INSTALLATION METHODOLOGY

INSTALLATION METHODOLOGY
SECTION 6

CONTENTS

SYMBOLS USED IN THIS SECTION

DL	Dead Load	6-4
LL	Live Load	6-4
FS	Factor of Safety	6-4
SPT	Standard Penetration Test	6-5
N	SPT Blow Count	6-5
N_q	Bearing Capacity Factor	6-5
GWT	Ground Water Table	6-5
PL	Proof Load	6-6
Q_{ult}	Ultimate Uplift Capacity	6-8
Kt	Empirical Torque Factor	6-8
T	Average Installation Torque	6-8
SS	Square Shaft	6-8
RS	Round Shaft	6-8
H_d/S_d	Helix to Shaft Diameter Ratio	6-11
Q_{act}	Actual Capacity	6-13
Q_{calc}	Calculated Capacity	6-13
Q_{act}/Q_{calc}	Capacity Ratio	6-13
CID	Cubic Inch Displacement	6-16

DISCLAIMER

The information in this manual is provided as a guide to assist you with your design and in writing your own specifications.

Installation conditions, including soil and structure conditions, vary widely from location to location and from point to point on a site.

Independent engineering analysis and consulting state and local building codes and authorities should be conducted prior to any installation to ascertain and verify compliance to relevant rules, regulations and requirements.

Hubbell Power Systems, Inc., shall not be responsible for, or liable to you and/or your customers for the adoption, revision, implementation, use or misuse of this information. Hubbell, Inc., takes great pride and has every confidence in its network of installing contractors and dealers.

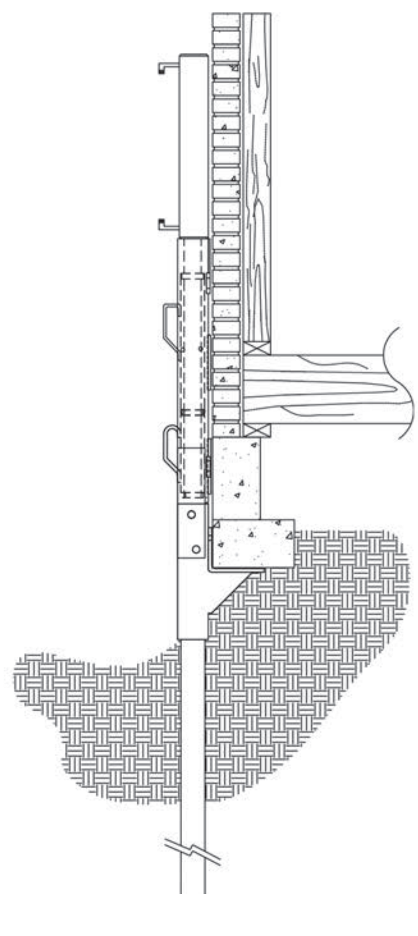
Hubbell Power Systems, Inc., does NOT warrant the work of its dealers/installing contractors in the installation of CHANCE® Civil Construction foundation support products.

ATLAS RESISTANCE® PIERS

ATLAS RESISTANCE® Piers develop their capacity as a result of a pile tip or end bearing reaction in soil or rock that is achieved by hydraulically driving hollow pier sections to suitable strata utilizing the reaction weight of an existing structure or any other mass or reaction assembly capable of resisting pushing loads in excess of design loads required. The friction reduction collar on the initial or starter section allows for an end bearing pile. Most ATLAS RESISTANCE® Piers are installed to a force equal to a minimum of 150% of the calculated total load at each pier placement. The total load condition is a sum of the structure Dead Loads (DL) and all known potential Live Loads (LL). In addition to the usual calculated loads, it is extremely important to include loads imposed from soil overburden over a projected area, primarily outside of the foundation wall footprint (toe or heel) of the footing. The area of the projection plus the height of soils above it produce a loading condition that is quite often in excess of the structure load itself. When lifting the structure is desired, an additional "soil wedge" area and/or volume should be considered relative to the soil type and its particular characteristics. To be conservative in design calculations it is prudent to consider the long term loading effect from soils outside of the vertical and horizontal plane of the soil overburden even when stabilization only is desired.

LOAD VERIFICATION

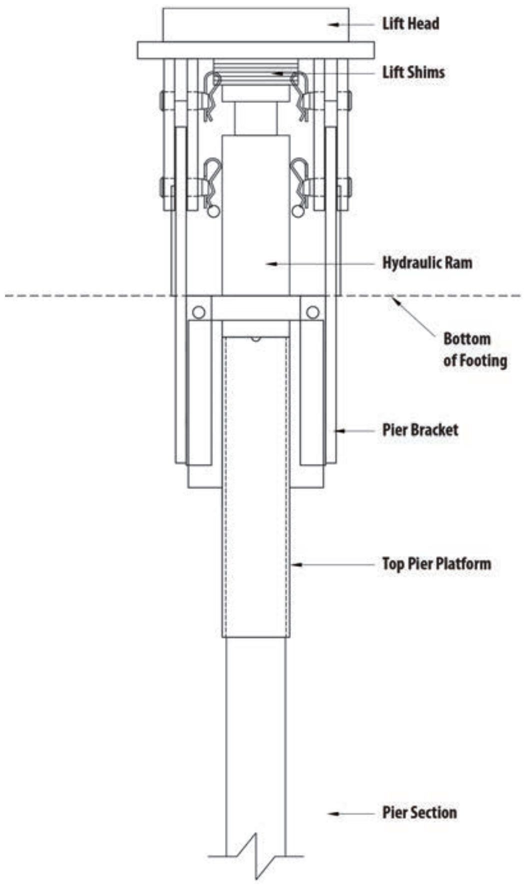
ATLAS RESISTANCE® Piers are installed using hydraulic cylinders with known effective areas. Although larger cylinders are available for extreme load conditions, the standard installation cylinders have an effective area of 8.29 in^2. The effective area of the cylinder is multiplied by the hydraulic pressure monitored by a gauge mounted between the hydraulic pump and the cylinder. The net result of this number is the actual force (in lbs) achieved as the pier sections are driven against the reaction weight of the structure until the required load is achieved or structure lift occurs. Additional pier sections are added as necessary until a competent bearing stratum is reached. The force is logged at the end of each pier section driven on the field installation log.



