Pile failed at 1975 on the digital readout box.

Anchor Geometry:	RS450	**Lead Section:**	Single 12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/19/2011	**Weather:**	Sunny, 60s	**Water Level (fbgs):**	0.8
Date of Test:	4/19/2015	**Site:**	DOE	**Depth of Installation (ft):**	8
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	200	1010	2.5	0.0000	0.0
2	400	2020	2.5	0.0000	0.0
3	600	3030	2.5	0.0015	0.0
4	800	4040	2.5	0.0045	0.0
5	1000	5050	2.5	0.0095	0.1
6	1200	6060	2.5	0.0185	0.2

7	1400	7070	2.5	0.0310	0.3
8	1600	8080	2.5	0.0475	0.4
9	1800	9090	2.5	0.0710	0.6
10	2000	10100	2.5	0.1025	0.9
11	2400	12120	2.5	0.1980	1.7
12	2800	14140	2.5	0.3720	3.1
13	3200	16160	2.5	1.3865	11.6
14	3600	18180	2.5	2.8650	23.9

Notes:
1. Final displacement at 2.8805 inches, rebounded after 5 minutes to 2.5925 inches.
2. Something popped around 3200, load relaxed to about 1400 on readout box. Re-Zeroed and reloaded to 3200.

Anchor Geometry:	RS6625	**Lead Section:**	PP	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/21/2011	**Weather:**	Sunny, 60s	**Water Level (fbgs):**	1
Date of Test:	4/19/2015	**Site:**	DOE	**Depth of Installation (ft):**	4
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	50	252.5	2.5	0.0015	0.1
2	100	505	2.5	0.0135	0.5
3	150	757.5	2.5	0.0350	1.2
4	200	1010	2.5	0.0680	2.4
5	300	1515	2.5	0.1875	6.5

Notes:
1. Final displacement at 0.8125 inches, rebounded after 5 minutes to 0.7070 inches.
2. Pile failed at 400 on the digital readout box.

Anchor Geometry:	RS6625	**Lead Section:**	PP	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/21/2011	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	0.8
Date of Test:	4/18/2015	**Site:**	DOE	**Depth of Installation (ft):**	8
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A
Increment #	**Digital Reading**	**Load (lbs)**	**Time**	**Displacement (in.)**	**S/D (%)**
1	100	505	2.5	0.0000	0.0
2	200	1010	2.5	0.0030	0.1

3	300	1515	2.5	0.0055	0.2
4	400	2020	2.5	0.0095	0.3
5	500	2525	2.5	0.0105	0.4
6	600	3030	2.5	0.0165	0.6
7	700	3535	2.5	0.0190	0.7
8	800	4040	2.5	0.0245	0.9
9	900	4545	2.5	0.0325	1.1
10	1000	5050	2.5	0.0400	1.4
11	1200	6060	2.5	0.0605	2.1
12	1400	7070	2.5	0.0885	3.1
13	1600	8080	2.5	0.1315	4.6
14	1800	9090	2.5	0.6605	23.0

Notes:
1. Final displacement at 1.9420 inches, rebounded after 5 minutes to 1.9300 inches.
2. Pile failed at 1000 on the digital readout box.

Anchor Geometry:	RS6625	**Lead Section:**	Single 12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/19/2011	**Weather:**	Sunny, 70s	**Water Level (fbgs):**	1
Date of Test:	4/19/2015	**Site:**	DOE	**Depth of Installation (ft):**	4
Technician:	MNR	**Test #:**	RT	**Days Rest**	N/A

Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0040	0.0
2	200	1010	2.5	0.0145	0.1
3	300	1515	2.5	0.0320	0.3
4	400	2020	2.5	0.0560	0.5
5	500	2525	2.5	0.0845	0.7
6	600	3030	2.5	0.1285	1.1
7	700	3535	2.5	0.2050	1.7
8	800	4040	2.5	0.3190	2.7
9	900	4545	2.5	0.5085	4.2
10	1000	5050	2.5	0.7370	6.1
11	1200	6060	2.5	1.3390	11.2
12	1400	7070	2.5	2.3705	22.8

Notes:
1. Final displacement at 2.3800 inches, rebounded after 5 minutes to 2.0725 inches.
2. Pile failed at 1975 on the digital readout box.

Anchor Geometry:	RS6625	**Lead Section:**	Single 12	**Installation Torque (ft-lbs.)**	N/A
Installation Date:	9/19/2011	**Weather:**	Sunny, 60s	**Water Level (fbgs):**	0.8

Date of Test:	4/18/2015	Site:	DOE	Depth of Installation (ft):	8
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	200	1010	2.5	0.0375	0.3
2	400	2020	2.5	0.0500	0.4
3	600	3030	2.5	0.0580	0.5
4	800	4040	2.5	0.0655	0.5
5	1000	5050	2.5	0.0740	0.6
6	1200	6060	2.5	0.0860	0.7
7	1600	8080	2.5	0.1225	1.0
8	2000	10100	2.5	0.1785	1.5
9	2400	12120	2.5	0.2780	2.3
10	2800	14140	2.5	0.4135	3.4
11	3200	16160	2.5	0.7480	6.2
12	3600	18180	2.5	1.4665	12.2
13	4000	20200	2.5	3.5015	29.2

Notes:
1. Final displacement at 3.5225 inches, rebounded after 5 minutes to 3.1800 inches.

