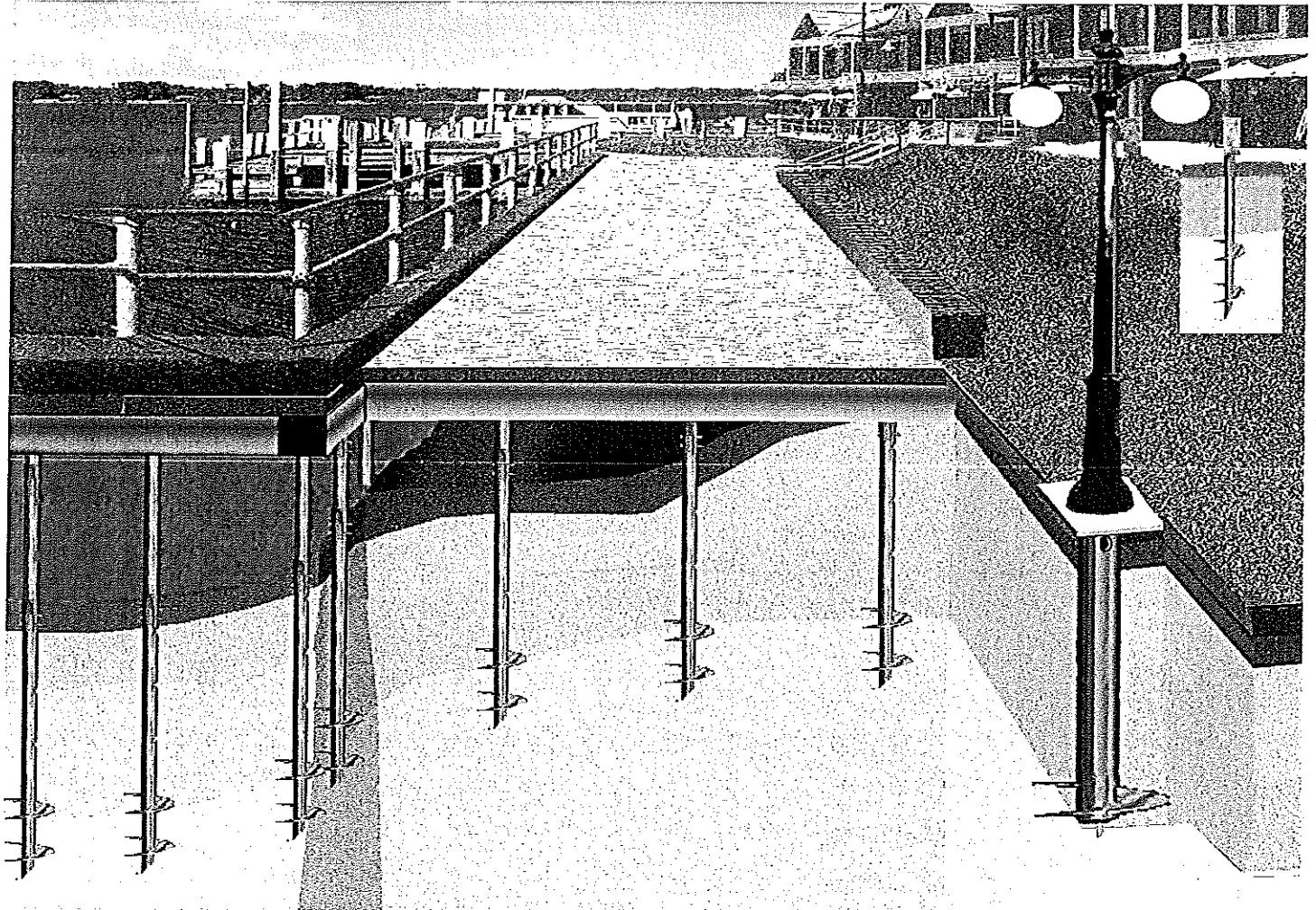


**HELICAL PIER
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SCREW PILE DESIGN ENGINEERING HANDBOOK

By: Richard Schmidt, P. Eng. / Mamdouh Nasr, M. Engineer

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ALMITA MANUFACTURING LTD
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HPS

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Forward

The purpose of this manual is to briefly discuss Screw Pile design. It is our goal to make this manual as user friendly, as possible, so we will continue to make changes, and updates. If there are sections that need further explanation, or if there is additional information you would like included in a future version, please feel free to contact me.

This manual is available at www.helicalpiersystems.com

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Introduction to Screw Piles

A screw piling is a circular hollow steel pipe section (shaft) with one or more tapered steel plates (helixes) welded to the shaft. The plates are shaped as a helix with a carefully controlled pitch, which allows the pile to be inserted, with minimal soil disruption, into the ground. The central shaft is used to transmit torque during installation and to transfer axial loads to the helical plates upon foundation loading. The central shaft also provides a major component of the resistance to lateral loading. The pile is directed toward the soil and mechanically rotated with constant downward pressure, advancing the pile into the soil. Once installed, the anchor has bearing capacity in both tension and compression in the subsurface by transferring the structures load to the bearing stratum. The pile installation angle can range from vertical to nearly horizontal.

Screw pile foundations are also referred to as Helical Anchors, Screw Anchors, Torque Piles and/or Helical Piles or Piers. For this manual, screw anchors will assume to be in tension and screw piles in compression. *Figure AA.* shows a *typical pile* configuration for pilings with shaft sizes in excess of 3-1/2" diameter. *Figure BB.* shows a *typical pier* configuration.