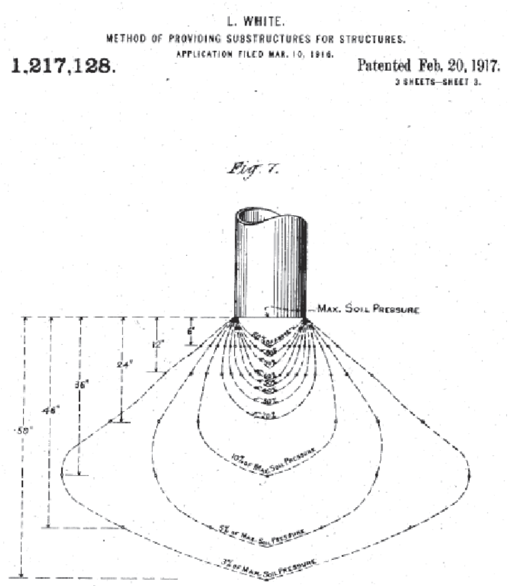
Installation Configuration
Figure 6-1

TWO STAGE SYSTEM METHODOLOGY

The installation of ATLAS RESISTANCE® Piers incorporates a two stage method that consists of driving each pier individually using the reaction from adjacent line loads. The integrity of the foundation determines the extent to which additional Factors of Safety (FS) can be achieved between the installation force and final lift loads. Figure 6-1 provides a schematic drawing that illustrates the installation of pier sections. The second stage occurs when all or the majority of the piers are loaded simultaneously using a manifold or series of manifolds and hydraulic rams placed at each pier. The manifolds and rams are connected to a pump or series of pumps depending on the number of piers being lifted. During the lifting stage the hydraulic pressure is monitored on each manifold system gauge. Typical 25 ton lifting rams have an effective area of 5.15 in2. The load at each pier is monitored at the final lock off and noted on the field installation logs. The actual lift or lock off load at each pier can then be compared to the installation loads at each pier to determine the actual Factor of Safety developed between installation loads and actual loads required to produce structural lift and support. Figure 6-2 provides a schematic drawing illustrating the lift stage.



Restoration Using Lift Head and Hydraulic Ram
Figure 6-2



Assumed Stress Bulb Under Pile Tip
Figure 6-3

BEARING CAPACITY

The compressive bearing capacity of ATLAS RESISTANCE® Piers is developed predominantly by end-bearing due to the friction reduction collar at the lead end of the initial or starter section. Friction calculations do not normally enter into design steps unless required to comply with some older municipal codes. Increased tip areas (larger diameter pipe) will typically increase load resistance during installation of the pile. Standard pier section diameters are 2-7/8", 3-1/2", and 4-1/2". The selection of pier size is determined through consideration of pile load requirement, column stability (buckling concerns) structure integrity and the ability to drive the pile past seasonal zones of influence relative to available reaction forces. Bracket assemblies are coupled with the appropriate pier section size to service both the geotechnical and structural requirements.

CLAY SOILS

In clay soil conditions defined as very stiff to hard, i.e., Standard Penetration Test (SPT) "N" values in excess of 35-40 blows/foot, it has been shown empirically that an ATLAS RESISTANCE® Pier can generate substantial end-bearing capacity, often in excess of 50,000-60,000 lbs of bearing resistance. While the high capacities defy absolute calculation for both very dense sand and hard clay, empirical data developed over the last several decades gives evidence to this phenomenon. Data developed by A.S. Vesic (1972) for the Transportation Research Board suggests that hard/dense soil develops very high capacities due to the formation of a larger pile bulb at the base of an end-bearing foundation. This phenomenon results in higher values for the bearing capacity factor (Nq), especially for driven piles. Figure 6-3 is an excerpt from Patent 1.217.128 issued to L. White. It is a graphical rendition of the assumed large stress bulb formed under a pile tip.

SAND SOILS

ATLAS RESISTANCE® Piers also develop substantial end-bearing capacities in granular soils, but the sand or gravel must typically exhibit a high relative density with "N" values in excess of 30-35 blows/ft. The same pile bulb described above for clay soils will form at the base of an ATLAS RESISTANCE® Pier in sand soils. In granular soils, the overburden pressure (effective vertical confining stress) has a large influence on bearing capacity, so the deeper the pier tip is embedded, the higher the bearing capacity will be for a given sand deposit of uniform density. A design condition consisting of a shallow ground water table (GWT) will require ATLAS RESISTANCE® Piers to be installed to a sufficient depth to counteract the reduction in confining stress caused by the buoyancy effect of the water.

BEDROCK BEARING SURFACE

The presence of an intact bedrock surface represents an ideal ground condition for a totally end-bearing load transfer for any type of foundation. In this case the ATLAS RESISTANCE® Pier is installed to the rigid bearing surface represented by the bedrock layer, with load confirmation being verified by monitoring of the hydraulic pressure and effective area of the installation cylinder. The design capacity in this case is directly related to the structural strength of the pier shaft and bracket assembly.

INSTALLATION OVERVIEW

When the loading, structural and geotechnical conditions have been determined, the proper pier brackets and pier sections can be selected. Following excavation for the installation, the footing (if present) is notched to a point flush with the wall to be underpinned. Should steel reinforcement be encountered, notify the Engineer of Record prior to cutting. This procedure is performed to minimize the eccentricity of the pier assembly. In situations where notching the footing is prohibited, consideration needs to be given to the published pier capacity ratings if the footing extension from the wall is excessive, possibly increasing the eccentric load on the pier assembly resulting in a lower capacity. The bottom of the footing should be prepped and/or a load bearing grout added between the pier bracket and footing to provide a uniform bearing connection. This is a critical point, especially in high load conditions. Failure to comply with this step could result in a point load on the bracket and cause an early bracket failure.

When the bracket and installation equipment are properly positioned and anchored to the foundation or wall, the starter section can be placed in a vertical and plumb position. Activate the hydraulic pump to advance and retract the installation cylinder as necessary to drive the pier sections (see photo at top right). The pressure is recorded at the end of each 42" pier section. Continue driving pier sections until reaching strata capable of resisting the estimated Proof Load (PL) or until structure lift occurs. When approaching the end of the drive, a good rule of thumb is to drive pipe until either the structure begins to lift and/or the pressure continues to build. If a small amount of movement has occurred but the pressure remains constant, an experienced installer will continue to drive pipe until either a more significant movement is noted or a consistent build in pressure occurs. Depending on the integrity of the foundation and the comfort level of the installer, this will often result in substantial Factors of Safety in excess of 1.5. When driving the pier pipe is completed, the installation equipment is removed, pier sections are cut off to an appropriate elevation relative to the bracket type and load transfer components are set in place.