Anchor Geometry:	RS8625	Lead Section:	PP	Installation Torque (ft-lbs.)	N/A

Installation Date:	9/21/2011	Weather:	Overcast, light breeze, 40s	Water Level (fbgs):	0.1
Date of Test:	4/23/2015	Site:	DOE	Depth of Installation (ft):	4
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	100	505	2.5	0.0040	0.1
2	200	1010	2.5	0.0180	0.6
3	300	1515	2.5	0.0245	0.9
4	400	2020	2.5	0.0450	1.6
5	500	2525	2.5	0.0595	2.1
6	600	3030	2.5	0.0855	3.0
7	700	3535	2.5	0.1160	4.0
8	800	4040	2.5	0.1585	5.5
9	900	4545	2.5	0.2275	7.9
10	1000	5050	2.5	0.4105	14.3
11	1100	5555	2.5	1.0545	36.7

Notes:
1. Final displacement at 1.3165 inches, rebounded after 5 minutes to 1.1175 inches.
2. Pile failed at 1150 on the digital readout box.

Anchor Geometry:	RS8625	Lead Section:	Single 12	Installation Torque (ft-lbs.)	N/A

Installation Date:	9/19/2011	Weather:	Sunny, 70s	Water Level (fbgs):	1
Date of Test:	4/23/2015	Site:	DOE	Depth of Installation (ft):	4
Technician:	MNR	Test #:	RT	Days Rest	N/A
Increment #	Digital Reading	Load (lbs)	Time	Displacement (in.)	S/D (%)
1	200	1010	2.5	0.0035	0.0
2	400	2020	2.5	0.0160	0.1
3	600	3030	2.5	0.0410	0.3
4	800	4040	2.5	0.0795	0.7
5	1000	5050	2.5	0.1325	1.1
6	1200	6060	2.5	0.2300	1.9
7	1400	7070	2.5	0.3980	3.3
8	1600	8080	2.5	0.6895	5.7
9	1800	9090	2.5	1.2515	10.4
10	2000	10100	2.5	2.6300	21.9

Notes:
1. Final displacement at 2.6345 inches, rebounded after 5 minutes to 2.3080 inches.
2. Pile failed at 2000 on the digital readout box.

B-3 SUMMARY TABLE OF LOAD TESTS

Geometry	Average Diameter (in.)	Depth (ft)	Load "Q" (lbs)			Δ @ $Q_{10}/2$ (in.)	Δ @ $Q_{20}/2$ (in.)	Installation Torque (ft-lbs)	K_t (ft^{-1})	
			5%	10%	20%				10%	20%
DOE										
Repeat Tests on Single-Helix RS Coated Piles from 2013										
RS2875-SCBP-HCO	14	9	14600	18800	22800	0.18	0.36	1300	14.5	17.5
RS2875-SCBP-NCH	14	9	15000	20400	24400	0.40	0.50	1400	14.6	17.4
RS2875-SCBP	14	9	14000	20000	24950	0.41	0.58	1500	13.3	16.6
RS2875-SCG	14	9	8200	11850	16400	0.51	0.70	1200	9.9	13.7
RS2875-Plain	14	9	17100	21100	24400	0.18	0.28	1700	12.4	14.4
RS2875-GAL	14	9	13500	18000	21600	0.29	0.43	1200	15.0	18.0
RS450-SCBP-HCO	14	9	18800	21200	25900	0.13	0.22	2500	8.5	10.4
RS450-SCBP-NCH	14	9	18800	23600	28000	0.20	0.33	2200	10.7	12.7
RS450-SCBP	14	9	19200	23600	28000	0.20	0.33	2000	11.8	14.0
RS450-SCG	14	9	15700	19800	23900	0.20	0.34	2100	9.4	11.4
RS450-Plain	14	9	15400	17600	19800	0.08	0.42	2800	6.3	7.1
RS450-GAL	14	9	16000	19600	23800	0.12	0.25	2300	8.5	10.3
Tests on SS5 and RS Anchors Near Coated Piles from 2013										
SS5-12 CP10	12	15	5350	7400	8300	0.2	0.24	467	15.8	17.8
SS5-12/12 3D CP11	12	15	7050	8200	9100	0.15	0.18	600	13.7	15.2
SS5-12/12/12 3D CP12	12	15	8150	9000	10400	0.2	0.24	700	12.9	14.9
RS19 - 14	14	9	7300	11250	15400	0.47	0.77	1067	10.5	14.4
Repeat Tests on SS5 Anchors Near Coated Piles from 2013										
SS5-14 CP3	14	15RT	5200	6200	7000	0.22	0.28	400	15.5	17.5
SS5-14 CP6	14	15RT	8150	9250	9600	0.17	0.18	400	23.1	24.0
SS5-14 CP6	14	15RT	6125	7200	8000	0.22	0.37	312	23.1	25.6
SS5-14 CP7	14	15RT	6975	8200	9100	0.23	0.31	700	11.7	13.0
SS5- 10/12/14 CP8	12	15RT	9700	11500	12900	0.23	0.26	867	13.3	14.9
SS5-12/14 3D CP9	13	16RT	5225	5725	6050	0.22	0.23	700	8.2	8.6
SS5-10/12 3D CP14	11	15RT	6450	8500	10300	0.24	0.36	550	15.5	18.7
SS5-10/12 3D CP16	11	15RT	5200	6725	8400	0.15	0.25	500	13.5	16.8
SS5-12 CP10	12	15RT	5100	6000	6800	0.14	0.18	467	12.8	14.6
SS5-12/12 3D CP11	12	15RT	4550	6000	7350	0.27	0.38	600	10.0	12.3
SS5-12/12/12 3D CP12	12	15RT	5500	7300	8975	0.23	0.39	700	10.4	12.8
Tests on Helical Anchors in Back Field from 2013										
RS2875-8/10/12 3D	10	10	17000	22700	29200	0.21	0.35	2000	11.4	14.6
RS2875-8/10/12 3D	10	20	3000	6300	8000	0.23	0.28	467	13.5	17.1
RS2875-8/10/12 3D	10	30	5300	6600	7100	0.28	0.31	467	14.1	15.2
RS2875-10	10	10	8900	10800	12800	0.14	0.20	800	13.5	16.0
RS2875-10	10	20	3300	3600	3700	0.08	0.10	300	12.0	12.3
RS2875-10/10 3D	10	10	9500	12200	15100	0.22	0.30	1400	8.7	10.8

