Engineered Foundation Solutions

Industrial | Commercial | Residential

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Helical Pile Engineering Handbook

Toll Free: 1-866-497-8175 or 1-877-547-1017

The purpose of this manual is to briefly discuss helical pile design. It is our goal to make this manual as user friendly as possible and 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 Helical Pier Systems, HPS.

This manual is available online at www.helicalpiersystems.com

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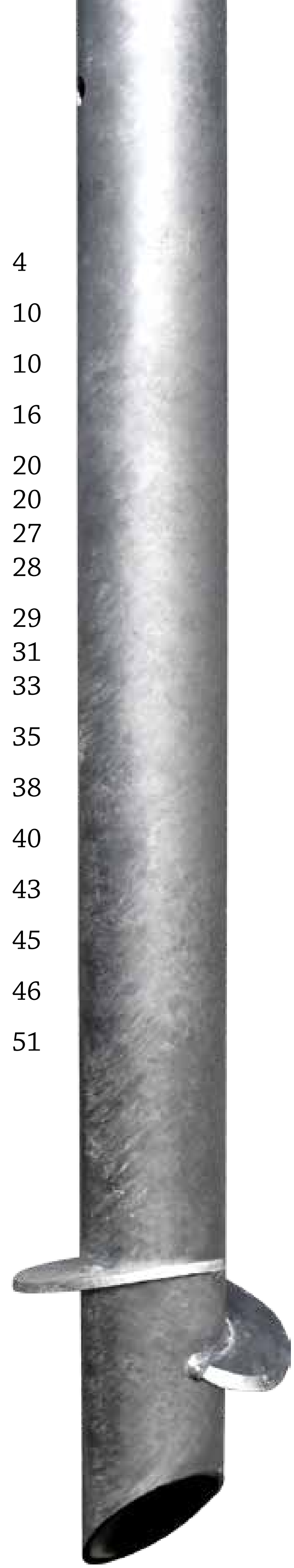
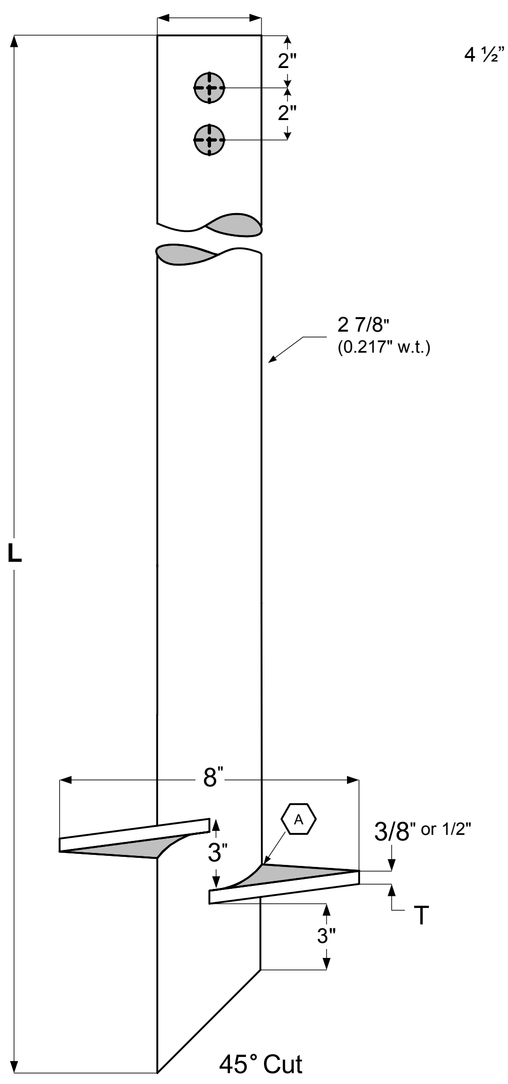
Table of Contents



Introduction to Helical Piles

A helical pile can be manufactured with a hollow round shaft or solid square bar, 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 into the ground with minimal soil disruption. 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 pile 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.

Helical pile foundations are also referred to as anchors, screw anchors, and/or torque piles. For this manual, screw anchors will assume to be in tension and helical piles in compression.
Figure AA shows a typical 2 ⅞" pile configuration with a single helix. *Figure BB* shows a typical pier configuration with a double helix.



Pile Specifications:

All holes are 15/16" Diameter

NOTES:

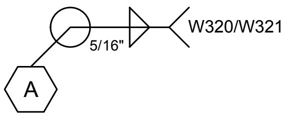
Shaft: 2 ⅞" or 3 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 70 KSI and minimum tensile strength of 85 KSI.

Shaft: 4 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 90 KSI and minimum tensile strength of 105 KSI.

Helix: Structural quality steel to conform per latest CSA Standards W40.21, ASTM A36)

Welding: performed by shop qualified to CSA Standard W47.1.

If required: Hot Dipped Galvanizing: per latest CSA standard G164-M and ASTM A153.



Hx – Helix Diameter:

6" – 42"

Typically Helix '2' diameter is greater than Helix '1'.

P – Pitch of Helix

3" or 6"

T: Helix Thickness:

⅜", ½", or ¾"

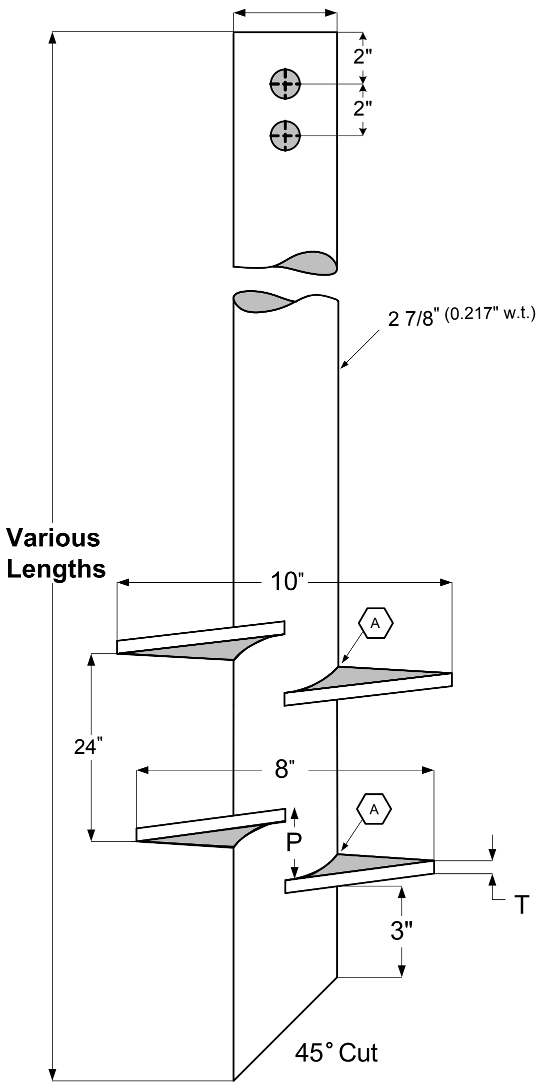
Distance between helixes is 3 helix diameters

Note: More than two helixes may be used, spaced at 3 helix diameters apart

Figure AA Single Helix Screw Pier/Pile

Helical Piles can be manufactured using almost any pipe size. Typical pipe sizes range from 2 ⅞" to 12 ¾" O.D., although pipe in excess of 42" has been used. Helix sizes and thickness are dependent on the shaft diameter, soil conditions and applied loads, ranging from 6" to larger than 60" in diameter and usually from ⅜" to 1" thickness. The length of the helical 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 favorable soil. To increase the depth of a pile, additional lengths can be welded or bolted on and installed to a deeper depth.

HPS' helical piles typically consist of a steel shaft and one or more helical plates. Spacing between any two helixes is usually 3 times the diameter. Helix size and quantity will depend upon the required capacity of the pile and the soil properties and conditions.



Pile Specifications:

All holes are 15/16" Diameter

NOTES:

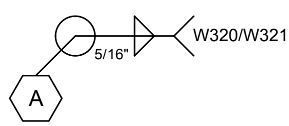
Shaft: 2 ⅞" or 3 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 70 KSI and minimum tensile strength of 85 KSI.

Shaft: 4 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 90 KSI and minimum tensile strength of 105 KSI.

Helix: Structural quality steel to conform per latest CSA Standards W40.21, ASTM A36)

Welding: performed by shop qualified to CSA Standard W47.1.

If required: Hot Dipped Galvanizing: per latest CSA standard G164-M and ASTM A153.



Hx – Helix Diameter:

6" – 42"

Typically Helix '2' diameter is greater than Helix '1'.

T: Helix Thickness:

⅜", ½", or ¾"

P – Pitch of Helix

3" or 6"

Distance between helixes is 3 helix diameters

Note: More than two helixes may be used, spaced at 3 helix diameters apart

Figure BB Double Helix Screw Pier/Pile

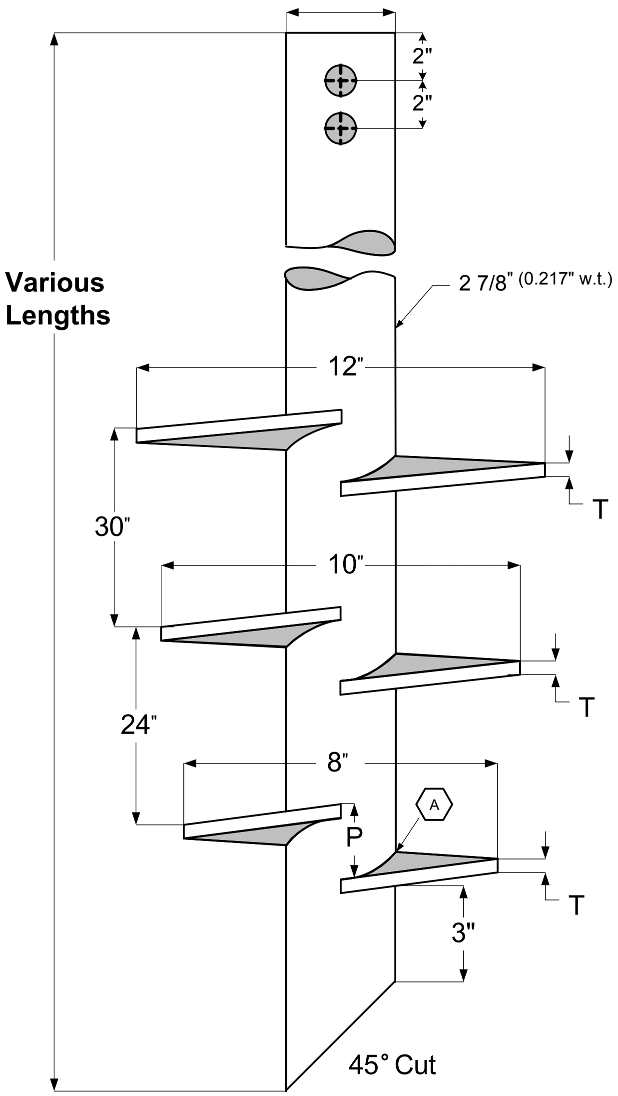


Figure CC Triple Helix Screw Pier/Pile

Pile Specifications:

All holes are 15/16" Diameter

NOTES:

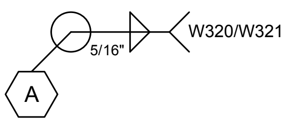
Shaft: 2 ⅞" or 3 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 70 KSI and minimum tensile strength of 85 KSI.

Shaft: 4 ½" Diameter, pipe will meet or exceed ASTM structural grade pipe standards with a minimum yield strength of 90 KSI and minimum tensile strength of 105 KSI.

Helix: Structural quality steel to conform per latest CSA Standards W40.21, ASTM A36)

Welding: performed by shop qualified to CSA Standard W47.1.

If required: Hot Dipped Galvanizing: per latest CSA standard G164-M and ASTM A153.



Hx – Helix Diameter:

6" – 42"

Typically Helix '2' diameter is greater than Helix '1'.