When all piers have been installed, the manifolds and hydraulics are loaded uniformly as much as possible (see photo at bottom right). Upon transfer of load to the entire pier assembly, lift pressures are noted at each pier and recorded on the field log. The actual verified Factor of Safety between installation pre-load and final lock off can then be confirmed. Table 6-1 is an example of the driving (installation) and lift forces that could be involved in the installation of ATLAS RESISTANCE® Piers.

INSTALLATION METHODOLOGY

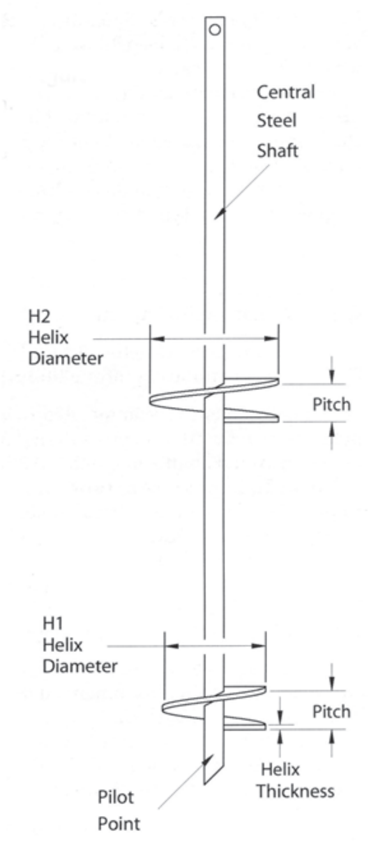
Installation Load vs Lift Load, Table 6-1

FIRST STAGE – INSTALLATION LOAD SUMMARY (DRIVE) – STD. DRIVE CYLINDER EFFECTIVE AREA (SQ. IN) 8.29			SECOND STAGE – PIER LIFT/LOCK SUMMARY (LIFT) – STD LIFT RAM EFFECTIVE AREA (SQ. IN) 5.15			F/S DRIVE vs LIFT
PIER NUMBER	PSI	LOAD	PIER NUMBER	PSI	LOAD	
1	4,200	34,818	1	4,000	20,600	**1.7**
2	4,600	38,134	2	4,000	20,600	**1.9**
3	4,600	38,134	3	4,500	23,175	**1.6**
4	4,800	39,792	4	4,500	23,175	**1.7**
5	5,000	41,450	5	4,800	24,720	**1.7**

Refer to the *ATLAS RESISTANCE® Standard, Heavy Duty and Modified 2-Piece Pier Systems Model Specification* found under the Resources tab on www.abchance.com for detailed installation instructions.

CHANCE® HELICAL PILE/ANCHORS

By definition, a helical pile/anchor is a low soil displacement foundation element specifically designed to minimize disturbance during installation. In their simplest forms, helical pile/anchors consist of at least one helix plate and a central steel shaft (see Figure 6-4). The helix geometry is very important in that it provides the downward force or thrust that pulls a helical pile/anchor into the ground. The helix must be a true ramped spiral with a uniform pitch to maximize efficiency during installation. If the helix is not formed properly, it will disturb the soil more than if a true helix advances at a rate of one pitch per revolution. The central steel shaft transmits the rotational energy or torque from the machine to the helix plate(s). Most helical piles in North America use a low displacement (less than 4.5 inches (114 mm) diameter shaft in order to reduce friction and soil displacement during installation. A helical pile/anchor functions very similar to a wood screw except that it has a discontinuous thread-form and is made to a much larger scale.



Helical Pile/Anchor
Figure 6-4

INSTALLATION TORQUE/LOAD CAPACITY RELATIONSHIP

Before installation, a helical pile/anchor is simply a screw with a discontinuous thread and a uniform pitch. When installed into soil, a helical pile/anchors functions as an axially loaded end-bearing deep foundation. The helix plates serve a two-fold purpose. The first purpose is to provide the means to install the helical pile/anchor. The second purpose is to provide the bearing element means for load transfer to soil. As such, helical pile/anchor design is keyed to these two purposes, both of which can be used to predict the ultimate capacity.

Section 5 detailed how helix plates act as bearing elements. The load capacity is determined by multiplying the unit bearing capacity of the soil at each helix location by the projected area of each helix. This capacity is generally defined as the ultimate theoretical load capacity because it is based on soil parameters either directly measured or empirically derived from soil exploration sounding data.

The purpose of this section is to provide a basic understanding of how installation torque (or installation energy) provides a simple, reliable means to predict the load capacity of a helical pile/anchor. More importantly, this prediction method is independent of the bearing capacity method detailed in Section 5, so it can be used as a "field production control" method to verify load capacity during installation.

The installation torque-to-load capacity relationship is an empirical method originally developed by the A. B. Chance Company in the late 1950's and early 1960's. Hubbell Power Systems, Inc. has long promoted the concept that the torsion energy required to install a helical anchor/pile can be related to the ultimate load capacity of a pile/anchor. Precise definition of the relationship for all possible variables remains to be achieved. However, simple empirical relationships, originally derived for tension loads but also valid for compression loads, have been used for a number of years. The principle is that as a helical anchor/pile is installed (screwed) into increasingly denser/harder soil, the resistance to installation (called installation energy or torque) will increase. Likewise, the higher the installation torque, the higher the axial capacity of the installed pile/anchor. Hoyt and Clemence (1989) presented a landmark paper on this topic at the 12th International Conference on Soil Mechanics and Foundation Engineering. They proposed the following formula that relates the ultimate capacity of a helical pile/anchor to its installation torque:

$$Q_{ult} = K_t \times T \qquad \textbf{Equation 6-1}$$

where

Q_{ult} = Ultimate uplift capacity [lb (kN)]

K_t = Empirical torque factor [ft^{-1} (m^{-1})]

T = Average installation torque [lb-ft (kN-m)]

Hoyt and Clemence recommended K_t = 10 ft^{-1} (33 m^{-1}) for square shaft (SS) and round shaft (RS) helical anchors less than 3.5" (89 mm) in diameter, 7 ft^{-1} (23 m^{-1}) for 3.5" diameter round shafts, and 3 ft^{-1} (9.8 m^{-1}) for 8-5/8" (219 mm) diameter round shafts. The value of K_t is not a constant - it may range from 3 to 20 ft^{-1} (10 to 66 m^{-1}), depending on soil conditions, shaft size and shape, helix thickness, and application (tension or compression). For CHANCE® Type SS Square Shaft Helical Piles/Anchors, K_t typically ranges from 10 to 13 ft^{-1} (33 to 43 m^{-1}), with 10 ft^{-1} (33 m^{-1}) being the recommended default value. For CHANCE® Type RS Pipe Shaft Helical Piles/Anchors, K_t typically ranges from 3 to 10 ft^{-1} (10 to 33 m^{-1}), with 9 ft^{-1} (30 m^{-1}) being the recommended default for Type RS2875; 7 ft^{-1} (23 m^{-1}) being the recommended default for Type RS3500.300; and 6 ft^{-1} (20 m^{-1}) being the recommended default for Type RS4500.337.