RS2875-10/10 3D	10	20	4200	4650	5000	0.18	0.20	500	9.3	10.0
RS2875-10/10/10 3D	10	10	13000	18300	23300	0.27	0.42	1933	9.5	12.1
RS2875-10/10/10 3D	10	20	5400	6200	6700	0.20	0.22	600	10.3	11.2
RS2875-12	12	10	8800	11200	14350	0.15	0.33	1000	11.2	14.4
RS2875-12	12	20	4125	4375	4550	0.14	0.15	400	10.9	11.4
RS2875-12/12 3D	12	10	11500	14600	19000	0.30	0.48	1350	10.8	14.1
RS2875-12/12 3D	12	20	5175	6075	6500	0.23	0.25	500	12.2	13.0
RS2875-12/12/12 3D	12	10	15800	20800	27400	0.37	0.58	2367	8.8	11.6
RS2875-12/12/12 3D	12	20	5450	7300	8250	0.40	0.45	650	11.2	12.7
SS5-12/12/12 3D	12	10	9900	14000	18800	0.35	0.55	1600	8.8	11.8
SS5-12/12/12 3D	12	20	5300	6350	7100	0.22	0.25	650	9.8	10.9
SS175-8/10/12 3D	10	10	15200	20500	25200	0.24	0.35	2333	8.8	10.8
SS175-8/10/12 3D	10	10RT	13500	17600	20600	0.25	0.33	2333	7.5	8.8
SS175-8/10/12 3D	10	20	5500	6000	6000	0.08	0.08	633	9.5	9.5
SS5-10/12/14 3D	12	10	16600	22100	25200	0.24	0.32	2200	10.0	11.5
SS5-10/12/14 3D	12	20	6900	8000	8500	0.23	0.25	567	14.1	15.0
SS5-10/12/14 3D	12	30	6300	7450	8500	0.28	0.30	533	14.0	15.9
SS5-10/12/14 3D	12	40	5500	7000	7550	0.33	0.37	467	15.0	16.2
RS2875-10/12/14 3D	12	10	22100	27300	**31800***	0.19	0.25	2933	9.3	10.8
RS2875-10/12/14 3D	12	20	7800	8750	9350	0.21	0.22	833	10.5	11.2
RS2875-10/12/14 3D	12	30	7850	9200	9600	0.33	0.34	633	14.5	15.2
RS2875-10/12/14 3D	12	40	7400	8600	9100	0.32	0.33	600	14.3	15.2
SS5 RS Combo-10/12/14	12	10	14100	20400	26200	0.35	0.53	2400	8.5	10.9
SS5 RS Combo-10/12/14	12	20	7800	9000	9400	0.25	0.26	633	14.2	14.8
SS5 RS Combo-10/12/14	12	30	8000	9100	9600	0.22	0.23	533	17.1	18.0
SS175-10/12/14 3D	12	10	15800	22500	29800	0.33	0.54	2467	9.1	12.1
SS175-10/12/14 3D	12	20	6750	8050	8900	0.26	0.32	467	17.2	19.1
RS125-8/10/12 3D	10	10	11100	17800	22800	0.35	0.53	1467	12.1	15.5
SS5-14/14/14 1.5D	14	10	12500	16250	19500	0.20	0.30	2933	5.5	6.6
SS5-14/14/14 1.5D	14	20	6700	7600	8325	0.18	0.20	433	17.6	19.2
SS5-14/14/14 3D	14	10	12500	18750	25500	0.30	0.55	2400	7.8	10.6
SS5-14/14/14 3D	14	20	6650	7600	8350	0.17	0.20	767	9.9	10.9
Repeat Tests on Helical Anchors in Back Field from 2013										
SS5-12/14 1.5D	13	40	5500	7100	7575	0.29	0.43	333	21.3	22.7
SS5-14/14/14 1.5D	14	20RT	6150	7925	9750	0.3	0.42	433	18.3	22.5
SS5-14/14/14 3D	14	20RT	6750	8350	9850	0.28	0.35	767	10.9	12.8
RS2875-12	12	20RT	3850	4375	4900	0.15	0.21	400	10.9	12.3
RS2875-12/12 3D	12	20RT	4650	6075	6500	0.29	0.35	500	12.2	13.0
RS2875-12/12/12 3D	12	20RT	5350	7350	9200	0.29	0.42	667	11.0	13.8
RS2875-8/10/12 3D	10	30RT	6700	7800	8400	0.15	0.16	467	16.7	18.0
RS2875-10/10/10 3D	10	20RT	5500	6500	7225	0.15	0.17	600	10.8	12.0
New Screws Installed in Back Field in 2014										

