HELI-PILE®

Simplified Design and Inspection Guide

March 2020

Preface

This simplified design and inspection guide was originally prepared for a short course presented by the author and Kevin M. McNeill, P.E., of D&B Engineering Contractors, Inc., on August 3, 2000, in conjunction with the GeoDenver 2000 Geotechnical Engineering Conference sponsored by the American Society of Civil Engineers. This current version is an update and revision of several versions published since 2000.

The material presented herein is the result of the author's experience and knowledge in designing, specifying, installing, inspecting and monitoring performance of helical piles and tension anchors since 1986. This is intended to be a practical, mostly non-technical, simplified design and inspection guide/reference for engineers and other foundation professionals using HELI-PILE®. It is the sole work of the author. No guarantee or warranty is expressed or implied by the author or HELI-PILE®. As always, the information presented herein must be coupled with sound engineering judgment.

Acknowledgements

The author acknowledges the contributions of Robert L. Jones, Chairman of HELI-PILE®, to this guide and to the entire helical pile industry. Bob is one of a select group of serious pioneers of helical pile technology in the world. In 1986 Bob was the first in the world to use helical piles for the repair of failed lightly loaded residential foundations in highly expansive clay soils. He is among the first in the world to seriously use helical piles for new foundations under lightly loaded residential structures in highly expansive soils. He is the first in the world to use helical piles for heavy multiple-story structures. He is the inventor, developer and patent holder of load transfer hardware and installation equipment now copied and used throughout the industry. He is the first in the world to manufacture the square hollow structural section (HSS) tubular helical pile, now copied and used throughout the industry, significantly in oil and gas. He is the inventor and patent holder of the modular helical pile technology described in this guide.

Bob Jones' foresight has led his companies to the forefront in the field. It is estimated since 1986 D&B Engineering Contractors, a specialty deep foundation contractor Bob founded in 1967 and now owned and managed by Dale Jones, has installed over 600,000 helical piles in the Front Range area of Colorado alone. As of the writing, no properly designed and installed helical pile by D&B Engineering Contractors has failed. This is a credit to Bob's and Dale's demand for high quality control and their insistence on the use of correct equipment, materials and procedures by knowledgeable engineers and trained installation personnel.

The author also acknowledges the contributions of Dale Jones, President and Owner of D&B Engineering Contractors, Fez Smith of Strategic Fence and Wall, Eric Strickland of Strickland Construction, and Jared Dalton and Richard Dalton of Intermountain Helical Piers Corporation, all dedicated specialty helical pile installation contractors whose photographs and drawings of structures founded on helical piles and specialized installation equipment appear in this guide.

John S. Pack, P.E., March, 2020

HELI-PILE®

SIMPLIFIED DESIGN AND INSPECTION GUIDE

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SECTION 1. DETAILED DESCRIPTION AND MECHANCICAL CAPACITIES

This book is for helical piles and anchors made by International Marketing & Research, Inc., Wheat Ridge (Denver), Colorado, USA, d/b/a HELI-PILE® (www.helipile.com).

1.1 Shapes and Sizes

HELI-PILE® compression helical piles are made identical to helical anchors for tension and lateral loads. They all are made and look the same. The term "pile" generally refers to compression, the term "anchor" generally refers to tension.

All HELI-PILE® helical piles and anchors consist of an initial length of steel shaft (called a "lead section" or "starter") with one or more split circular steel plates formed in the shape of a helix rigidly affixed to the shaft, hence the terms "helical pile" and "helical anchor." See photos and figures below. Each circular steel plate is called a "helix" in singular or "helices" in plural. The circular steel plates may also be called "helical plates" or "helical bearing plates." Drawings of many HELI-PILE® products can be found at www.helipile.com.

HELI-PILE® shaft is manufactured in the following shapes:

- -RCS (Round-Corner Square solid bar, includes modular, Photos 1-1 and 1-2)
- -Square HSS (Square Hollow Structural Sections, also called square tubular, Photo 1-3)
- -Round HSS (Round Hollow Structural Sections, also called round tubular, Photo 1-4)
- -Pipe (similar to Photo 1-4)

Photo 1-1 RCS

Photo 1-2 RCS Modular

Photo 1-3 Square HSS

Photo 1-4 Round HSS

For section properties and strength characteristics for common HELI-PILE® material, refer to Tables 1-2, 1-3, 1-4, 1-5 and 1-6 at the end of this section.

Typical cross-sectional dimensions for the shaft types are shown in Table 1-1.

Shaft Type	Typical Dimension Across Flats or Diameter	Typical Wall Thickness
RCS (solid)	1.5 in to 1.75 in (38.1 mm to 44.5 mm)	NA (no wall)
Square HSS	2.5 in to 4 in (63.5 mm to 102 mm)	0.25 in to 0.5 in (6.4 mm to 13 mm)
Round HSS*	6.625 in to 8.625 in (168 mm to 219 mm)	0.28 in to 0.322 in (7.11 mm to 8.18 mm)
Pipe*	5.5 in to 7 in (140 mm to 178 mm)	0.304 in to 0.362 in (7.72 mm to 9.19 mm)

*Larger and smaller shaft diameters with varying wall thickness are available.

Table 1-1. Typical HELI-PILE® Shaft Cross-sectional Dimensions

For illustrations of typical helical pile lead sections and extensions see Figures 1-1 and 1-2, and Photos 1-1 through 1-8. For installation information see Sections 1.2 and 4. For a typical installation equipment preview see Section 1.3.

When the lead section is installed to its full length, if further pile depth is required, one or more extensions are added, and pile installation continues. An extension may be plain (no helix) or have one or more helices affixed to it.

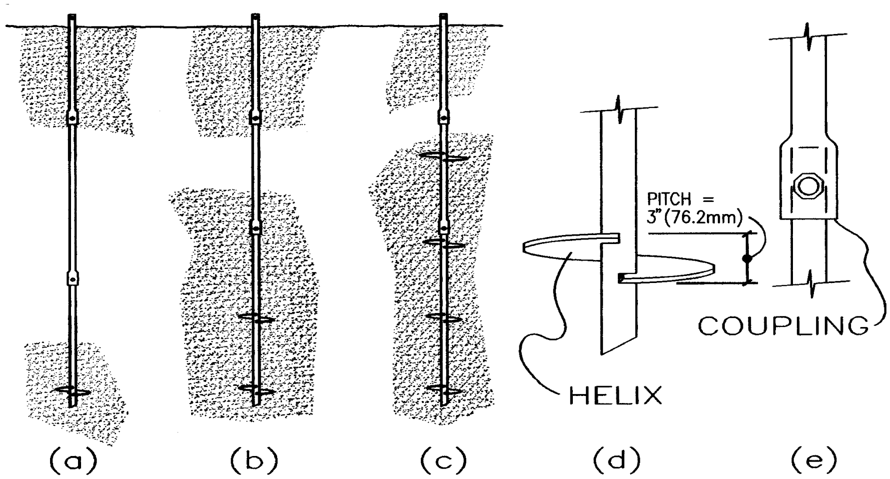


Figure 1-1. Typical helical pile configurations, helix, and coupling

Figure 1-1 illustrates a variety of helical pile configurations. Figure 1-1(a) shows a single helix rigidly attached to the central shaft of the lead section with two plain extensions (no helices). Figure 1-1(b) shows a double helix lead section (two helices attached to the central shaft) with two plain extensions. Figure 1-1(c) shows a triple helix lead section (three helices attached to the central shaft), plus an extension with a single helix attached to the central shaft, and one plain extension. Figure 1-1(d) is an expanded view of a typical helix welded to a square or round shaft. It also shows the helix "pitch" or the axial distance between the helix leading edge and trailing edge along the shaft axis. The pitch for all HELI-PILE® helices is uniform at 3 inches (76.2 mm). This is so a multiple-helix helical pile or anchor is installed at constant helix pitch eliminating an auguring effect that would be produced from non-uniform helix pitch. Figure 1-1(e) is an expanded view of a typical bolted coupling of an RCS shaft (see Photo 1-5).

Figure 1-2 is a helical pile as it may appear supporting a new foundation grade beam or column base. This figure depicts a double helix lead or starter section, two plain extensions, and a new construction load transfer device or cap. The load transfer cap is embedded within the concrete foundation. Helix axial spacing along the central shaft is three diameters of the smaller helix. This is true for all helix and shaft sizes.

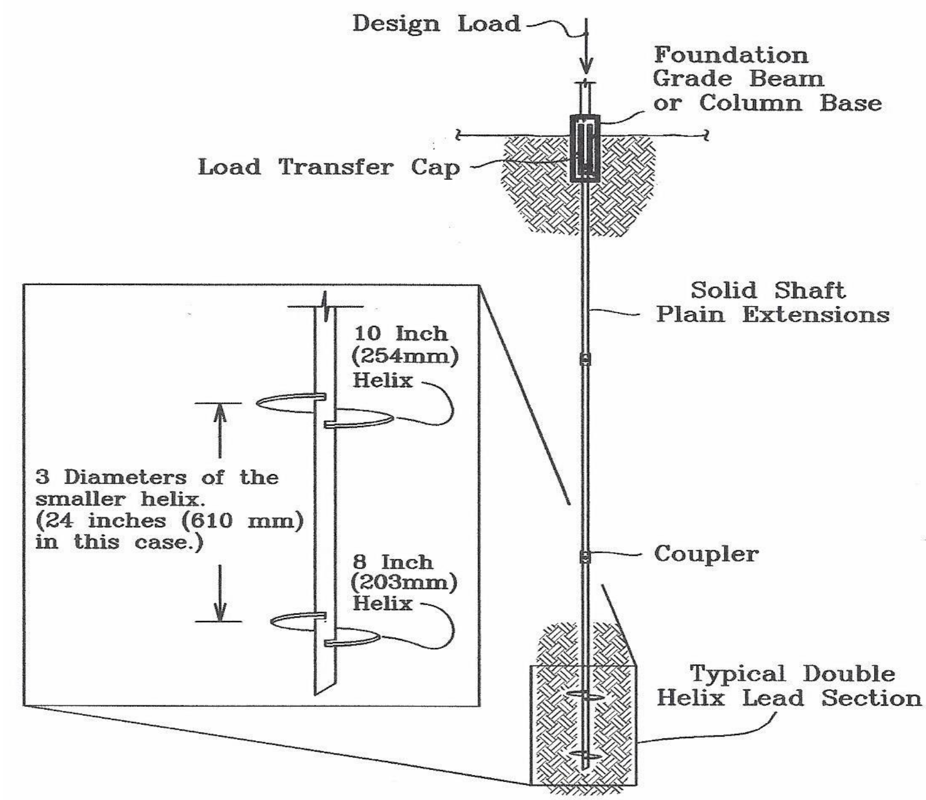


Figure 1-2. Double helix helical pile supporting a foundation grade beam

Photo 1-5 is of an 8-inch (203 mm) and 10-inch (254 mm) diameter double helix lead section similar to Figures 1-1(b) and 1-2. Photo 1-5 also shows a cold forged coupling welded to an RCS shaft similar to Figure 1-1(e). This lead section is a HELI-PILE® HPCL-15X810-03 solid steel 1.5-inch (38.1 mm) RCS shaft 3 ft (0.9 m) long. Lead sections are typically 3 ft (0.9 m), 5 ft (1.5 m), or 7 ft (2.1 m) long, as are extensions. Longer or shorter lead sections and extensions are available. All helices in Photo 1-5 are welded directly to the shaft. HELI-PILE® steel surfaces are galvanized per ASTM B633, A153, or A123 as requested by the customer. Occasionally steel surfaces are non-galvanized when specified.

Modular: Photo 1-6 is of an 8-inch (203 mm) and 10-inch (254 mm) diameter double helix lead section using modular technology patented by International Marketing & Research, Inc., and marketed under the brand name HELI-PILE® Modular Helical Piles and Anchors. This is an HPL-15X-03 3 ft (0.9 m) long lead section with an HPH-15X-08 helix and an HPH-15X-10 helix. This technology gives flexibility to change lead section configurations by adding or removing helices at the job site to conform to actual soil conditions. No field cutting or welding of helices is required. In addition, extension lengths may be altered at the

Photo 1-5 RCS lead section with helices welded directly to shaft

Photo 1-6 Lead section with modular helices rigidly keyed to the shaft

job site to fit field conditions as needed. The helices are axially spaced apart 3 diameters of the smaller helix, 24 inches (610 mm) in this case. See www.helipile.com for details.

Photo 1-6 also shows each helix and the coupler keyed and locked in preparation for installation. By removal of the keys each helix and the coupler can be unlocked and slid up and down the shaft directly without having to screw them along the shaft. Replacement of the keys locks each helix and coupler in position, they cannot slide out. Installation of the modular helical pile is identical to any RCS helical pile, uses the same tooling.

Modular is currently only made in 1.5 inch (38.1 mm) and 1.75 inch (44.5 mm) solid RCS shaft. The patented square thread bar fits all common solid RCS drive tools. Threaded extensions with conventional bolted couplings are available. Photo 1-7 is a modular "Terminator" extension. It is merely a normal extension but with square thread bar. It can serve as any normal extension or terminate a pile or tieback as a threaded adapter. It is manufactured in lengths of 3 ft (0.9 m), 5 ft (1.5 m), or 7 ft (2.1 m) and is galvanized per ASTM B633. Photo 1-8 is a Terminator extension bolt coupled to a plain extension.

Photo 1-9 is a modular plate cap that screws on. Photo 1-10 is a reinforcing steel cap that screws on. Photo 1-11 shows a tieback nut screwed on a Terminator extension used as a tieback threaded adapter.

Photo 1-7 Modular “Terminator” extension

Photo 1-8 Terminator extension bolt coupled to plain extension

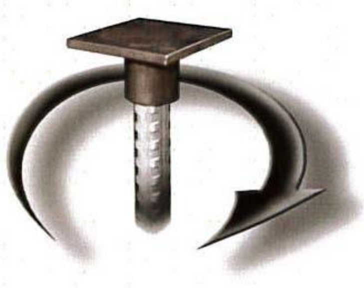


Photo 1-9 Modular Plate Cap

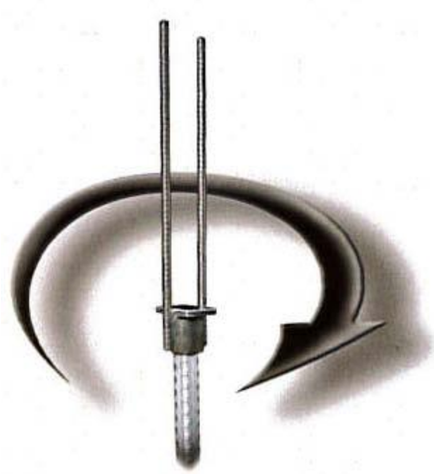


Photo 1-10 Modular Rebar Cap

Photo 1-11 Modular Tieback Nut

Another advantage of the patented Modular System (U.S. Patent 6,817,810) is that it eliminates all the problems associated with terminating helical piles and tiebacks. The Terminator is high strength threaded square bar that bolts on and drives piles. The load transfer caps and tieback nuts screw on with full capacity in compression and tension. There are no holes to drill and no welding, simply screw on load transfer hardware. There is no wasted shaft because any cutoff can be reused as a lead on another pile by locking in a modular helix and beveling the point. See Photo 1-12.

Photo 1-12 Modular Lead Using Cut-off Terminator Extension and Modular Helix

Photo 1-13 is a Round HSS helical pile, 8.625-inch (219.1 mm) diameter shaft with a single 16 inch (406 mm) diameter helix, ¾ inch (19.1 mm) thick. Large round HSS shafts are used primarily where lateral loads and bending moments are high. This particular application did not require galvanized steel.

Photo 1-13 Round HSS lead section with a single helix configuration

Photo 1-14 Square HSS lead with a triple helix configuration

Photo 1-14 is a 3-inch (76.2 mm) Square HSS shaft 7 feet (2.1 m) long with 0.25-inch (6.35 mm) wall thickness. It has a triple 10-inch (254), 12-inch (305 mm), and 14-inch (356 mm) diameter helix configuration. Each helix is 0.5 inch (12.7mm) thick.