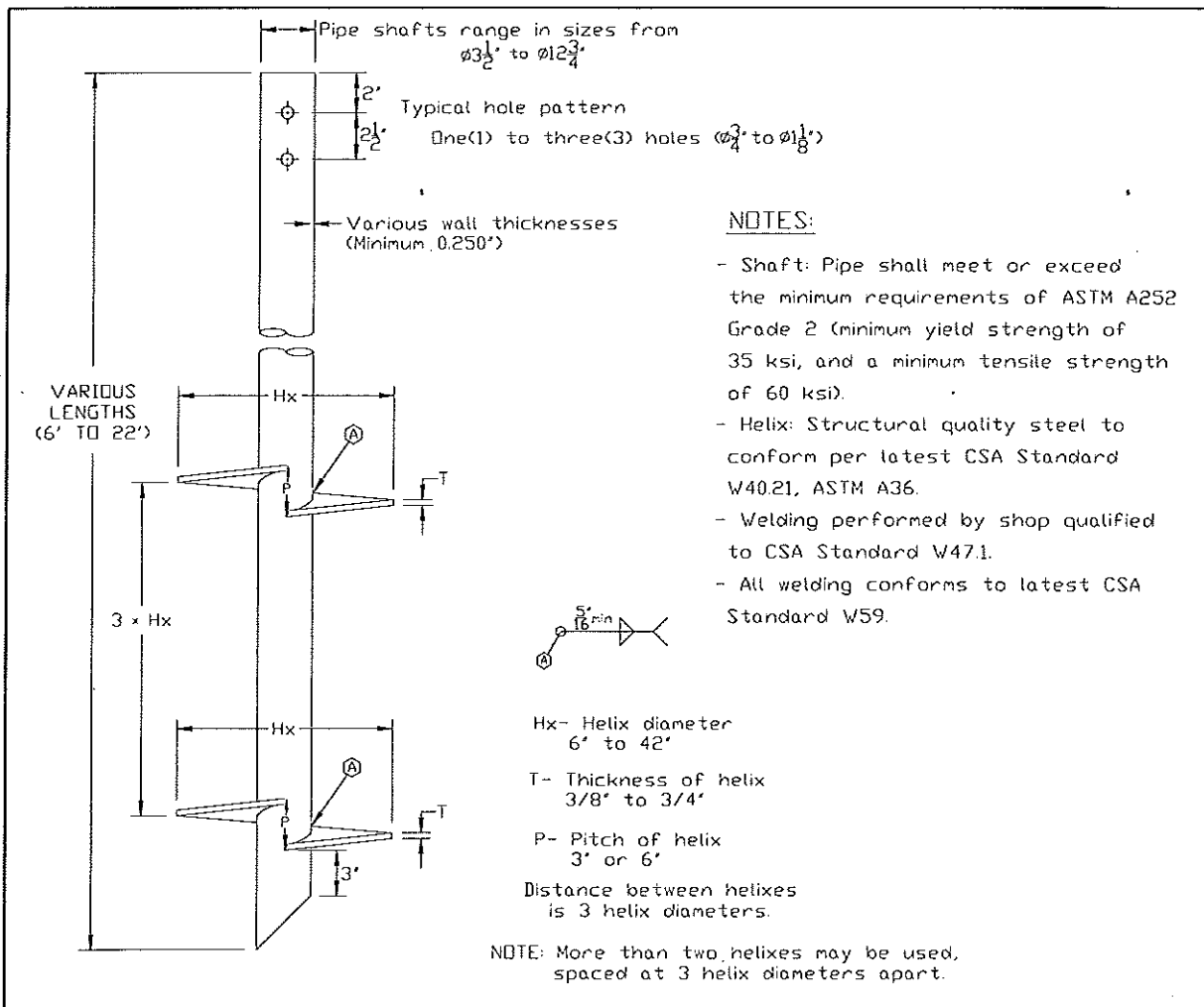


Figure AA. Multi-Helix Screw Pile

Screw Piles can be manufactured using almost any pipe size. Typical pipe sizes range from 2-7/8" to 16" O.D., although pipe in excess of 30" has been used. Helix sizes are dependent on the size of pipe, soil conditions and applied loads, ranging from 6" to larger than 42" in diameter. The length of the screw pile is generally limited to the available reach of the installation equipment (in most cases, 20 feet or less). Installation depth is limited by or controlled by the available torque and depth of favourable soil. To increase the depth of a pile, additional lengths can be welded or bolted on and installed to a deeper depth.

Helical Pier Systems' screw piles and screw anchors typically consist of a round steel shaft and one or more helical plates. Spacing between any two helixes is usually (3) three times the diameter of the smaller, lower helix and set in increments of the helix pitch. Helix size and quantity will depend upon the required capacity of the pile and the soil properties and conditions.

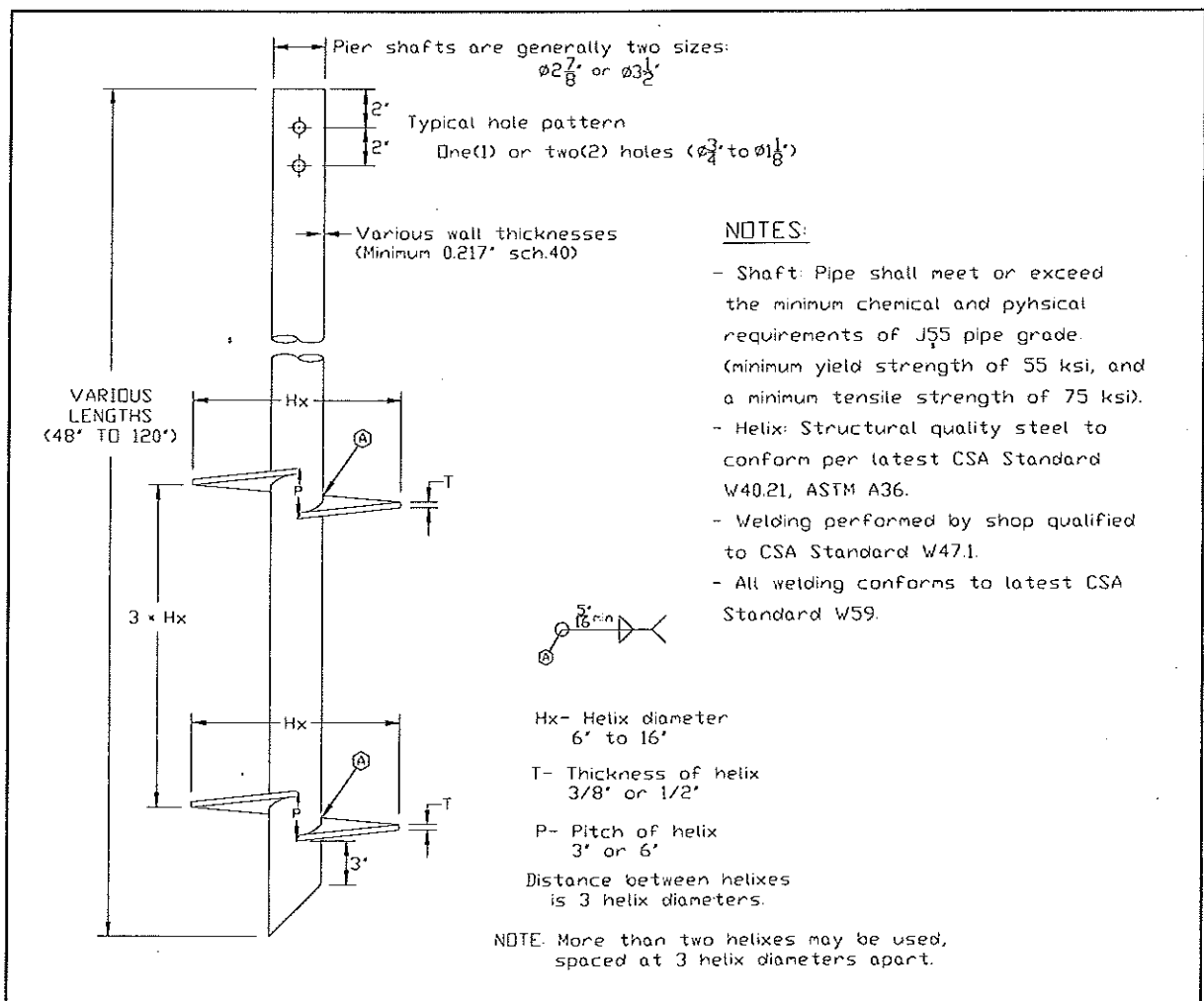


Figure BB. Multi-Helix Screw Pier / Anchor

Design Criteria:

American Society of Civil Engineers defines "Bearing Capacity" as that load which can be sustained by a pile foundation without producing objectionable settlement or material movement – initial or progressive – resulting in damage to the structure or interfering with its use.

Bearing Capacity depends on:

1. Type and properties of the soil;
2. Surface and/or groundwater conditions;
3. Geometry of the pile (pipe size, helix size, number of helixes, material thickness);
4. Pile material (new steel only);
5. Size of pile (cross-section, length);
6. Embedment depth of pile;
7. Position of pile (vertical, horizontal or battered);
8. Spacing between piles (interaction of piles, group effect);
9. Installation torque;
10. Type of loading (alternating, step-loading, static and others).

Installation:

For piles / piers / anchors subjected to uplift (and / or frost jacking) the embedment depth of the uppermost helix shall be at least five (5) helix diameters or deeper than the maximum frost penetration depth that is in the area.

The leading edge on the helical plates are rounded back and sharpened to facilitate ease in installation and minimize disturbance of the soil during installation.

The lead ends of the piles are cut to a 45 to aid in targeting of the pile during installation.

Helixes are cut from plate steel and formed using matching metal dies. The dies are set to provide the helix with the required pitch, typically 3.00" or 6.00". The helical shape is a "True Flight", the helical plate shall be normal to the central shaft (within 3 degrees) over its entire length. The helix is shaped so that it threads into the soil much like a wood screw going into a piece of wood.