RS2875-8/10/12 3D Trial Pile	10	30	6100	6675	7050	0.19	0.22	N/A	#VALUE!	#VALUE!
RS2875-10/10/10 3D	10	30	5300	7350	8075	0.31	0.36	N/A	#VALUE!	#VALUE!
RS2875-10/10/10 3D	10	30RT	5900	6650	7200	0.10	0.12	N/A	#VALUE!	#VALUE!
RS2875-12	12	30	3575	4200	4550	0.20	0.24	N/A	#VALUE!	#VALUE!
RS2875-12	12	30RT	3000	3200	3500	0.11	0.12	N/A	#VALUE!	#VALUE!
RS2875-12/12 3D	12	30	4650	5600	6050	0.28	0.30	N/A	#VALUE!	#VALUE!
RS2875-12/12 3D	12	30RT	4050	4700	5050	0.18	0.20	N/A	#VALUE!	#VALUE!
RS2875-12/12/12 3D	12	30	4200	6900	8050	0.50	0.53	N/A	#VALUE!	#VALUE!
RS2875-12/12/12 3D	12	30RT	5550	6550	7350	0.20	0.33	N/A	#VALUE!	#VALUE!
RS2875 10/12/14 3D	12	10	20200	27100	**33500***	0.28	0.35	2833	10	11.8
RS2875 10/12/14 3D	12	20	7050	7800	8100	0.22	0.22	833	9	9.7
RS2875 10/12/14 3D	12	20RT	7650	8750	9800	0.17	0.20	833	11	11.8
RS2875 10/12/14 3D	12	30	3900	4450	4500	0.28	0.28	700	6	6.4
RS350-10	10	10	7800	9700	12300	0.13	0.27	1300	7	9.5
RS350-12	12	10	9550	13400	17400	0.30	0.49	1367	10	12.7
RS350-14	14	10	11800	15400	19600	0.18	0.42	2133	7	9.2
RS350-16	16	10	14200	17500	20200	0.23	0.3	2566	7	7.9
RS2875-16	16	10	9800	14400	20200	0.43	0.82	1766	8	11.4
RS350-12	12	20	4175	4300	4550	0.18	0.19	400	11	11.4
RS350-12	12	20RT	4000	4250	4550	0.05	0.07	400	11	11.4
RS350-12/12 3D	12	10	9300	14050	21200	0.33	0.75	2133	7	9.9
RS350-12/12 3D	12	20	5850	6500	6550	0.22	0.22	533	12	12.3
RS350-12/12 3D	12	20RT	5650	6625	7300	0.15	0.18	533	12	13.7
RS350-12/12/12 3D	12	10	12800	17900	22200	0.35	0.48	2600	7	8.5
RS350-12/12/12 3D	12	10RT	19200	23000	26200	0.21	0.26	2600	9	10.1
RS350-12/12/12 3D	12	20	7000	7800	8100	0.22	0.23	867	9	9.3
RS350-8/10/12 3D	10	10	14775	20700	27000	0.23	0.41	2300	9	11.7
RS350-8/10/12 3D	10	20	5350	6050	6075	0.12	0.12	633	10	9.6
RS350-8/10/12 3D	10	20RT	4800	5750	6250	0.08	0.15	633	9	9.9
RS350-10/12/14 3D	12	10	22500	28600	36900	0.26	0.40	3067	9	12.0
RS350-10/12/14 3D	12	20	6500	7600	8100	0.24	0.26	967	8	8.4
RS350-10/12/14 3D	12	20RT	7000	10900	13100	0.38	0.54	967	11	13.5
SS125-12	12	10	5000	7400	10475	0.32	0.65	600	12	17.5
SS125-12	12	10RT	6100	9650	13300	0.45	0.68	600	16	22.2
SS125-10/12 3D	11	10	3100	4075	5400	0.15	0.36	1333	3	4.1
RS125-8/10 3D	9	20	4450	5275	5550	0.15	0.15	300	18	18.5
RS125-8/10/12 3D	10	20	2525	3200	3525	0.33	0.35	200	16	17.6
RS125-8/10/12 3D	10	20RT	2800	3200	3525	0.13	0.18	200	16	17.6
SS5-14/14/14 1.5D	14	30	6650	8000	8600	0.23	0.27	467	17	18.4
SS5-14/14/14 1.5D	14	30RT	5950	7500	8100	0.28	0.30	467	16	17.3
SS5-14/14/14 3D	14	30	6750	8400	9100	0.28	0.30	467	18	19.5
SS5-14/14/14 3D	14	30RT	6550	7650	8100	0.17	0.19	467	16	17.3