Helix diameters typically range from 6 inches (152 mm) to 16 inches (406 mm) and larger. All HELI-PILE® helices are 0.5 inch (12.7 mm) thick minimum. For larger piles, helices 0.75 inch (19.1 mm) thick may be used. For even larger piles, helices 1 inch (25 mm) thick may be used. All helices are 80 ksi (552 MPa) steel. The helices are formed into the shape of a helix with a typical 3-inch (76.2 mm) pitch, the axial distance between the leading and trailing edges (see Figure 1-1(d)). Thus, under ideal soil conditions, helical screw piles and anchors with a 3-inch (76.2 mm) pitch should advance into the soil 3 inches (76.2 mm) per revolution. In reality, typical advancement is less than 3 inches (76.2 mm), sometimes much less, due to soil conditions. This ordinarily does not affect the torque vs. capacity relationship.

www.helipile.com contains select drawings of common HELI-PILE® helical piles and helical tension anchors. Latest revisions of the drawings may be downloaded. These drawings illustrate the magnitude of sizes and shapes available from HELI-PILE®. The wide variety of sizes and shapes is to match the limitless soil and loading conditions possible. The drawings also give information on bolt sizes and grades. Only the most common sizes and shapes are shown on the website. Please contact HELI-PILE® for information on items not shown.

1.2 Installation

For all helical piles and tension anchors, each helix is a circular steel plate split radially on one side of the shaft and shaped into the form of a helix. This gives each helix a leading and trailing edge. As the shaft is rotated, the helix leading edge bites into and engages the soil transferring rotational force, or installation torque, into an axial force driving the helical screw pile into the soil. (See Sections 1.3 and 4 for installation equipment information.)

As the helical pile or anchor is installed, no hole is created and no drill spoils are generated that must be discarded. When the top of the advancing lead section shaft reaches grade, shaft extensions with or without helices are added, as necessary. The helical pile or anchor is advanced in this manner until the required pile capacity, with an appropriate safety factor, is reached as evidenced by the measured installation torque or refusal. (The relationship between measured installation torque and pile capacity is discussed in Section 3.) Lead sections and extensions typically are available in lengths of 3 ft (0.9 m), 5 ft (1.5 m), and 7 ft (2.1 m). Longer and shorter leads and extensions are available. Figures 1-1(a), 1-1(b), and 1-1(c) show plain extensions in use above the lead sections. Figure 1-1(c) also shows an extension with a helix attached to it. Figure 1-2 shows plain extensions in use. Photo 1-5 shows the end of an extension bolted to the double helix lead section. Photo 1-6 is a HELI-PILE® Modular helical pile with modular helices keyed and locked to the shaft. Square HSS, Round HSS, and pipe shafts use bolted extensions. See Photos 1-15 and 1-16.

The lead section and subsequent extensions are typically coupled together by means of a coupling and bolt or modular coupler designed to transfer the ultimate installation torques and axial loads either in tension or compression. See Figure 1-1(e) and Photos 1-5, 1-6, 1-8, 1-12, 1-15, 1-16. For RCS shapes, HELI-PILE® couplings are cold forged and welded to the shaft (Photos 1-5, 1-8, 1-12). The cold forged welded coupler is not susceptible to shaft steel weakening as occurs on rare occasions with hot-upset forged couplings used by some manufacturers. For square HSS and pipe shapes, couplings are slightly larger size sections welded to the shaft (Photos 1-15 and 1-16).

Photo 1-15 Square HSS Coupling

Photo 1-16 Round HSS Coupling

1.3 Installation Equipment Preview

The helical pile or tension anchor is installed by applying a rotational force, or installation torque, to the shaft. This force is applied typically by a hydraulically powered torque motor mounted on wheeled, tracked or hand-carried equipment. See Section 4 for photos of various types of installation equipment and a further discussion on installation. Photo 1-17 previews typical installation equipment. A more detailed description of installation procedures and equipment is given in Section 4.

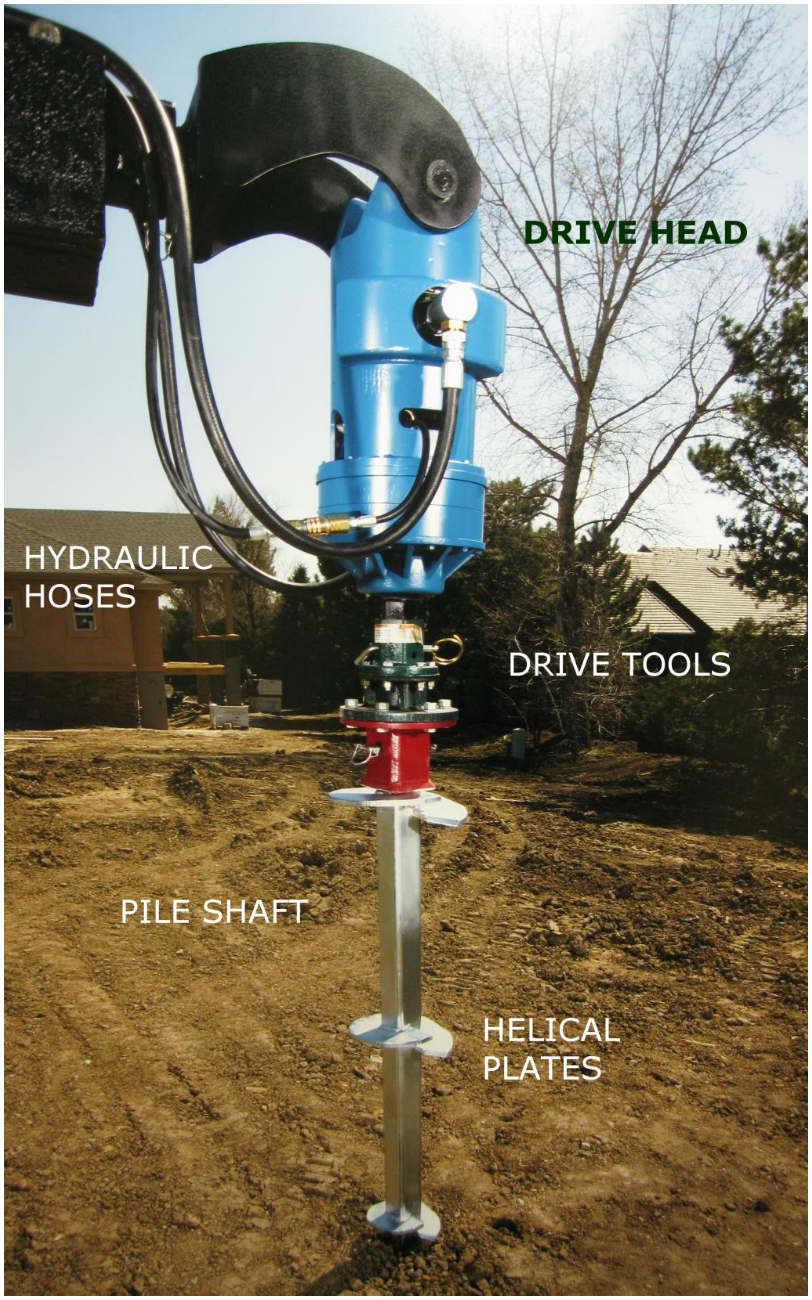


Photo 1-17 Typical specialized installation equipment

1.4 Materials and Mechanical Capacities (see Section 3.1 for Geotechnical Capacities)

HELI-PILE® round corner square solid steel (RCS, ASTM A29) shaft material has a minimum yield strength of 90 ksi (621 MPa). Square and Round HSS (ASTM A500) tubular shaft has a minimum yield strength of 60 ksi (414 MPa) and 50 ksi (345 MPa), respectively, by special order. Pipe shaft (ASTM A252 Gr 3) has a minimum yield strength of 45 ksi (310 MPa). All helix steel has a minimum yield strength of 80 ksi (552 MPa). All welding is done per American Welding Society (AWS) specifications. HELI-PILE® galvanizing is routinely per ASTM B633. Hot-dip galvanizing per ASTM A153 or A123 is available upon request.

1.4.1 Mechanical Capacities, Properties, and Steel Specifications

Table 1-2 below lists the section properties of commonly stocked HELI-PILE® material. Other shapes and sizes are available upon request.

Square Shaft Size and Type	Wall Thickness	A_s Steel Area of the Shaft	I Moment of Inertia	S Section Modulus	R Radius of Gyration
HPC15X HP15X 1.5 inch (38.1mm) RCS[1]	NA	2.20 in² (1,420 mm²)	0.396 in⁴ (16.5 cm⁴)	0.528 in³ (8.65 cm³)	0.425 in (10.8 mm)
HPC17 HP17 1.75 inch (44.5mm) RCS[1]	NA	3.01 in² (1,940 mm²)	0.745 in⁴ (31.0 cm⁴)	0.852 in³ (14.0 cm³)	0.498 in (12.6 mm)
HPFT25 2.5 inch (63.5mm) Sq HSS	0.233 in (5.92 mm)	1.97 in² (1,270 mm²)	1.63 in⁴ (67.8 cm⁴)	1.30 in³ (21.3 cm³)	0.908 in (23.1 mm)
HPFT3 3 inch (76.2mm) Sq HSS	0.233 in (5.92 mm)	2.44 in² (1,570 mm²)	3.02 in⁴ (126 cm⁴)	2.01 in³ (32.9 cm³)	1.11 in (28.2 mm)
HPFT331 3 inch (76.2mm) Sq HSS	0.291 in (7.39 mm)	2.94 in² (1,900 mm²)	3.45 in⁴ (144 cm⁴)	2.30 in³ (37.7 cm³)	1.08 in (27.4 mm)
HPFT425 4 inch (102 mm) Sq HSS	0.233 in (5.92 mm)	3.37 in² (2,170 mm²)	7.80 in⁴ (325 cm⁴)	3.90 in³ (63.9 cm³)	1.52 in (38.6 mm)
HPFT438 4 inch (102 mm) Sq HSS	0.349 in (8.86 mm)	4.78 in² (3,080 mm²)	10.3 in⁴ (429 cm⁴)	5.13 in³ (84.1 cm³)	1.47 in (37.1 mm)
HPFT4 4 inch (102 mm) Sq HSS	0.465 in (11.8 mm)	6.02 in² (3,880 mm²)	11.9 in⁴ (495 cm⁴)	5.97 in³ (97.5 cm³)	1.41 in (35.8 mm)
6.625 inch (168mm) Round HSS	0.260 in (6.60 mm)	5.20 in² (3,350 mm²)	26.4 in⁴ (1,100 cm⁴)	7.96 in³ (130 cm³)	2.25 in (57.2 mm)
8.625 inch (219mm) Round HSS	0.300 in (7.62 mm)	7.85 in² (5,060 mm²)	68.1 in⁴ (2,830 cm⁴)	15.8 in³ (259 cm³)	2.95 in (74.9 mm)
5.5 in Pipe (140mm) A252 Gr3	0.304 in (7.72 mm)	4.96 in² (3,200 mm²)	16.8 in⁴ (699 cm⁴)	6.11 in³ (97.5 cm³)	1.84 in (35.8 mm)
7 in Pipe (178mm) A252 Gr3	0.362 in (9.19 mm)	7.55 in² (4,870 mm²)	41.7 in⁴ (1,740 cm⁴)	11.9 in³ (195 cm³)	2.35 in (59.7 mm)

[1]All 1.5 inch and 1.75-inch solid smooth shafts (HPC15X & HPC17) and modular solid shafts (HP15X & HP17) have the same physical properties.

Table 1-2. Section Properties of Common HELI-PILE® Shafts

Table 1-3 below is a mechanical **compression** capacity and steel specification table for commonly stocked HELI-PILE® helical piles and anchors. Other shapes and sizes are available upon request. For ultimate mechanical tension capacities see Table 1-4. Many Round HSS and Pipe sizes are available that are not shown below. Please contact HELI-PILE®.

1 Cat. No. Shaft Size and Type	2 Shaft and Helix Galvanizing (if specified)	3 Shaft Steel Minimum Yield Strength, F_y	4 Maximum Shaft Torque*	5 New Fdns. Ultimate Mechanical Capacity, Compr.[3]	6 Underpin Ultimate Capacity, Bracket Limited	7 Helix Steel Minimum Yield Strength, F_y	8 Ultimate Per Helix Capacity, Compr. or Tension[1]
HPC15X 1.5 inch (38.1 mm) RCS	ASTM B633, A123 or A153	90 ksi (621 MPa)	7,000 ft-lbs (9.49 kN-m)	70,000 lbs (311 kN)	70,000 lbs (311 kN)	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPC17 1.75 inch (44.5 mm) RCS	ASTM B633, A123 or A153	90 ksi (621 MPa)	11,000 ft-lbs (14.9 kN-m)	110,000 lbs (489 kN)	110,000 lbs (489 kN)	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT25 2.5 inch (63.5 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	7,000 ft-lbs (9.49 kN-m)	70,000 lbs (311 kN)	70,000 lbs (311 kN)	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT3 3.0 inch (76.2 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	11,000 ft-lbs (14.9 kN-m)	110,000 lbs (489 kN)	110,000 lbs (489 kN)	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT331 3.0 inch (76.2 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	15,000 ft-lbs (20.3 kN-m)	150,000 lbs (667 kN)	150,000 lbs (667 kN)	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT425 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	20,000 ft-lbs (27.1 kN-m)	200,000 lbs (890 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT438 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	30,000 ft-lbs (40.7 kN-m)	300,000 lbs (1,330 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT4 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	30,000+ ft-lbs (40.7+kNm)	300,000+ lbs (1,330+ kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
6.625 inch (168mm) Round HSS	ASTM B633, A123 or A153	50 ksi (345 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
8.625 inch (219mm) Round HSS	ASTM B633, A123 or A153	50 ksi (345 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
5.5 in Pipe (140mm)	ASTM B633, A123 or A153	45 ksi (310 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
7 in Pipe (178mm)	ASTM B633, A123 or A153	45 ksi (310 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®

*Maximum shaft torque based on full-scale torque testing. It includes allowable inelastic shaft wrap (twist).

[1]All helices are 0.5 inch (12.7 mm) thick. Helix capacities given are for 12-inch (305 mm) diameter and smaller. Larger helices are rated at 80% of the given value.

[2]Round HSS and Pipe maximum shaft torques are variable based on the number of bolts in the coupling, helix thickness and other factors. Please contact HELI-PILE®.

[3]For modular couplings and caps, all nut threads must be fully engaged.

Table 1-3. Mechanical **Compression** Specifications of Common HELI-PILE® Material

Table 1-4 below is a mechanical **tension** capacity and steel specification table for commonly stocked HELI-PILE® helical piles and anchors. Other shapes and sizes are available upon request. For ultimate mechanical compression capacities see Table 1-3. Many Round HSS and Pipe sizes are available that are not shown below. Please contact HELI-PILE®.