T: Helix Thickness:

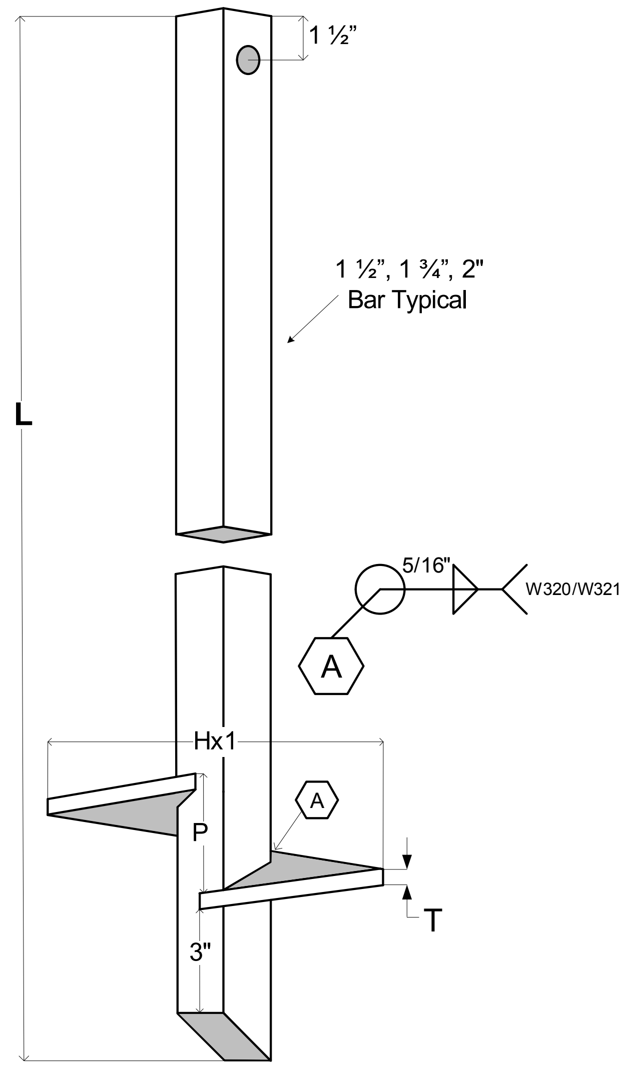
⅜", ½", or ¾"

P – Pitch of Helix

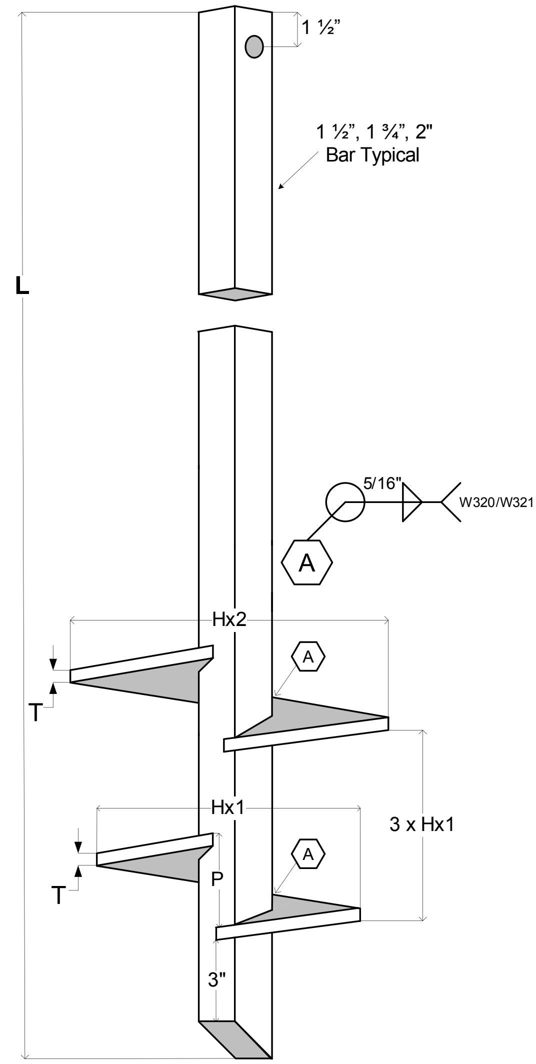
3" or 6"

Distance between helixes is 3 helix diameters

Note: More than two helixes may be used, spaced at 3 helix diameters apart



Single Square Helix Screw Pier/Pile



Double Square Helix Screw Pier/Pile

Notes:

Shaft: meets or exceeds ASTM Structural Grade Bar Standards with minimum yield strength of 95 KSI and a minimum tensile strength of 120 KSI.

Helix: Structual quality plate to conform for latest CSA Standard G 40.21 minimum grade CSA 44W.

Welding: Welding performed by a shop qualified to CSA Standard W47.1 and in adherance to CSA Standard W59.

If required: Hot Dipped Galvanizing: as per latest CSA Standard G164-M and ASTM A153, on request.

Hx - Helix Diameter 6" to 18"

T - Thickness of Helix ⅜" or ½"

P - Pitch of Helix 3" or 6"

L - Length of pile 2' to 10'

Notes:

Shaft: meets or exceeds ASTM Structural Grade Bar Standards with minimum yield strength of 95 KSI and a minimum tensile strength of 120 KSI.

Helix: Structual quality plate to conform for latest CSA Standard G 40.21 minimum grade CSA 44W.

Welding: Welding performed by a shop qualified to CSA Standard W47.1 and in adherance to CSA Standard W59.

If required: Hot Dipped Galvanizing: as per latest CSA Standard G164-M and ASTM A153, on request.

Hx - Helix Diameter 6" to 18"

T - Thickness of Helix ⅜" or ½"

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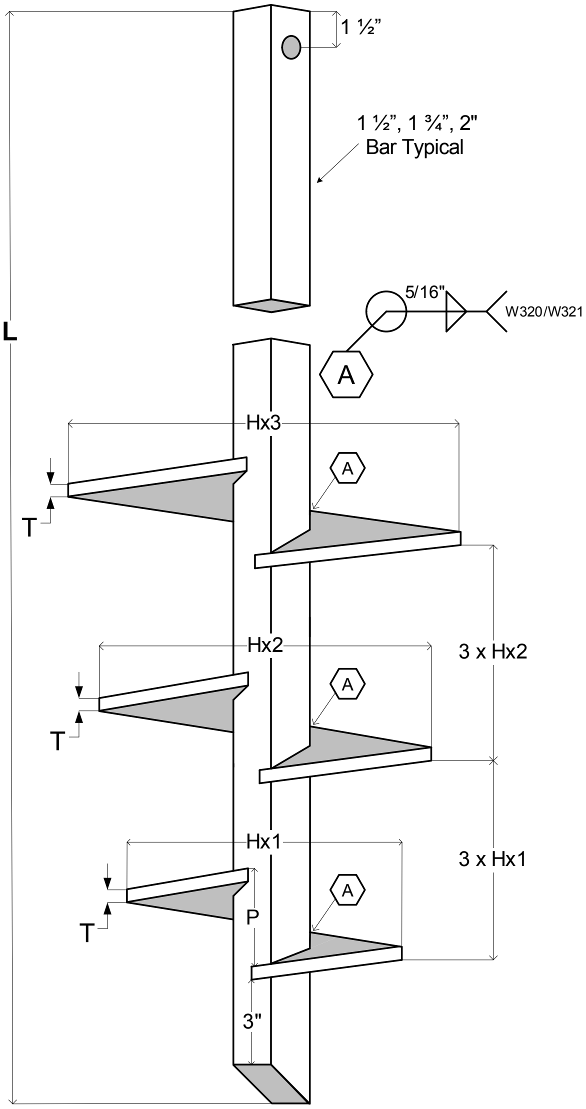
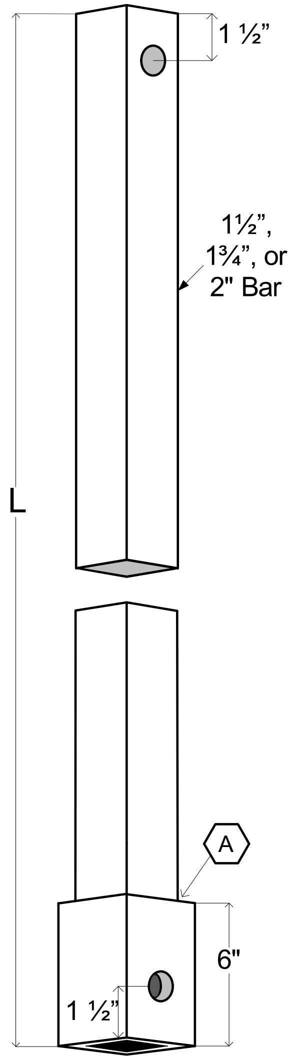


Triple Square Helix Screw Pier/Pile



Square Shaft Extension

Notes:

Shaft: meets or exceeds ASTM Structural Grade Bar Standards with minimum yield strength of 95 KSI and a minimum tensile strength of 120 KSI.

Helix: Structual quality plate to conform for latest CSA Standard G 40.21 minimum grade CSA 44W.

Welding: Welding performed by a shop qualified to CSA Standard W47.1 and in adherance to CSA Standard W59.

If required: Hot Dipped Galvanizing: as per latest CSA Standard G164-M and ASTM A153, on request.

Hx - Helix Diameter 6" to 18"

T - Thickness of Helix ⅜" or ½"

P - Pitch of Helix 3" or 6"

L - Length of pile 2' to 10'

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 subjected to uplift (and/or frost jacking) the embedment depth of the uppermost helix shall be at least 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 of 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 helical 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 helical pier capacity. Continuous monitoring of torque during installation will provide the installer with a profile of the underlying soil conditions.

History of Helical Piles

Helical 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. Helical piles were first used primarily for their resistance to tensile forces. Utility companies frequently used helical piles as tie-downs for transmission towers and utility poles. Recent years have seen helical 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 helical piles the ideal foundation for many mainstream construction projects. Many different types of equipment are used to install helical piles, excavators, skid steers, truck mounted, etc. The hydraulic torque motors have improved significantly over the past 10 years, from the small 5,000 ft./lb., hand held torque motors to the large 150,000 ft./lb. truck or excavator mounted units. With the new advances in equipment technology it is possible to install one piece piles up to 50' in length. Although most piles are installed in short segments either bolted or welded together.

Helical Pile Uses

HPS products have been used on a wide variety of projects in Alberta, Canada, the United States and throughout the world. Uses for helical piles include, but are not limited to foundations for commercial and residential buildings, temporary structures, light standards, oil and gas industry structures, bank retention, retaining wall tie-backs and power utility industry structures. A helical pile can be used in almost any situation and where driven or cast in place piles are currently used. HPS manufactures, installs and supplies our network of installers helical piles for many industries, including:

New Construction Foundation

Helical piles are well suited for new construction foundations. The piles are incorporated into the footing or structural grade beam. The piles will terminate with a pier cap that will be embedded into the concrete footer or grade beam. Pile size and spacing will be determined by the load of the structure and soil bearing capacity

Fast and economical helical piles can be installed and incorporated into the grade beam.

Foundation Repair

HPS manufactures a round shaft pile and lift bracket systems that are hydraulically screwed in along side of the foundation to provide additional support and prevent further settlement.

With HPS patented Dura-Lift foundation support bracket, the concrete foundation can be lifted back to a level position. Our lift system has been designed to fit under the concrete foundation to lift the structure. The Dura-Lift brackets are available in various sizes and load capacities for lifting both residential and commercial structures.

Oil and Gas Industry

Helical 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, helical piles can be placed under pump-jacks and compressor stations. Other possible 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.

Temporary Buildings and Modular Structures

Helical 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 installation equipment. Helical piles are removable and 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 helical 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.

General Foundations

Because of the ability of a helical pile to deal with various loadings, the helical 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

HPS' contractors are capable of completing projects of almost 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 customer's needs.

Slope and Bank Stabilization

HPS' piles can be used in a variety of situations, including slope restoration/stabilization. Once the fault line has been found, piles can be screwed in almost horizontally into more stable soil. Once installed, an appropriate retaining wall is attached to help maintain the slope integrity.