The Canadian Foundation Engineering Manual (2006) recommends values of K_t = 7 ft^{-1} for pipe shaft helical piles with 90 mm OD, and K_t = 3 ft^{-1} for pipe shaft helical piles approaching 200 mm OD.

The correlation between installation torque (T), and the ultimate load capacity (Q_{ult}) of a helical pile/anchor, is a simple concept but a complicated reality. This is partly because there are a large number of factors that can influence the determination of the empirical torque factor K_t. A number of these factors (not including soil), are summarized in Table 6.2.

It is important to understand that torque correlation is valid when the helical pile/anchor is advancing at a rate of penetration nearly equal to one helix pitch per revolution. Large displacement shafts [>8-5/8" (219mm)] are less likely to advance at this rate, which means torque correlation cannot be used as a means to determine capacity.

Factors Influencing K_t, Table 6-2

Factors Affecting Installation Torque (T)	Factors Affecting Ultimate Capacity (Q_{ult})
Method of Measuring Installation Torque (T)	Number and Size of Helix Plates
Installed Depth Used to Determine "Average" Torque	Direction of Loading (Tension or Compression)
Applied Down-Force or "Crowd"	Geometry of Couplings
Rate of Rotation	Spacing of Helix Plates
Alignment of Pile/Anchor	Shape and Size of Shaft
Rate of Advance	Time between Installation and Loading
Geometry of Couplings	
Shape and Size of Shaft	
Shape and Size of Shaft	
Number & Size of Helix Plates	
Pitch of Helix Plates	

The factors listed in Table 6-2 are some of the reasons why Hubbell Power Systems, Inc. has a dealer certification program. Contractors who install helical piles/anchors are trained in the proper methods and techniques before they are certified. In order for Equation 6-1 to be useful, installation torque must be measured. There are a variety of methods used to measure torque. Hubbell Power Systems, Inc. offers two in-line torque indicators; in-line indicators are the best method to determine torque for capacity prediction. Other useful methods to measure torque are presented later in this section. For torque correlation to be valid, the rate of penetration should be between 2.5" to 3" per revolution. The rotation speed should be consistent and in the range of 5 to 15 RPM. And, the minimum effective torsional resistance criterion (the average installation torque) should be taken over the last 3 feet of penetration; unless a single helix pile is used for compression load, where it is appropriate to use the final (last) installation torque.

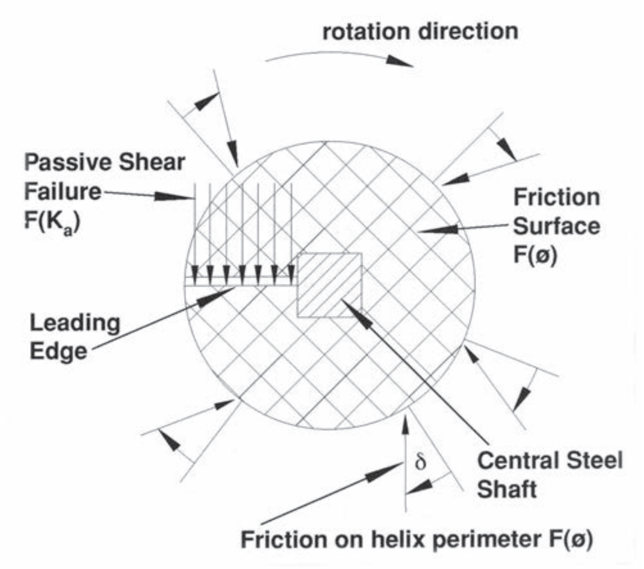
ICC-ES Acceptance Criteria AC358 for Helical Pile Systems and Devices Section 3.13.2 provides torque correlation (K_t) values for conforming helical pile systems based on shaft size and shape. They are the same as recommended by Hubbell Power Systems, Inc. and by Hoyt and Clemence. Hubbell Power Systems, Inc. helical piles are conforming per AC358. The AC358 K_t values are the same for both tension and compression axial loads.

The International Building Code (IBC) 2009 & 2012 Section 1810.3.3.1.9 states there are three ways to determine the load capacity of helical piles – including well documented correlations with installation torque.

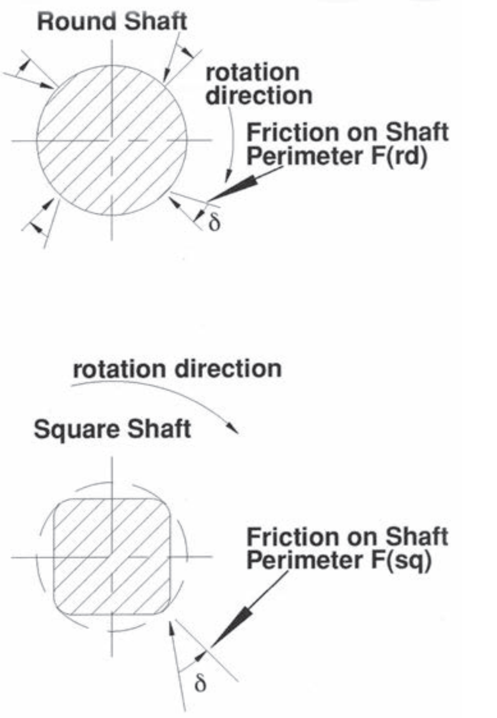
Soil Factors Influencing K_t

Locating helix bearing plates in very soft, loose, or sensitive soils will typically result in K_t values less than the recommended default. This is because some soils, such as salt leached marine clays and lacustrine clays, are very sensitive and lose considerable shear strength when disturbed. It is better to extend the helical pile/anchor beyond sensitive soils into competent bearing strata. If it's not practical to extend the helical pile/anchor beyond sensitive soils, testing is required to determine the appropriate K_t.