1 Cat. No. Shaft Size and Type	2 Shaft and Helix Galvanizing (if specified)	3 Shaft Steel Minimum Yield Strength, F_y	4 Maximum Shaft Torque*	5 New Fdns. Ultimate Mechanical Capacity, Tension[3]	6 Underpin Ultimate Capacity, Bracket Limited	7 Helix Steel Minimum Yield Strength, F_y	8 Ultimate Per Helix Capacity, Compr. or Tension[1]
HPC15X 1.5 inch (38.1 mm) RCS	ASTM B633, A123 or A153	90 ksi (621 MPa)	7,000 ft-lbs (9.49 kN-m)	70,000 lbs (311 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPC17 1.75 inch (44.5 mm) RCS	ASTM B633, A123 or A153	90 ksi (621 MPa)	11,000 ft-lbs (14.9 kN-m)	110,000 lbs (489 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT25 2.5 inch (63.5 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	7,000 ft-lbs (9.49 kN-m)	60,000 lbs (267 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT3 3.0 inch (76.2 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	11,000 ft-lbs (14.9 kN-m)	62,000 lbs (276 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT331 3.0 inch (76.2 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	15,000 ft-lbs (20.3 kN-m)	62,000 lbs (276 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT425 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	20,000 ft-lbs (27.1 kN-m)	65,000 lbs (289 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT438 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	30,000 ft-lbs (40.7 kN-m)	105,000 lbs (467 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
HPFT4 4.0 inch (102 mm) Sq HSS	ASTM B633, A123 or A153	60 ksi (414 MPa)	30,000+ ft-lbs (40.7+kNm)	105,000 lbs (467 kN)	Per Application	80 ksi (552 MPa)	70,000 lbs (311 kN)
6.625 inch (168mm) Round HSS	ASTM B633, A123 or A153	50 ksi (345 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
8.625 inch (219mm) Round HSS	ASTM B633, A123 or A153	50 ksi (345 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
5.5 in Pipe (140mm)	ASTM B633, A123 or A153	45 ksi (310 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®
7 in Pipe (178mm)	ASTM B633, A123 or A153	45 ksi (310 MPa)	Variable[2] Contact HELI-PILE®	Variable[2] Contact HELI-PILE®	Per Application	80 ksi (552 MPa)	Variable[2] Contact HELI-PILE®

*Maximum shaft torque based on full-scale torque testing. It includes allowable inelastic shaft wrap (twist).

[1]All helices are 0.5 inch (12.7 mm) thick. Helix capacities given are for 12-inch (305 mm) diameter and smaller. Larger helices are rated at 80% of the given value.

[2]Round HSS and Pipe capacities are variable based on the number of bolts in the coupling, helix thickness and other factors. Please contact HELI-PILE®.

[3]For modular couplings and caps, all nut threads must be fully engaged.

Table 1-4. Mechanical **Tension** Specifications of Common HELI-PILE® Material

Tables 1-5 and 1-6 correlate the shaft sizes and helix sizes to the bearing area, assuming a horizontal projection of helix area. Table 1-5 is for square shafts and Table 1-6 is for round shafts. The helix bearing areas are the horizontal projection of the helix less the overall cross-sectional area of the shaft, less the horizontal gap between the leading and trailing edge and less the area of the "rock cut" leading edge (see Figure 5-5 in Section 5.8). For RCS solid shafts in compression, for all helices that are first on the lead section, or for single helix lead sections, the cross-sectional area of the shaft must be added back in.

RCS and Square HSS*

Square Shaft Size and Type	Overall Cross-sectional Area of the Shaft	Steel Area of the Shaft	6-inch (152 mm) Diameter Helix Bearing Area[2]	8-inch (203 mm) Diameter Helix Bearing Area[2]	10-inch (254 mm) Diameter Helix Bearing Area[2]	12-inch (305 mm) Diameter Helix Bearing Area[2]	14-inch (356 mm) Diameter Helix Bearing Area[2]	16-inch (406 mm) Diameter Helix Bearing Area[2]
1.5 inch (38.1mm) RCS[1]	2.20 in^2 (1,420 mm^2)	2.20in^2 (1,420 mm^2)	22.8 in^2 (14,700 mm^2)	42.9 in^2 (27,700 mm^2)	69.0 in^2 (44,500 mm^2)	101 in^2 (65,200 mm^2)	139 in^2 (89,700 mm^2)	184 in^2 (119,000 mm^2)
1.75 inch (44.5mm) RCS[1]	3.01 in^2 (1,940 mm^2)	3.01in^2 (1,940 mm^2)	22.2 in^2 (14,300 mm^2)	42.3 in^2 (27,300 mm^2)	68.5 in^2 (44,200 mm^2)	101 in^2 (65,200 mm^2)	139 in^2 (89,700 mm^2)	183 in^2 (118,000 mm^2)
2.5 inch (63.5mm) Sq HSS (HPFT25)	6.22 in^2 (4,010 mm^2)	1.97in^2 (1,270 mm^2)	19.6 in^2 (12,600 mm^2)	39.8 in^2 (25,700 mm^2)	66.1 in^2 (42,600 mm^2)	98.4 in^2 (63,500 mm^2)	137 in^2 (88,400 mm^2)	181 in^2 (117,000 mm^2)
3.0 inch (76.2mm) Sq HSS (HPFT3)	8.95 in^2 (5,770 mm^2)	2.44in^2 (1,570 mm^2)	17.3 in^2 (11,200 mm^2)	37.6 in^2 (24,300 mm^2)	63.9 in^2 (41,200 mm^2)	96.3 in^2 (62,100 mm^2)	135 in^2 (87,100 mm^2)	179 in^2 (115,000 mm^2)
3.0 inch (76.2mm) Sq HSS (HPFT331)	8.92 in^2 (5,750 mm^2)	2.94in^2 (1,900 mm^2)	17.3 in^2 (11,200 mm^2)	37.6 in^2 (24,300 mm^2)	63.9 in^2 (42,600 mm^2)	96.3 in^2 (62,100 mm^2)	135 in^2 (87,100 mm^2)	179 in^2 (115,000 mm^2)
4.0 inch (102 mm) Sq HSS (HPFT425)	15.9 in^2 (10,300 mm^2)	3.37in^2 (2,170 mm^2)	NA	31.5 in^2 (20,300 mm^2)	58.0 in^2 (37,400 mm^2)	90.4 in^2 (58,300 mm^2)	129 in^2 (83,200 mm^2)	174 in^2 (112,000 mm^2)
4.0 inch (102 mm) Sq HSS (HPFT438)	15.9 in^2 (10,300 mm^2)	4.78in^2 (3,080 mm^2)	NA	31.5 in^2 (20,300 mm^2)	58.0 in^2 (37,400 mm^2)	90.4 in^2 (58,300 mm^2)	129 in^2 (83,200 mm^2)	174 in^2 (112,000 mm^2)
4.0 inch (102 mm) Sq HSS (HPFT4)	15.8 in^2 (10,200 mm^2)	6.02in^2 (3,880 mm^2)	NA	31.6 in^2 (20,400 mm^2)	58.1 in^2 (37,500 mm^2)	90.5 in^2 (58,400 mm^2)	129 in^2 (83,200 mm^2)	174 in^2 (112,000 mm^2)

*Common square shapes manufactured by HELI-PILE®. Other helix and shaft sizes are available. Contact HELI-PILE®.

[1]All solid shafts and modular shafts have the same physical properties and helix bearing areas.

[2]Helix bearing area is the horizontal projection of the helix less the overall cross-sectional area of the shaft, less the horizontal gap between the leading and trailing edges, and less the area of the "rock cut" leading edge (see Figure 5-5 in Section 5.7). For all helices that are first on the lead section, or for single helix lead sections, the overall area of the shaft must be added back in.

Table 1-5. HELI-PILE® Physical Properties and Helix Bearing Areas for **Square** Shafts

Round HSS and Pipe*

Round Shaft Size and Type	Overall Cross-sectional Area of the Shaft	Steel Area of the Shaft	12-inch (305 mm) Diameter Helix Bearing Area[1]	14-inch (356 mm) Diameter Helix Bearing Area[1]	16-inch (406 mm) Diameter Helix Bearing Area[1]	18-inch (457 mm) Diameter Helix Bearing Area[1]	20-inch (508 mm) Diameter Helix Bearing Area[1]	22-inch (559 mm) Diameter Helix Bearing Area[1]
6.625 inch (168mm) Round HSS	34.5 in^2 (22,300 mm^2)	5.20in^2 (3,350 mm^2)	74.5 in^2 (48,100 mm^2)	113 in^2 (72,900 mm^2)	158 in^2 (102,000 mm^2)	209 in^2 (135,000 mm^2)	266 in^2 (172,000 mm^2)	329 in^2 (212,000 mm^2)
8.625 inch (219mm) Round HSS	58.4 in^2 (37,700 mm^2)	7.85in^2 (5,060 mm^2)	N/A	91.4 in^2 (59,000 mm^2)	137 in^2 (88,400 mm^2)	188 in^2 (121,000 mm^2)	245 in^2 (158,000 mm^2)	308 in^2 (199,000 mm^2)
5.5 in Pipe (140mm) A252 Gr3	23.8 in^2 (15,400 mm^2)	4.96in^2 (3,200 mm^2)	84.1 in^2 (54,300 mm^2)	123 in^2 (79,400 mm^2)	168 in^2 (108,000 mm^2)	218 in^2 (141,000 mm^2)	275 in^2 (177,000 mm^2)	338 in^2 (218,000 mm^2)
7 in Pipe (178mm) A252 Gr3	38.5 in^2 (24,800 mm^2)	7.55in^2 (4,870 mm^2)	70.8 in^2 (45,700 mm^2)	110 in^2 (71,000 mm^2)	155 in^2 (100,000 mm^2)	206 in^2 (133,000 mm^2)	263 in^2 (170,000 mm^2)	326 in^2 (210,000 mm^2)

*Other shaft and helix sizes are available. Contact HELI-PILE®.

[1]Helix bearing area is the horizontal projection of the helix less the overall cross-sectional area of the shaft, less the horizontal gap between the leading and trailing edges, and less the area of the "rock cut" leading edge (see Figure 5-5 in Section 5.7).

Table 1-6. HELI-PILE® Physical Properties and Helix Bearing Areas for **Round** Shafts

END OF SECTION 1

SECTION 2. GENERAL DESIGN STEPS AND COST ESTIMATING

These design steps are written for new foundations but apply equally to underpinning existing foundations. Before each design step can begin, the parameter in **bold** associated with that step must first be ascertained, then the design step can be completed. Cost estimating follows Step Five.

THE RESULT OF ALL DESIGN STEPS IS THAT **MECHANICAL CAPACITY MUST ALWAYS EQUAL OR EXCEED GEOTECHNICAL CAPACITY.** See the geotechnical capacity discussions in Section 3.

1. STEP ONE: Find out the **Design load** imposed on each pile or anchor: compression, tension and lateral, dead and live, including dynamic and seismic, per Allowable Stress Design (ASD). (Usually Owner provided.) Determine shaft and helix requirements based on loads.
2. STEP TWO: Ascertain the **Shaft bending moment** at grade due to lateral loads. (Sometimes Owner provided.) Modify shaft and helix requirements as necessary.
3. STEP THREE: Check **combined axial and lateral loading** in the pile or anchor shaft. (Almost never Owner provided.) Modify shaft requirements as necessary.
4. STEP FOUR: Verify the **Pile or anchor head deflection limits**, axial and lateral. (Sometimes Owner provided.) Modify shaft and helix requirements as necessary.
5. STEP FIVE: Ascertain **Location accessibility** of each pile or anchor. (Site visit or photos) Modify shaft and helix requirements as necessary.
6. REQUIRED FOR ALL STEPS: **Site Soil profile**. (Sometimes Owner provided.)

Design of helical piles and tension anchors is commonly performed per Allowable Stress Design (ASD). HELI-PILE® uses ASD. The determination of nominal loads per the latest edition of the publication ASCE 7 is recommended. LRFD is growing in use in foundation engineering but not used in this booklet.

2.1 STEP ONE: Find out the **Design load** imposed on each pile or anchor: compression, tension and lateral, dead and live, including dynamic and seismic, per Allowable Stress Design (ASD). (Usually Owner provided)

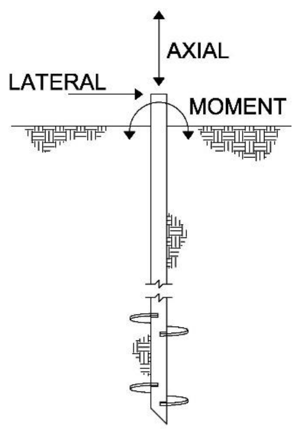


Figure 2-1. Helical Pile Loading

All loads are typically provided by the structural engineer. See Figure 2-1. Loads should include all dead and live loads, including dynamic and seismic (nominal loads). These should be unfactored design loads per ASD. In sizing piles, HELI-PILE® typically applies a 2 safety factor to all axial compression and tension ASD design loads provided by the structural engineer. See Section 3.4 for a discussion on safety factors. For lateral loads, no safety factors are applied by HELI-PILE® to the minimum design load.

The shaft and helix steel property tables in Section 1 may be used for shaft selection based on design loading with appropriate safety factor. However, deflection limits, discussed in Section 2.4 may govern and require a larger shaft size and/or helix configuration. This must be checked.

DESIGN REQUIREMENTS: Once load information is obtained, pile or anchor sizing starts by using the tables in Section 1 to select the shaft that best meets the load condition. The size selected is subject to subsequent modification based on the results of Sections 2.2 through 2.6. Use soil information from Section 2.6 and design considerations in Section 5 to modify the shaft selection as necessary. For example, slenderness buckling issues in soft soil may exist. Wait until completion of Design Step Five for cost estimating. Drawings of many HELI-PILE® products can be found at www.helipile.com.

2.2 STEP TWO: Ascertain the **Shaft bending moment** at grade due to lateral load. (Sometimes Owner provided. If there is no lateral load, there is no moment, continue to Step Four.)

This section applies to all structures but is particularly important for pipe racks and elevated equipment supports at industrial facilities.

For a vertical compression pile, the point of lateral load application, either on the pile itself or on the structure supported by the pile, will determine the shaft bending moment at grade. This moment is typically provided by the structural engineer.

The connection design of the shaft to the structure is critical. A free-head connection is where the top of the pile shaft is free to rotate. See Figure 2-2 (a). This is also commonly called a "flag pole" connection wherein the top of the pile shaft "waves in the breeze" like a flag pole. Lateral deflection is greatest in this condition. A fixed-head connection is where the top of the pile shaft is not free to rotate, also called a moment connection, Figure 2-2 (b). This condition occurs where the pile top is embedded in concrete or rigidly welded to the structure. Lateral deflection is least in this condition. The structural engineer must inform the helical pile designer what connection to use.

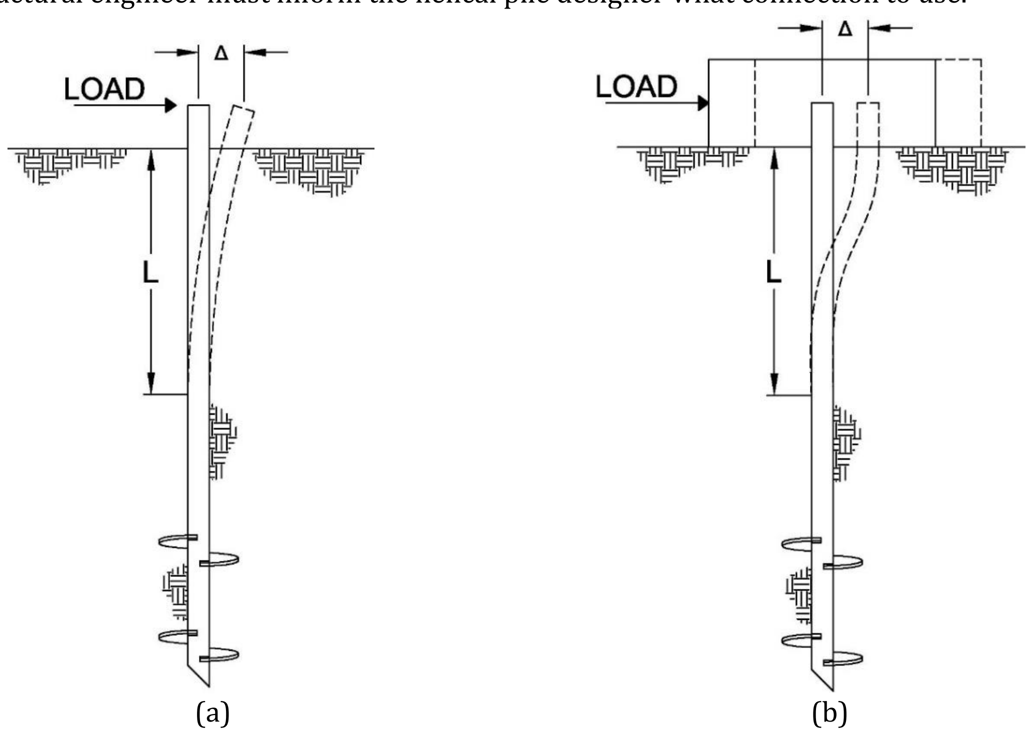


Figure 2-2. (a) Free-head, (b) Fixed-head

With the maximum moment at grade, together with the connection, deflection limits, and soil profile information, the maximum shaft bending moment magnitude, location, and deflection can be estimated. Soil conditions must be considered because the point of maximum moment will be below the ground surface, unless the soil is unusually dense. Typically, a computer program such as LPILE by Ensoft, Inc. (www.ensoftinc.com), is employed to estimate the magnitude and location of the maximum shaft moment and estimate lateral deflection.