SS5-12/14/16 3D	14	10	12900	18350	24000	0.38	0.62	3400	5	7.1
SS5-12/14/16 3D	14	10RT	17300	21100	24000	0.25	0.33	3400	6	7.1
SS5-12/14/16 3D	14	20	6700	8000	9900	0.23	0.37	633	13	15.6
SS175-10/12/14 3D	12	30	5700	6700	7075	0.22	0.25	500	13	14.2
SS175-10/12/14 3D	12	30RT	7550	8150	8600	0.1	0.13	500	16.3	17.2
***Note: Value extrapolated from average capacity ratios of similar piles at same depth**										
Repeat Tests on Shallow Helical Anchors in Back Field from 2011										
RS2875 PP	N/A	4	-	-	2950	-	-			
RS2875 PP	N/A	4RT	-	-	1500	-	-			
RS2875 PP	N/A	8	-	-	4550	-	-			
RS2875 PP	N/A	8RT	-	-	7000	-	-			
RS2875-12	12	4	6000	7400	9400					
RS2875-12	12	4RT	4650	6300	7850	0.31	0.40			
RS2875-12	12	8	10600	13300	16100	-	-			
RS2875-12	12	8RT	7200	10000	12500	0.33	0.43			
RS450 PP	N/A	4	-	-	2500	-	-			
RS450 PP	N/A	4RT	-	-	1250	-	-			
RS450 PP	N/A	8	-	-	8400	-	-			
RS450 PP	N/A	8RT	-	-	5000	-	-			
RS450-12	12	4	6000	8000	10400					
RS450-12	12	4RT	5300	7300	9050	0.27	0.40			
RS450-12	12	8	12750	15250	17500					
RS450-12	12	8RT	14500	15800	17550	0.05	0.07			
RS6625 PP	N/A	4	-	-	6200	-	-			
RS6625 PP	N/A	4RT	-	-	2000	-	-			
RS6625 PP	N/A	8	-	-	11500	-	-			
RS6625 PP	N/A	8RT	-	-		-	-			
RS6625-12	12	4	8000	9200	10800					
RS6625-12	12	4RT	4750	5800	6800	0.11	0.19			
RS6625-12	12	8	17750	20000	22500					
RS6625-12	12	8RT	15200	17400	19100	0.15	0.18			
RS8625 PP	N/A	4	-	-	7400	-	-			
RS8625 PP	N/A	4RT	-	-	5750	-	-			
RS8625-12	12	4	14200	15800	17200	-	-			
RS8625-12	12	4RT	7800	9000	9900	0.10	0.13			
Ag-Farm										
Aged Tests and Repeats on Single-Helix										
SS5-12 #1	12	20	4550	5500	6600	0.23	0.28	667	9.2	9.9
SS5-12 #1	12	20RT	4750	6700	9000	0.34	0.53	667	11.2	13.5
SS5-12 #2	12	20	4600	6650	8500	0.32	0.58	533	12.5	15.9
SS5-12 #2	12	20RT	5100	6300	7450	0.25	0.32	533	11.8	14.0
SS5-12 #3	12	20	5100	6125	6900	0.22	0.25	533	11.5	12.9

SS5-12 #4	12	20	4450	5550	6850	0.22	0.32	667	8.3	10.3
SS5-12 #4	12	20RT	4300	6250	9100	0.39	0.67	667	9.4	13.6
SS5-12 #5	12	20	3400	3950	4900	0.22	0.65	733	5.4	6.7
SS5-12 #5	12	20RT	3650	5200	6600	0.38	0.52	733	7.1	9.0
SS5-12 #6	12	20	4250	5300	6300	0.23	0.3	767	6.9	8.2
SS5-12 #6	12	20RT	4250	6150	7950	0.38	0.54	767	8.0	10.4
1st Time Tests										
SS5-8/10/12 3D	10	10	9000	17500	24000	0.45	0.62	1867	9.4	12.9
SS5-8/10/12 3D	10	20	6100	7450	8600	0.21	0.25	733	10.2	11.7
SS5-8/10/12 3D	10	20RT	5800	7800	9600	0.22	0.35	733	10.6	13.1
RS2875-8/10/12 3D	10	10	17000	29000	39000	0.41	0.61	N/A	-	-
RS2875-8/10/12 3D	10	20	6300	10000	12250	0.42	0.50	900	11.1	13.6
RS2875-8/10/12 3D	10	20RT	6950	9800	12300	0.27	0.40	900	10.9	13.7
RS2875-8/10/12 3D	10	30	7500	12100	15150	0.40	0.50	-	-	-
Combo-8/10/12 3D	10	10	19000	29500	42000	0.35	0.62	3033	9.7	13.8
Combo-8/10/12 3D	10	20	6800	9600	11600	0.33	0.42	800	12.0	14.5
Combo-8/10/12 3D	10	20RT	6700	8950	10950	0.22	0.34	800	11.2	13.7
Pitch Series										
RS2875-8" w/ 3" Pitch	8	10	6850	9300	10750	0.25	0.41	1250	7.4	8.6
RS2875-12" w/ 3" Pitch	12	10	15500	19000	23500	0.19	0.31	2000	9.5	11.8
RS2875-12" w/ 3" Pitch	12	20	7400	8950	9850			1000	9.0	9.9
RS2875-12" w/ 4" Pitch	12	10	20100	26200	29600	0.28	0.34	2800	9.4	10.6
RS2875-12" w/ 4" Pitch	12	20	7150	8300	9350			1533	5.4	6.1
RS2875-12" w/ 6" Pitch	12	10	16600	20600	24000	0.17	0.24	3600	5.7	6.7
RS2875-12" w/ 6" Pitch	12	20	6900	8100	9100			1667	4.9	5.5
RS2875-18" w/ 3" Pitch	18	10	19500	28100	32000*	0.51		2600	10.8	12.3
RS2875-18" w/ 6" Pitch	18	10	18400	25750	30000*			3650	7.1	8.2
RS2875-18" w/ 6" Pitch	18	20	10000	19400	-	0.87	-	1700	11.4	-
***Note: Value extrapolated from average capacity ratios of similar piles at same depth**										

B-4 FIELD TESTS

Sowers Drive Cone Penetration Tests

			Site:		DOE	
Date:	20141027		*Operators:*		Hagedorn, Ruberti	
Location:	93' S Driveway, 75' W Paved Road		*Hammer Mass:*		15 lb	
Probe:	Sowers		*Hammer Drop:*		20"	
Depth (ft)	**N_{0-2}**	**$N_{2-3.75}$**	**$N_{3.75-5.5}$**	**W (%)**	**Casagrande (Drops)**	**Fall Cone Penetration (mm)**
1	13	20	20	22.2	N/A	2.1
2	13	17	18	21.9	N/A	1.4
3	12	13	14	25.1	N/A	1.5
4	10	14	11	27.7	N/A	2.9
5	11	11	8	29.7	N/A	3.8
6	14	13	17	31.6	N/A	2.7
7	12	15	20	38.9	N/A	4.0
8	15	20	24	42.2	>200	7.5
9	13	19	20	43.1	130	12.0
10	12	13	15	46.6	150	6.7
11	10	10	11	49.9	88	11.5
12	7	8	8	52.9	84	14.0