Piles are installed through the use rotary hydraulics attached to a variety of equipment: boom mounted power utility trucks, skid steers, mini and large excavators, nodwells and many other types of equipment, even handheld units are used.

Torque will be continuously monitored and recorded throughout the installation of each screw piling. Continuous recording chart recorders are used, by measuring the hydraulic pressure that is used to drive in the piling. For small shaft piers there is a direct relationship between installation torque and screw pier capacity. Continuous monitoring of torque during installation will provide the installer with a profile of the underlying soil conditions.

History of Screw Piles

Screw piles were first used as foundations for buildings and bridges built over weak or wet soil. They had limited use for much of the 19th and early 20th century as the installation was difficult without mechanical assistance. During the 1960's, hydraulic torque motors became readily available and the installation process became much easier. Screw piles were first used primarily for their resistance to tensile forces. Utility companies frequently used screw piles as tie-down anchors for transmission towers and utility poles. Recent years have seen screw piles being used in many different applications. The piles strong resistance to both uplift and bearing pressure allowed them to be used in situations where resistance to combinations of these forces was required. Many advantages over traditional pilings, such as speed of installation and immediate loading capability have made screw piles the ideal foundation for many mainstream construction projects. Large truck mounted torque heads are available (in excess of 60,000 ft. lbs.) and excavator hoes with capabilities of achieving torque greater than 140,000 ft. lbs. have been assembled. With this new advance in equipment it is possible to install piles of large diameter (both helix and pipe) and high capacity.

Screw Pile Uses:

Screw piles and helical piers have been used on a wide variety of projects in Alberta, Canada, the United States and throughout the world. Uses for screw piles include foundations for commercial and residential buildings, temporary structures, light standards, oil and gas industry structures, bank retention, retaining wall tie-backs and in the power utility industry. A screw pile can be used in almost any situation and where driven or cast in place piles are currently used.

Helical Pier Systems currently supplies screw piles for many industries, including:

Oil and Gas Industry

Screw piles are ideal for many applications within the oil and gas industry. The piles are rugged, low maintenance, and mobile, which makes them ideal for use in the field. With a strong resistance to vibration and/or cyclical loading, screw piles can be placed under pump-jacks and compressor stations. Other applications include: pipe-racking, skid buildings, flare stacks, tanks, dehydrators, separators, etc. Our installation trucks are fully capable of installing piles in all climates and conditions, and our field crew is properly trained to perform in-situ modifications, if they have access to the design Engineer.

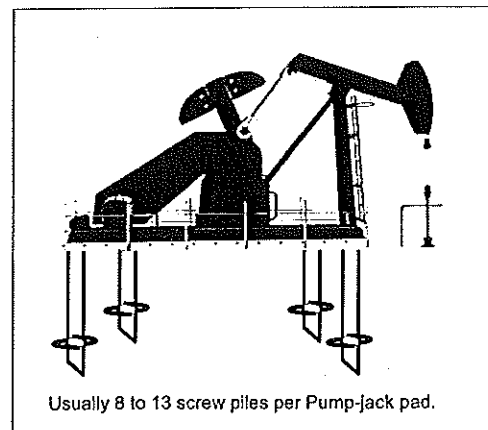


Figure C. Pump-Jack Foundation

Temporary Building

Screw piles are well suited for use under mobile or temporary buildings. They can be installed in all weather and terrain conditions, limited only by the mobility of the truck. Screw piles are reusable, making them as mobile as the building. With no curing time, the building can be placed and welded immediately after installation. Varying shaft lengths allows the building to be installed on uneven or sloping ground. Because screw pilings are placed well below the frost line, winter heaving and surface erosion have little effect on the pilings

strength. Optional leveling pile caps ensure the building remains level, regardless of the soil situation.

Street Light Bases

Our street light bases are custom constructed to meet individual needs. Cap thickness and size, slot or hole size, cable-way position and size, shaft size and length, and helix diameter are all variables in the street light base design. The street light bases are designed for resistance to bending moments, shearing forces, uplift loads and bearing loads.

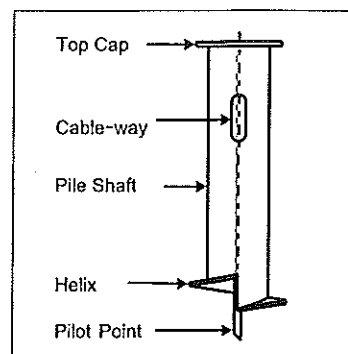


Figure D. Street Light Base

They have many advantages over concrete pilings, including: quick installation reducing traffic disruption, installation in most any type of weather, little to no ground disturbance making clean up easy, no spoils to remove, and one stop installation - pole can be set on immediately after install. The pile can be easily removed and reused, allowing quick and easy relocation of standards. To increase product life expectancy the base is often hot-dipped galvanized for extra protection. The environmentally friendly installation is vibration free and quiet, allowing placement in sensitive areas.

Typical applications for the street light base include: light poles for: residential lighting, parking lots, and street and highway lighting, one or two mast arms, street signage, flag poles, building signage, bumper posts and column supports.

Slope Stabilization

Helical Pier Systems' anchors that can be used in a variety of situations, including slope restoration/ stabiliz-ation. Once the fault line has been found, anchors can be screwed in almost horizontally into more stable soil. Once installed, an appropriate retaining wall is attached, which helps maintain the slope integrity.

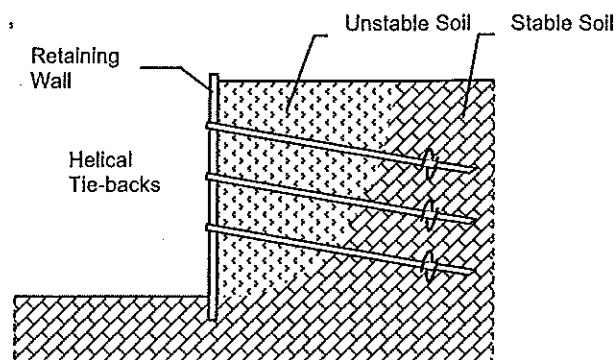
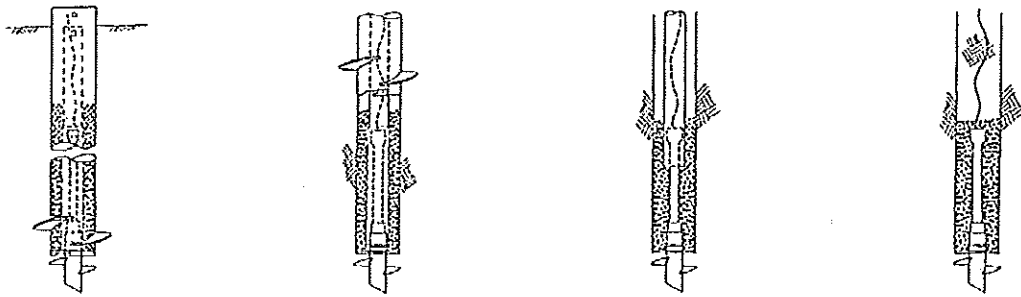


Figure E. Retaining Wall Tie-Backs

Cathodic Protection

Almita has developed and patented a new, cost effective way to install cathodic protection for underground structures. This procedure (see *Figure F.*) is a method of placing cathodic anodes to depth without trenching or drilling. This system also allows anodes to be battered under tanks and structures. By using the screw pile as a casing, the anode is installed into

the desired location and the screw pile backed out, leaving minimal disturbance to the site. A cable is plowed in, to connect individual anodes to the rectifier.



1. The entire assembly is screwed into the ground to desired depth. (Charcoal added; enough so as to surround the anode in a bed of charcoal).