LPILE takes the proposed shaft properties then uses the bending moment at grade, axial compression load, and soil profile to estimate maximum moment and lateral deflection. Pile shaft selection will be based on the maximum moment and/or estimated lateral deflection. This is typically an iterative process where several shaft sizes are proposed and analyzed.

The tables in Section 1 may be used for shaft selection based on bending moments. However, deflection limits, discussed in Section 2.4, may govern and require a larger shaft size. This must be checked.

Bending moments in tension anchors due to lateral loads are checked similarly.

Research shows that computer simulations for lateral deflection typically estimate greater deflection than reality. Field lateral load testing as discussed in Section 5.11.4 is recommended. Field lateral load testing not only produces actual deflections, but also verifies soil parameter input. Subsequent computer simulations will be more realistic with verified soil input.

Research shows that moment from lateral loading and deflection is usually dissipated in approximately the upper 10 feet of soil. This allows a combination of pile shafts to be used to economize the pile with the upper shaft designed to take the moment within the lateral deflection limits and the lower less expensive shaft designed to take the vertical compression/tension load. An example is shown in Figure 2-3. Also see Photo 5-2.

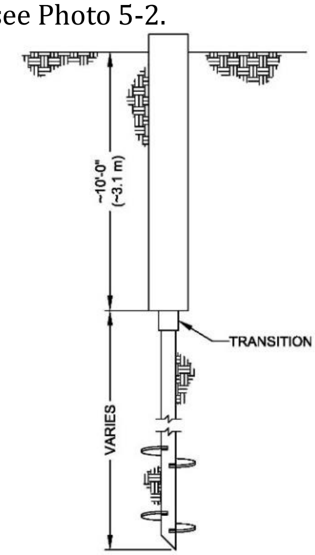


Figure 2-3. Combination of Larger and Smaller Pile Shafts for Economy.

DESIGN REQUIREMENTS: Once moment data is obtained, pile or anchor sizing continues by using the tables in Section 1 to modify (or keep) the shaft selected in Step 1 that best meets the moment condition. The size selected is subject to subsequent modification based on the results of Sections 2.3 through 2.6. Use soil information from Section 2.6 and design considerations in Section 5 to modify the shaft selection as necessary. Wait until completion of Design Step Five for cost estimating.

2.3 STEP THREE: Check **combined axial and lateral loading** in the pile or anchor shaft. (Almost never Owner provided. If there is no combined loading, continue to Step Four.)

It is recommended that combined axial and lateral loading be considered in pile or anchor shaft design. Besides design axial and lateral loads from Design Steps One and Two, additional moment may exist due to eccentric loading from mislocated piles or anchors or on underpinning piles where the pile centerline is offset from the existing foundation load point. Experience has shown that mislocation up to 1.5 inches (38.1 mm) usually may be ignored. In light residential and commercial structures up to 4 inches (102 mm) may be ignored. The 2018 International Building Code, Chapter 18 on deep foundations, allows up to 3 inches (76.2 mm) of mislocation for deep foundations. For large or heavy eccentricities, the helical pile or anchor should be checked for the resultant moment and combined loading. HELI-PILE® recommends mislocation be specified at 1.5 inches (38.1 mm) maximum. Installation contractors can meet this specification even in rocky, cobbly soil.

DESIGN REQUIREMENTS: Check combined axial and lateral loading using methods found in the latest edition of the Steel Construction Manual by AISC. Modify the shaft requirements as necessary.

2.4 STEP FOUR: Verify the **Pile or anchor head deflection limits**, axial and lateral. (Sometimes Owner provided. If no deflection limits are provided, try calling the Owner's representative. If still not obtainable, use common deflection limits or best judgement.)

Owners typically provide a structure's deflection limits. Common in the industry for residential and light commercial is 1 inch (25.4 mm) of vertical downward deflection and 0.5 inch (12.7 mm) of lateral deflection. However much depends on the structure and its purpose. Much tighter deflection limits for industrial structures are common. Pipe rack lateral deflection limits of less than 0.1 inch (2.5 mm) 20 feet (6.1 m) above grade have been specified and met by HELI-PILE®. Lateral deflection limits usually govern helical pile shaft design for pipe racks and similar structures.

The soil/structure interaction can be estimated using the computer method outlined in Section 2.2. HELI-PILE® uses programs such as LPILE by Ensoft, Inc. (www.ensoftinc.com), and HelixPile by Deep Excavation, LLC (www.deepexcavation.com). See Section 2.8 for software comments.

Research shows that computer simulations for lateral deflection typically estimate greater deflection than reality. Field lateral load testing as discussed in Section 5.11.4 is recommended. Field lateral load testing not only produces actual deflections, but also verifies soil parameter input. Subsequent computer simulations will be more realistic with verified soil input.

DESIGN PROCESS: Once deflection information is obtained, pile or anchor sizing continues by using the tables in Section 1 and the results of the computer simulations to modify (or keep) the shaft selected in Step 2 that best meets the deflection limits. The size selected is subject to subsequent modification based on the results of Section 2.5 and 2.6. Use soil information from Section 2.6 and design considerations in Section 5 to modify the shaft selection as necessary. Wait until completion of Design Step Five for cost estimating.

2.5 STEP FIVE: Ascertain **Location accessibility** of each pile or anchor. (Do a site visit. If no site visit is possible, obtain photographs or other descriptions of each pile location. Speak with the owner or project manager if need be.)

The exact pile or anchor location has much to do with which pile can be installed and its cost. Location accessibility determines the type and size of installation equipment and the size of the pile or anchor to be installed. This also relates to installation speed. Time is money. For example, underpinning a structure in a basement requires smaller hand-carried equipment than installing helical piles for in new foundation in wide-open spaces. Likewise, helical piles for a basement underpinning project will typically be of less capacity than piles for a new foundation so more smaller capacity piles will be required and will take time to install.

DESIGN PROCESS: Once specific pile location accessibility is known, pile or anchor sizing continues by using the tables in Section 1 to modify (or keep) the shaft selected in Step 3 that is best installed at the specific pile location. Use soil information from Section 2.6 and design considerations in Section 5 to modify the shaft selection as necessary.

Design is now complete. Cost estimating may proceed in accordance with Section 2.7.

2.6 REQUIRED FOR ALL STEPS: Site Soil profile. (Sometimes Owner provided. If no soil information is available, seek permission to go on-site to do a helical test probe or helical test pile as described below. If that is not possible, use best judgement.)

The site soil profile is used in all design steps described above. There are three basic procedures to determine soil profile for helical piles and anchors:

1. Helical Test Probe
2. Helical Test Install
3. Conventional geotechnical investigation

2.6.1 Helical Test Probe

The helical test probe uses an actual helical pile. Because helical piles and anchors typically screw out as easily as they screw in, performing a helical test probe is fast and relatively inexpensive. All helical steel is removed and there is no permanent site impact. The speed allows many test probes to be performed where only a few exploration borings might be completed in a given day. The more helical test probes performed at a site, the more knowledge is obtained, and the more likely it is that an installing contractor can “sharpen the pencil”, even perhaps giving a fixed price without contingency. This is a great advantage to an owner or general contractor. Photo 2-1 is a helical test probe.

Photo 2-1 Helical Test Probe

The helical test probe is an actual helical pile installation where a log is kept of torque vs. depth. This information can be correlated to boring logs if borings are done. The torque values provide capacity information throughout the soil profile which aids in determining pile or anchor depth, shaft size, and number of helices and diameters. Speed of installation, which also relates directly to cost, can be measured.

For the helical test probe, it is recommended to use a single 0.5-inch (12.7 mm) thick, 8-inch (203 mm) diameter helix on a 1.75-inch (44.5 mm) solid square shaft lead section (HPCL-178-03 or 05 or 07). This is because it will penetrate deeper into the soil profile than larger diameter helices, or multiple helices, before its maximum torque is reached.

If project loading conditions will require a multiple helix lead section for the production piles or anchors, a direct proportion of helix area to torque can be used to roughly estimate the torque at various depths where the larger diameter or multiple helix lead sections might bear. For example, suppose a helical test probe using a 1.75-inch (44.5 mm) helical pile with a single 8-inch (203 mm) diameter helix (area = 42.3 in^2 (27,300 mm^2)) achieved 3,000 ft-lb (4.07 kN-m) of torque at a depth of 15 ft (4.6 m). What would be the estimated torque for a 1.75-inch (44.5 mm) 8 inch–10 inch (203 mm–254 mm) double helix lead section at the same depth? Using a direct proportion, the estimated torque would be

$$\frac{42.3\ \text{in}^2\ (27{,}300\ \text{m}^2)}{3{,}000\ \text{ft-lb}\ (4.07\ \text{kN-m})} = \frac{42.3\ \text{in}^2\ (27{,}300\ \text{mm}^2) + 68.5\ \text{in}^2\ (44{,}200\ \text{mm}^2)}{x}$$

$$x = \underline{7{,}860\ \text{ft-lb}\ (10.7\ \text{kN-m})}$$

This roughly estimated torque assumes essentially a linear relationship between helix area and torque which is not always the case. Engineering judgment or further testing may be required.

The presence of unforeseen obstructions, such as cobbles, boulders, construction debris, etc., or, soft or loose soil, or other conditions which might affect helical pile or anchor capacity can be discovered with a helical test probe. Making known the presence of such anomalies in the soil formation before construction commences reduces the possibility of delays during construction and/or price contingencies that could raise the cost of the project.

2.6.2 Helical Pile Test Install

A helical pile test install is similar to a test probe. It is merely installing the design lead section and recording depth vs. installation torque. This allows the design professionals to evaluate the lead section, make adjustments as necessary, and make cost evaluations. Helical pile test installations allow preliminary designs and alternatives to be tested. Several configurations and shaft sizes can be evaluated quickly. Several locations on a site can be evaluated quickly. The goal is to maximize efficiencies and cost benefits for production pile installation while meeting load and deflection requirements. Helical pile test install information saves time and money.

2.6.3 Conventional Geotechnical Investigation

A conventional geotechnical investigation is where exploration borings are drilled, certain field tests performed, soil samples taken, laboratory testing is done, and the site is characterized. Exploration borings must be sufficiently deep to evaluate the soil profile for a deep foundation solution. Test pits are typically insufficient to provide such information.

Even if helical test probes and installs are performed, information derived from a conventional geotechnical investigation can be useful. Boring logs allow ongoing correlation with the production helical pile and anchor installation logs. Pile and anchor depths can be correlated with boring logs to act as a check to ensure the pile is not bearing on an anomaly in the formation such as fill debris, tree stumps, car bodies, etc. The most useful field test is the Standard Penetration Test (SPT), ASTM D 1586. See Section 2.6.3.1.

Another useful field test is pH and resistivity for corrosion purposes, Section 5.13. Resistivity and pH testing must be done in the field to accurately portray field conditions. Laboratory testing for pH and resistivity can be misleading because lab samples are saturated to perform the test. This may not mimic field conditions. Field testing for pH and resistivity is recommended.

2.6.3.1 Standard Penetration Test (SPT), ASTM D 1586

Accurate SPT N Values (blows per foot (305 mm)) can be useful for estimating helical pile or anchor depth and capacities. The following discussion is experienced based.

Helical piles should not bear in formations with SPT N Values less than around 8. Such soils are soft and likely to be compressible thus causing unacceptable deflections for compression piles and anchors over time. However, some formations are very soft over great depths. A multiple helix lead section with 4 or 5 or 6 or more helices should work; load testing is in order.

Soils with SPT N Values less than around 15 will typically require more helices on the lead section to obtain installation torques commensurate with most structural loads. Where N values exceed 15 to 25, typical structural loads are typically supported with single, double, or triple helix lead sections. The higher the blow counts, the higher the installation torques that will be achieved with a given lead section configuration.

Helical piles and tension anchors with common lead section helix configurations are readily installed into soils with SPT N values up to 90+. For soils with high SPT blow counts, installation compression pressure (called “crowd pressure”) should be applied to the pile or anchor shaft by the installation equipment to keep the pile or anchor advancing. Just as screwing a wood screw into pine is easy, when screwed into oak, higher compression pressure must be applied for the screw to continue advancing. The same principle applies to helical piles and anchors. The denser the soil, the more crowd must be applied to the shaft to keep it advancing. The goal is to achieve as close to approximately 3 inches (76.2 mm) of advance (helix pitch) per pile revolution as possible.

In some high N Value soils pile penetration even approximating helix pitch per revolution, even with high crowd, is not possible because the soil is so dense. However, experience has shown this condition does not adversely affect torque vs. capacity.

2.6.3.2 Active Zone Determination

As with any deep foundation, the helix or helices of the pile or anchor must extend beyond the active zone into stable material. In highly expansive soils, HELI-PILE® has found through experience and pile performance monitoring that single helix piles installed to a minimum of 4,000 ft- lbs (5 kN-m) of installation torque are below the active zone. Water will not penetrate into this soil formation.

Helical test probes are the preferred method to identify the active zone because the installation torque feedback indicates where tight stable formations exist or where the formation will limit water infiltration thus keeping the formation stable into which the helix or helices are embedded. See the discussion on this topic in Section 5.4 on expansive clays. Other methods, if accurate, are acceptable.

2.6.3.3 Groundwater Depth

Knowledge of groundwater conditions is valuable but not critical to successful helical pile or anchor installation or performance. Since no hole is created, no casing is required. The presence of groundwater does not affect the torque vs. capacity relationship, although depth of the pile may be affected since groundwater can affect shear strength. Natural groundwater fluctuations do not adversely affect helical pile or anchor capacities when installed correctly with a 2 safety factor.

2.6.3.4 Soil Profile Qualitative Description

The presence of conditions that may affect the installation of helical piles and tension anchors needs to be known. Such items include cobbles, boulders, dense coarse gravel or sandstone / claystone lenses, soft soil lenses, debris, bedrock, etc.

Boring logs are very useful in detecting such conditions. Helical test probes and pile test installs can also detect such conditions.

2.7 Cost Estimating

Once the design steps from Sections 2.1 through 2.6 are complete, the total number of piles or anchors on the job should be known. The estimated depth of piles or anchors should be known. Shaft sizes are known. All quantities are known so the total cost of material can be calculated. Material shipping can also be estimated.

The selection of installation equipment will be made by the installation contractor. Equipment selection will be based on the design information plus the site access information as discussed in Section 2.5. Time to install all piles or anchors will be estimated by the installation contractor. Final installed quotes are typically provided by the installation contractor. Designers and owners are best served by getting installed quotes from HELI-PILE® recommended experienced installation contractors. Or, depending on the project location, HELI-PILE® can train the owner’s contractor.

2.8 Software

Software is available that is designed to analyze geotechnical data and determine predicted depth and installation torque requirements. It is HELI-PILEs® experience that this software can be very misleading if not used properly. The creators and distributors of this software make it clear that it is just a guide, not necessarily accurate. There is a tendency in the industry to treat the results of such software as gospel, the “It came from a computer so it must be right” syndrome. Nothing is further from the truth in this industry. Software results can be useful when used in conjunction with experience and sound engineering judgment. Such software will become more useful as its ability to deal with the myriad of soil and loading conditions increases. Software results must be compared with actual field results to evaluate reliability.