Mini Drive Probe Torque-Tests

Results for SP-1 at the DOE Site

Date: 10/28/14							**Site: DOE**					
Location: 3' North of SP-3							**Operators: MNR - MAH**					
Probe: SP-1			**Hammer Mass: 22 lbs**				**Hammer Drop: 19 5/8"**					
Diameter: (in)			**Length (in)**		**Torque Wrench**		**Torque Meter**		**Torque Wrench**		**Torque Meter**	
1			**12**									
Depth (ft.)	**N_{0-3}**	**N_{3-6}**	**N_{6-9}**	**N_{9-12}**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**Peak F_S (psf)**	**Residual F_S (psf)**	**Peak F_S (psf)**	**Residual F_S (psf)**
2	7	7	9	6	102	90	90	78	779.2	687.5	687.5	595.9
4	6	10	11	12	132	108	124.8	108	1008.4	825.1	953.4	825.1
6	7	11	14	18	144	120	138	120	1100.1	916.7	1054.2	916.7
8	9	12	17	20	144	120	144	114	1100.1	916.7	1100.1	870.9
10	7	10	11	12	102	78	84	72	779.2	595.9	641.7	550.0
12	5	5	7	7	72	54	60	45.6	550.0	412.5	458.4	348.4

Notes: 1) High range torque meter used (19.9-99.6 ft-lbs)
2) New anvil.

Results for SP-2 at the DOE Site

Date: 10/28/14							**Site: DOE**					
Location: 3' North of SP-3							**Operators: MNR - MAH**					
Probe: SP-2			**Hammer Mass: 22 lbs**				**Hammer Drop: 19 5/8"**					
Diameter: (in) 1.25			**Length (in)** 12		**Torque Wrench**		**Torque Meter**		**Torque Wrench**		**Torque Meter**	
Depth (ft.)	**N_{0-3}**	**N_{3-6}**	**N_{6-9}**	**N_{9-12}**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**Peak F_S (psf)**	**Residual F_S (psf)**	**Peak F_S (psf)**	**Residual F_S (psf)**
2	10	19	17	16	180	156	180	150	880.1	762.7	880.1	733.4
4	12	13	15	16	150	120	132	116.4	733.4	586.7	645.4	569.1
6	11	21	26	44	210	162	216	153.6	1026.7	792.1	1056.1	751.0
8	14	19	22	26	300	270	300	240	1466.8	1320.1	1466.8	1173.4
10	9	12	14	16	120	90	120	84	586.7	440.0	586.7	410.7
12	7	8	9	10	48	30	0	0	234.7	146.7	0.0	0.0

Notes: 1) High range torque meter used (19.9-99.6 ft-lbs)
2) New anvil.
3) Pocket of water experienced between 3-4'

Results for SP-3 at the DOE Site

Date: 10/27/14							**Site: DOE**					
Location: 3' West and 3' North of Sowers Cone							**Operators: MNR - MAH**					
Probe: SP-3			**Hammer Mass: 22 lbs**				**Hammer Drop: 19 5/8"**					
Diameter: (in) 1.5			**Length (in)** 12		**Torque Wrench**		**Torque Meter**		**Torque Wrench**		**Torque Meter**	
Depth (ft.)	**N_{0-3}**	**N_{3-6}**	**N_{6-9}**	**N_{9-12}**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**T_P (in-lbs.)**	**T_R (in-lbs.)**	**Peak F_S (psf)**	**Residual F_S (psf)**	**Peak F_S (psf)**	**Residual F_S (psf)**
2	18	24	22	23	240	240	252	216	814.9	814.9	855.6	733.4
4	15	19	19	20	210	168	192	150	713.0	570.4	651.9	509.3
6	14	24	38	56	240	216	276	204	814.9	733.4	937.1	692.6
8	15	25	28	38	360	360	360	336	1222.3	1222.3	1222.3	1140.8
10	11	16	20	21	72	60	72	60	244.5	203.7	244.5	203.7
12	8	11	11	11	30	12	0	0	101.9	40.7	0.0	0.0

Notes: 1) High range torque meter used (19.9-99.6 ft-lbs) 2) New anvil.

Results for TP-1 at the DOE Site

Date: 10/30/14							Site: DOE					
Location: 5' North, 3' East of Tapered Cone 1 (1.414"-0.587")							Operators: MNR - MAH					
Probe: TP-1 (1.201"-0.804")				Hammer Mass: 22 lbs			Hammer Drop: 19 5/8"					
Diameter: (in)			Length (in)		Torque Wrench		Torque Meter		Torque Wrench		Torque Meter	
1.0025			12									
Depth (ft.)	N_{0-3}	N_{3-6}	N_{6-9}	N_{9-12}	T_P (in-lbs.)	T_R (in-lbs.)	T_P (in-lbs.)	T_R (in-lbs.)	Peak F_S (psf)	Residual F_S (psf)	Peak F_S (psf)	Residual F_S (psf)
2	6	11	16	21	312	276	324	276	2371.6	2098.0	2462.8	2098.0
4	5	8	13	15	240	198	228	180	1824.3	1505.1	1733.1	1368.2
6	6	12	20	28	210	150	204	144	1596.3	1140.2	1550.7	1094.6
8	5	11	18	27	360	360	348	324	2736.5	2736.5	2645.3	2462.8
10	4	7	9	13	270	228	252	204	2052.4	1733.1	1915.5	1550.7
12	3	4	5	7	96	84	102	96	729.7	638.5	775.3	729.7
Notes: 1) High range torque meter used (19.9-99.6 ft-lbs) 2) New anvil.												