2. The outer shaft is disconnected and backed out, leaving the inner shaft and anode in place.

3. The inner shaft is hooked onto at the surface, disconnected at the base and backed out, leaving the anode and wire.

4. The wire lead to the electrode is left sticking out of the ground ready to connect to the rectifier load.

Figure F. Almita Cathodic Anode Installation Method

General Foundations

Because of the ability of a screw pile to deal with various loadings, the screw pile can be used in many load bearing situations. Included are the aforementioned and the following;

- static loads (e.g. under buildings)
- alternating loads (e.g. under pumps jacks)
- vibratory loads (e.g. under compressors)
- loads with high moment of overturn (e.g. communication towers)
- grade beams (e.g. in conventional buildings)
- structural floor slabs

Helical Pier Systems' contractors are capable of completing projects of most any size, ranging from less than a dozen piles to major industrial projects in excess of 500 piles. All piles are individually designed to meet customers needs.

PART 1. SOIL MECHANICS

During loading, the force applied to the pile is transferred to the surrounding soil. Thus, the ultimate capacity of the pile is dependent upon the strength of the soil. In general, there are two types of soils; cohesive and cohesionless. Cohesive soils are defined as soils whose internal friction angle is approximately zero ($\phi=0$) while cohesionless soils are those whose internal friction angle is greater than zero ($\phi>0$). Soils are also grouped according to strength. The chart below, *Table 1.1*, outlines common soil classification.

SOIL CLASS	DESCRIPTION OF SOIL
1	Rock
2	Dense sand
3	Compact Clay and Gravel Mixed
4	Compacted Sand
5	Loose Sand, gravel and clay
6	Clay Loam, Damp Clay
7	Silt Loam, wet clay
8	Swamp, peat

Table 1.1 Soil Classifications

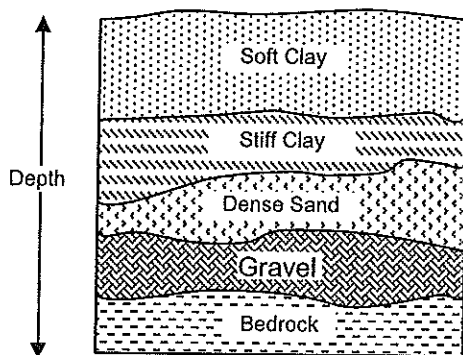


Figure 1.1 Soil Stratification

In nature, soil is rarely homogeneous. It tends to develop in layers or stratum, each with individual strengths and weaknesses. *Figure 1.1* illustrates this stratification. As the pile is driven into the ground, it will pass through different stratum. Because each layer has different characteristics, different torque values will be observed as the pile passes through each layer. During an ideal installation, the torque values will be constantly increasing, indicating that the pile is being inserted into more dense soil. If a drop in torque is recorded, it is most likely that a soft layer (such as soft clay) was found. The pile must continue to be inserted past the soft

layer until a more dense soil (i.e. higher torque) is found.

The two types of soil, cohesive and cohesionless, behave very differently when exposed to stress. As the name implies, the particles of sand in cohesionless soils act independently of each other. This gives such soils many fluid-like characteristics. When placed under stress, cohesionless soils tend to reorganize into a more compact configuration. Cohesive soils, in contrast, have more rigid behaviour. Stiff clays behave almost like rock, remaining solid and inelastic until failure. Soft clays have more putty like characteristics, bending and remoulding when under stress.

During tensile loading conditions, the upward force pulls on the entire pile. In wet to moderately wet soils, a suction force develops, helping to counteract the tension. The water in the soil exerts a small force, known as pore pressure, on the surrounding soil. When an upward force is applied, a low pressure area is created directly beneath the helix. This low pressure area causes inward pressure, or suction, and pulls down the helix. This

phenomenon is more pronounced in clays, where the soil is unable to move to fill the void. *Figure 1.2* illustrates this further.

Soils derive their strength and ultimately their load capacity from several characteristics. The internal friction angle, ϕ , the adhesion factor, α , the unit weight of the soil, γ , the undrained shear strength of soil, C_u , and the lateral earth pressure coefficient, K are all factors that affect the holding capacity of soils. Although many of these variables are related, they are dependent on the type, moisture content, and location of soils.

During installation, the surrounding soil is displaced by the rotary action of the pile. This creates a zone of compacted soil immediately adjacent to the pile, as shown in *Figure 1.3*. This compacted soil places pressure on the pile surface, effectively increasing the holding capacity of the pile

The pressure placed on the pile also helps create a friction force between the shaft and the soil. The shaft adhesion factor is a measure of this friction force and generally varies with soil type, density, and the soils internal friction angle. This friction helps to resist the applied force, and is used in determining the ultimate capacity of the pile. The displaced soil pressure also helps to reconsolidate any soil disrupted during the installation. Soil adhesion along the anchor's shaft significantly contributes to the anchor's overall vertical capacity. Adams and Klym(1972) found that that adhesion provides a substantial resistance to anchors installed in soft clays with shaft diameter greater than 76.2 mm. The adhesion between the pile shaft and the soil is taken as a function of the soil undrained shear strength.

The undrained shear strength of the soil is defined as the maximum value of shear stress that may be induced before the soil yields or fails. This variable is only present in cohesive soils, and generally increases with soil density (i.e. stiff clay > soft clay). Essentially, the greater the shear strength of the soil, C_u , the greater the bearing capacity, see *Table 1.2*. The shear strength of the soil tends to increase with density and depth, the inverse to the shaft adhesion factor. *Figure 1.4* illustrates this soil behavior.

Figure 1.2 Suction Forces under Tension

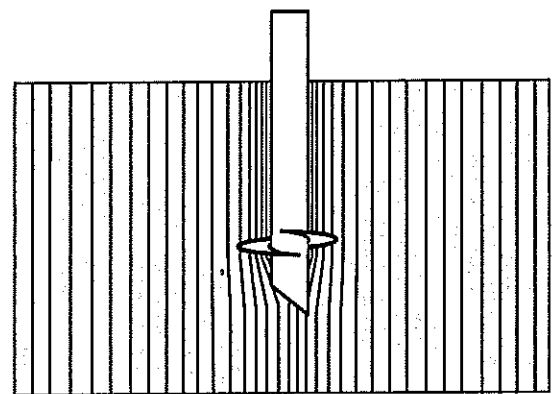
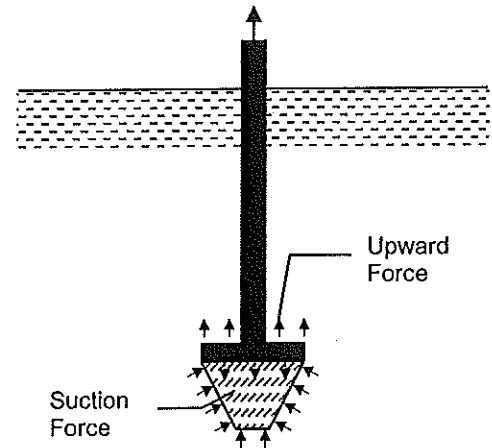


Figure 1.3 Soil Displacements

Consistency	Undrained Shear Strength, C_u kPa (psf)	
Very Soft	< 12	(< 250)
Soft	12 - 25	(250 - 520)
Firm	25 - 50	(520 - 1045)
Stiff	50 - 100	(1045 - 2090)
Very Stiff	100 - 200	(2090 - 4180)
Hard	> 200	(> 4180)

Table 1.2 Undrained Shear Strength of Soil (CFEM 1992)