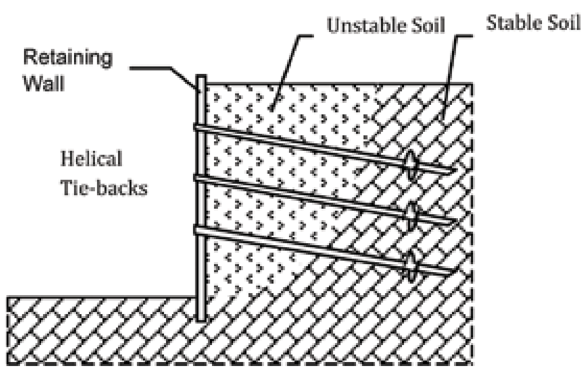


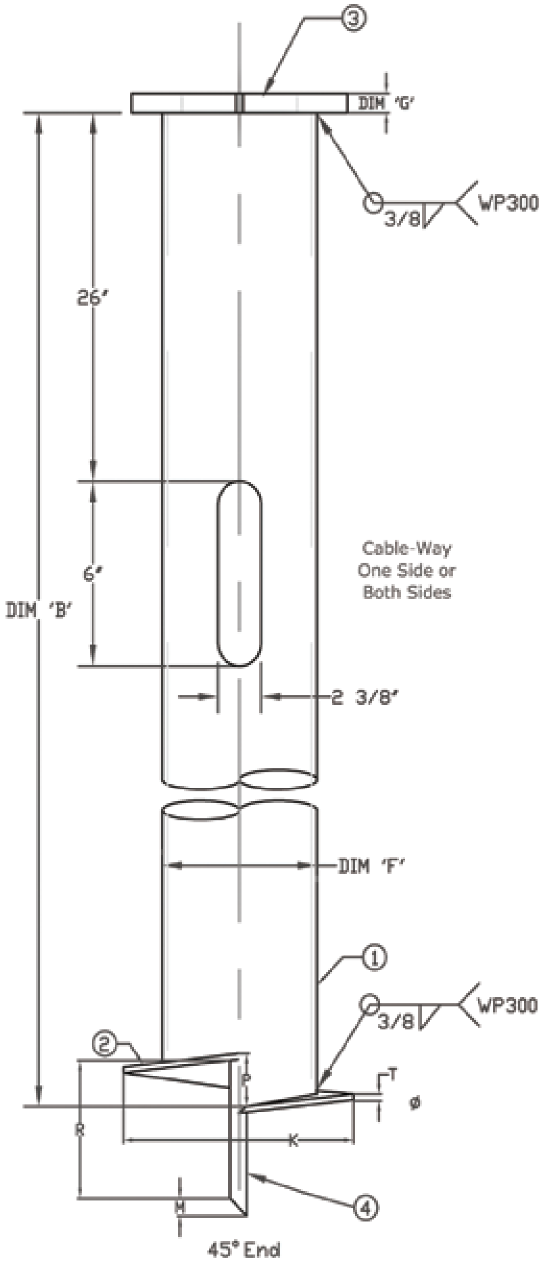
Figure E Retaining Wall Tie-Backs

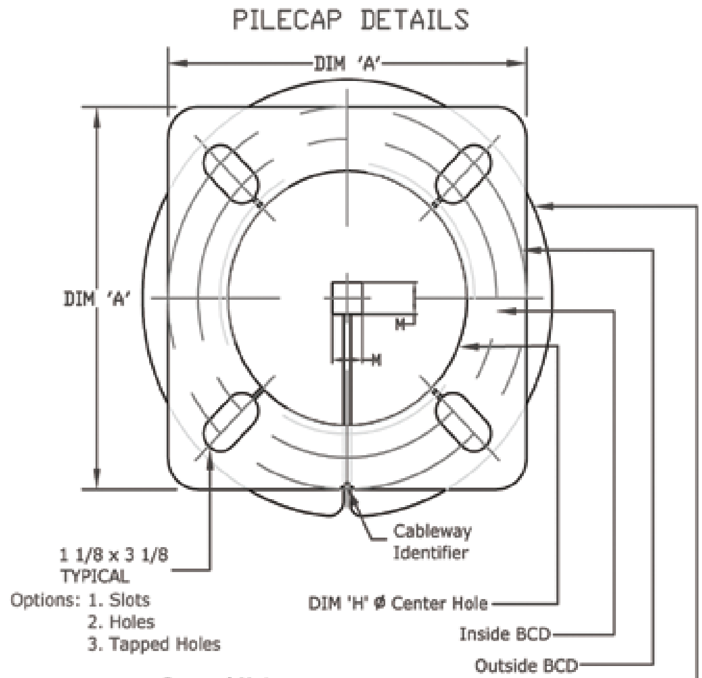
Street Light Bases

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.

They have many advantages over concrete pilings; quick installation reducing traffic disruption, installation in almost 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.





General Notes:

- All dimensions are in inches or as otherwise stated.
- All weights are in Lbs or as otherwise stated.
- Only new material used in the manufacture of the base.
- Shaft steel pipe, seamless or straight welded to conform to latest ASTM A252, grade 3.
- Base plate, Helix and Pilot point: Structural quality steel to conform to latest CSA G40,21.
- Welding performed by shop qualified to CSA W47.1.
- All Welding conforms to latest version of CSA W59.
- All welds typical for joint type.
- Company stamp and date on cableway side of base plate, Ex. HPS MFG 07 / 07 /00.
- Base is Hot-Dipped Galvanized inside and out.
- Hot-Dipped to latest of CSA G164-M and ASTM A153.
- Ensure structure is free from galvanizing slag.

Item	Description
1	( ) Diameter (w.t.) Pipe x ( ) Shaft
2	Helix: ( ) Plate. ( ) Diameter. ( ) Pitch.
3	Base Plate: ( ) Plate x ( ) x ( )
4	HSS (1 ¼") x (1 ¼") x ( ) Spike.

ULTIMATE LOAD CAPAITY OF BASE	MAXIMUM ALLOWABLE SERVICE LOAD OF BASE	B.C.D.	DIM 'A'	DIM 'B'	DIM 'C'	DIM 'D'	DIM 'E'	DIM 'F'	DIM 'G'	DIM 'H'
SHEAR: 63 kip MOMENT: 50 kip-FT	SHEAR: 29 kip MOMENT: 23 kip-FT	14	14	8'-7.75'	8'-0'	1.25-7UNC-2B	1.25 DIA. X 3.5	10.75	1.25	10
SHEAR: 51 kip MOMENT: 31 kip-FT	SHEAR: 24 kip MOMENT: 14.7 kip-FT	13	13	7'-7.5'	7'-0'	1-8UNC-2B	1 DIA. X 3.0	8.625	1	8
SHEAR: 51 kip MOMENT: 31 kip-FT	SHEAR: 24 kip MOMENT: 14.7 kip-FT	11	11	5'-7.5'	5'-0'	1-8UNC-2B	1 DIA. X 3.0	8.625	1	8
SHEAR: 43 kip MOMENT: 24 kip-FT	SHEAR: 20 kip MOMENT: 11.2 kip-FT	10	10	6'-7.5'	6'-0'	1-8UNC-2B	1 DIA. X 2.5	6.625	1	6
SHEAR: 43 kip MOMENT: 24 kip-FT	SHEAR: 20 kip MOMENT: 11.2 kip-FT	10	10	5'-7.5'	5'-0'	1-8UNC-2B	1 DIA. X 2.5	6.625	1	6

THE MAXIMUM LOADS STATED ON THIS DRAWING ARE BASED ON A LIFE SPAN USING 4X10^7 CYCLES OF APPLIED LOADING

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 and Damp Clay
7	Silt Loam and Wet Clay
8	Swamp and Peat

Table 1.1 Soil Classifications

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 behavior. 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.

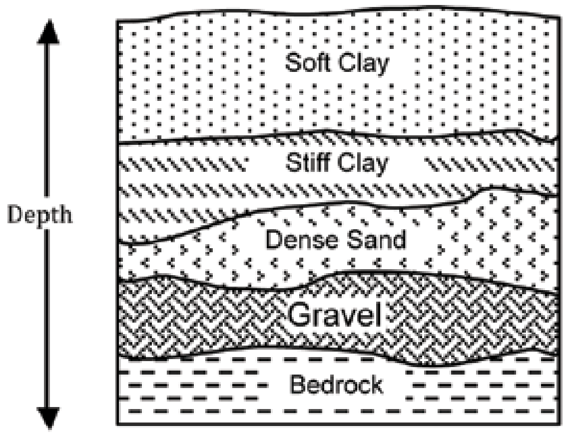


Figure 1.1 Soil Stratum

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.

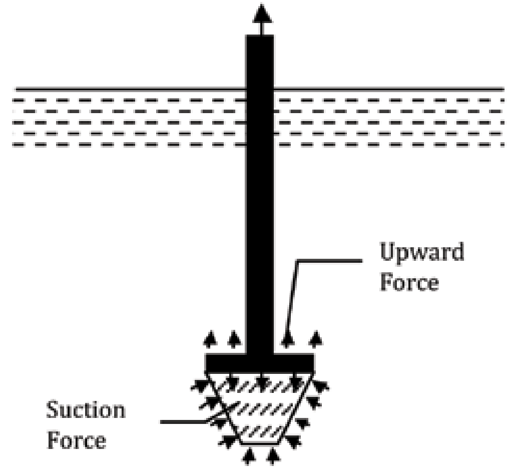


Figure 1.2 Suction Forces under Tension

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 pile's shaft significantly contributes to the pile's overall vertical capacity. Adams and Klym (1972) found that adhesion provides a substantial resistance to piles 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.

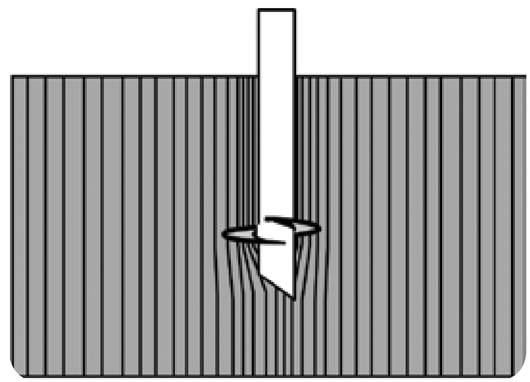


Figure 1.3 Soil Displacements

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.

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)

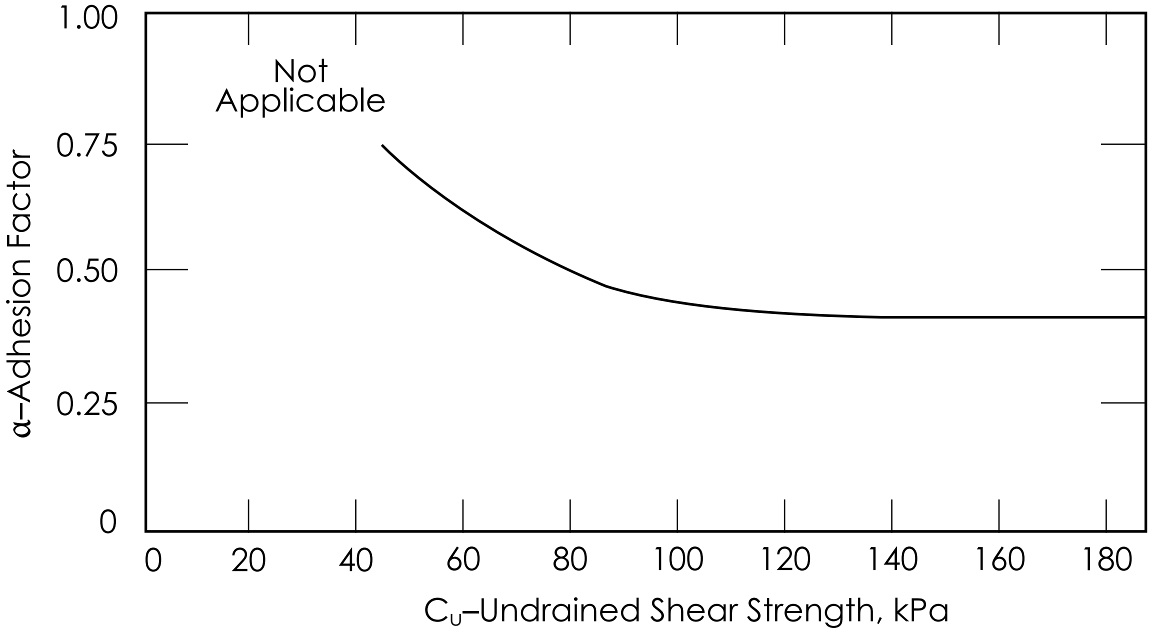


Figure 1.4 Reduction of Undrained Shear Strength for Pile Design (after CFEM, 1992)

Each soil, based on its composition and water content, has a unique density and weight. A common way to classify soils it 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, 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:

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 1.3 Typical Soil Parameters—Cohesionless Soil

Soil Description	Undrained Shear Strength kPa (psf)	Young's Modulus E (MPa) (ksf)
Very Soft	< 10 (< 0.210)	< 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)

Table 1.4 Typical Soil Parameters—Cohesive Soil

Part 2 Bearing and Uplift Capacity

Multi-Helix Helical 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*.