Full-scale load testing has shown that helical anchors/piles typically have at least the same capacity in compression as in tension. In practice, compression capacity is generally higher than tension capacity because the pile/anchor bears on soil below rather than above the helix plates, plus at least one helix plate is bearing on undisturbed soil. Soil above the bearing plates is disturbed by the slicing action of the helix, but not overly disturbed by being "augured" and removed. Typically, the same values of K_t are used for both tension and compression applications. This generally results in conservative results for compression applications. A poorly formed helix shape will disturb soil enough to adversely affect the torque-to-capacity relationship, i.e., K_t is reduced. To prevent this, Hubbell Power Systems, Inc. uses matching metal dies to form helix plates which are as near to a true helical shape as is practically possible. To understand all the factors that K_t is a function of, one must first understand how helical piles/anchors interact with the soil during installation.



Top View of Helix
Figure 6-5



Friction Forces Action on Central Shafts
Figure 6-6

Torque Resistance Factors

There are two main factors that contribute to the torque resistance generated during a pile/anchor installation, friction and penetration resistance. Of the two factors, friction is the larger component of torque resistance.

Friction Has Two Basic Parts:

(1) Friction on the helix plate and friction along the central steel shaft. Friction resistance increases with helix size because the surface area of the helix in contact with the soil increases with the square of the diameter (see Figure 6-5). Likewise, friction resistance increases with pitch size, i.e., the larger the pitch, the greater the resistance. This is analogous to the difference between a coarse thread and a fine thread bolt. Basic physics tells us that "work" is defined as force time's distance. A larger pitch causes the helix to travel a greater distance per revolution, thus more work is required.

(2) Friction along the central steel shaft is similar to friction on the helix plate. Friction resistance increases with shaft size because the surface area of the shaft in contact with the soil increases as the diameter increases. An important performance factor for helical pile/anchors is the helix to shaft diameter ratio (H_d/S_d). The higher the H_d/S_d ratio, the more efficient a given helical pile/anchor will be during installation. Friction resistance also varies with shaft shape (see Figure 6-6). A round shaft may be the most efficient section to transmit torque energy, but it has the disadvantage of full surface contact with the soil during installation. When the central steel shaft is large (> 3" [76 mm] in diameter) the shaft friction resistance contributes significantly to the total friction resistance. However, a square shaft (< 3" [76 mm] in diameter) has only the corners in full surface contact with the soil during installation, thus less shaft friction resistance. Friction energy (energy loss) required to install a helical pile/anchor is related to the helix and shaft size. The total energy loss due to friction is equal to the sum of the

friction loss of all the individual helix plates plus the length of shaft subjected to friction via contact with the soil.

Penetration Resistance Has Two Basic Parts:

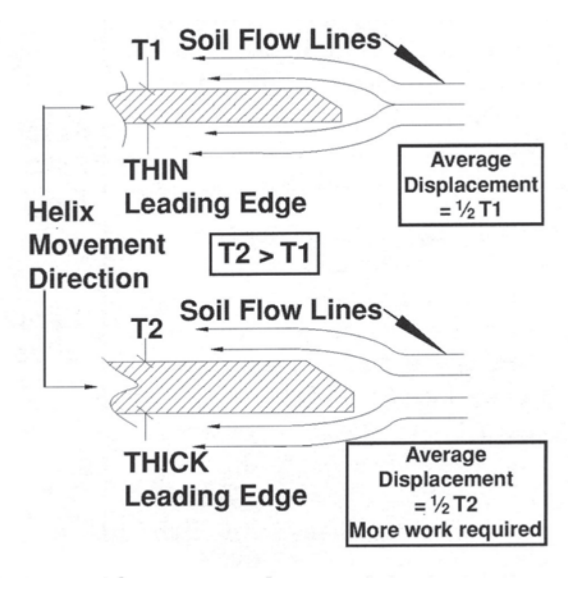
(1) Shearing resistance along the leading edge of the helix plate to allow passage of the helix plate and penetration resistance of the shaft/pilot point. Shearing resistance increases with helix size because leading edge length increases as the diameter increases. Shearing resistance also increases with helix thickness because more soil has to be displaced with a thick helix than with a thin helix (see Figure 6-7). The average distance the soil is displaced is equal to approximately 1/2 the helix thickness, so as the thickness increases the more work (i.e., energy) is required to pass the helix through the soil.

(2) Penetration resistance increases with shaft size because the projected area of the hub/pilot point increases with the square of the shaft radius (see Figure 6-8). The average distance the soil is displaced is approximately equal to the radius of the shaft, so as the shaft size increases, the more work (i.e., energy) is required to pass the hub/pilot point through the soil.

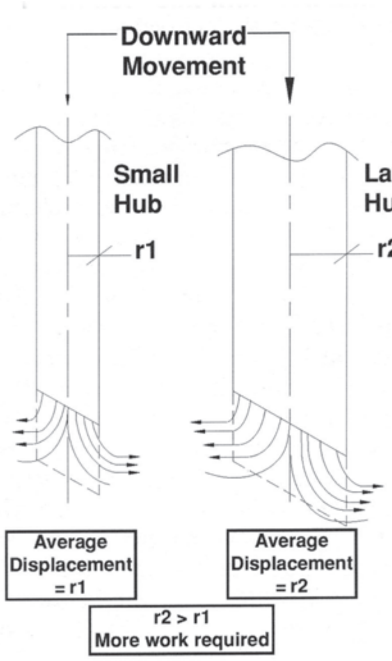
The penetration energy required to install a helical pile/anchor is proportional to the volume of soil displaced times the distance traveled. The volume of soil displaced by the anchor/pile is equal to the sum of the volumes of all the individual helix plates plus the volume of the soil displaced by the hub/pilot point in moving downward with every revolution.

Energy Relationships

Installation energy must equal the energy required to penetrate the soil (penetration resistance) plus the energy loss due to friction (friction resistance). The installation energy is provided by the machine and consists of two components, rotation energy supplied by the torque motor and downward force (or crowd) provided by the machine. The rotation energy provided by the motor along with the inclined plane of a true helical



Section View of Leading Edge with Flow Lines
Figure 6-7



Shaft/Pilot Point with Flow Lines
Figure 6-8

INSTALLATION METHODOLOGY

form generates the thrust necessary to overcome the penetration and friction resistance. The rotational energy is what is termed "installation torque." The downward force also overcomes penetration resistance, but its contribution is usually required only at the start of the installation, or when the lead helix is transitioning from a soft soil to a hard soil.

From an installation energy standpoint, the perfect helical pile/anchor would consist of an infinitely thin helix plate attached to an infinitely strong, infinitely small diameter central steel shaft. This configuration would be energy efficient because penetration resistance and friction resistance is low. Installation torque to capacity relationships would be high. However, infinitely thin helix plates and infinitely small shafts are not realistically possible, so a balanced design of size, shape, and material is required to achieve consistent, reliable torque to capacity relationships.