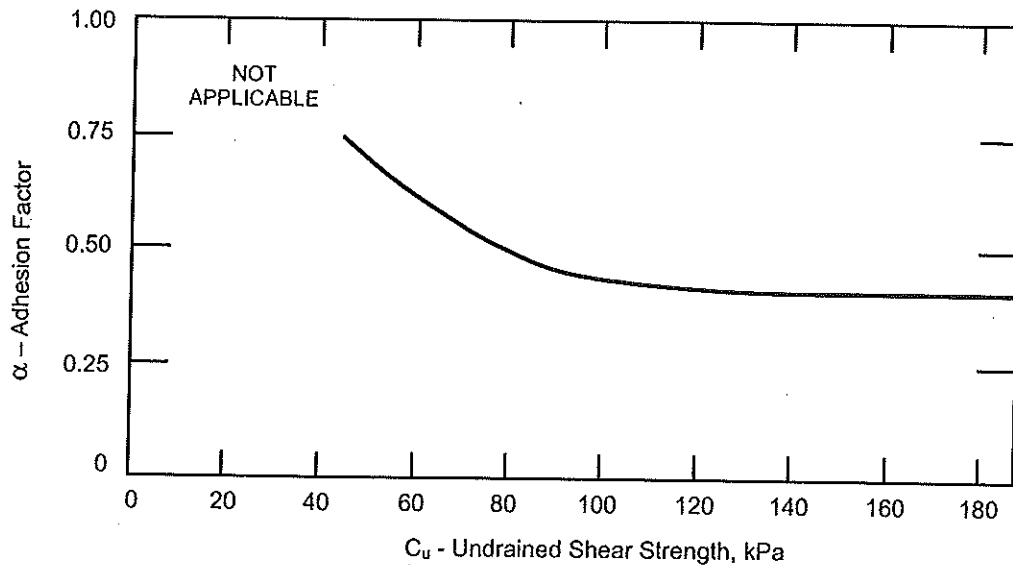


Figure 1.4: Reduction of Undrained Shear Strength for Anchorage Design (after CFEM, 1992)

Each soil, based on its composition and water content, has a unique density and weight. A common way to classify soils is to determine the weight of a unit volume, known as the unit weight of the soil.

$$\gamma = W / V$$

Eqn. 1.1

Where

W = weight of sample
V = Volume of sample

This variable is often used to describe the force or load the soil places on the pile. During tension, the soil around the pile, especially the helix, acts like ballast and helps to resist motion. This is particularly important in the case of tensile loading. A soil with a higher unit weight will place more downward pressure on the pile, thereby increasing the uplift capacity.

During the installation process, soil disruption should be kept to a minimum to preserve the soils integrity. By forming the helix to a true helical shape, the pile tends to cut through the soil, causing relatively little soil disruption and preserving the soils strength. Sufficient downward pressure (crowd) is maintained to ensure that for every revolution, the pile travels one pitch distance downward. The use of an installation torque recorder allows for the verification that the above is happening. The recorded torque values are also valuable as a quality control process and to determine the capacity of the pile.

The above information is meant to introduce an individual to the field of soil mechanics and explain the terms and ideas used to explain soil behavior. All facts and figures presented are for representational purposes and are not meant to substitute for actual soil studies. A more in-depth discussion of soil mechanics is beyond the scope of this manual and a

qualified geotechnical engineer should be consulted. The Variables, Tables and Figures contained in this manual are similar to those typically found in soil reports provided by a qualified Engineer and/or geologist.

ADDITIONAL INFORMATION:

Table 1.3. Typical Soil Parameters – *Cohesionless Soil*

Soil Description	Relative Density	Standard Penetration Resistance, N (blows/foot)	Angle of Internal Friction, ϕ (degrees)	Young's Modulus E (MPa) (ksf)
Very Loose	< 0.2	< 4	< 30	< 10 (< 210)
Loose	0.2 – 0.4	4 - 10	30 – 35	10 – 20 (210 – 420)
Compact	0.4 – 0.6	10 – 30	35 – 40	20 – 50 (420 – 1045)
Dense	0.6 – 0.8	30 – 50	40 – 45	50 – 80 (1045 – 1670)
Very Dense	> 0.8	> 50	> 45	> 80 (> 1670)

Table 1.4. Typical Soil Parameters – *Cohesive Soil*

Soil Description	Undrained Shear Strength, kPa (psf)	Young's Modulus E, MPa (ksf)
Very Soft	< 10 (< 210)	< 3 (< 65)
Soft	10 – 25 (210 – 520)	3 – 10 (65 – 210)
Firm	25 – 50 (520 – 1045)	10 – 25 (210 – 520)
Stiff	50 – 100 (1045 – 2090)	25 – 60 (520 – 1255)
Very Stiff	100 – 200 (2090 – 4180)	60 – 120 (1255 – 2505)
Hard	200 – 300 (4180 – 6265)	120 – 360 (2505 – 3760)
Very Hard	> 300 (> 6265)	> 360 (> 3760)

Part 2. BEARING AND UPLIFT CAPACITY

MULTI-HELIX SCREW PILE

When an axial compression or tension force is applied to a vertical pile, the load is partly supported by the shaft friction, the shear resistance along a cylindrical surface connecting the top and bottom helices and either bearing resistance below the bottom helix (compression loading), as shown in *Figure 2.1* or bearing capacity above the top helix (uplift loading), as shown in *Figure 2.2*.

Figure 2.1. Compression Loading Forces Acting on a Multi-helix Screw Pile

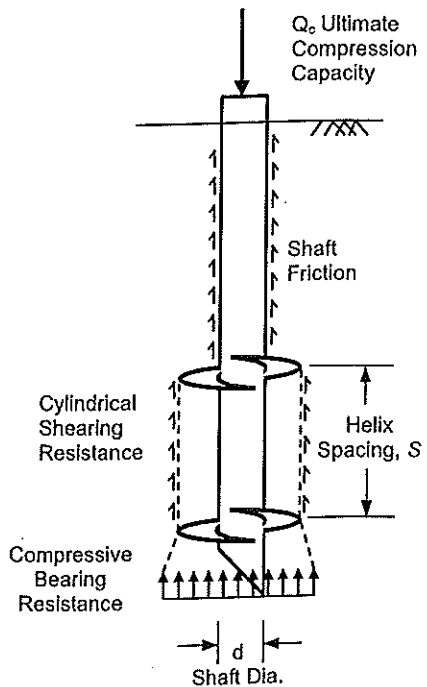
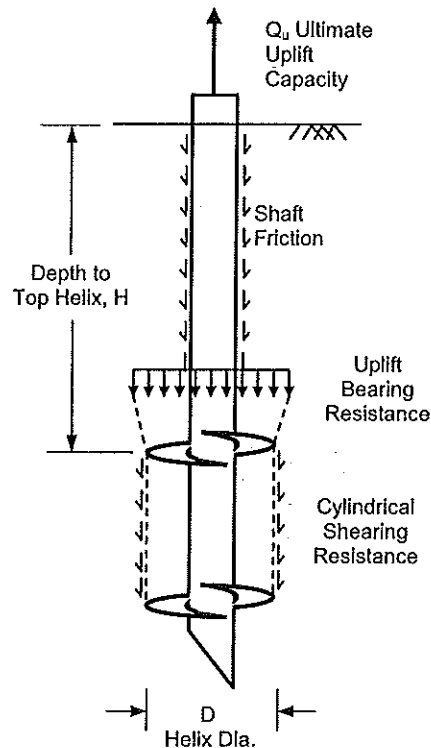


Figure 2.2. Tension Loading Forces Acting on a Multi-helix Screw Pile



1. COHESIVE SOIL

1.1 COMPRESSION LOADING

Thus, in the case of compressive loading, the total failure resistance can be summarized as follows:

$$Q_c = Q_{\text{helix}} + Q_{\text{bearing}} + Q_{\text{shaft}} \quad \text{Eqn. 2.1}$$

Where:

- Q_c = ultimate pile compression capacity, (kN)
- Q_{helix} = shearing resistance mobilized along the cylindrical failure surface, (kN)
- Q_{bearing} = bearing capacity of pile in compression, (kN)
- Q_{shaft} = resistance developed along steel shaft, (kN)