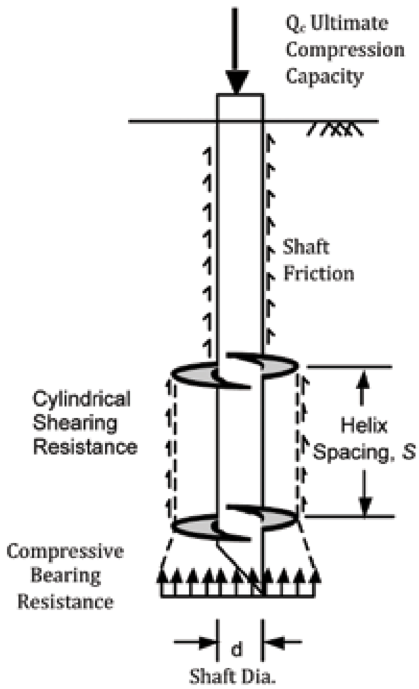


Figure 2.1 Compression Loading Forces Acting on a Multi-Helix Scew Pile

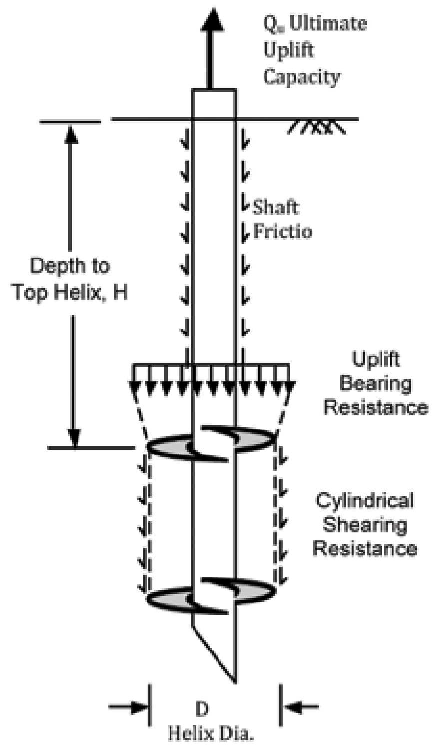


Figure 2.2 Tension Loading Forces Acting on a Multi-Helix Helical Pile

1.Cohesive Soil

1.1 Compression Loading

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

$$Q_c = Q_{helix} + Q_{bearing} + Q_{shaft} \qquad \textbf{Eqn. 2.1}$$

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 helical pile using a cylindrical shearing method as proposed by Mooney (1985) is:

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

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, (m^2)
- 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 *Figure 1.4*)
- Sf = spacing ratio factor

Pile Toe Diameter (m)	N_c
< 0.5	9
0.5–1.0	7
> 1.0	6

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

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

Table 2.2 Bearing Capacity Factors, N_c for Cohesive Soils, and Modified for Helix Selection

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 helical 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:

$$Q_c = Sf\ (\pi\ D\ L_c)\ C_u + A_H\ C_u\ N_c \qquad \textbf{\textit{Eqn. 2.3}}$$

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):

$$Q_t = Sf\ (\pi\ D\ L_c)\ C_u + A_H\ (C_u\ N_u + \gamma'\ H) + \pi\ d\ H_{eff}\ \alpha\ C_u \qquad \textbf{\textit{Eqn. 2.4}}$$

Where:

Q_t = ultimate helical pile uplift capacity, (kN)
γ' = effective unit weight of soil above water table or buoyant weight if below water table, (kN/m^3)
N_u = dimensionless uplift bearing capacity factor for cohesive soils
H = embedment depth, (m)
Sf = spacing ratio factor

For multi-helix helical 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 helical 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.

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

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:

$$Q_t = (\pi\ D\ L_c)\ C_u + A_H\ (C_u\ N_u + \gamma'\ H) \qquad \textbf{\textit{Eqn. 2. 6}}$$

2. Cohesionless Soil

2.1 Compression Loading

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

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

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

$$Q_{bearing} = \gamma'\ H\ A_H\ Nq \qquad \textbf{Eqn. 2.8}$$

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

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

Where:

Q_c = ultimate compression capacity, (kN)
γ' = effective unit weight of soil, (kN/m^3)
K_s = coefficient of lateral earth pressure in compression loading
ϕ = soil angle of internal friction, degree
A_H = area of the bottom helix, (m^2)
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 helical pile shaft, (m)

Explanation of some of the terms:

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

$$N_q = e^{\pi \tan\phi}\ \tan^2\ (\ 45^o\ +\ \phi/2\ ) \qquad \textbf{Eqn. 2.11}$$

Values of N_q are summarized in *Table 2.3.*

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

Table 2.3 Bearing Capacity Factor, N_q, for Cohesionless Soils

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*).

Installation Method	K_s/K_o
Piles, Large Displacement (≥ Ø8–5/8" shaft)	1 to 2
Piles, Small Displacement (< Ø8–5/8" shaft)	0.75 to 1.25

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

Relative Density	K_o
Loose	0.5
Medium-Dense	0.45
Dense	0.35

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

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 Ko for driven piles.

For the shallow condition (i.e H/D < 5), the ultimate compression capacity of a multi-helix helical 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:

$$Q_c = \gamma' H A_H N_q + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_s \tan\phi$$ ***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 helical 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 pile conditions and F_q^* as follows:

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

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

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

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

Where:

Q_t = ultimate helical pile uplift capacity, (kN)
γ' = effective unit weight of soil, (kN/m^3)
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, (m^2)
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 helical pile shaft, (m)
F_q = 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.

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

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

This coefficient, K_u is used to empirically quantify the lateral stress acting on the failure surface as the helical 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.

Soil Friction Angle, ϕ	Meyerhof's Coefficient for Foundation Uplift	Recommended Coefficients for Helical Piles
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

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

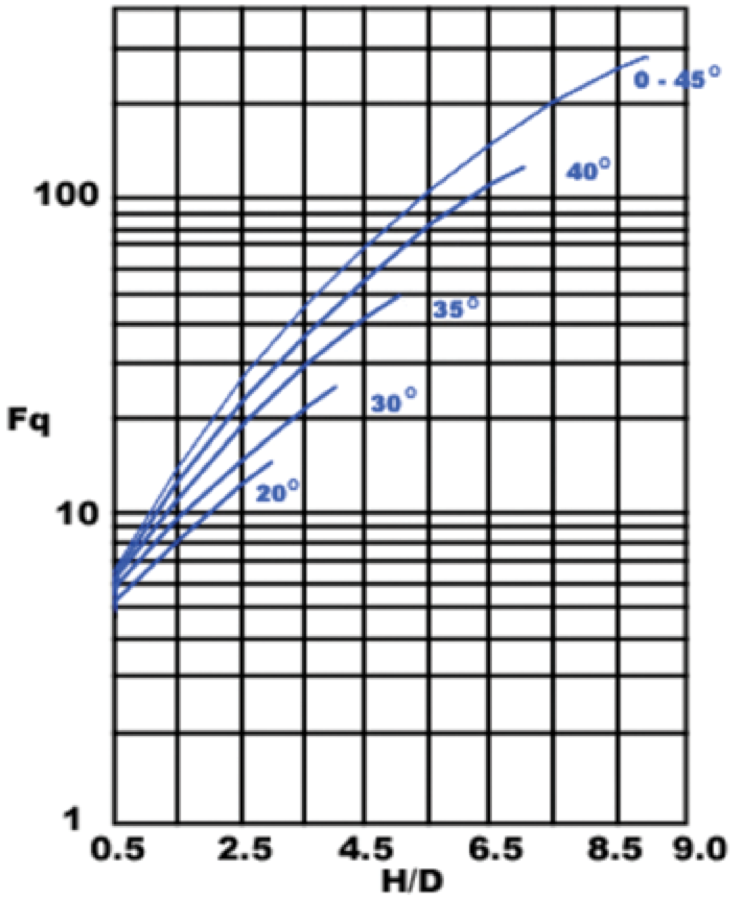


Figure 2.3 Variation of Breakout Factor with Embedment Depth for Shallow Pile Condition based on Mitsch and Clemence's Theory (after Das, 1990)

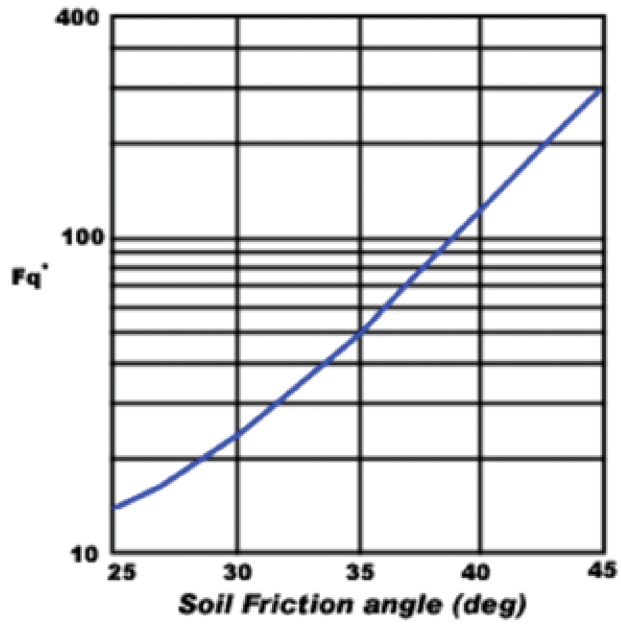


Figure 2.4 Variation of Breakout Factor with Embedment Depth for Deep Pile Condition Based on Mitsch and Clemence's Theory (after Das, 1990)

Single Helix Helical Pile

For a single helix helical 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 helical piles should be adjusted to not include the cylindrical component.

1. Cohesive Soil

1.1 Compression Loading

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

1.2 Tension Loading

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

2. Cohesionless Soil

2.1 Compression Loading

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

2.2 Tension Loading

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

$$Q_t = \gamma'\ H\ A_H\ F_q \qquad \textbf{Eqn. 2.18}$$

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

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

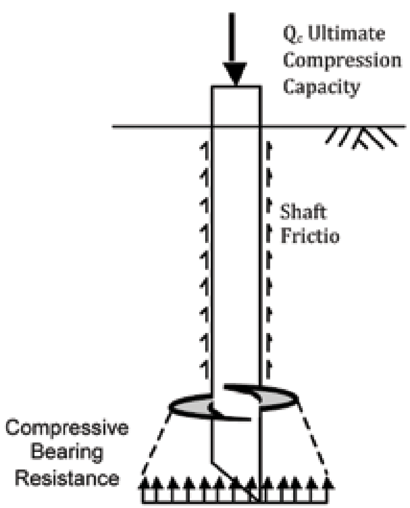


Figure 2.5 Compression Loading Forces Acting on Single Helix Helical Pile

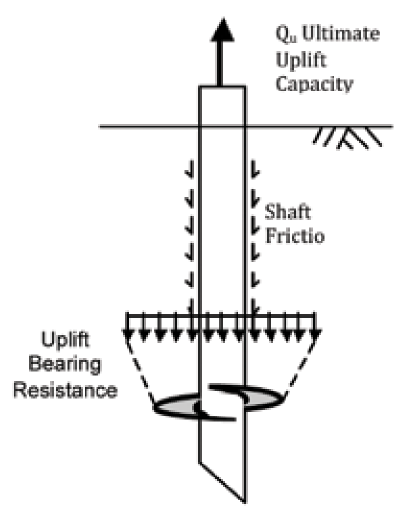


Figure 2.6 Tension Loading Forces Acting on Single Helix Helical Pile

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 helical pile.

Torque Installation Method for Predicting Capacity

An empirical method has been derived and used in the helical pile industry for many years. Installation torque is used to calculate the ultimate capacity of the screw pile. The average torque achieved during the last 3 to 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, Kt can be calculated using the following:

$$K_t = Q_t \ / \ T \qquad \textbf{\textit{Eqn. 2.20}}$$

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 2 to 20, 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 helical 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 3-½" pipe helical is recommended to be around 7 for most soils and the factor for 2-⅞" pipe is usually in the 7 to 10 range for most soils.

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

HPS 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.
All pile method will be used to estimate pile capacity for each case.
All pile has 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
- 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:

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

Where: $K \approx k_h B \approx 0.305k_1/1.5B \approx k_1/5B$ ***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*.

Consistency	Stiff	V. Stiff	Hard
Undrained shear strength (C_u) kN/m^2	50–100	100–200	>200
Range of k_1 MN/m^3	15–30	30–60	>60
Soil modulus (K) MN/m^2	3–6	6–12	>12

Table 3.1 Relationship of Modulus of Subgrade Reaction (k_1) to Undrained Shearing Strength of Stiff Overconsolidated Clay (After Elson)

For most normally consolidated clays and for granular soils the soil modulus is assumed to increase linearly with depth, for which

Stiffness factor $T = \sqrt[5]{(EI/n_h)}$ (in units of length) ***Eqn. 3.3***

Where: $K = n_h \times x/B$ ***Eqn. 3.4***

Soil Compactness Condition	n_h (Above Groundwater) KN/m^3	n_h (Below Groundwater) KN/m^3
Loose	2200	1300
Compact	6600	4400
Dense	18000	11000

Table 3.2 Values of n_h for Cohesionless Soils (Terzaghi, 1955)

Having calculated the stiffness factors *R* or *T*, the criteria for behavior as a short rigid pile or as a long elastic pile are related to the embedded length *L* as follows in *Table 3.3*.

Pile Type	Soil Modulus	
	Linearly Increasing	Constant
Rigid (free head)	$L \leq 2T$	$L \leq 2R$
Elastic (free head)	$L \geq 4T$	$L \geq 3.5R$

Table 3.2 Values of n_h for Cohesionless Soils (Terzaghi, 1955)

HPS utilizes and recommends All Pile method to determine the ultimate lateral resistance for an HPS helical type piling. These piles are most often classified as "Unrestrained or Free-Head short rigid piles". (See Broms (1964a) and Broms (1964b) in the References).