Results for TP-2 at the DOE Site

Date: 10/28/14							Site: DOE					
Location: 3' East of SP-2							Operators: MNR - MAH					
Probe: TP-2 (1.414"-0.587")				Hammer Mass: 22 lbs			Hammer Drop: 19 5/8"					
Diameter: (in)			Length (in)		Torque Wrench		Torque Meter		Torque Wrench		Torque Meter	
1.0005			12									
Depth (ft.)	N_{0-3}	N_{3-6}	N_{6-9}	N_{9-12}	T_P (in-lbs.)	T_R (in-lbs.)	T_P (in-lbs.)	T_R (in-lbs.)	Peak F_S (psf)	Residual F_S (psf)	Peak F_S (psf)	Residual F_S (psf)
2	5	9	18	25	390	288	408	240	2976.4	2198.0	3113.8	1831.6
4	4	9	13	20	330	210	360	180	2518.5	1602.7	2747.4	1373.7
6	9	15	26	37	312	240	336	240	2381.1	1831.6	2564.3	1831.6
8	5	12	25	41	504	450	480	384	3846.4	3434.3	3663.3	2930.6
10	4	8	13	18	330	276	312	276	2518.5	2106.4	2381.1	2106.4
12	3	5	8	11	180	156	168	156	1373.7	1190.6	1282.1	1190.6

Notes: 1) High range torque meter used (19.9-99.6 ft-lbs) 2) New anvil.

Results for Mini Cone at the DOE Site

Date: 10/30/14							Site: DOE					
Location: 3' South of Mini SPT							Operators: MNR - MAH					
Probe: Mini Cone			Hammer Mass: 22 lbs				Hammer Drop: 19 5/8"					
Diameter: (in)			Length (in)		Torque Wrench		Torque Meter		Torque Wrench		Torque Meter	
0.996			9									
Depth (ft.)	N_{0-3}	N_{3-6}	N_{6-9}	N_{9-12}	T_P (in-lbs.)	T_R (in-lbs.)	T_P (in-lbs.)	T_R (in-lbs.)	Peak F_S (psf)	Residual F_S (psf)	Peak F_S (psf)	Residual F_S (psf)
2	10	13	10	N/A	138	96	126	96	1417.0	985.7	1293.8	985.7
4	4	5	8	N/A	102	72	79.2	72	1047.3	739.3	813.2	739.3
6	4	6	10	N/A	120	84	108	81.6	1232.1	862.5	1108.9	837.9
8	8	13	18	N/A	210	168	186	153.6	2156.3	1725.0	1909.8	1577.1
10	6	7	9	N/A	120	84	96	78	1232.1	862.5	985.7	800.9
12	4	4	7	N/A	60	36	51.6	45.6	616.1	369.6	529.8	468.2
Notes: 1) High range torque meter used (19.9-99.6 ft-lbs) 2) New anvil.												

Results for Mini SPT at the DOE Site

Date: 10/30/14								Site: DOE						
Location: 3' South of TP-1 (1.201"-0.804")								Operators: MNR - MAH						
Probe: Mini SPT			Hammer Mass: 22 lbs					Hammer Drop: 19 5/8"						
Diameter: (in)			Length (in)			Torque Wrench		Torque Meter		Torque Wrench		Torque Meter		
0.992			9											
Depth (ft.)	Recovery (in/in)	N_{0-3}	N_{3-6}	N_{6-9}	N_{9-12}	T_P (in-lbs.)	T_R (in-lbs.)	T_P (in-lbs.)	T_R (in-lbs.)	Peak F_S (psf)	Residual F_S (psf)	Peak F_S (psf)	Residual F_S (psf)	
2	6.5"/9"	6	9	13	N/A	150	84	120	84	1552.6	869.5	1242.1	869.5	
4	6.5"/9"	3	6	7	N/A	96	84	91.2	84	993.7	869.5	944.0	869.5	
6	7.25"/9"	6	10	14	N/A	198	156	189.6	150	2049.5	1614.7	1962.5	1552.6	
8	9"/9"	6	10	14	N/A	192	156	180	150	1987.4	1614.7	1863.2	1552.6	
10	9"/9"	4	6	8	N/A	114	90	102	87.6	1180.0	931.6	1055.8	906.7	
12	4"/9"	2	3	5	N/A	84	60	68.4	60	869.5	621.1	708.0	621.1	

Notes: 1) High range torque meter used (19.9-99.6 ft-lbs).

Miniature Field Vane Tests

Date: Fall 2013				**Site: DOE Site 2**		
Location: CP-10 3" towards WWTP				**Operators: NW & JE**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weight (g)**	**Dry Weight (g)**	**Water Content (%)**
1.5	60.3	16.45	1.05	27.44	22.32	24.1
2.5	64.5	17.60	1.41	33.59	26.46	28.5
3.5	32.2	8.79	1.04	38.61	28.82	35.2
4.5	45.1	12.30	1.05	52.2	42.03	24.8
5.5	68.3	18.63	1.05	42.85	33.29	29.7
6.5	101.9	27.80	1.05	34.6	26.43	32.2
7.5	128.8	35.14	1.03	40.91	30.8	34.0
8.5	81.3	22.18	1.04	42.05	30.39	39.7
9.5	97.2	26.52	1.14	38.72	28.12	39.3
10.5	84.4	23.03	1.05	58.29	42.28	38.8
11.5	55.6	15.17	1.04	39.95	27.8	45.4
12.5	52.8	14.41	1.03	29.14	19.63	51.1