For a cohesive soil the ultimate compression capacity of the helical screw pile using a cylindrical shearing method as proposed by Mooney (1985) is:

$$Q_c = Sf (\pi D L_c) C_u + A_H C_u N_c + \pi d H_{eff} \alpha C_u \quad \text{Eqn. 2.2}$$

Where:

- D = diameter of helix, (m)
- L_c = is the distance between top and bottom helical plates, (m)
- C_u = undrained shear strength of soil, (kPa)
- A_H = area of the helix, (m²)
- N_c = dimensionless bearing capacity factors (*Tables 2.1 and 2.2*)
- d = diameter of the shaft, (m)
- H_{eff} = effective length of pile, H_{eff} = H – D, (m)
- α = Adhesion factor (see fig. 1.4)
- Sf = Spacing Ratio Factor

Table 2.1. Bearing Capacity Factor N_c Related to the Pile Diameter (after CFEM, 1992)

Pile Toe Diameter (m)	N _c
Smaller than 0.5	9
0.5 to 1.0	7
Larger than 1.0	6

Table 2.2 Bearing Capacity Factors, N_c for Cohesive Soils, and Modified for Helix Selection (after ALMITA)

Helix Diameter	N _c
< 0.50 m (< 20 in)	9.0
0.51 m (20 in)	8.33
0.56 m (22 in)	7.67
0.61 m (24 in)	7.33
0.76 m (30 in)	7.0
0.91 m (36 in)	6.67
0.97 m (38 in)	6.33
> 1.0 m (40 in)	6.0

Explanation of some of the terms:

The prediction of the bearing resistance developed from the bottom helix is independent of the embedment depth. The bearing capacity factor N_c, proposed by Meyerhof (1976), provides reasonable predictions for screw piles loaded in compression. Values of N_c are summarized in *Table 2.1 and Table 2.2*.

For estimation of the shaft adhesion, an effective shaft length H_{eff} is used in the calculation, which the effective shaft length is defined as the embedment length (H) minus the top helix

diameter (D). The adhesion developed along the steel shaft is considered in cases where sufficient installation depth (deep pile) is provided. For shallow condition (i.e. embedment ratio $H/D < 3$),

the shaft adhesion is considered as insignificant, and thus, Q_{shaft} is not included in the equation. *Figure 1.4* describes the determination of the, α , adhesion factor.

In the case where shaft resistance is considered negligible the compression capacity equation simplifies to:

$$Q_c = S_f (\pi D L_c) C_u + A_H C_u N_c \quad \text{Eqn. 2.3}$$

1.2 UPLIFT LOADING

For predicting the total uplift capacity, a cylindrical shear model is also adopted and the ultimate tension capacity can be determined using the following equation (Mooney 1985):

$$Q_t = S_f (\pi D L_c) C_u + A_H (C_u N_u + \gamma' H) + \pi d H_{\text{eff}} \alpha C_u \quad \text{Eqn. 2.4}$$

Where:

- Q_t = ultimate screw pile uplift capacity, (kN)
- γ' = Effective unit weight of soil above water table or buoyant weight if below water table, (kN/m³)
- N_u = dimensionless uplift bearing capacity factor for cohesive soils
- H = embedment depth, (m)
- S_f = Spacing Ratio Factor

For multi-helix screw piles loaded in tension, the ultimate capacity is dependent upon the embedment depth. Generally there are two contributing factors to an increase in the total uplift capacity with increasing depth. First, the shaft resistance increases with embedment depth and secondly, the bearing resistance developed above the top helix is dependent on the depth that the screw pile was installed to. The uplift bearing capacity factor, N_u increases with the embedment ratio (H/D) to a limiting value of approximately equal to 9.

$$N_u = 1.2 (H/D) \leq 9 \quad \text{(Meyerhof 1973)} \quad \text{Eqn. 2.5}$$

Similar to the compression test, for short piles installed at a shallower depth, the term for predicting the shaft adhesion can be neglected since the result is insignificant to the total uplift capacity. The equation can be summarized to:

$$Q_t = (\pi D L_c) C_u + A_H (C_u N_u + \gamma' H) \quad \text{Eqn. 2.6}$$

2. COHESIONLESS SOIL

2.1 COMPRESSION LOADING

For a cohesionless soil the ultimate compression capacity of the helical screw pile using a cylindrical shearing method (Where $H/D \geq 5$) as proposed by Mitsch and Clemence (1985) is:

$$Q_c = Q_{helix} + Q_{bearing} + Q_{shaft}$$

$$Q_{helix} = 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_s \tan \phi \quad \text{Eqn. 2.7}$$

$$Q_{bearing} = \gamma' H A_H N_q \quad \text{Eqn. 2.8}$$

$$Q_{shaft} = 1/2 P_s H_{eff}^2 \gamma' K_s \tan \phi \quad \text{Eqn. 2.9}$$

$$Q_c = \gamma' H A_H N_q + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_s \tan \phi + 1/2 P_s H_{eff}^2 \gamma' K_s \tan \phi \quad \text{Eqn. 2.10}$$

Where:

- Q_c = ultimate compression capacity, (kN)
- γ' = Effective unit weight of soil, (kN/m³)
- K_s = coefficient of lateral earth pressure in compression loading
- ϕ = Soil angle of internal friction, degree
- A_H = area of the bottom helix, (m²)
- N_q = dimensionless bearing capacity factor, *Table 2.3*.
- D_a = average helix diameter, (m)
- H = the embedment depth of pile, (m)
- D_1 = diameter of top helix, (m)
- H_{eff} = effective shaft length, (m)
- H_1 = depth to top helix, (m)
- H_3 = depth to bottom helix, (m)
- P_s = the perimeter of the screw pile shaft, (m)

Explanation of some of the terms:

Meyerhof (1963) suggested that the bearing capacity factor N_q , can be calculated using:

$$N_q = e^{\pi \tan \phi} \tan^2(45^\circ + \phi/2) \quad \text{Eqn. 2.11}$$

Values of N_q are summarized in Table 2.3.

Table 2.3 Bearing Capacity Factor, N_q , for Cohesionless soils

Internal Friction Angle, ϕ	0°	5°	10°	15°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	42°	44°
N_q	1	2	3	4	6	8	10	12	15	18	23	29	38	49	64	85	115

K_s , coefficient of lateral earth pressure in compression loading, which can be estimated by using the following two tables (*Table 2.4 and 2.5*).

Table 2.4. Values of the Coefficient of Horizontal Soil Stress, K_s (after Kulhawy, 1984)

Installation Method	K_s/K_o
Piles, Large Displacement ($\geq \text{Ø}8\text{-}5/8$ " shaft)	1 to 2
Piles, Small Displacement ($< \text{Ø}8\text{-}5/8$ " shaft)	0.75 to 1.25

Table 2.5. Typical Values of K_o for Normally Consolidated Sand (after Kulhawy, 1984)

Relative Density	K_o
Loose	0.5
Medium-Dense	0.45
Dense	0.35

CFEM (1990) suggested that K_s is usually assumed to be equal to the coefficient of original earth pressure, K_o , for bored piles, and twice the value of K_o for driven piles.