Lateral Ultimate Resistance of Piles

For uniform cohesionless soils, All Pile has established the graphical relationships for $H/K_pB^3\gamma$ and $M_U/B^4\gamma\ K_p$ shown in *Figure 3.4* (For short piles) and *Figure 3.5* (For long piles), from which the ultimate lateral resistance H_u can be determined.

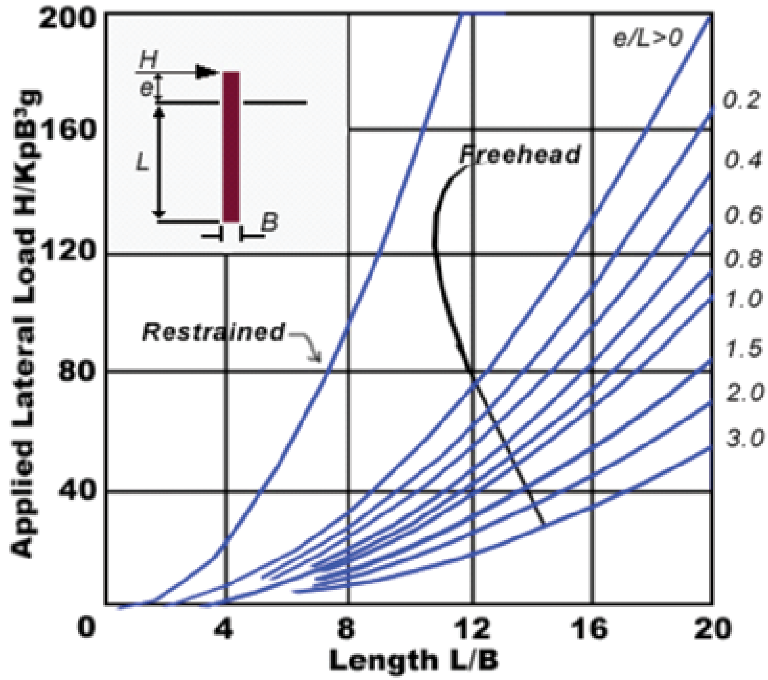


Figure 3.4 Ultimate Lateral Resistance of Short Pile in Cohesionless Soil related to Embedded Length

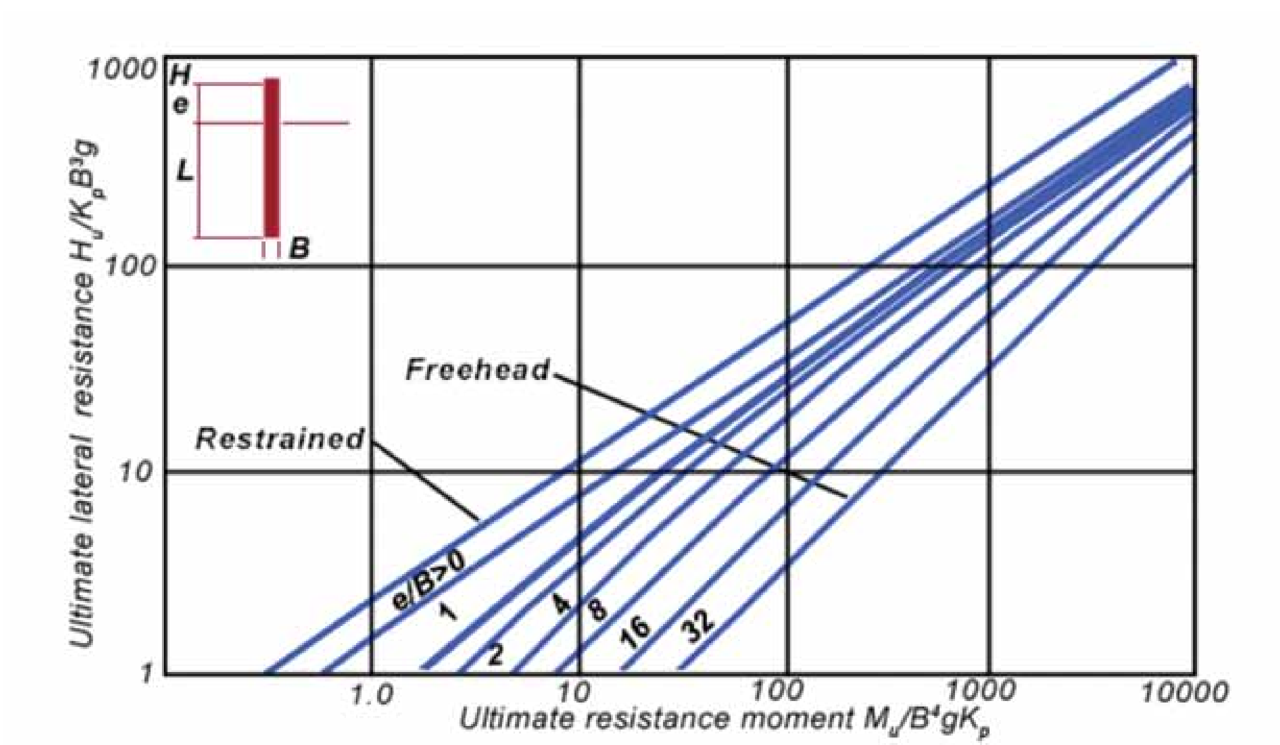


Figure 3.5 Ultimate Lateral Resistance of Long Pile in Cohesionless Soil Related to Embedded Length

For uniform cohesive soils, All Pile has established the graphical relationships for H/C_uB^2 and M_U/C_uB^3 *Figure 3.6* (For short piles) and *Figure 3.7* (For long piles), from which the ultimate lateral resistance H_u can be determined.

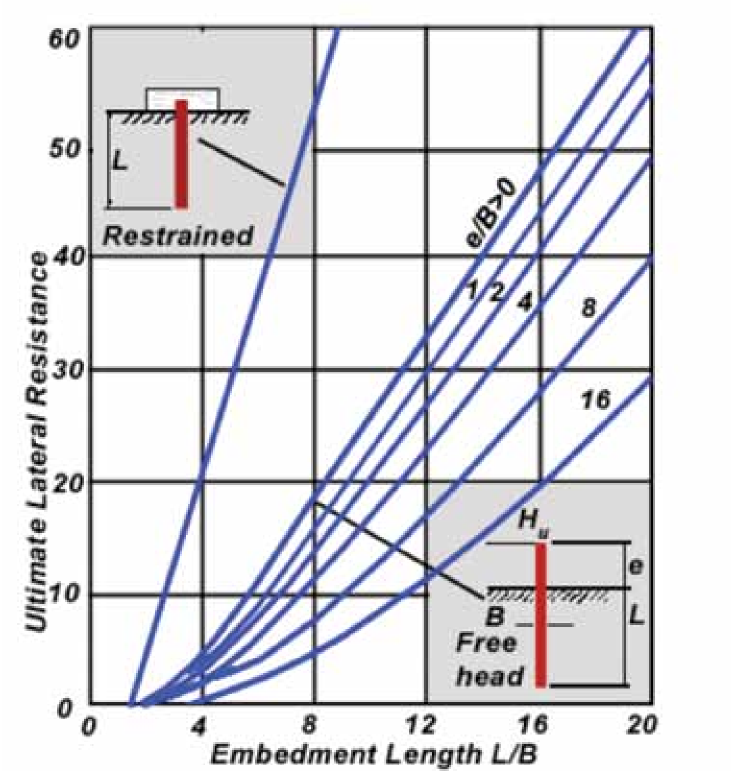


Figure 3.6 Ultimate Lateral Resistance of Short Pile in Cohesive Soil Related toEmbedded Length

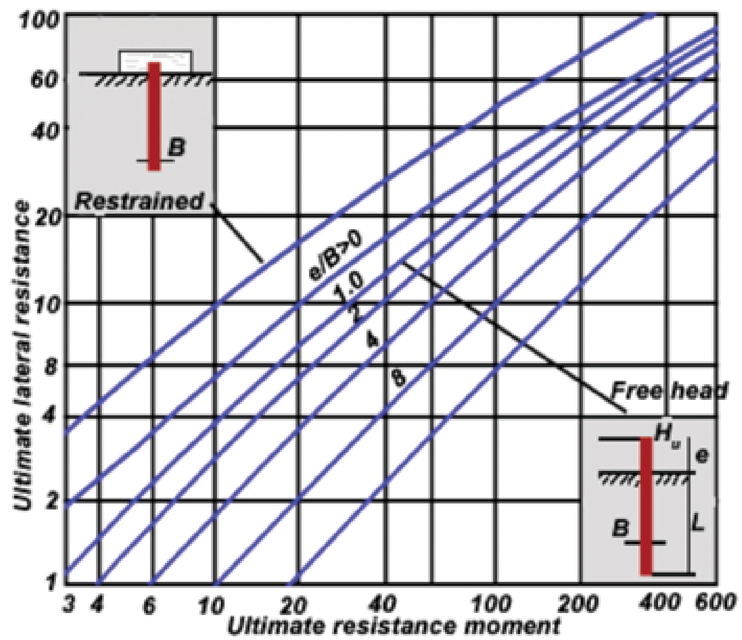


Figure 3.7 Ultimate Lateral Resistance of Long Pile inCohesive Soil Related to Embedded Length

Deflection of Vertical Piles Carrying Lateral Loads

In cohesive soils the deflection behavior depends on the dimensionless length βL.
Where:

$\beta = \sqrt[4]{(KB / 4EI)}$ **Eqn 3.5**

Where Y_0 is the pile head deflection for lateral load (H) in the dimensionless lateral deflection in *Figure 3.8*.

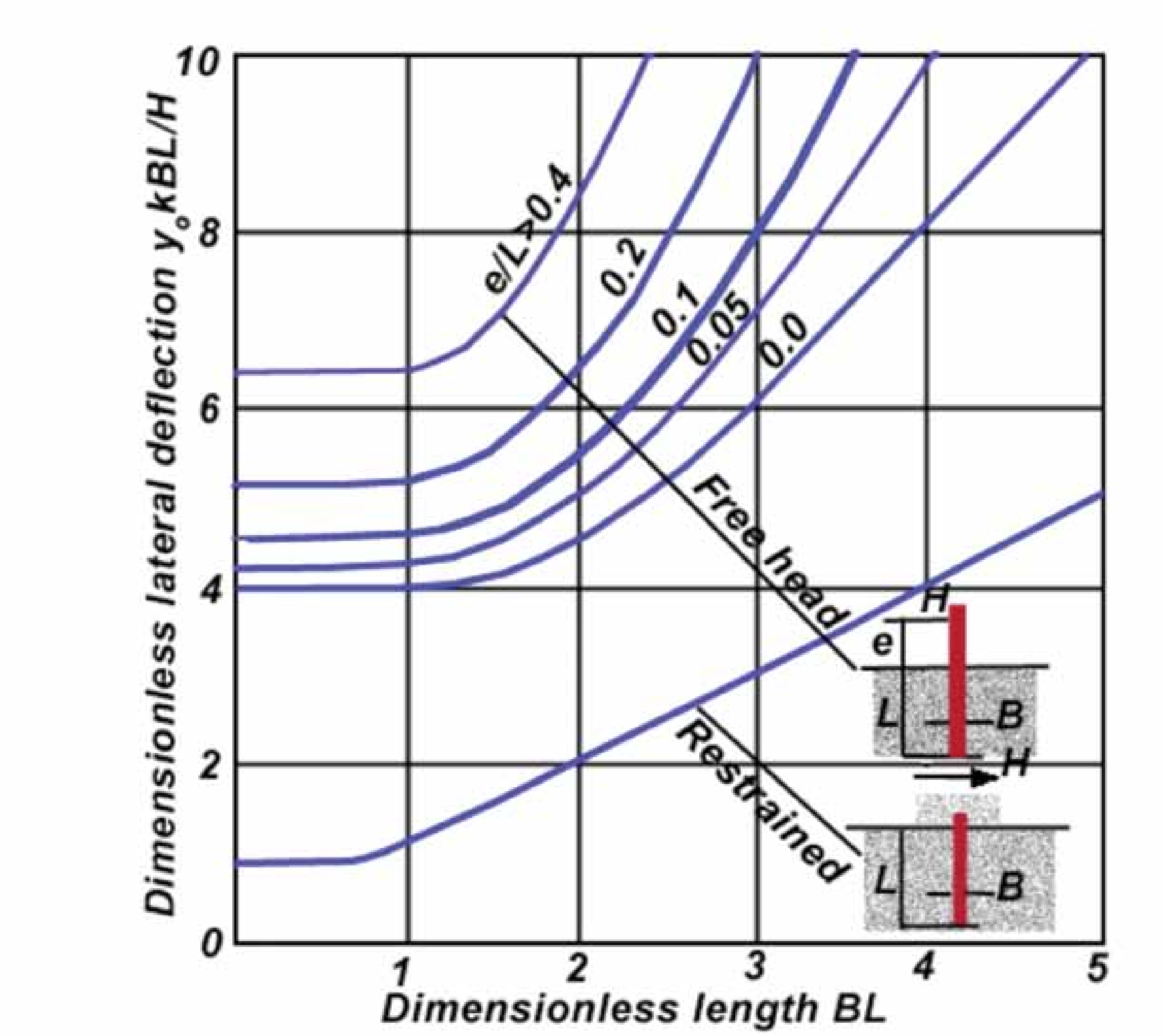


Figure 3.8 Lateral Deflection of Pile Head in Cohesive Soil (All Pile)

In cohesionless soils the deflection behavior depends on the dimensionless length ηL.
Where:

$\eta = \sqrt[5]{(\eta_h / EI)}$ **Eqn 3.6**

Where Y_0 is the pile head deflection for lateral load (H) in the dimensionless lateral deflection in *Figure 3.9*.