As stated previously, the empirical relationship between installation torque and ultimate capacity is well known, but not precisely defined. As one method of explanation, a theoretical model based on energy exerted during installation has been proposed [Perko (2000)]. The energy model is based on equating the energy exerted during installation with the penetration and friction resistance. Perko showed how the capacity of an installed helical pile/anchor can be expressed in terms of installation torque, applied downward force, soil displacement, and the geometry of the pile/anchor. The model indicates that K_t is weakly dependent on crowd, final installation torque, number of helix plates, and helix pitch. The model also indicates that K_t is moderately affected by helix plate radius and strongly affected by shaft diameter and helix plate thickness.

The important issue is energy efficiency. Note that a large shaft helical anchor/pile takes more energy to install into the soil than a small shaft pile/anchor. Likewise, a large diameter, thick helix takes more energy to install into the soil than a smaller diameter, thinner helix. The importance of energy efficiency is realized when one considers that the additional energy required to install a large displacement helical pile/anchor contributes little to the load capacity of the pile/anchor. In others words, the return on the energy "investment" is not as good. This concept is what is meant when Hubbell Power Systems, Inc. engineers say large shaft diameter and/or large helix diameter (>16" diameter) pile/anchors are not efficient "torque-wise." This doesn't mean large diameter or large helix plate piles are not capable of producing high load capacity, it just means the installation energy, i.e. machine, must be larger in order to install the pile.

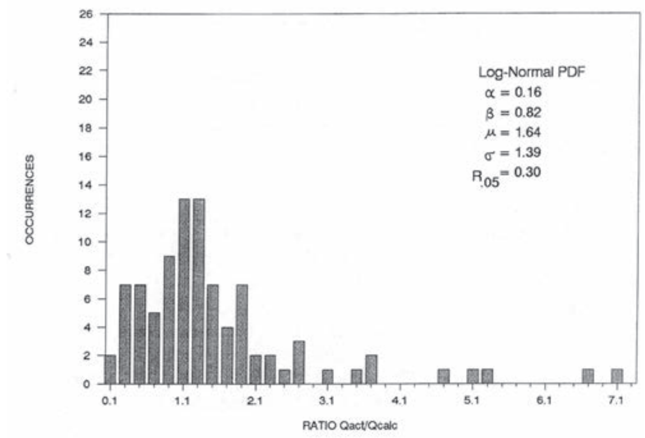
If one considers an energy balance between the energy exerted during loading and the appropriate penetration energy of each of the helix plates, then it can be realized that any installation energy not specifically related to helix penetration is wasted. This fact leads to several useful observations. For a given helix configuration and the same available installation energy (i.e., machine):

1. Small displacement shafts will disturb less soil than large displacement shafts.
2. Small displacement shafts result in less pore pressure buildup than large displacement shafts.
3. Small displacement shafts will penetrate farther into a given bearing strata than large displacement shafts.
4. Small displacement shafts will penetrate soils with higher SPT "N" values than large displacement shafts.
5. Small displacement shafts will generate more axial load capacity with less deflection than large displacement shafts.
6. K_t varies inversely with shaft diameter.

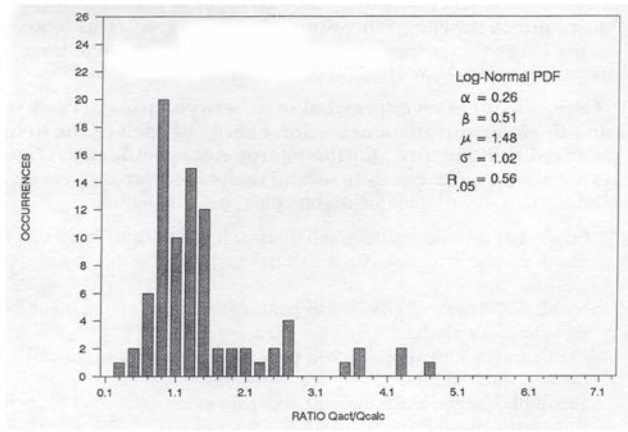
Reliability of Torque/Capacity Model

Hoyt and Clemence (1989) analyzed 91 tension load tests at 24 different sites with sand, silt and clay soils all represented. All of the tests used in the study were short term; most were strain controlled and included a final loading step of imposing continuous deflection at a rate of approximately 4 inches (102 mm) per minute. This final load was taken as the ultimate capacity. The capacity ratio Q_{act}/Q_{calc} was obtained for each test by dividing the actual capacity (Q_{act}) by the calculated capacity (Q_{calc}). Q_{calc} was calculated by using three different load capacity models: (1) Cylindrical shear, (2) Individual bearing, and (3) Torque correlation. These data were then compared and plotted on separate histograms (see Figures 6-9 and 6-10, cylindrical shear histogram not shown).

All three capacity models exhibited the capability of over-predicting pile/anchor capacity. This would suggest



Individual Bearing Method
Figure 6-9



Torque Correlation Model
Figure 6-10

the use of appropriate Factors of Safety. However, the authors did not discriminate between "good" and "poor" bearing soils when analyzing the results. In other words, some of the test data analyzed were in areas where the helix plates were located in soils typically not suitable for end bearing, (i.e., sensitive) clays and loose sands.

All three capacity models' mean values were quite close, but the range and standard deviation were significantly lower for the torque correlation method than for the other two. This improved consistency is probably due to the removal of several random variables from the capacity model. Therefore, the installation torque correlation method yields more consistent results than either of the other two methods. The installation torque method does have one disadvantage, however, in that it cannot be used until after the helical pile/anchor has been installed. Therefore, it is better suited to on-site production control and termination criteria than design in the office.

Perko (2012) suggested that if both individual bearing capacity and torque correlation are used to determine the bearing capacity of a helical pile/anchor, the resulting capacity will be accurate to within 97.7% reliability.

Measuring Installation Torque

The torque correlation method requires the installation torque to be measured and recorded in the field. There are several methods that can be used to measure torque, and Hubbell Power Systems, Inc. has a complete line of torque indicators to choose from. Each one is described below along with its advantages and disadvantages:

• Shaft Twist

A.B. Chance Company stated in early editions of the Encyclopedia of Anchoring (1977) that for standard SS5 Anchors, "the most secure anchoring will result when the shaft has a 1 to 1-1/2 twist per 5-foot section." Shaft twist is not a true torque-indicating device. It has been used as an indication of "good bearing soil" since Type SS anchors were first introduced in the mid-1960's. Shaft twist should not be used exclusive of a true torque-indicating device. Some of the reasons for this are listed below.