Date: Fall 2013				**Site: DOE Site 2**		
Location: CP-11 3" towards 116				**Operators: NW & JE**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12/12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weight (g)**	**Dry Weight (g)**	**Water Content (%)**
1.5	44.1	12.03	2.26	46.54	37.12	27.0
2.5	64.4	17.57	2.38	50.6	40.48	26.6
3.5	31.6	8.62	2.26	48.39	36.29	35.6
4.5	27.7	7.56	2.31	63.76	48.64	32.6
5.5	45.8	12.50	2.27	58.57	46.56	27.1
6.5	70.7	19.29	2.26	53.03	40.67	32.2
7.5	49.6	13.53	2.29	75.71	56.75	34.8
8.5	30.6	8.35	2.52	77.75	56.26	40.0
9.5	40.7	11.10	2.34	60.69	43.45	41.9

10.5	33.7	9.19	1.04	43.34	30.78	42.2
11.5	33.7	9.19	1.01	34.14	23.8	45.4
12.5	24.9	6.79	1.09	24.23	16.17	53.4

Date: Fall 2013				**Site: DOE Site 2**		
Location: CP-12 3.5" towards Du Bois				**Operators: NW & JE**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12/12/12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weight (g)**	**Dry Weight (g)**	**Water Content (%)**
1.5	50.4	13.75	1.04	28.14	22.3	27.5
2.5	72.9	19.89	2.34	54.76	41.84	32.7
3.5	60.4	16.48	2.32	47.29	37.19	29.0
4.5	74.7	20.38	2.27	50.83	39.23	31.4
5.5	61.4	16.75	1.04	37.13	28.6	31.0
6.5	57.3	15.63	1.09	37.95	29.43	30.1
7.5	52.8	14.41	1.11	44.92	33.16	36.7
8.5	43.6	11.90	1.04	41.04	29.89	38.6
9.5	35.1	9.58	1.04	29.42	20.95	42.5
10.5	34.4	9.39	1.08	64.59	46.01	41.4
11.5	49.1	13.40	1.05	55.01	38.35	44.7
12.5	23.6	6.44	1.01	50.88	34.1	50.7

Date: 4/25/15				**Site: DOE Site 2**		
Location: CP-10 3" towards WWTP				**Operators: MNR-MAH**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weigh t (g)**	**Dry Weigh t (g)**	**Water Content (%)**
1	43.6	11.90	2.2	26.89	22.27	23.0
2	83.5	22.78	2.21	19.66	15.89	27.6
3	59	16.10	2.26	25.43	20.3	28.4
4	43.2	11.79	2.27	29.04	22.04	35.4
5	69.3	18.91	2.27	21.51	17.79	24.0
6	91.4	24.94	2.27	42.16	31.17	38.0
7	89.3	24.36	2.29	38.36	29.5	32.6
8	73.7	20.11	2.24	25.13	19.18	35.1
9	90.1	24.58	2.25	17.77	13.25	41.1
10	70.4	19.21	2.27	55.64	40.78	38.6
11	57.6	15.72	2.21	66.83	46.42	46.2

12	43.5	11.87	2.21	59.78	41.29	47.3

Date: 4/25/15				**Site: DOE Site 2**		
Location: CP-11 3" towards 116				**Operators: MNR-MAH**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12/12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weight (g)**	**Dry Weight (g)**	**Water Content (%)**
1	20.9	5.70	2.24	21.81	17.84	25.4
2	72.1	19.67	2.27	38.34	31.02	25.5
3	41.7	11.38	2.25	21.34	17.94	21.7
4	13.2	3.60	2.24	42.07	29.96	43.7
5	30.1	8.21	2.24	40.49	30.78	34.0
6	52.9	14.43	2.21	55	40.35	38.4
7	89.1	24.31	2.26	36.8	28.04	34.0
8	83.8	22.86	2.3	52.87	38.74	38.8
9	93.6	25.54	2.25	62.36	44.42	42.5
10	88.9	24.26	2.23	51.2	35.63	46.6
11	83.8	22.86	2.22	53.96	37.75	45.6
12	19.8	5.40	2.24	58.67	39.14	52.9

Date: 4/25/15				**Site: DOE Site 2**		
Location: CP-12 3.5" towards Du Bois				**Operators: MNR-MAH**		
Vane Dimensions: 2"-1"-1"				**Readout: CDI Multitorq**		
Shaft Geometry: SS5				**Lead Geometry: 12/12/12**		
Depth (ft.)	**Peak Torque (in-lbs)**	**Peak S_u (psi)**	**Tare Weight (g)**	**Wet Weight (g)**	**Dry Weight (g)**	**Water Content (%)**
1	3	0.82	2.21	20.06	15.42	35.1
2	70.6	19.26	2.22	35.06	26.2	36.9
3	58.2	15.88	2.23	33.73	26.08	32.1
4	47.2	12.88	2.24	49.36	36.64	37.0
5	79.7	21.75	2.22	31.7	25.98	24.1
6	51.3	14.00	2.22	23.31	18.45	29.9
7	53.6	14.62	2.22	43.67	32.62	36.3
8	39.9	10.89	2.22	42.27	30.75	40.4
9	43	11.73	2.25	39.01	28.42	40.5
10	41.4	11.30	2.22	34.69	24.99	42.6
11	50.6	13.81	2.27	49.16	34.43	45.8
12	39.2	10.70	2.21	43.32	30.27	46.5