HelixPile and LPILE are design programs HELI-PILE® recommends with the above caveat. Both are independent, not affiliated with HELI-PILE® or any other manufacturer. HelixPile is developed by Deep Excavation LLC (www.deepexcavation.com). LPILE is developed by Ensoft, Inc., (www.ensoftinc.com).

2.9 Underpinning

Underpinning existing structures is not specifically the focus of this design guide. However, the design steps outlined in Section 2 and the other considerations and information herein generally apply to underpinning as well.

For general underpinning instructions please contact HELI-PILE® (www.helipile.com).

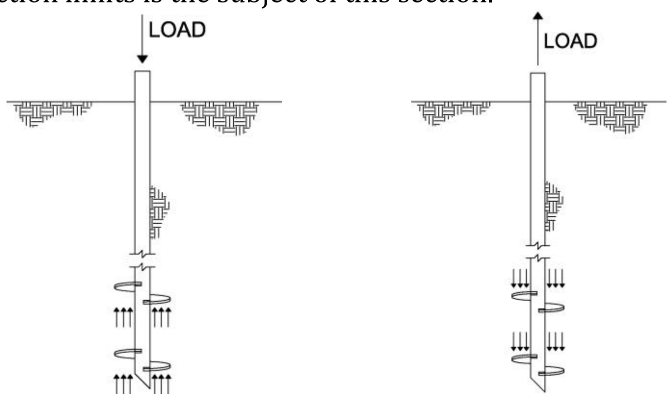
END OF SECTION 2

SECTION 3. HELI-PILE® AXIAL GEOTECHNICAL CAPACITY ESTIMATION

Axial geotechnical capacity is the helical pile or anchor capacity allowed by the soil not considering the mechanical capacity of the pile. All references to "capacity" in this section refer to geotechnical capacity. Mechanical capacities are covered in Section 1.4. Lateral loading is covered in Section 5.11.

Geotechnical capacity must always be equal to or less than mechanical capacity.

Axial compression or tension load imposed on a helical pile is transmitted to the helices via the pile shaft then transferred to the soil via the helices as shown in Figure 3-1. Estimating the magnitude of the load that can be transferred to the existing soil within acceptable deflection limits is the subject of this section.



(a) (b)

Figure 3-1. Load Transfer to Soil in Compression (a) and Tension (b)

Three common methods for estimating axial geotechnical capacity are:

1. Installation torque vs. capacity (reasonably accurate, used throughout the industry)
2. Full-scale field load testing (most accurate; time consuming and more expensive)
3. Soil bearing capacity equations (least accurate, usually conservative)

3.1 Installation Torque vs. Capacity

3.1.1 Compression

Much research by the helical pile industry, including academia, has found the relationship between ultimate helical pile compression capacity and installation torque is

$$Q_u = k_t T \qquad \text{(Eq. 3-1)}$$

where Q_u = Ultimate compression capacity, lbs (kN) (no safety factor)
k_t = Empirical installation torque coefficient, ft^{-1} (m^{-1})
T = Measured installation torque, ft-lbs (kN-m)

Design helical pile compression capacity is given by

$$Q_d = Q_u / SF \qquad \text{(Eq. 3-2)}$$

Where Q_d = Design compression capacity, lbs (kN)(with safety factor)
SF = Safety factor selected by the designer, typically 2 for helical piles

When a helical pile is axially loaded in compression, it is an end-bearing deep foundation element. In soils where installation torque can be achieved and measured, pile compression capacity can be closely estimated. The pile compression capacity is the total axial compression load that can be transmitted to the soil via the helices within the pile's deflection limits. (A small percentage of the load is transmitted to the soil via shaft friction but is usually neglected in capacity calculations except for helical piles with larger shaft dimensions or diameters, typically larger than 4 inches (102 mm).)

Torque vs. capacity is an empirical relationship developed over the years through full-scale field load testing by the helical pile industry and is now universal. The principle is: As a helical pile is rotated into denser and stronger soil, the resistance to rotation, called "installation torque," is measured. The higher the installation torque, the higher the pile compression capacity because higher installation torque is an indication of denser and stronger soil. This principle has been verified through thousands of full-scale field load tests. It is recognized by the International Building Code.

The actual empirical torque coefficient, k_t, for a particular pile will vary from soil to soil depending on helix shape, number of helices, helix size, spacing, shaft cross-sectional shape, crowd pressure, etc. What is now accepted in the industry is that for 1.5-inch (38.1 mm) and 1.75-inch (44.5 mm) RCS solid square shaft helical piles, the empirical torque coefficient k_t has a default value of 10 ft^{-1} (33 m^{-1}). HELI-PILE® HPC and HP Modular solid square 1.5-inch and 1.75-inch shaft helical piles use this empirical torque coefficient. k_t for HELI-PILE® HPFT tubular helical piles are listed in Table 3-1.

Full-scale load testing by HELI-PILE® and the industry in general has shown that the empirical torque coefficient, k_t, reduces as the outside shaft dimension or diameter increases.

Table 3-1 tabulates the recommended k_t values for the various shaft sizes made by HELI-PILE®. Table 3-1 is based on HELI-PILE® in-house full-scale field load testing and the information in Helical Pile Foundation Design Guide, Deep Foundations Institute, 2019, p. 26. Table 3-1 reflects shaft outside dimensions or diameters only; they govern k_t. For square shapes it is the outside dimensions across the diagonal that determines k_t. On any project, full-scale load testing to determine k_t at that site will override the values given in Table 3-1.

Shaft Outside Dimension	Recommended Empirical Torque Coefficient k_t*
1.50-inch square RCS (38.1mm)	10 ft^{-1} (33 m^{-1})
1.75-inch square RCS (44.5mm)	10 ft^{-1} (33 m^{-1})
2.50-inch square HSS (63.5mm)	10 ft^{-1} (33 m^{-1})
3.00-inch square HSS (76.2mm)	Granular: 10 ft^{-1} (33 m^{-1}) Cohesive: 8 ft^{-1} (26 m^{-1})
4.00-inch square HSS (102mm)	Granular: 10 ft^{-1} (33 m^{-1}) Cohesive: 7 ft^{-1} (23 m^{-1})
5.5-inch pipe (140mm)	5 ft^{-1} (16 m^{-1})
6.625-inch round HSS (168.3mm)	4 ft^{-1} (13 m^{-1})
7.00-inch pipe (178mm)	4 ft^{-1} (13 m^{-1})
8.625-inch round HSS (219.1mm)	3 ft^{-1} (10 m^{-1})

*Full-scale load testing at a specific site will override values given.

Table 3-1. Recommended Empirical Torque Coefficients k_t for HELI-PILE® Material

Example of estimating pile capacity using (Eq. 3-1):

ULTIMATE CAPACITY: A 3-inch 5/16 wall (HPFT331) tubular HELI-PILE® is installed to 15,000 ft-lbs (20 kN-m) of installation torque in a granular soil. Determine pile ultimate and design capacities.
From Eq. 3-1, Q_u = 10 ft^{-1} x 15,000 ft-lbs = 150,000 lbs
(Q_u = 33 m^{-1} x 20kN-m = 660 kN)
DESIGN CAPACITY: Use a 2 safety factor
From Eq. 3-2, Q_d = $Q_u/2$ = 150,000 lbs / 2 = 75,000 lbs (660 kN /2 = 330 kN).
(For a discussion on safety factors, please see Section 3.4.)

RELIABILITY: Years of testing and experience show the torque vs. capacity relationship is reliable. An increasing number of designers and building officials are allowing the torque vs. capacity relationship to satisfy requirements for field testing of helical piles.

The number of helices on the shaft beyond the mechanical minimum required to take the ultimate load does not increase the load capacity when the torque vs. capacity relationship is adhered to. By placing more helices on a shaft, or helices with larger diameters, the result is that higher torques will be achieved for a given soil formation. For example, if a shallower pile is required, then more helices and/or helices with greater diameters should be used. If a deeper pile is required, then less helices and/or helices with smaller diameters should be used. A word of caution: whenever attempts are made to shorten or lengthen helical piles, the parties involved must ensure all helices are in a stable formation that will remain stable throughout the life of the structure.

The torque vs. capacity relationship may not be valid where the lead helix grinds into a hard material as evidenced by the helix (or helices) advancing substantially less than the helix pitch (3 inches (76.2mm) per revolution). If the helix or helices seem to advance very slowly per revolution, or not at all, it is called the *refusal condition*. Refusal, or grinding, does not mean that the pier will not take its rated compression capacity. It simply means that the capacity cannot necessarily be predicted by measuring the installation torque. For a more detailed discussion of the refusal condition, see Section 5.8.

OUT-OF-PLUMB PILES: Full-scale load testing has shown that vertical helical piles may be installed with up to a five-degree batter (five degrees out of plumb) and still take their full rated vertical capacities. This is to facilitate a batter that may be required to install adjacent to walls, eaves or other obstructions during underpinning operations. This also facilitates new foundation installations where pile groups are used as described in Section 5.7. See Figure 5-3.

3.1.2 Tension

Figure 3-1 (b) shows a helical pile in tension. k_t values in tension applications are about 10% less than in compression (Helical Pile Foundation Design Guide, Deep Foundations Institute, www.dfi.org (2019), p. 27). Eq. 3-1 is may be used with this 10% reduction applied.

In tension, same as compression, the torque vs. capacity relationship may not be valid where the lead helix grinds into a hard material as evidenced by the helix (or helices) advancing substantially less than the helix pitch (typically 3 inches (76.2mm) per revolution. This is called the refusal condition. In such a case, the pile or anchor must be full-scale field load tested to determine tension capacity. Or, the tension capacity can be estimated based on the installation torque achieved just prior to reaching the refusal condition.

For a more detailed discussion of the refusal condition see Section 5.8.

3.1.3 Installation Torque Measurement

Accurate measurement of installation torque can be accomplished in three ways:

1) Mechanical Torque Measurement: The shear pin torque indicator or limiter is a mechanical device used to measure installation torque (Photos 3-1(a) & (b)). The device is mounted between the helical pile or anchor shaft and the installing torque drive head. Short small diameter steel shear pins are placed in the holes around the circumference of the device to keep the normally free spinning cylinder from spinning. When torque is applied to the device, the shear pins will break in shear when the torque exceeds the shear strength of the total number of shear pins inserted in the device. For the shear pin torque indicator in Photo 3-1(a) each individual shear pin is worth 500 ft-lbs (680 N-m). If, for instance, 22 shear pins were loaded into shear pin torque indicator (a), upon applying installation torque to the helical pile, torque force will transfer through the shear pins in the device until it increases to 22 x 500 ft-lbs (0.680kN-m) = 11,000 ft-lbs (14.9 kN-m) whereupon the shear pins will shear or break.

(a)

(b)

Photo 3-1 Shear Pin Torque Indicators or Limiters.

For the shear pin torque indicator in Photo 3-1(b) each individual shear pin is worth 1,000 ft-lbs (1.36 kN-m). If, for instance, 22 shear pins were loaded into shear pin torque indicator (b), upon applying installation torque to the helical pile, torque force will transfer through the shear pins in the device until it increases to 22 x 1,000 ft-lbs (1.36kN-m) = 22,000 ft-lbs (29.8 kN-m) whereupon the shear pins will shear or break.

The shear pin torque indicator or limiter is typically used only when actually measuring torque. In other words, it is usually not placed on the helical pile shaft until the torque measurement is taken. However, some installing contractors prefer to leave the device on during the entire installation of the pile. When this is done, it is possible the originally loaded shear pins will slightly fatigue during the installation process. When they finally shear completely, they may shear at a slightly reduced torque value because of this fatigue that occurs during the installation process. In such cases, immediately upon shearing the original pins, a new set of shear pins must be loaded into the shear pin torque indicator and sheared again. This ensures the desired installation torque.

One of the significant advantages of the shear pin torque indicator over other types, such as an electronic torque monitor (see below), is that it limits the amount of torque that can be placed on the helical pile. By placing the proper number of shear pins in the device, the installing contractor is assured of never placing too much torque on the pile.

2) Electronic Torque Monitor: Another type of torque measuring device is the electronic torque monitor (Photo 3-2). This device uses an internal strain gauge and a transducer that converts the mechanical torque values to electronic signals that can be output to a smart phone or other data receiving device. The electronic torque monitor is mounted between the helical pile or anchor shaft and the installing torque drive head.

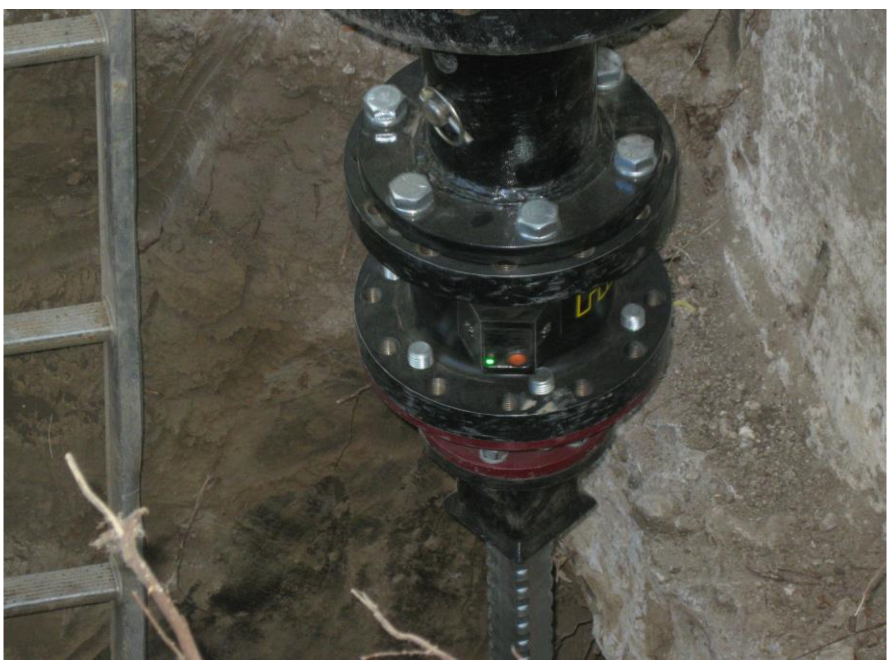


Photo 3-2 Electronic Torque Monitor

Caution must be exercised when using an electronic torque monitor. It is not a limiter. If close attention is not paid to the torque read-out device during installation, it is easy to over torque a pile.

3) Hydraulic Pressure Measurement: Measurement of the hydraulic pressure drop across the installing hydraulic torque motor allows one to convert this pressure drop to installation torque using torque motor manufacturer supplied conversion data. Torque drive-head manufacturers supply torque vs. pressure charts. These devices are not limiters.

3.2 Full-scale Field Load Testing

3.2.1 Compression Axial Load Testing

Full-scale field load testing is the most reliable and preferred method for determining helical pile capacity, compression or tension.

Conventional Load Test Apparatus: Examples of conventional compression load test apparatus are shown in Photo 3-3 and Figures 3-2 and 3-3. For instructions please contact HELI-PILE® (www.helipile.com).

Photo 3-3 Compression load test set-up for a helical pile.