INSTALLATION METHODOLOGY


Shear Pin Torque Limiter
Figure 6-11

Advantages:

- Simple, cheap, easy to use.
- Doesn't require any additional tooling.
- Visible indication of torque.

Disadvantages:

- Qualitative, not quantitative torque relationship.
- Not very accurate.
- Shaft twist can't be correlated to installation torque on a consistent basis.
- Type SS5, SS150, SS175, SS200, and SS225 shafts twist, or wrap-up, at different torque levels.
- Shaft twist for a round shaft is not obvious without other means of reference.

• Shear Pin Torque Limiter

A shear pin torque limiter is a mechanical device consisting of two shear halves mounted to a central pin such that the shear halves are free to rotate (see Figure 6-11). Shear pins inserted into perimeter holes prevent the shear halves from rotating and are rated to shear at 500 ft-lb of torque per pin. Required torque can be achieved by loading the shear halves with the appropriate number of pins, i.e., 4000 ft-lb = 8 pins. The shear pin torque limiter is mounted in line with the torque motor and pile/anchor tooling.

Advantages:

- Simple design, easy to use.
- Tough and durable, will take a lot of abuse and keep working.
- Accurate within ± 5% if kept in good working condition.
- Torque limiter - used to prevent exceeding a specified torque.
- Relatively inexpensive to buy and maintain.
- Easy interchange from one machine to another.

Disadvantages:

- Point-wise torque indicator, i.e., indicates torque at separate points, not continuously.
- Requires constant unloading and reloading of shear pins.
- Limited to 10,000 ft-lb.
- Sudden release of torsional (back-lash) energy when pins shear.
- Fits tools with 5-1/4" bolt circle only.

• Digital Torque Indicator

A digital torque indicator is a device consisting of strain gauges mounted to a torsion bar located between two bolt flanges (see Figure 6-12). This tool measures installation torque by measuring the shear strain of the torsion bar. The digital display reads torque directly. The digital torque indicator is mounted in-line with the torque motor and
pile/anchor tooling.

Mechanical Dial Torque Indicator
Figure 6-12

Wireless Remote Display
Figure 6-13

Remote Data Logger
Figure 6-14

Advantages:

- Simple torsion bar & strain gauge design, easy to use.
- Continuous reading torque indicator.
- Digital display reads torque directly.
- Accurate within ± 2% if kept in good working condition.
- Fits tools with 5-1/4" and 7-5/8" bolt circles.
- Calibrated with equipment traceable to US Bureau of Standards before leaving plant.
- Can be used as a calibration tool for other types of torque indicators.
- Easy interchange from one machine to another.
- Reliable, continuous duty torque indicator.
- Comes with wireless remote display and an optional remote data logger.

Disadvantages:

- Drive tools must be switched out when installing different types of helical pile/anchor.

• DP-1 Differential Pressure Torque Indicator

A differential pressure torque indicator is a hydraulic device consisting of back-to-back hydraulic pistons; hoses, couplings, and a gauge (see Figure 6-15). Its' operation is based on the principle that the work output of a hydraulic torque motor is directly related to the pressure drop across the motor. The DP-1 hydraulically or mechanically "subtracts" the low pressure from the high to obtain the "differential" pressure. Installation torque is calculated using the cubic inch displacement and gear ratio of the torque motor. The DP-1 piston block and gauge can be mounted anywhere on the machine. Hydraulic hoses must be connected to the high and low pressure lines at the torque motor.

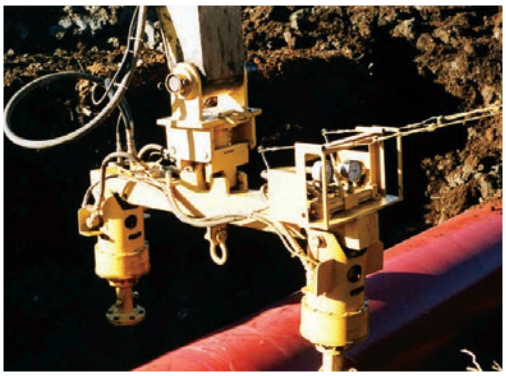
Advantages:

- Indicates torque by measuring pressure drop across hydraulic torque motor.
- No moving parts.
- Continuous reading torque indicator.
- Very durable - the unit is not in the tool string.
- Pressure gauge can be located anywhere on the machine.
- Analog type gauge eliminates "transient" torque peaks.

- Pressure gauge can be overlaid to read torque (ft-lb) instead of pressure (psi).
- Accurate within ± 5% if kept in good working condition.
- After mounting, it is always ready for use.
- Can be provided with multiple readout gauges.

Disadvantages:

- Requires significant initial installation setup time and material, i.e., hydraulic fittings, hoses, oil.
- Requires a hydraulic pressure-to-torque correlation based on the torque motor's cubic inch displacement (CID) and gear ratio.
- For two-speed torque motors, pressure-to-torque correlation changes depending on which speed the motor is in (high or low).
- Requires periodic recalibration against a known standard, such as the digital torque indicator, or shear pin torque limiter.
- Sensitive to hydraulic leaks in the lines that connect the indicator to the torque motor.
- Relatively expensive.
- Difficult interchange from one machine to another.



Differential Pressure
Torque Indicator
Figure 6-15

TORQUE INDICATOR and MOTOR CALIBRATION

All torque indicators require periodic calibration. Hubbell Power Systems, Inc. recommends that torque indicators be calibrated at least once per year. The digital torque indicator can be used in the field to calibrate other indicators, such as hydraulic pressure gauges and the DP-1. As torque motors age, the relationship between hydraulic pressure and installation torque will change. Therefore, it is recommended that hydraulic torque motors be periodically checked for pressure/torque relationship throughout their service life. Hubbell Power Systems, Inc. has torque test equipment available to recalibrate torque indicators and torque motors.

INSTALLATION TERMINATION CRITERIA

The Engineer of Record can use the relationship between installation torque and ultimate load capacity to establish minimum torque criteria for the installation of production helical piles/anchor. The recommended default values for K_t of [10ft^{-1} (33m^{-1})] for CHANCE® Type SS, [9ft^{-1} (30m^{-1})] for Type RS2875, [7ft^{-1} (23m^{-1})] for Type RS3500 and [6ft^{-1} (20m^{-1})] for Type RS4500 will typically provide conservative results.