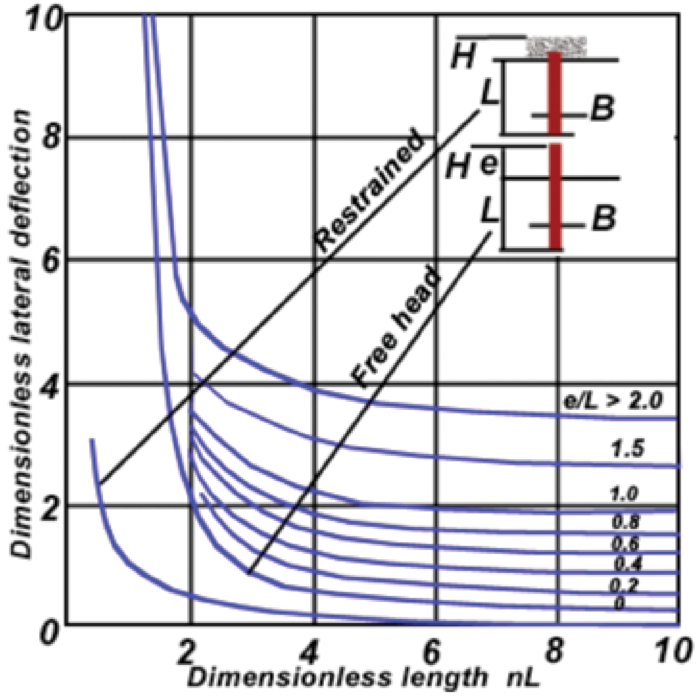


Figure 3.9 Lateral Deflection of Pile Head in Cohesionless Soil (All Pile)

Lateral Pile Deflections

For the subgrade reaction models, it is assumed that the soil around a pile can be simulated by a series of horizontal springs, each spring representing the behavior of a layer of soil of unit height. When the pile is forced against the soil under the action of the horizontal loads, the soil deforms and generates an elastic reaction assumed to be identical to the force that would be generated by simulating spring subjected to the same deformation. With the further assumption that the soil is homogenous, i.e., all springs are identical, the soil's behavior can be estimated if the equivalent spring constant is known. This spring constant is called the coefficient of subgrade reactions k_s (dimension: force/volume).

Coefficient of Subgrade Reaction

The coefficient of horizontal subgrade reaction may be estimated by the following method.

a) In cohesionless soil

$$k_s = n_h \, (z / d)$$ ***Eqn. 4.1***

Where:

k_s = coefficient of horizontal subgrade reaction (force per volume)
z = depth
d = pile diameter
n_h = coefficient related to soil density as given in *Table 4.1*

Soil Compactness Condition	n_h (kN/m³)	
	Above Groundwater	Below Groundwater
Loose	2200	1300
Compact	6600	4400
Dense	18000	11000

Table 4.1 Values of n_h for Cohesionless Soils

b) In cohesive soil

$$k_s = 67 \, C_u / d$$ ***Eqn. 4.2***

Where:

k_s = coefficient of horizontal subgrade reaction (force per volume)
C_u = undrained shear strength of the soil
d = pile diameter

Determination of Moments and Deflections

This section considers only the most common case of piles with a rigid cap at ground surface. (All Pile)

The distribution and magnitude of moments and deflections in a pile subjected to horizontal forces are essentially a function of the relative stiffnesses, T, of the pile-soil system. For sand, *T* is given by the following relation:

$$T = (4EI / n_h)^{1/5} \qquad \textbf{Eqn. 4.3}$$

and for overconsolidated clay

$$T = (EI / k_s d)^{1/4} \qquad \textbf{Eqn. 4.4}$$

Where:

E = elastic modulus of pile material
I = moment of interia of pile cross section
n_h = a constant as given in *Table 4.1*, above
k_s = coefficient of horizontal subgrade reaction

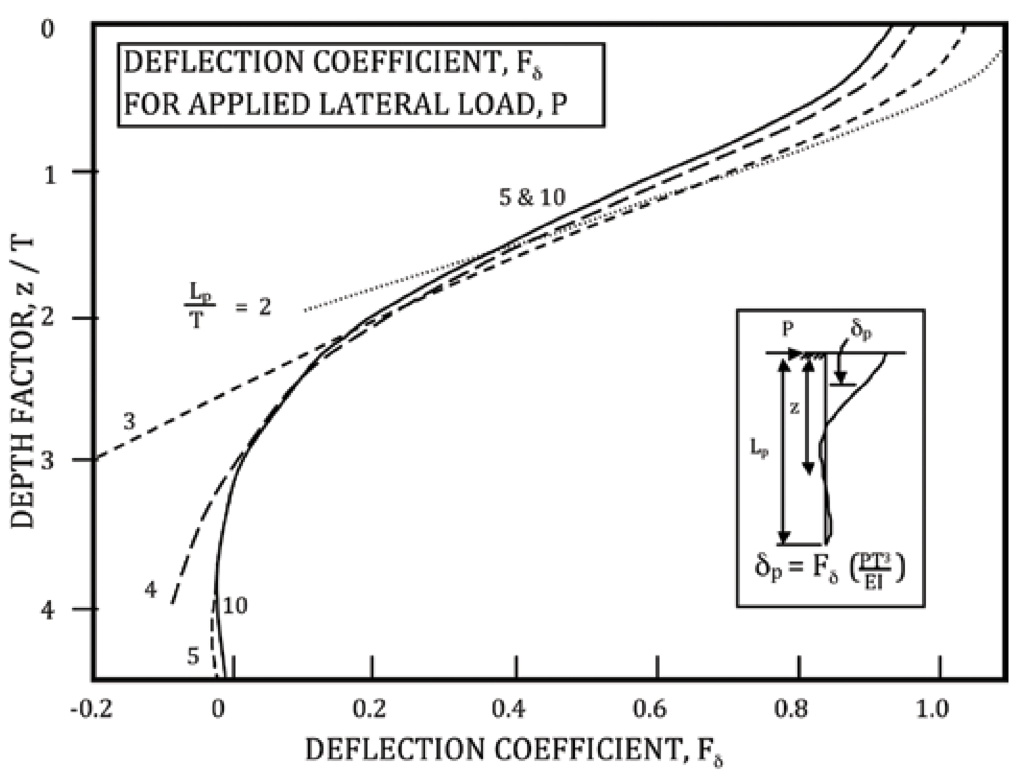
From the value of *T*, the moments, M_p, in the pile and the deflections, δ_p, of the pile cap may be computed at any depth using the following formulae:

$$M_p = F_m (P T) \qquad \textbf{Eqn. 4.5}$$

$$\delta_p = F_\delta (P T^3 / E I) \qquad \textbf{Eqn. 4.6}$$

Where:

M_p = moment at depth z
δ_p = deflection at depth z
F_m = moment coefficient at depth z, as given in *Figure 4.2*
F_δ = deflection coefficient at depth z, as given in *Figure 4.1*
P = applied horizontal load
T = relative stiffness



Figuire 4.1 Deflection Coefficients of Laterally Loaded Piles (All Pile)

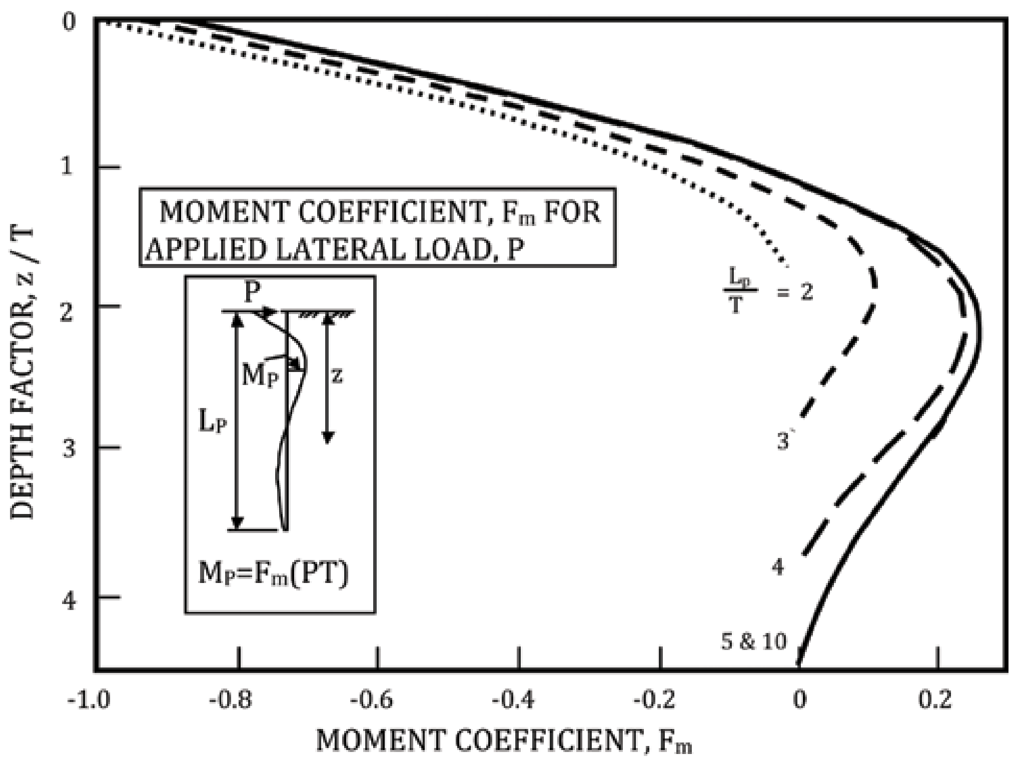


Table 4.2 Moment Coefficients for Laterally Loaded Piles (All Pile)

Part 5 Buckling of Piles

Helical piles by design are long and slender, and although extremely rare, are susceptible to buckling when placed under extreme compressive loading conditions. The buckling of piles can be caused by one of two situations. Extreme compressive forces may cause the shaft to fold and buckle. This would occur in the upper portion of the pile where the soil is weak. The more common buckling situation is when a pile is exposed to lateral loading. A pile exposed to lateral loading behaves similar to any supporting member under lateral loading. The lower part of the pile will remain stationary while the upper part will start to bend. A helical pile will behave similar to that of slender deep pile with the helix supplying little lateral or bending moment resistance, unless it is designed to supply resistance (i.e. shallow condition or shallow helix embedment).

Included in this section are varying methods for determining the structural capacity of the pipe shaft portion of the helical pile. There are different ways to determine the ultimate piling shaft capacity subjected to axial loading; and we have selected Poulos and Davis (1980) method to estimate the ultimate vertical capacity (Pr) the pile can take before starts buckling.

Poulos and Davis (1980) suggested the following:

During loading, a partly embedded vertical pile subjected to a vertical load. The stiffness factors *R* and *T* as calculated from *Eqn. 3.1 and 3.3* and have been used to obtain the equivalent length of a freestanding pile with a fixed base, from which the factor of safety against failure due to buckling can be calculated using conventional structural design methods.

For a partly embedded pile carrying a vertical load *P*, the equivalent height L_e, of the fixed-base pile is shown in *Figure 5.1b*.