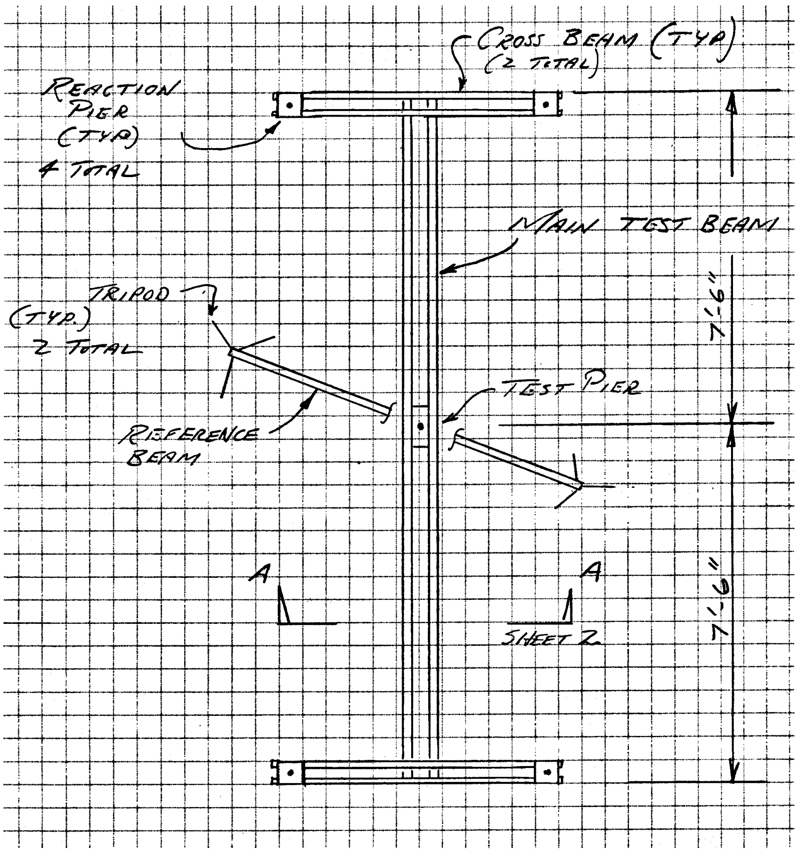


Figure 3-2. Plan View of Compression Load Test Equipment

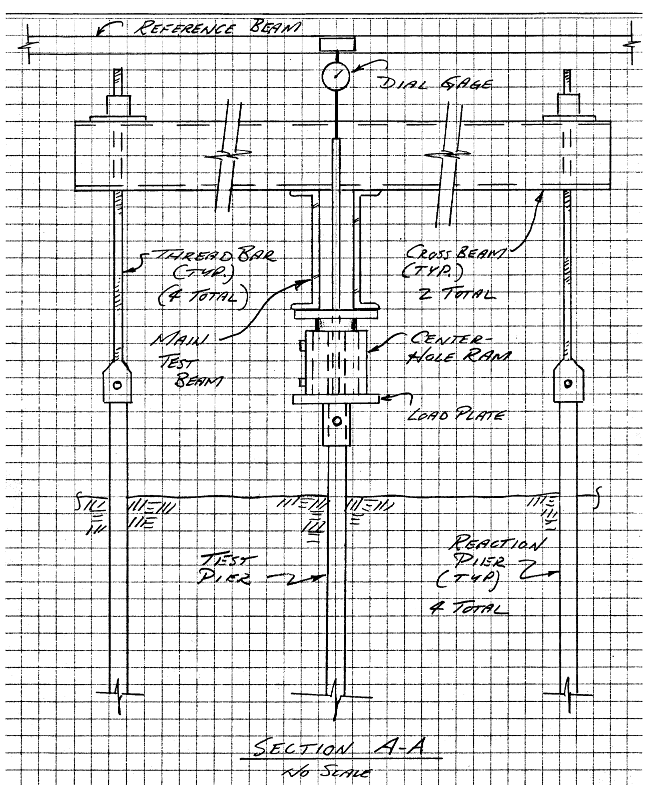


Figure 3-3. Cross-section View of Compression Load Test Equipment

QuadPod Load Test Apparatus: An alternative field compression load test is shown in Photo 3-4 and Figure 3-4. Called the "QuadPod", it is patented by HELI-PILE®. It consists of four battered piles installed to terminate above ground at a central point. The test pile also terminates at the same point above ground. A hydraulic ram is placed over the test pile and connected to the four battered piles which take the reaction force. The test force is placed axially on the test pile. This apparatus complies with ASTM D1143. It can impose up to a 250 kip test load. One of the great benefits is that it fits in the back of a pickup truck and set up time is fast. For instructions please contact HELI-PILE® (www.helipile.com).

Photo 3-4 QuadPod Compression Load Test Apparatus

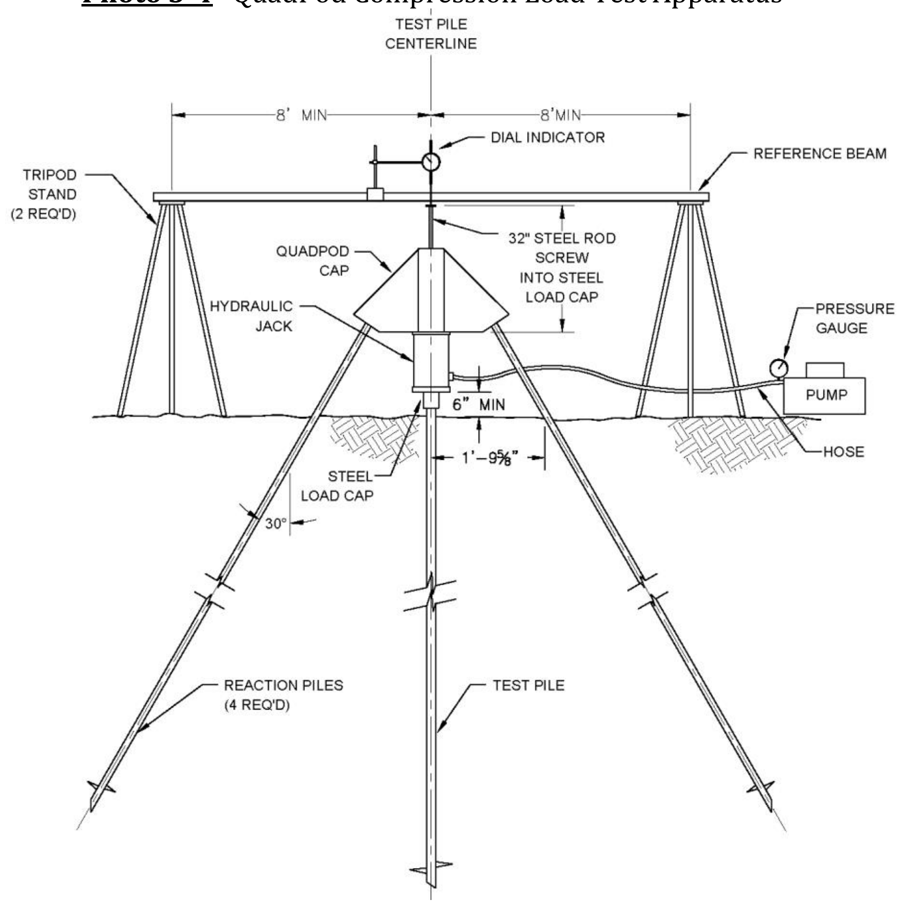


Figure 3-4. QuadPod Compression Load Test Apparatus

The typical full-scale field load test specification followed by HELI-PILE® is ASTM D1143-07 adapted to helical piles. The typical test procedure followed is Procedure A: Quick Test. The reader is referred to the ASTM publication for details on this specification.

The results of full-scale field load testing supersede the HELI-PILE® rated geotechnical capacities for its helical piles and tension anchors.

One of the main differences between full-scale field load testing helical piles versus other types of deep foundation systems is that nothing is left in the field. Since helical piles usually screw out as fast as they screw it, all deep foundation elements may be removed. Nothing is left on-site except maybe a few tire tracks in the dirt.

A downside to full-scale field load testing is that it requires permission from the owner to be on-site and it takes time to set up and run. As can be seen in Photo 3-3 and Figure 3-2 four reaction piles must be installed in addition to the test pile. However, the benefits far outweigh the detriments. An experienced HELI-PILE® installation contractor can set up and run a test in a couple of hours.

3.2.2 Tension Axial Load Testing

Examples of full-scale field tension load test apparatus are shown in Photo 3-4 and Figure 3-4. Tension testing is faster that compression testing in that no reaction pile are necessary.

For full-scale field tension testing, HELI-PILE® typically follows ASTM D3689-07 Procedure A: Quick Test. HELI-PILE® instructions are at www.helipile.com.

Photo 3-5 Tension load test set-up for Helical Tension Anchor.

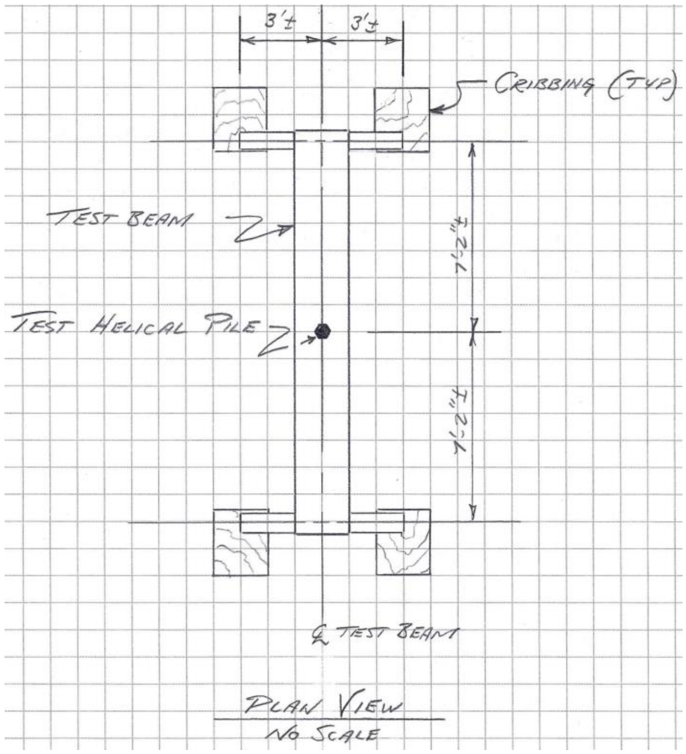


Figure 3-5. Typical Tension Load Test Layout – Plan View

Photo 3-6 shows a typical tieback test set-up with a center-hole ram surrounding the visible tension threadbar. The test frame between the wall and the ram allows for a connection of the visible threadbar to the actual tieback threadbar not visible within the frame. Typically, a dial indicator is set up at the end of the threadbar to measure deflection (not shown). The modular Terminator extension may serve as the threadbar.

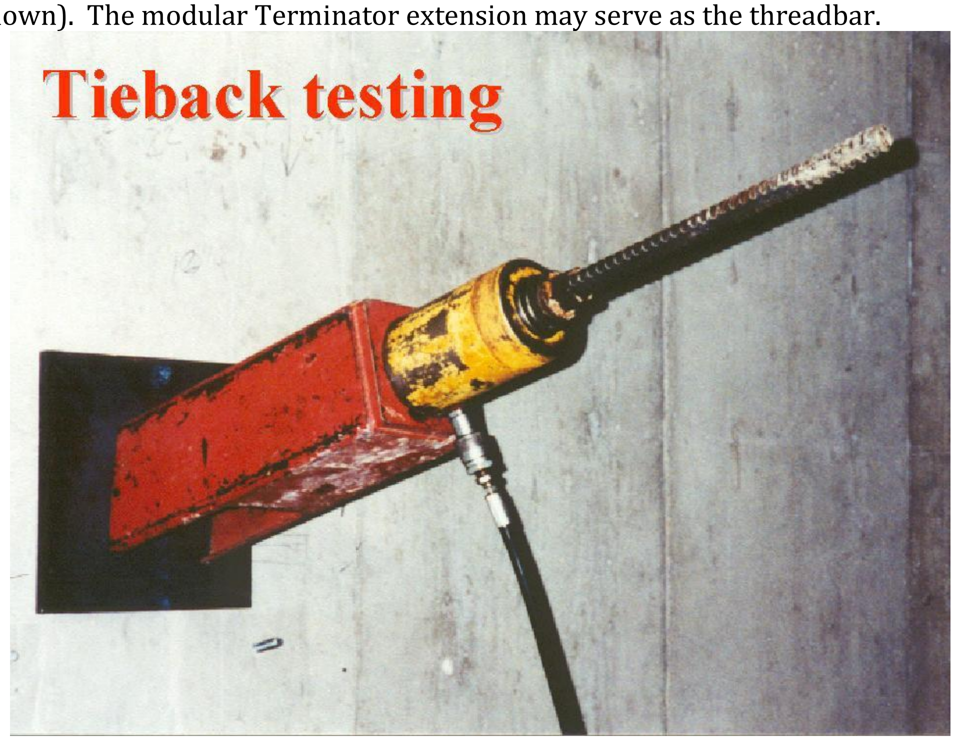


Photo 3-6 Typical tieback test set-up.

Lateral load testing is covered in Section 5.11.4.

3.3 Bearing Capacity Equations and Software

The bearing capacity equation method is the theoretical method to estimate helical pile capacity by using the bearing area of the helix (or helices) multiplied by the calculated bearing capacity of the soil into which each helix is installed. The reader is directed to Chapter 4 "Bearing Capacity" in Helical Piles, A Practical Guide to Design and Installation, Perko (2009). This is a detailed discussion of the bearing capacity method. HELI-PILE® helix areas are provided in Tables 1-5 and 1-6 for designers wishing to use this method.

HELI-PILE® rarely uses this method due to its conservatism and potential inaccuracies. This conclusion is based on decades of experience. Determination of correct geotechnical input is critical to the proper use of this method. Conservatively low calculated soil bearing values or use of high safety factors will inordinately affect calculated helical pile capacity.

Our reasoning is this: Helical piles and anchors are typically installed to torque, not depth. This means they find the soil that matches the required pile capacity as they are installed; the installation torque vs. capacity method of Section 3.1. On the other hand, drilled concrete pier or caisson installation provides no reliable way to determine soil strength or bearing capacity by installation characteristics. Therefore, utilizing conservative soil strength parameters and high safety factors is appropriate for drilled concrete piers. This is not necessary with helical piles and tension anchors.

Software has been developed that use bearing capacity equations to design helical piles and tension anchors. While design software has improved in recent years, it should be recognized that the results of such programs can be conservative, misleading, and unreliable depending actual soil conditions at a particular site and accurate geotechnical input. Use of such programs must be carefully coupled with experience with helical devices and knowledge of the site; best coupled with full-scale field load tests.

"HelixPile" is design software that can be recommended with the above caveat. It is developed by Deep Excavation LLC (www.deepexcavation.com), independent and not affiliated with HELI-PILE® or any other helical pile manufacturer.

Other methods that have been used successfully to determine pile or anchor characteristics include the "Helical Test Probe," "Helical Pile Test Install," and "Standard Penetration Test (SPT)." These methods are described in Section 2.6. Also see "Estimating Helical Pile or Anchor Depth" in Section 5.1.

3.4 Safety Factors, Minimum Installation Torque, and Minimum Depth

Safety Factors: The use of safety factors with helical piles and tension anchors is to ensure that the design load capacity is met with a reasonable margin of safety. It is to account primarily for unknowns in the soil but also the rare but potential imperfections in manufacture and installation.

The 2018 International Building Code recognizes a 2 safety factor for helical piles.

The industry standard and common safety factor used in the field and in the examples given herein is 2. However, it is left to the designer to decide what safety factor to use. In permanent vertical compression helical piles designers rarely use a safety factor less than 2. However, for decks or other non-critical applications 1.5 is sometimes used. It is common in all types of permanent tieback construction, not just helical tiebacks, to use a safety factor of 1.5. While this writer feels a safety factor of 2 should be used whenever possible for vertical piles, especially in cohesive soils, a lower safety factor can be used when engineering judgment calls for it. At no time in HELI-PILEs® experience since 1986 has the use of a safety factor less than 2, when logically and prudently considered, caused a problem in any structure. A safety factor greater than 2 is rare in helical pile and tension anchor technology and generally not necessary.

Other deep foundation technologies use higher factors of safety to account for the uncertainty in soil data and manufacture of the foundation element itself. For instance, in drilled concrete pier design it is not unusual to a factor of safety of 3 or more. This is unnecessary in helical technology.

Minimum Installation Torque: Through experience, HELI-PILE® recommends a minimum installation torque of 3,000 ft-lbs (4.1 kN-m) for all structural applications, even if the design load is very light, such as for a residential deck. This rule of thumb has proven successful since 1986 for thousands of installations: zero failures.