For the shallow condition (i.e $H/D < 5$), the ultimate compression capacity of a multi-helix screw pile in sand can be predicted by summing the bearing capacity of the bottom helix and the frictional resistance along the cylinder of soil between the helices without the shaft resistance. Therefore, Equation 2.10 can be expressed as follows:

$$Q_c = \gamma' H A_H N_q + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_s \tan \phi \quad \text{Eqn. 2.12}$$

2.2 UPLIFT LOADING

For predicting the total uplift capacity, a cylindrical shear model proposed by Mitsch and Clemence (1985) is suggested and the ultimate tension capacity can be determined. Zhang (1999) suggests that there are two distinct failure mechanisms for screw piles loaded in tension in the cohesionless soil, namely the shallow or the deep condition. The shallow condition describes the mechanism where a truncated pyramidal shaped failure surface propagates for the top helix to the ground surface. The central angle of the truncated cone is approximately equal to the soil friction angle, ϕ . A cylindrical failure surface is formed below the top helix. For helical piles installed in a much deeper depth, a failure zone develops directly above the top helix. The overburden pressure confines this failure surface, and therefore the failure zone does not propagate to the ground surface. Meyerhof and Adam (1968)'s theory stated that there is a maximum embedment ratio $(H/D)_{cr}$, where the failure mode changes from shallow to deep and this maximum value increases with an increase in the relative density (D_r), and the internal soil friction angle, ϕ of the sand. Das (1990) expressed the ultimate bearing capacity proposed in Mitsch and Clemence's theory in terms of breakout factor F_q for shallow anchor conditions and F_q^* as follows:

For Multi-helix Screw Pile installed in Shallow Condition $H/D < (H/D)_{cr}$

$$Q_t = \gamma' H A_H F_q + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_u \tan \phi \quad \text{Eqn. 2.13}$$

For Multi-helix Screw Pile installed in Deep Condition $H/D > (H/D)_{cr}$

$$Q_t = \gamma' H A_H F_q^* + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_u \tan \phi + 1/2 P_s H_{eff}^2 \gamma' K_u \tan \phi \quad \text{Eqn. 2.14}$$

Where:

- Q_t = ultimate screw pile uplift capacity, (kN)
- γ' = effective unit weight of soil, (kN/m³)
- ϕ = the soil angle of internal friction, degree
- K_u = dimensionless coefficient of lateral earth pressure in uplift for sands
- H = embedment depth, (m)
- A_H = area of the bottom helix, (m²)
- D_a = average helix diameter, (m)
- D_1 = diameter of top helix, (m)
- H_{eff} = effective shaft length, $H_{eff} = H_1 - D_1$, (m)
- H_1 = depth to top helix, (m)
- H_3 = depth to bottom helix, (m)
- P_s = the perimeter of the screw pile shaft, (m)
- F_{q_s} = breakout factor for shallow condition, see Figure 2.3
- F_q = breakout factor for deep condition, see Figure 2.4

Explanation of some of the terms:

Embedment ratio (H/D) is defined as the depth to the top helix, H divided by the top helix diameter, D .

Table 2.6. Critical Embedment Ratio, $(H/D)_{cr}$ for Circular Anchor (after Meyerhof and Adam, 1968)

Friction Angle, ϕ	20°	25°	30°	35°	40°	45°	48°
Depth $(H/D)_{cr}$	2.5	3	4	5	7	9	11

This coefficient, K_u is used to empirically quantify the lateral stress acting on the failure surface as the screw pile is pulled out from the soil. The lateral stress outside the cylindrical failure surface increases to a passive state due to the screw action during the installation process. The magnitude of the increase is dependent upon the amount of disturbance and the changes in stress level during the installation.

Table 2.7. Recommended Uplift Coefficients, K_u for Helical Anchors (after Mitsch and Clemence, 1985)

Soil Friction Angle, ϕ	Meyerhof's Coefficient for Foundation Uplift	Recommended Coefficients for Helical Anchors
25°	1.20	0.70
30°	1.50	0.90
35°	2.50	1.50
40°	3.90	2.35
45°	5.30	3.20

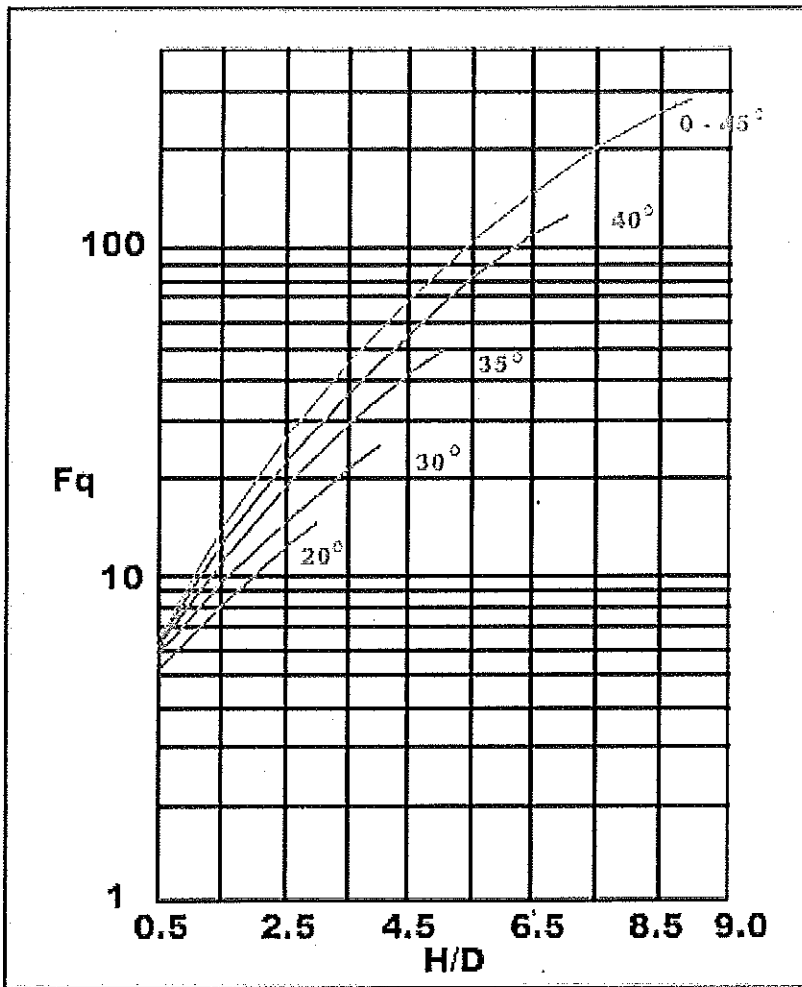


Figure 2.3: Variation of Breakout Factor with Embedment Depth for Shallow Anchor Condition based on Mitsch and Clemence's Theory (after Das, 1990)

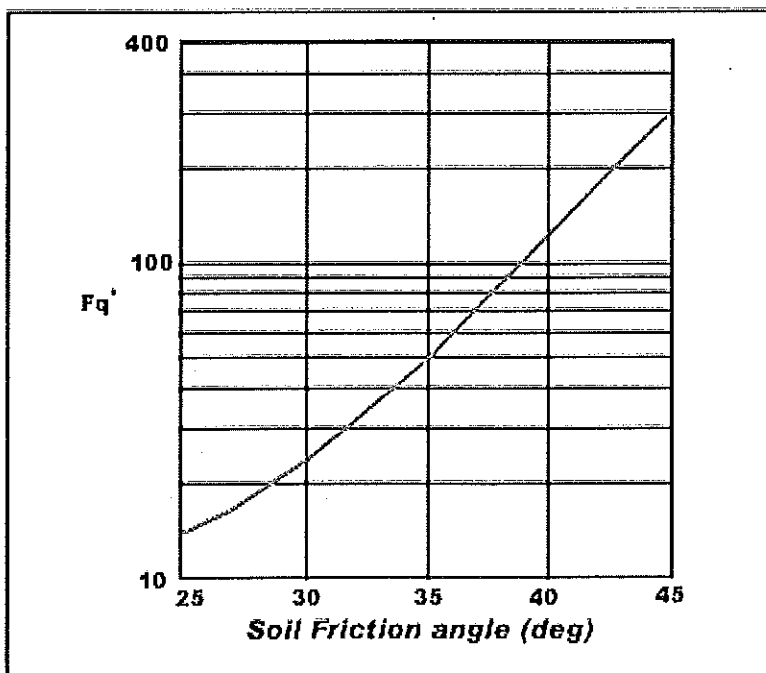


Figure 2.4: Variation of Breakout Factor with Embedment Depth for Deep Anchor Condition based on Mitsch and Clemence's Theory (after Das, 1990)

SINGLE HELIX SCREW PILE

For a single helix screw pile, the cylindrical shearing resistance connecting the top and bottom helix for multi-helix piles does not develop. Therefore, the total resistance is derived from shaft and bearing resistance (see Figures 2.5 and 2.6). Equations used to obtain axial capacity for the multi-helix screw piles should be adjusted to not include the cylindrical component.