For soil with a constant modulus:

Depth to a point of fixity $z_f = 1.4\ R$ ***Eqn. 5.1***

For soils having a linearly-increasing modulus:

$z_f = 1.8\ T$ ***Eqn. 5.2***

The relationships of equations 5.1 and 5.2 are only approximate, but they are valid for structural design purposes provided that l_{max}, which is equal to L/R, is greater than 4 for soils having a constant modulus and provided that z_{max}, which is equal to L/T, is greater than 4 for soils having a linearly-increasing modulus. *From Eqn. 5.1 and 5.2* the equivalent length L_e of the fixed-base pile (or column) is equal to $e + z_f$ and the critical load for buckling is:

$$P_{cr} = \frac{\pi^2 EI}{4R^2\ (S_R + Z_R)^2}$$ For free-headed conditions ***Eqn. 5.3***

$$P_{cr} = \frac{\pi^2 EI}{R^2\ (S_R + Z_R)^2}$$ For fixed- (and translating-) headed conditions ***Eqn. 5.4***

Where:

$S_R = L_S \; / \; R$ ***Eqn. 5.5***

$J_R = L_U \; / \; R$ ***Eqn. 5.6***

L_S = Equivalent free length of embedded portion of pile (*Figure 5.1*)

L_U = Unsupported pile length

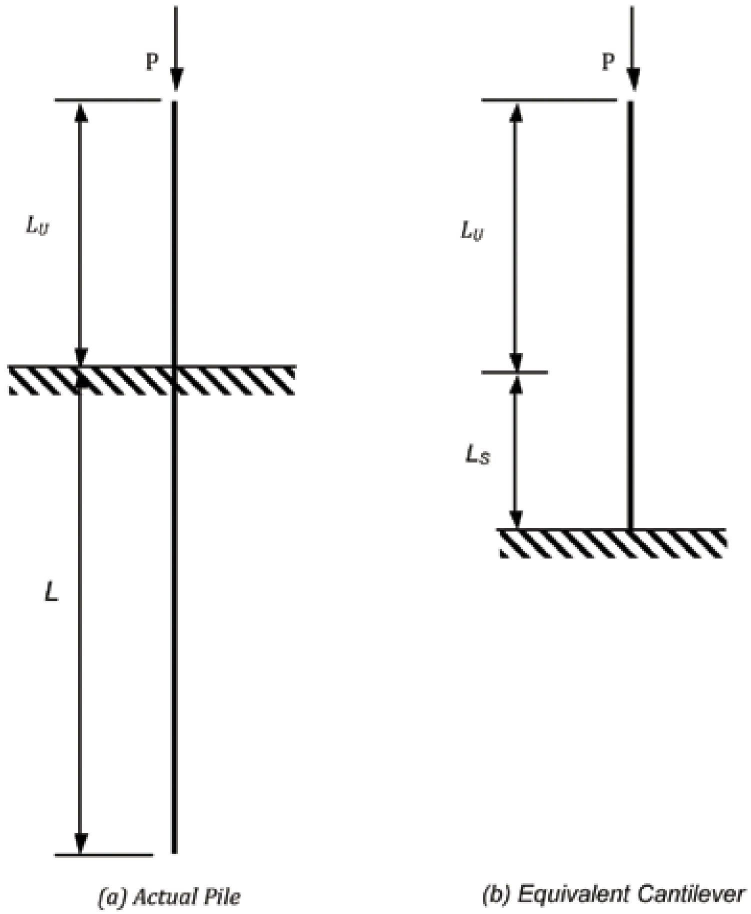


Figure 5.1 Partially Embedded Piles (after Poulos and Davis 1980)

Part 6 Use of Helical Piles as Tiebacks

HPS has been manufacturing multi-helix helical piles since 1977. These piles have established a consistent record of performance through extensive use in tieback applications for the electric utility and oil and gas industry. Construction application for helical piles in retaining wall tie backs continue to grow.

Compared to a grouted anchor a helical pile's advantage is how it removes the performance uncertainties and costs associated with a grouted anchor when used in loose sandy soils or in low shear strength clay soils. When placed in the soil, the helical pile acts as a bearing device. This is a fundamental difference compared to a grouted anchor formed in the soil and reliant on friction between soil and grout. Collapse of a prepared hole can change a grouted anchor's dimensions. There is little opportunity to assess the problem's magnitude and exact location because it is in the hole, out of sight. Protecting grout from such an occurrence adds the extra costs of installing casing. A helical pile averts these drawbacks by requiring neither an open hole nor a casing.

Helical piles can be designed to hold large capacities.

Advantages of using HPS helical piles as tiebacks include:

- Competitive installing costs
- Immediate proof testing and loading- no waiting time for grout to cure
- Installs in any weather
- Speeds excavation and construction
- Removable and Reusable
- No spoil to remove

Estimating the lateral loads (*Figure 6.1*) acting against retaining walls as exerted by the soil requires knowledge of:

- Soil type and conditions
- Structural dimensions of the retaining structure
- Ground water table

Every wall tieback situation is unique, but there are some aspects that merit attention. The placement of the pile is influenced by the height of the soil backfill against the wall. *Figure 6.2* shows this condition and a guideline for setting the location of the tieback pile. Experience indicated that the tieback should be located close to the point of maximum wall bulge and/or close to the most severe transverse crack. In many cases the tieback placement location must be selected on a case-by-case basis.

Another factor to consider is the height of soil cover over the helical pile. *Figure 6.2* also indicates that the minimum height of the cover is 6 times the diameter of the largest helical plate. Finally, the helical pile must be installed a sufficient distance away from the wall in order that the helical plate(s) can develop an anchoring capacity by passive pressure. This requires the length of installation to be related to the height of soil backfill.

From all the above information we can figure out the soil active pressure and the water pressure against the wall. Upon preliminary design of pile rows depth, the load on each row/ Meter width of the wall can be calculated. With HPS previous experience with helical piles, we can decide the horizontal spacing between piles and accordingly the load on each helical pile can be determined.

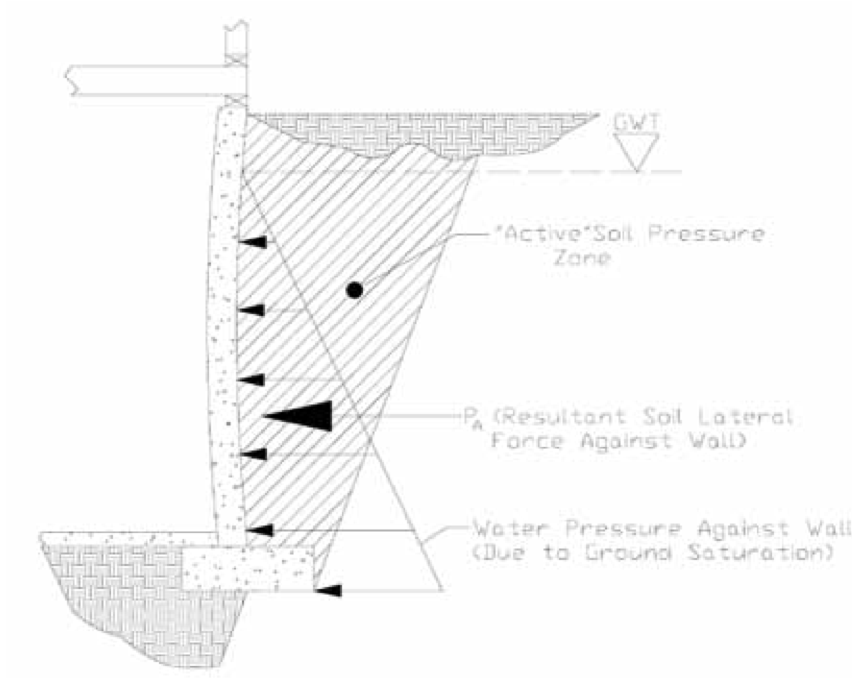


Figure 6.1 Earth and Water Pressure Distribution Behind Retaining Wall

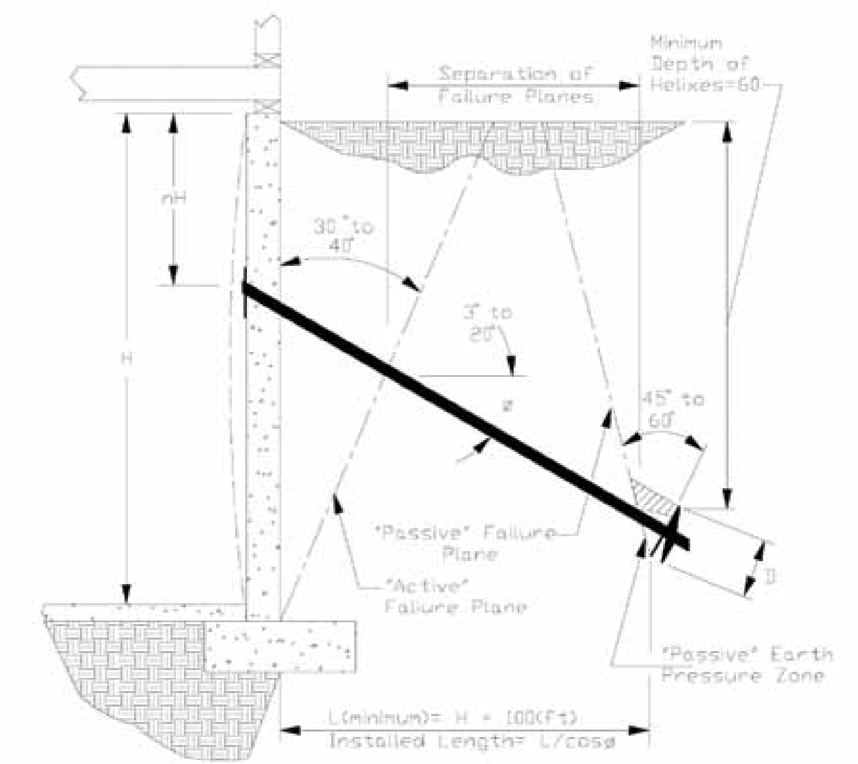


Figure 6.2 Typical Installation Depth and Length for Helical Tiebacks

Depending on the spacing between Helices (S) / Helix diameter (D) ratio, the design method of the helical piles will be either:

1. Individual Plate Method

Adam and Klym (1971) stated that at S/D ≥ 2, each helix plate can be assumed to behave independently of the other. HPS extensive tests showed that this method can be used if S/D ≥ 3.

The individual bearing method assumes that bearing failure occurs above each individual helix. The total uplift resistance is the sum of the individual capacities.

$$Q_t = Q_{shaft} + \Sigma\ Q\ I\ (\text{bearing}) \qquad \textit{Eqn 6.1}$$

Where:

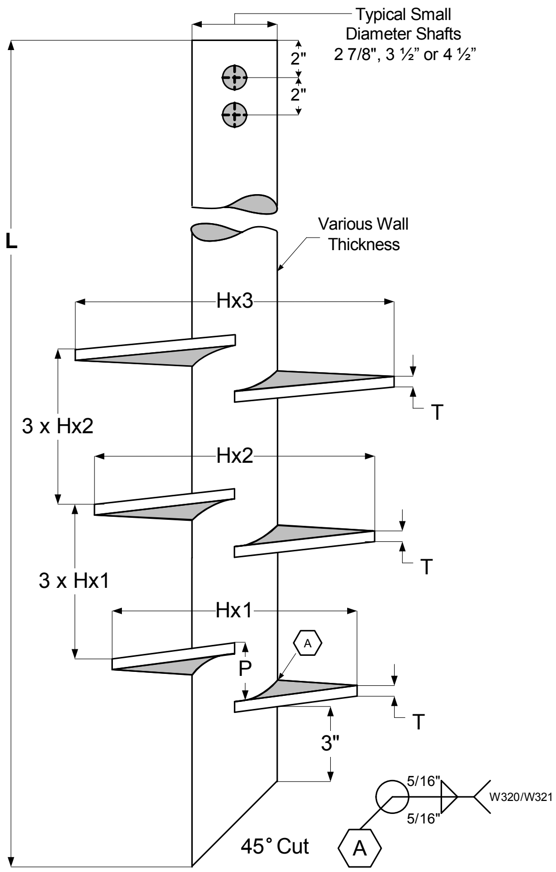
Q_t = ultimate uplift capacity
Q_{shaft} = adhesion developed along the steel shaft (*Part 2*)
Σ Q I (bearing) = sum of the bearing capacity of each individual helix (*Part 2*)

2. Cylindrical Shear Method

Please refer back to *Part 2* for the design.

Part 7 Selection of Helical Pile

HPS helical pile shaft sizes range from 2-⅞" to 36" in diameter with varying wall thicknesses. *Table 7.1* lists the most common and readily available pipe shaft sizes. The small diameter shafts are mainly used for compression and tension loads where lateral loads are minimal. Larger diameter shafts are used when the helical piling is subjected to large compressive loads and/or lateral loads and/or moments of overturn. There are many determining factors that lead to the selection of a pipe shaft used for a helical piling. The criteria that directly lead to the selection of the appropriate shaft size are: axial load, tension load, lateral load, moment of overturn, torque considerations, installation equipment, helix size, soil conditions and possibly others. (See *Parts 3, 4 and 5* for shaft designing).



Notes:

Shaft: (Pipe) meets or exceeds ASTM Standards with a minimum yield strength of 70 KSI and a minimum tensile strength of 85 KSI.

Shaft: (Bar) meets or exceeds ASTM Standards with minimum yield strength of 95 KSI and a minimum tensile strength of 120 KSI.

Helix: Structual quality plate to conform for latest CSA Standard G 40.21 minimum grade, ASTM A36.