Minimum Depth: For compression applications, in cohesive and fine granular soils, the helices must be installed at least five diameters of the uppermost helix below the ground surface for their torque vs. capacity relationship to be valid. (A.B. Chance Company "Technical Manual," 2000, p. 10). In dense granular soils such as sands and gravels, compression capacity may remain valid at depths less than five helix diameters below ground surface. Full-scale field load testing is recommended.

As an example, if an 8 in-10 in (203 mm-254 mm) double helix lead section were used, its minimum depth would be such that the 10 in (254 mm) helix is 5 x 10 in = 50 inches (5 x 254 mm = 1.3 m) below ground surface.

For tension applications, the minimum depth recommendation is 10 times the diameter of the uppermost helix below ground surface (Helical Pile Foundation Design Guide, Deep Foundations Institute, www.dfi.org (2019), p. 22). For shallower depths, full-scale field load testing is recommended.

END OF SECTION 3

SECTION 4. INSTALLATION

4.1 Installation

Please see Photos 4-1 through 4-51 for photographs of various installation methods.

Photo 4-1 shows a hydraulically powered drive head (also called a "power head", "torque head," "torque motor"). Bolted or pinned to the kelly bar that protrudes from the bottom of the drive head is a hex or square kelly adapter. Bolted or pinned to the kelly adapter is the helical pile drive tool. The top of the helical pile shaft inserts into the drive tool.

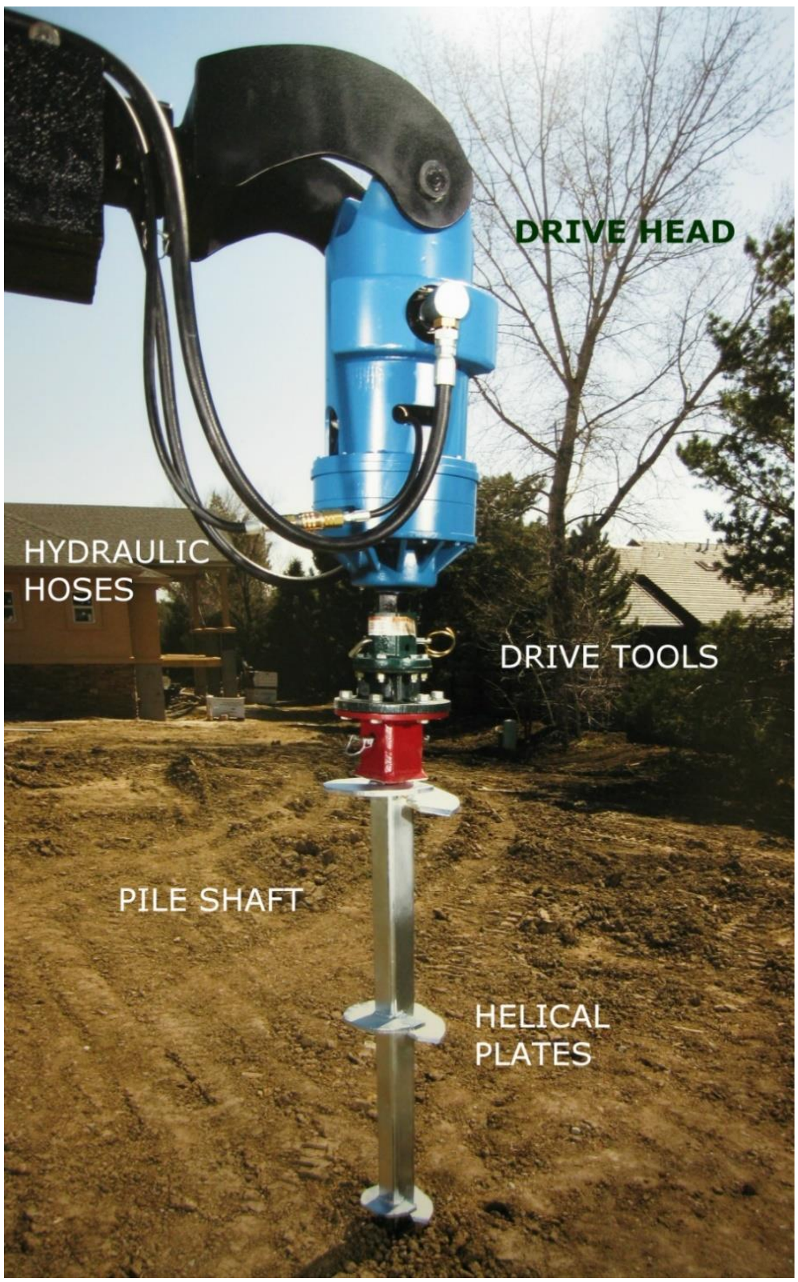


Photo 4-1 Helical pile drive head with kelly bar adapter and drive tool.

Helical piles may be installed with many different pieces of equipment ranging from large tracked excavator/backhoes to small hand-carried installers. There are four requirements for a piece of installation equipment: 1) Sufficient torque for the required pile capacity, 2) Sufficient axial compression pressure (or "crowd") to maintain an advancement rate of about 3 inches (76.2 mm) per revolution, 3) A revolution rate of about 5 to 35 rpm, and 4) Proper size to access the work site.

For projects where access allows, installation is accomplished by attaching a hydraulically driven drive head to the boom of a backhoe, trackhoe, excavator, or skid steer loader, as in Photo 4-1. For tight-access or low overhead projects the drive head may be attached to a carriage frame or merely hand-held. See the photographs below.

Drive heads ideal for helical pile installation typically operate with about 2,850 psi (19.7 Mpa) maximum hydraulic pressure. A drive head with 11,000 ft-lbs (14.9 kN-m) of torque should have from 30 to about 60 gpm (114 to 227 liter/min) hydraulic fluid flow. For smaller equipment, 2,850 psi (18.6 Mpa) maximum pressure is still required, however, the hydraulic fluid flow requirements will reduce to as little as about 8 to 30 gpm (30.2 to 56.8 liters/min). With the advent of larger helical piles on the market today, drive heads in excess of 80,000 ft-lbs (108 kN-m), even reportedly over 500,000 ft-lbs (678 kN-m), are available.

In soils of high ground water or in highly caving soils where casing would be required for drilled shafts, helical piles are economical because no hole is created, no casing is required. Regarding schedule, it has been shown that in such conditions approximately ten helical piles can be installed to over 40 ft (12 m) deep in the time it takes to install one cased drilled shaft, and that does not include the concreting time for the drilled shaft. Helical piles require no concrete in the ground.

In tight access locations and environmentally sensitive areas, helical piles can be installed with small skid steer type loaders, small excavators, or hand-carried equipment. Specialty helical pile contractors have installed deep foundations with a 100,000 lbs (445 kN) ultimate capacity per pile inside areas as small as telephone booths and in crawl spaces under existing floors. For hand-carried equipment being used inside an existing building, the hydraulic pump and engine stay outside the building; only the torque motor and hydraulic hoses go inside, thus noise, exhaust and dust are kept outside.

4.2 Hydraulic Drive Heads and Tooling Sold by HELI-PILE®

HELI-PILE® does not manufacture hydraulic drive heads. However, all drive heads sold by us are modified and adapted in-house specifically for the installation of helical piles and anchors. We maintain a fully equipped hydraulics shop with expert mechanics. Photo 4-1 is an example of a drive head purchased by HELI-PILE® that was modified and adapted specifically for helical pile installation for re-sale. Hoses are included with all drive heads.

HELI-PILE® manufactures all installation tooling. Examples are the drive tools in Photo 4-1. HELI-PILE® also manufactures the bails and jibs that connect drive heads to the mobile machine such as skid steers, backhoes, excavators and hand-held equipment.

HELI-PILE® maintains a complete hydraulic shop to service all drive heads and tooling sold.

Photos 4-2 through 4-4 are examples of some of the two-speed drive heads sold by HELI-PILE®. Other sizes available. The specifications given in the captions are 1) Max torque output, 2) Operating weight, 3) Hydraulic flow requirement range and 4) maximum operating hydraulic pressure. HELI-PILE® can supply specifications for all drive heads sold.

<u>Photo 4-2</u> 83,000 ft-lbs, 2,200 lbs,
75-185 gpm, 5,000 psi max
(113 kN-m, 998 kg)
(284-700 l/m, 34.5 MPa max)

<u>Photo 4-3</u> 20,000 ft-lbs, 580 lbs
30-60 gpm, 2,850 psi max
(27.1 kN-m, 263 kg)
(114-227 l/m, 19.7 MPa max)

<u>Photo 4-4</u> 12,000 ft-lb, 420 lbs
30-60 gpm 2,850 psi max
(16.3 kN-m, 191 kg)
(114-227 l/m, 19.7 MPa max)

<u>Photo 4-5</u> 5,500 ft-lbs, 110 lbs
8-30 gpm, 2,850 psi max
(7.46 kN-m, 49.9 kg) (single speed)
(30-114 l/m, 19.7 MPa max)

4.3 Installation Methods of Helical Piles and Tension Anchors

The photographs below show a sampling of the variety of installation tools available to install helical piles and helical tension anchors. As can be seen, the equipment sizes range from large excavators down to small hand-carried equipment.

4.3.1 Examples of Installation Equipment for New Construction

Photo 4-6 Tracked Gradall excavator capable of installing over 60 helical piles per day.

Photo 4-7 Rubber-tire hydraulic excavator capable of installing over 60 helical piles per day.

Photo 4-8 Two tracked machines each capable of installing over 60 helical piles per day.

Photo 4-9 Tracked machine with adjustable frame installing battered helical piles for lateral loads.

Photo 4-10 This tracked installation machine is ideal in tight access locations and wide-open spaces.

Photo 4-11 Large hydraulic excavator capable of rapidly installing large diameter helical piles.

Photo 4-12 Skid-steer type machines installing helical piles for new construction.

Photo 4-13 Large hydraulic excavator capable of rapidly installing large diameter helical piles.

4.3.2 Examples of Installation Equipment for Underpinning

Photo 4-14 Skid-steer machine installing helical piles for foundation underpinning.

Photo 4-15 Backhoe installing helical piles for foundation underpinning.

Photo 4-16 Mini-excavator installing helical piles for foundation underpin.

Photo 4-17 Mini-excavator installing battered helical piles adjacent to existing building.

Photo 4-18 Skid-steer machine inside garage installing helical piles for foundation underpinning.

Photo 4-19 Backhoe installing helical piles for foundation underpinning.

Photo 4-20 Skid-steer machine installing helical piles for foundation underpinning.

Photo 4-21 Skid-steer machine inside a building installing helical piles for foundation retro-fit

4.3.3 Examples of Hand-Carried Installation Equipment

Photo 4-22 Hand-carried torque motor, yoke, and torque arm in tight access location.

Photo 4-23 Hand-carried mast for installation of helical piles in tight access location.

Photo 4-24 Hand-carried mast for installation of helical piles in tight access location.

Photo 4-25 Hand-carried mast for installation of helical piles in tight access location.

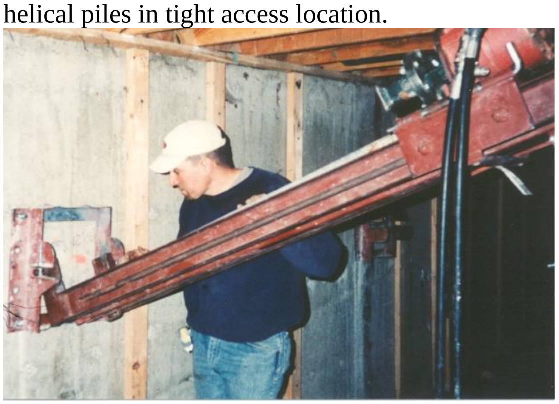


Photo 4-26 Hand-carried mast in near horizontal position to install helical tiebacks in low overhead.

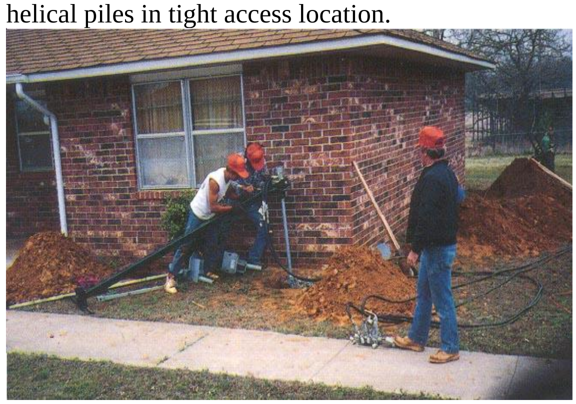


Photo 4-27 Hand-carried torque motor, yoke, and torque arm for tight access location.

4.3.4 Examples of Installation Equipment for Helical Anchors used as Tiebacks

Photo 4-28 Tracked machine to install helical tension anchors as tiebacks for retaining wall repair.

Photo 4-29 Loader mounted torque motor installing helical tension anchors as tiebacks for repair.

Photo 4-30 Skid-steer machine (on right) installing helical tension anchors as tiebacks for structure.

Photo 4-31 Skid-steer machine installing helical tension anchors as tiebacks for new retaining wall.

Photo 4-32 Backhoe mounted torque motor install-ling helical tension anchors as tiebacks for repair.

Photo 4-33 Skid-steer mounted drive head installing helical tension anchors as tiebacks in low overhead.

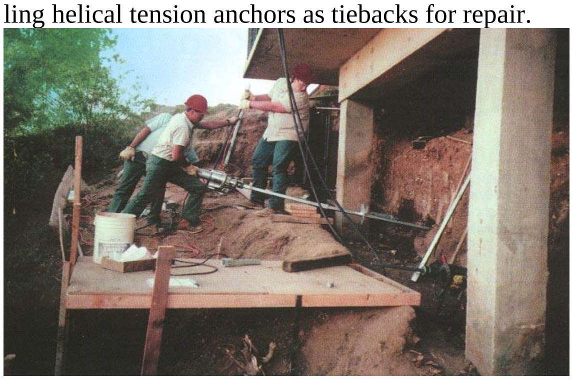


Photo 4-34 Hand-carried equipment installing helical tension anchors as tiebacks for repair.

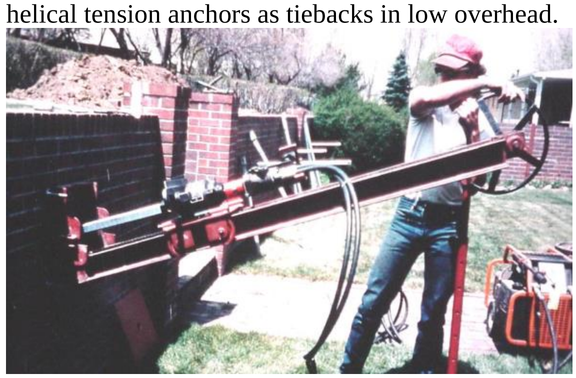


Photo 4-35 Hand-carried mast in near horizontal position installing helical tension anchors as tiebacks.

4.3.5 More Examples of Various Types of Installation Equipment

Photo 4-36 Rubber-tire hydraulic excavator installing helical piles for new foundation.

Photo 4-37 Rubber-tire Gradall excavator installing helical piles for new commercial construction.

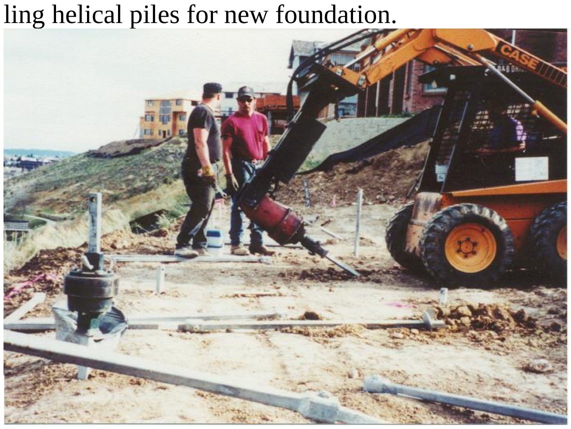


Photo 4-38 Skid-steer mounted torque motor installing battered helical tension anchor under itself.