For large projects that merit the additional effort, a pre-production test program can be used to establish the appropriate torque correlation factor (K_t) for the existing project soils. It is recommended that K_t be determined by dividing the ultimate load capacity determined by load test by the average installation (effective) torque taken over the last 3 feet (1 meter) of penetration into the bearing strata. The minimum effective torsional resistance criterion applies to the "background" resistance; torque spikes resulting from encounters with obstacles in the ground must be ignored in determining whether the torsional resistance criterion has been satisfied. The minimum effective torsional resistance criterion (the average installation torque taken over the last 3 feet of penetration) may not be applicable in certain soil profiles, such as, a relatively soft stratum overlying a very hard stratum. Engineering judgment must be exercised. See Appendix B for more detailed explanation of full-scale load tests. Large-scale projects warrant more than one pre-production test.

Whatever method is used to determine K_t, the production helical piles/anchors should be installed to a specified minimum torque and overall minimum depth. These termination criteria should be written into the construction documents. See www.abchance.com for model specifications that contain sections on recommended termination criteria for helical piles/anchors.

ICC-Evaluation Services ESR-2794 requires the following installation termination criteria:

- When installing single-helix anchors/piles that will be loaded in tension and all multi-helix anchors/piles, torsional resistance must be recorded at the final tip embedment minus 2 feet (710 mm) and final embedment minus 1 foot (305 mm), in addition to the resistance at final embedment.
- For single-helix compression piles, the final torsional resistance reading must be equal to or exceed the specified minimum.
- For multi-helix anchors and piles, the average of the final three torsional resistance readings must be equal to or exceed the specified minimum.
- The tip embedment and torsional resistance readings must be verified to meet or exceed the specified termination criteria before terminating installation.

Minimum Bearing Depth of Top-Most Helix

For deep foundation behavior, Hubbell Power Systems, Inc. recommends the minimum vertical depth of the top-most helix plate should be at least five times the diameter of the top-most helix. Natural factors such as frost depth and active zones (expansive soil) can also affect minimum depth. Hubbell Power Systems, Inc. recommends the minimum vertical depth of the top-most helix plate should be at least three times the diameter of the top most helix below the maximum frost depth or depth of active zone. For example, if the frost depth is 4 feet and the top-most helix plate is 12 in (305 mm), then the minimum depth to the top-most helix is 4 + 3 x (12 in) = 7 ft (2.1 m).

Tolerances

It is possible to install helical piles/anchors within reasonable tolerance ranges. For example, it is common to locate and install an pile/anchor within 1 inch (25 mm) of the staked location. Plumbness can usually be held within ± 1° of design alignment. For vertical installations a visual plumbness check is typically all that's required. For battered installations, an inclinometer can be used to establish the required angle. See www.abchance.com for model specifications that contain sections on recommended termination criteria for helical piles/anchors.

Torque Strength Rating

Torque strength is important when choosing the correct helical pile/anchor for a given project. It is a practical limit since the torque strength must be greater than the resistance generated during installation. In fact, the central steel shaft is more highly stressed during installation than at any other time during the life of the helical pile/anchor. This is why it is important to control both material strength variation and process capability in the fabrication process. Hubbell Power Systems, Inc. designs and manufactures helical piles/anchors to achieve the torque ratings published in the product family sections in Section 7. The ratings are listed based on product series, such as SS5, SS175, RS3500, etc.

The torque rating is defined as the maximum torque energy that should be applied to the helical pile/anchor during installation in soil. It is not the ultimate torque strength, defined as the point where the central shaft experiences torsion fracture. It is best described as an allowable limit, or "safe torque" that can be applied to the helical pile/anchor. Some other manufacturers publish torque ratings based on ultimate torque strength.

The designer should select the product series that provides a torque strength rating that meets or exceeds the anticipated torsion resistance expected during the installation. HeliCAP® Engineering Software (see Section 5) generates installation torque vs. depth plots that estimate the torque resistance of the defined soil profile. The plotted torque values are based on a K_t of 10 for Type SS and 9, 7 or 6 for Type RS. The torque ratings published in the product family sections in Section 7 are superimposed on the HeliCAP® Torque vs Depth plot, so the user can see at a glance when the estimated torque resistance equals or exceeds the torque rating of a given product series.

In some instances, it may be necessary to exceed the torque rating in order to achieve the minimum specified depth, or to install the helical pile/anchor slightly deeper to locate the helix plates farther into bearing stratum. This "finishing torque limit" should never exceed the published torque rating by more than 10%. To avoid fracture under impact loading due to obstruction laden soils, choose a helical product series with at least 30% more torque strength rating than the expected torque resistance. Note that the possibility of torsion fracture increases significantly as the applied torque increases beyond the published ratings. The need to install helical pile/anchors deeper is better accomplished by reducing the size and/or number of helix plates, or by choosing a helical product series with a higher torque rating.

References:

1. A.B. Chance Company, Encyclopedia of Anchoring, Bulletin 01-9401UA, 1977, A.B. Chance Company, Centralia, MO
2. A.B. Chance, a Division of Hubbell Power Systems, Inc., Product Selection Guide - Resistance Piers and Helical Piles for Remedial (Underpinning) Applications, Bulletin 01-0601, Hubbell, Inc., Centralia, MO, 2006.
3. Clemence, S. P., L.K. Crouch and R.W. Stephenson, Prediction of Uplift Capacity for Helical Anchors in Sand, Conference Proceedings from the Second Geotechnical Engineering Conference - Cairo University, Cairo, Egypt, 1994.
4. Crouch, L.K. and R.W. Stephenson (1991), Installation Torque Requirements and Uplift Capacity of Helical Soil Anchors Using Measured Geotechnical Properties of Soil, Doctoral Dissertation, University of Missouri-Rolla, Rolla, MO, 1994.
5. Hargrave, R.L., and R.E. Thorsten, Helical Piers in Expansive Soils of Dallas,Texas, Proceedings of the 7th International Conference on Expansive Soils, 1992.
6. Hoyt, R.M. and S.P. Clemence, Uplift Capacity of Helical Anchors in Soil, Proceedings of the 12th International Conference on Soil Mechanics and Foundation Engineering, Rio de Janeiro, Brazil, 1989.
7. Perko, Howard A., Energy Method for Predicting Installation Torque of Helical Foundations and Anchors, Proceedings of Sessions of Geo-Denver 2000, ASCE Geotechnical Special Publication N0. 100, 2000.