Welding: Welding performed by a shop qualified to CSA Standard W47.1 and in adherance to CSA Standard W59.

Galvanizing: Hot dipped as per latest CSA Standard G164-M and ASTM A153, on request.

Hx - Helix Diameter 6" to 18"

T - Thickness of Helix ⅜" or ½"

P - Pitch of Helix 3" or 6"

L - Length of pile 2' to 10'

Pipe Shaft Outside Diameter	Common Wall Thickness	Maximum Torque (Ft. Lbs.)
2-7/8"	0.217	8000
3-1/2"	0.254	16,000
4-1/2"	0.250, 0.237	21,500, 20,400
5-1/2"	0.275	43,600
6-5/8"	0.280, 0.250	53,900
8-5/8"	0.264, 0.322	67,000, 81,200
10-3/4	0.365, 0.250	+90,000
12-3/4"	0.375, 0.250	+90,000

Table 7.1 Common Pipe Sizes

The critical factors that dictate the helix size are axial load, tension load, torque consideration, installation equipment, soil conditions and pipe shaft size (see *Table 7.2*). *Table 7.2* shows the helix configurations that will fit on various pipe shaft sizes. The minimum sizes are the minimum physical sizes that will fit on pipe and the maximum are the maximum practical sizes available. (See Part 2 for Helix designing).

HPS Ltd helix sizes come in a wide variety of shapes and sizes, if necessary, custom designing to your specifications.

Helix diameters currently range from 6 to 48 inches, pitches are set at 3, 4, 6, 12 and 24, thickness of plate range from ¼, ⅜, ½, ¾, and 1 inches.

Pipe Shaft O.D. (inches)	Helix Diameter (inches)																					
	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48
2-7/8	X	X	X	X	X	X																
3-1/2		X	X	X	X	X	X	X														
4-1/2			X	X	X	X	X	X	X	X												
5-1/2				X	X	X	X	X	X	X	X	X	X									
6-5/8					X	X	X	X	X	X	X	X	X	X	X	X						
8-5/8					X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
10-3/4						X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
12-3/4							X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
14								X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
16										X	X	X	X	X	X	X	X	X	X	X	X	X
20												X	X	X	X	X	X	X	X	X	X	X
24													X	X	X	X	X	X	X	X	X	X
30																X	X	X	X	X	X	X
36																			X	X	X	X

Table 7.1 Helix Diameter vs. Pipe Shaft

Steps in Pile Selection:

1. Determine applied loads on pile: Dead load, live load & safety factors.
2. Determine site specific soils information: soil type, soil description, soil classification, water table levels and depth of frost penetration.
3. Compare soils information with pile load and location information. Pile spacing—is there a group effect among piles?
4. Design pile—pile geometry (*See parts 1 thru 5* of manual).
   Select: pile shaft, helix diameter and thickness, number of helixes, embedment depth, extension required? Bolt-On or Welded?
5. Estimate installation torque.
6. Evaluate design—practical? Can the designed pile be installed? Do soil conditions allow for installing? Equipment/Power? Possibly repeat Step 4.
7. Calculate ultimate pile capacity and apply Safety Factors (Minimum S.F. = 2.0).

The steps are to be used as a guide in the pile design process, other factors may come into play when designing a helical pile (ie. seismic considerations, soil chemistry, etc.)

- Canadian Foundation Engineering Manual (CFEM)
- Alberta Building Code
- ASTM A252 — Welded and Seamless Steel Pipe Piles
- CSA G40.21-M — Structural Quality Steel
- CSA W47.1 — Certification of Companies for Fusion Welding of Steel Structures
- CSA W59 — Welded Steel Construction Steel construction (Metal Arc Welding)
- CSGB 1-GP-184 — Coal Tar Epoxy (black) Coating
- SSPC-SP6 — Commercial Blast Cleaning
- ASTM A 153 — Specification for Zinc Coatings (Hot-Dip) on Iron and Steel Hardware
- CSA G164 — Hot Dip Galvanizing of Irregularly Shaped Articles

Helical Plate:

Minimum ASTM A36 or CSA G40.21 44W Hot Rolled Structural Steel Plate.

Helical Pile Pipe:

3-½" Diameters piers and under (includes 2-⅞" piers):
meets or exceeds ASTM structural grade pipe requirements (min. yield strength of 70 ksi and min. tensile strength of 85 ksi).

4-½" Diameter piles and larger: meet or exceeds ASTM structural grade pipe requirements, seamless or straight welded, Pipe wall thickness vary from Schedule 20 – Schedule 40 – Schedule 80, (min. yield strength of 90 ksi and min. tensile strength of 105 ksi).

Welding:

- All Welding is certified by the Canadian Welding Bureau (CWB) in Division 2.1. The welding design and welding fabrication of structural steel will be in accordance with the CSA Standard W47.1.
- All welding performed in accordance with the requirements of CSA Standard W59.1, Latest Edition.

Fasteners:

All bolts will be supplied as per customers' requirements.
Minimum requirements are ASTM A 325 bolts.
Bolts are bare metal (black), plated or hot-dipped galvanized.

Testing Standards:

When conducting Pile Load Tests they are preformed in accordance with ASTM D1143, Standard Method of Testing Piles Under Axial Compressive Load, ASTM D3689, Standard Method of Testing Individual Piles Under Static Axial Tensile Load, and ASTM D3966, Standard Method of Testing Piles Under Lateral Loads.

Torques:

The maximum torque for the 2 ⅞" pipe is 8,000 FT.LBS.
The maximum torque for the 3½" pipe is 16,000 FT/LBS.

Part 8 Hot-Dip Galvanizing for Corrosion Protection

For over 150 years galvanizing has had a proven history of commercial success as a method of corrosion protection in a myriad of applications worldwide.

HPS uses a round shaft pile and as the galvanizing process involves total immersion of the material, it is a complete process; all surfaces are coated, both inside and outside.

A primary factor governing corrosion behavior of the galvanized coating in liquid chemical environments is the pH of the solution. Galvanizing performs well in solutions and soils with a pH above 4.0 and below 12.5 within the pH range or 4.0 to 12.5 a protective film forms on the zinc surface and the galvanized coating protects the steel by slowing corrosion to a very low rate.

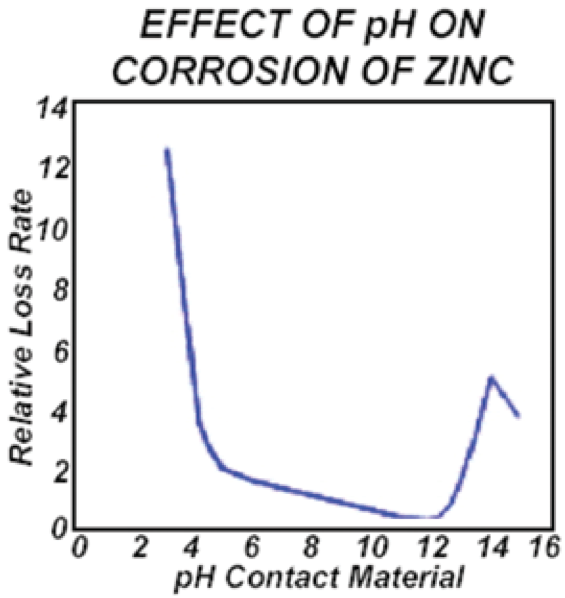


Figure 8.1

The pH range of the soil/water is another important factor. Galvanized coatings proved excellent corrosion resistance when the pH is above 4.0 and below 12.5. See *Figure 8.1*.

The National Bureau of Standards has conducted an extensive research program on the corrosion of metals in soils. Some of their research on galvanized steel pipe dates back to 1924. The expected life is based on a zinc coating thickness of 200μm.

The results of these tests also showed that the galvanized coating will prevent pitting of steel in soil, just as it does under atmospheric exposure, and that even in instances where the zinc coating was completely consumed, the corrosion of the underlying steel was much less than that of bare steel specimens exposed under identical conditions.

The expected life for a galvanized helical pile is calculated using a conservative coating thickness of 200 µm. The actual measured coating thickness of HPS' helical piles is usually in the 300–400 µm range. If this value is used then the life expectancy would be double.

The galvanized coating will provide 50–100 years of corrosion free service. The study also showed that even after all of the galvanized coating is consumed the residual zinc in the soil would reduce the corrosion on the remaining steel pile.

Cathodic Protection

Cathodic protection is an equally important method for preventing corrosion. Cathodic protection requires changing an element of the corrosion circuit, introducing a new corrosion element, and ensuring that the base metal becomes the cathodic element in the circuit.

There are two major variations of the cathodic method of corrosion protection. The first is called the impressed current method. In this method an external current source is used to impress a cathodic charge on all the iron or steel to be protected. While such systems generally do not use a great deal of electricity, they are often very expensive to install. The other form of cathodic protection is the sacrificed anode method, in which a metal or alloy that is anodic to the metal to be protected is placed in the circuit and becomes the anode. The protected metal becomes the cathode and does not corrode. The anode corrodes, thereby providing the desired sacrificial protection. In nearly all electrolytes encountered in everyday use, zinc is anodic to iron and steel. Thus the galvanized coating provides cathodic corrosion protection as well as larrier protection.

Further information on galvanizing can be obtained from the American Galvanizing Association (aga@galvanizeit.org).

Pipe Manufacturer's Specifications

Specifications	A252 Piling Pipe	
Scope	Covers nominal (average) wall steel pipe piles of cylindrical shape and applies to pipe piles in which the steel cylinder acts as a permanent load-carrying member or as a shell to form cast-in-place concrete piles.	
Kinds of Steel Permitted for Pipe Matedal	Open-hearth Basic-oxygen Electric-furnace	
Permissible Variations in Wall Thickness	Not more than 12.5% under the nominal wall thickness specified.	
Chemical Requirements	**Seamless and Welded Pipe:** Open-hearth, Electric-furnace or Basic-oxygen	**Phosphorus Max. %** 0.050
Hydrostatic Testing	None specified.	
Permissible Variations in Weights per Foot	The weight of any length of pile shall not vary more than 15% over or 5% under the weight specified. Each length shall be weighed separately.	
Permissible Variations in Outside Diameter	Shall not vary more than plus or minus 1% from the diameter specified.	
Mechanical Tests Specified	Tensile Test—Either longitudinal or transverse at option of manufacturer. Minimum yield determined by the drop of the beam, by the halt in the gage of the testing machine, or by the use of dividers.	
Number of Tests Required	One tensile property test per 200 lengths.	
Lengths	May be ordered in single or double random lengths or in uniform lengths: **Single Random**—16'-25' md. **Double Random**—Over 25' (mm. avg. of 35'). **Uniform**—Plus or minus 1 on length specified.	
Required Markings on Each Length (On Tags attached to each Bundle in case of Bundled Pipe)	**Rolled, Die Stamped or Paint Stenciled (Mfgrs. option)** Manufacturer's name, brand or trademark, heat number, method of pipe manufacture, size, weight, length, wall thickness and ASTM A252 and the Grade.	
General Information	Surface imperfections exceeding 25% of the nominal wall in depth are considered defects. Defects not exceeding 33.5% of the nominal wall in depth may be repaired by welding. Before welding, the defect shall be completely removed.	

Note: This is summarized information from ASTM Standards and API Specification 5L. Please refer to the specific Standard or Specification for more details.

Mechanical Properties

Mechanical Properties		Grade 1	Grade 2	Grade 3
Tensile Strength, min	Psi Mpa kg/mm^2	50,000 345 35.2	60,000 414 42.2	66,000 455 46.4
Yield Strength, min	Psi Mpa kg/mm^2	30,000 205 21.1	35,000 240 24.6	45,000 310 31.6
Elongation, min	%	30	25	24
Gauge Length	in	2 / (48t + 15)	2 / (40t + 12.50)	2 / (32t + 1.00)

GRADE 44W CARBON STRUCTURAL STEEL

Pier Helicals: CSA Grade 44W

Product	Plates		Shapes
Thickness, in. (mm)	To 3/4 (20), incl.	Over 3/4 to 1-1/2 (20 to 40), incl.	All
Carbon, max, %	0.25	0.25	0.26
Manganese, %	…	080–1.20	…
Phosphorus, max, %	0.04	0.04	0.04
Sulfur, max, %	0.05	0.05	0.05
Silicon, %	0.40 max	0.40 max	0.40 max
Copper, min, % when copper steel is specified	0.20	0.20	0.20

Mechanical Specifications: CSA 44W

Plates, Shapes, and Bars:	
Tensile strength, ksi (MPa)	58–80 (400-550)
Yield point, min, ksi (MPa)	44 (300)

Plates and Bars:	
Elongation in 8 in. (200 mm), min, %	20
Elongation in 2 in. (50 mm), min, %	23

Part B References

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Helical Pier Systems Ltd. recommends field testing to verify the theoretically predicted pile capacity and to determine allowable design loads and minimum acceptable Safety Factors for the specific project.

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