1. COHESIVE SOIL

1.1 COMPRESSION LOADING

$$Q_c = A C_u N_c + \pi d H_{eff} \alpha C_u \quad \text{Eqn. 2.15}$$

1.2 TENSION LOADING

$$Q_t = A_H (C_u N_u + \gamma' H) + \pi d H_{eff} \alpha C_u \quad \text{Eqn. 2.16}$$

2. COHESIONLESS SOIL

2.1 COMPRESSION LOADING

$$Q_c = \gamma' H A N_q + 1/2 P_s H_{eff}^2 \gamma' K_s \tan \phi \quad \text{Eqn. 2.17}$$

2.2 TENSION LOADING

For Single Helix Screw Piles Installed in Shallow Condition $H/D < (H/D)_{cr}$

$$Q_t = \gamma' H A_H F_q \quad \text{Eqn. 2.18}$$

For Single Helix Screw Piles Installed in Deep Condition $H/D > (H/D)_{cr}$

$$Q_t = \gamma' H A_H F_q^* + 1/2 P_s H_{eff}^2 \gamma' K_u \tan \phi \quad \text{Eqn. 2.19}$$

Figure 2.5. Compression Loading Forces Acting on Single Helix Screw Pile

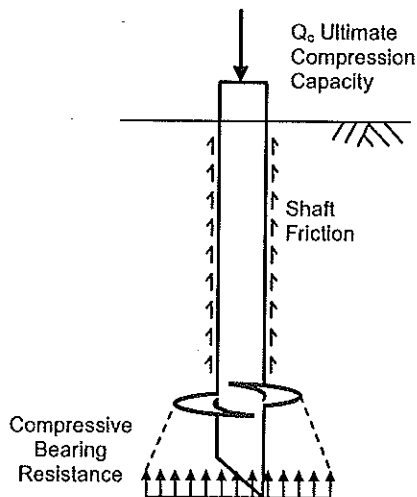
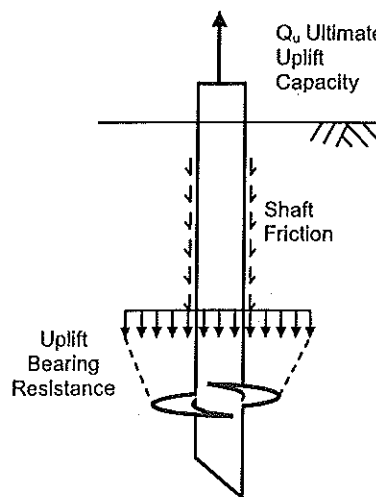


Figure 2.6 Tension Loading Forces Acting on Single Helix Screw Pile



Because the actual theory behind soil mechanics is extremely complicated and beyond the scope of this manual, the determination of the exact load capacity of each pile is impossible without actual load tests. A load test should be performed at each site to verify the above information. The above formulas provide guidelines that, when used with accurate soil data and appropriate safety factors, can be confidently used to design a suitable screw pile.

TORQUE INSTALLATION METHOD FOR PREDICTING CAPACITY

An empirical method has been derived and used in the screw anchor industry for many years. Installation torque is used to calculate the ultimate capacity of the screw anchor. The average torque achieved during the last three (3) to five (5) feet of installation is directly proportional to the ultimate axial capacity of the pier.

A pull out test to failure is preformed with the capacity achieved recorded as the ultimate capacity. Using the ultimate capacity at the given installation torque an empirical torque factor can be calculated. (*NOTE: A tension test is often performed instead of a compression test because they are quicker to setup and perform and the capacities are generally less than the compression tests – inherent factor of safety*).

From the pullout test, an empirical torque factor, K_t can be calculated using the following:

$$K_t = Q_t / T \quad \text{Eqn. 2.20}$$

where: T = Average Installation Torque (Ft.Lbs)
 Q_t = Ultimate Pier Capacity (Lbs.) from load test
 K_t = Empirical Torque Factor (1/ft)

Typical values for K_t range from 20 to 2, with the majority of soils giving a K_t value of 7 to 10. Unless load tests are preformed to provide a K_t value, a conservative K_t value should be selected when designing piles. It is important to note that the value for K_t is a combination of soil and anchor properties, primarily relating to friction during installation. As an example, K_t for a dense dry sand would normally be less than for a hard wet clay. The factor for 3-1/2" pipe anchors is recommended to be around 7 for most soils and the factor for 2-7/8" pipe anchors is usually in the 7 to 10 range for most soils.

Appropriate safety factors should then be applied (minimum S.F. = 2.0).

Helical Pier Systems Ltd. recommends that an architect or engineer design every project. Projects that have sufficient soil, load and/or historical data available allows for greater determination of the allowable design loads and minimum acceptable safety factor that can be achieved for the pile design.

Part 3. CALCULATING THE ULTIMATE RESISTANCE TO LATERAL LOADS

Vertical piles resist lateral loads and moments by deflection until the necessary reaction in the surrounding soil is mobilized. The behavior of the pile under such loading conditions depends on the stiffness of the pile and the soil strength.

The horizontal load capacity of vertical piles is limited in three different ways:

- Soil capacity
- Excessive bending stresses in the pile material
- Pile deflection exceeds the superstructure maximum allowed.

All three methods of failure should be considered in the design.

Brom's method (1964) will be used to estimate pile capacity for each case.

Brom's had classified the piles' behavior into two categories:

- Short pile failure where the lateral capacity of the soil adjacent to the pile is fully mobilized (CFEM, 1992)
- Long pile failure where the bending resistance of the pile is fully mobilized (CFEM, 1992).

Results are given for:

- Pile diameter, d ;
- Embedded length, L ;
- Lateral load capacity, H_U ;
- Yield moment of pile, M_{YIELD} ;
- Clay cohesion, C_U ;
- Coefficient of passive sand resistance, K_P ;
- Height of lateral load above ground, e ; and
- Soil unit weight, γ .

The first step is to determine whether the pile will behave as a short rigid pile or as an infinitely long flexible member. Calculating the stiffness factors R and T for the particular combination of pile and soil does this. The stiffness factors are governed by the stiffness (EI value) of the pile and the compressibility of the soil. The latter is expressed in terms of a 'soil modulus', which is not constant for any soil type but depends on the width of the pile and the depth of the particular loaded area of the soil being considered. The soil modulus K has been related to Terzaghi's concept of a modulus of horizontal subgrade reaction. In the case of stiff over-consolidated clay, the soil modulus is generally assumed to be constant with depth. Tomlinson (1987) identifies those factors as:

$$\text{Stiffness factor } R = \sqrt[4]{EI/K} \text{ (in units of length)} \quad \text{Eqn. 3.1}$$

$$\text{Where: } K \approx k_1 B \approx 0.305 k_1 / 1.5B \approx k_1 / 5B \quad \text{Eqn. 3.2}$$

Where: k_1 is Terzaghi's subgrade modulus as determined from load-deflection measurements on a 305mm square plate, and B is the width of the pile. Elson has shown that k_1 is related to the undrained shearing strength of the clay, as shown in *Table 3.1*. Values of n_h (After Terzaghi 1995) are shown in *Table 3.2*.