Photo 4-39 Backhoe installing helical screw piles at a slight batter for a sound wall.

Photo 4-40 Tracked machine installing battered helical piles for lateral load resistance.

Photo 4-41 Tracked machine installing helical tension anchors as tiebacks for retaining wall repair.

Photo 4-42 Mini-excavator mounted torque motor installing helical screw piles over wetland.

Photo 4-43 Large tracked hydraulic excavator installs large battered helical pile for high lateral load.

Photo 4-44 Skid-steer mounted torque motor installing helical piles.

Photo 4-45 Mini-excavator mounted torque motor installing helical piles.

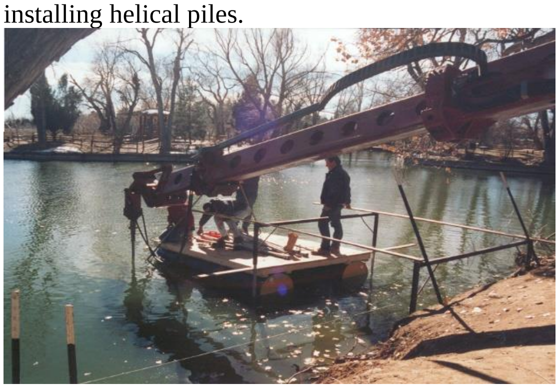


Photo 4-46 Hydraulic excavator boom mounted torque motor installing helical piles in lake.

Photo 4-47 Skid-steer mounted torque motor install-ling helical piles inside existing building.

Photo 4-48 Hydraulic excavator mounted torque motor installing helical piles in wet conditions.

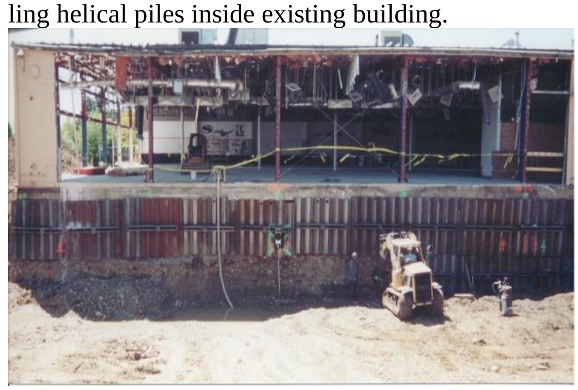


Photo 4-49 Tracked machine installing helical tension anchors as tiebacks for shoring.

Photo 4-50 Hand-carried mast mounted on wall in near horizontal position to install helical tiebacks.

Photo 4-51 Skid-steer mounted torque motor installing helical piles for a new addition.

END OF SECTION 4

SECTION 5. DESIGN CONSIDERATIONS

The following design considerations may or may not affect final helical pile or anchor design but should be considered for every design.

5.1 Estimating Helical Pile or Anchor Installed Depth

Estimating helical pile or tension anchor depth is an exercise in estimating the depth where the required installation torque or refusal condition will be achieved. The following methods provide reasonable depth estimates. No other methods, including computer programs, have proven consistently reliable.

The following sections in Section 2 can be used as guides in estimating helical pile or tension anchor depth:

2.6.1 Helical Test Probe
2.6.2 Helical Pile Test Install
2.6.3.1 Standard Penetration Test (SPT), ASTM D 1586

5.2 Predicted Settlement and Long-term Creep

Based on thousands of full-scale load tests and the historical record since 1986 of thousands of structures founded on helical piles manufactured by HELI-PILE® and others, vertical compression loaded helical piles properly designed and installed to a 2 safety factor do not settle beyond limits typically set by structural engineers. This means settlements are always less than 1 inch (25 mm), closer to ¼ inch (6 mm). Differential settlements during construction have never been a concern.

Long-term Creep: Full-scale long-term load testing has shown that a helical pile or tension anchor properly designed and installed in cohesive soils, with the installation torque required to carry the design load with a 2 safety factor, does not experience long-term creep (Chapel, Thomas A., "Field Investigation of Helical and Concrete Piers in Expansive Soils," Colorado State University Master's Thesis, 1998). Helical piles do not experience long-term creep in granular soils. Many years of helical pile history across the United States bear this out. If the reader has any experience to the contrary, HELI-PILE® welcomes the knowledge.

5.3 Software

Software is available that is designed to analyze geotechnical data and determine predicted depth and installation torque requirements. It is HELI-PILEs® experience that this software can be very misleading if not used properly. Software results must be compared with actual field results to evaluate reliability.

HelixPile and LPILE are design programs HELI-PILE® recommends with the above caveat. Both are independent, not affiliated with HELI-PILE® or any other manufacturer. HelixPile is developed by Deep Excavation LLC (www.deepexcavation.com). LPILE is developed by Ensoft, Inc. (www.ensoftinc.com).

5.4 Expansive Clay Soils (with two Case Histories)

HELI-PILE® helical piles are very successful in expansive clay soils. Our manufacturing facilities are located in the Denver, Colorado, USA, area, one of the world's most renowned natural laboratories for testing lightly loaded residential foundations in highly expansive soils. Two professional papers by John Pack of HELI-PILE® on this subject are presented below. These are presented here with permission of the publishers.

5.4.1 Paper No. 1

The following paper is reprinted from GEO-VOLUTION, The Evolution of Colorado's Geological and Geotechnical Engineering Practice, pp. 76-85; proceedings of the 2006 Biennial Geotechnical Seminar, November 10, 2006, Denver, Colorado; Geotechnical Practice Publication No. 4 by the American Society of Civil Engineers; reprinted by permission from ASCE.

Performance of Square Shaft Helical Pier Foundations in Swelling Soils

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Abstract

The use of square shaft helical pier foundations in swelling soils is a standard of practice in Colorado. Since 1986 it is estimated approximately 130,000 square shaft helical piers of the type described herein have been installed for both remedial repair and foundations for new construction in swelling soils, including the highly expansive steeply dipping bedrock areas of the Front Range. There are no documented failures or adverse performance of correctly specified and installed square shaft helical piers. The underlying principles for this performance are: 1) Installing square shaft helical piers to a minimum of 4,000 ft-lbs (5.4 kN-m) of installation torque, or refusal, ensures that the helical bearing plate (helix) is embedded below the active zone (depth of seasonal moisture change), 2) The use of only a single helix lead section ensures that no helical bearing plates embed within the active zone, 3) The small surface area of the square shaft reduces uplift forces on the pier to levels that eliminate heave, even where there is no dead load, 4) The smooth steel shaft surface may reduce uplift forces on the pier, 5) The square shaft shape may reduce uplift forces on the pier, 6) Water does not migrate along the sides of the shaft down to the soil in which the helix is embedded, 7) Specifying IBC and ISO 9001 listed square shaft helical piers ensures the correct material is furnished and installed for swelling soil conditions and 8) The use of trained and experienced installing contractors ensures that square shaft helical piers are correctly installed in swelling soils.

Introduction

The modern square shaft helical pier is a derivative of the helical screw pile that was invented some 300 years ago in Europe. In recent times, the helical screw pile concept has been refined in shape and size and adapted to high-strength, low-alloy steels to produce the deep foundation system in use today.

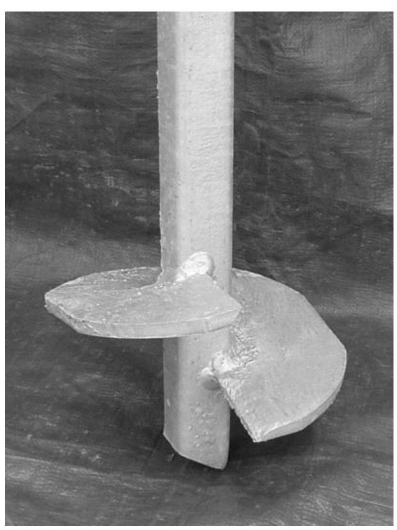
Square shaft helical piers for structural foundations were introduced to the United States in the 1960's and introduced to Colorado in the 1980's. Their use is a standard of practice in Colorado. Numerous manufacturers have a presence in Colorado along with corresponding installing contractors.

Since 1986 it is estimated approximately 130,000 square shaft helical piers of the type described herein have been installed for both remedial repair and foundations for new construction in swelling soils, including steeply dipping expansive bedrock found along the Front Range. There are no documented failures or adverse experiences with correctly specified and installed square shaft helical piers. The underlying principles for this performance are detailed below.

Swelling Soil in Colorado

The presence of swelling soils in Colorado is well documented (Chen, 1988, p. 14; Nelson and Miller, 1992, p. 4; Day, 2006, p. 9.1). It could be said that certain areas of Colorado, especially along the Front Range, are among the finest natural laboratories in North America for the examination of foundation performance in swelling soils. Steeply dipping bedrock formations are notorious for adverse effects on structural foundations. Bentonitic clays exist with swell pressures that can range as high as 40,000 psf (1,900 kPa) with Plasticity Indices (PI) exceeding 50. While most swelling soils usually do not exhibit characteristics as high as the aforementioned, problematic swelling soils through-out Colorado continue to adversely affect many types of foundation systems causing differential heave, structural distress and cosmetic damages. It is within this geological and historical setting that square shaft helical pier foundation performance is examined.

Square Shaft Helical Pier Description



[Paper No. 1] **Figure 1. Single Helix Square Shaft Helical Pier.**

The type of square shaft helical pier examined in this paper is shown in Figure 1. It consists of a central, square, solid-steel shaft to which a single split circular steel helical bearing plate, stamped in the shape of a helix, is welded. This steel bearing plate is simply called a “helix”. Shaft cross-section size typically ranges from 1.50 in square to 1.75 in square (38.1 mm square to 44.5 mm square). Lead section and extension length typically ranges from 3 ft to 10 ft (0.9 m to 3 m) long. Helix diameter typically ranges from 6.0 in to 14.0 in (150 mm to 360 mm). Helix thickness typically ranges from 0.375 in to 0.500 in (9.53 mm to 12.7 mm).

Square shaft helical piers for new construction are typically installed using a hydraulically powered drive head attached to wheeled or tracked equipment. Figure 2 shows a typical square shaft helical pier installation using hydraulic torque drive heads attached to the jibs of two tracked skid steer type machines. The drive head’s torque force is transferred to the helical bearing plate, or helix, via the square shaft. The leading edge of the helix engages the soil which causes the helix to screw into the soil thus guiding and pulling the shaft with it. As the top end of the shaft reaches grade, an extension is attached and installation continues. Successive extensions are attached until, in swelling soils, a minimum of 4,000 ft-lbs (5.4 kN-m) of installation torque, or refusal, is achieved.

[Paper No. 1] **Figure 2. Square Shaft Helical Pier Installation.**

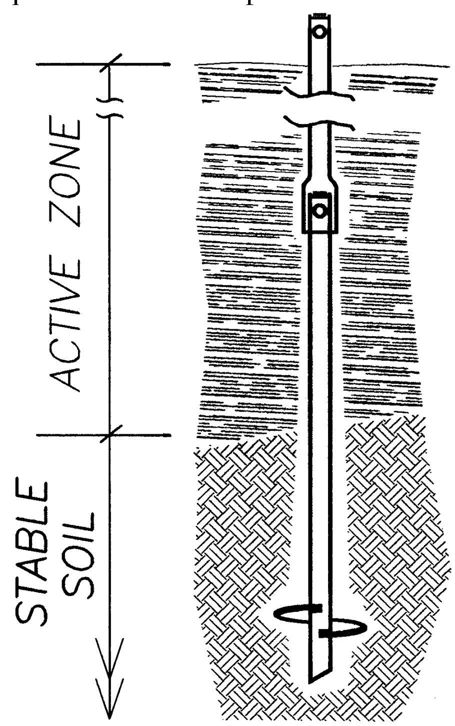
Underlying Performance Principles

There are no documented failures or adverse performance of correctly specified and installed square shaft helical piers in swelling soils. The underlying principles for this performance are given by the eight findings described below:

1. Installing square shaft helical piers to a minimum of 4,000 ft-lbs (5.4 kN-m) of installation torque, or refusal, ensures that the helical bearing plate (helix) is embedded below the active zone (depth of seasonal moisture change).

Any deep foundation, be it helical pier, drilled pier, driven pile, etc., must embed and transfer load through the active zone to stable material below. The active zone is defined as that zone or depth of seasonal moisture change, sometimes also called the "depth of wetting." It is the depth or zone where soil expansion or shrinkage forces adversely affect deep foundation performance. Swelling soils expand when the moisture content increases and contract or shrink when moisture content decreases. If the deep foundation is not sufficiently installed below the active zone, as moisture content changes, heave or shrinkage forces will be applied to the deep foundation which may cause it and the structure above to move.

Through monitoring thousands of square shaft helical pier installations in swelling soils over the 20 year period since 1986, it has been empirically found that if the square shaft helical pier is installed to a minimum of 4,000 ft-lbs (5.4 kN-m) of installation torque, or to the refusal condition, it is ensured that the helix is embedded in stable soil below the active zone. Figure 3 depicts a square shaft helical pier installed below the active zone.



[Paper No. 1] **Figure 3. Stable Square Shaft Helical Pier Installed Below the Active Zone.**

It will be noted that a certain depth of embedment is not required in square shaft helical pier technology. A minimum installation torque of 4,000 ft-lbs (5.4 kN-m) or refusal is specified, not an embedment length.

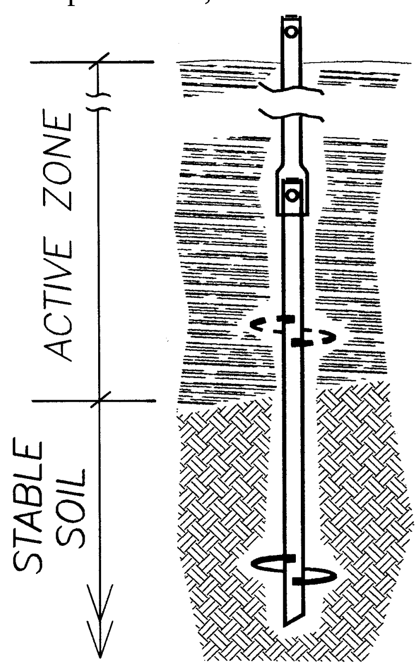
When a square shaft helical pier is installed to 4,000 ft-lbs (5.4 kN-m) of installation torque or refusal, it has been found that the soil into which the helix is embedded is very dense, so dense, in fact, that moisture will not reach the soil into which the helix is installed, even over the potential many years of primary and secondary swell. The extremely low permeability of such soil does not allow moisture to ever penetrate to the soil surrounding the helix. Thus, the square shaft helical pier remains stable.

Refusal. Refusal condition is defined as that point at which the square shaft helical pier will not penetrate or advance further into the formation because the material is too dense or hard. At refusal, installation torque typically reduces below the torque achieved just prior to reaching refusal. This occurrence does not indicate lower compression capacity of the pier. Rather, because advancement cannot continue, high compression capacity in a formation not susceptible to water infiltration is achieved.

2. The use of only a single helix ensures that no helical bearing plates (helices) embed within the active zone.

If helical bearing plates are embedded in an active soil zone that swells or shrinks, swelling or shrinkage forces will be applied to the plates which could lead to movement of the helical pier. Excluding helical plates from the active zone ensures that no such forces will be applied to any helices.

Figure 4 shows a single helix helical pier embedded in stable soil below the active zone. If the soil below the active zone is so dense that a second helix (shown in dashed lines) were embedded in the active zone, helical pier movement could possibly occur. By limiting the number of helices on a helical pier to one, no helices can remain in the active zone.



[Paper No. 1] **Figure 4. Helices Installed Below the Active Zone.**

3. The small surface area of the square shaft reduces uplift forces on the pier to levels that eliminate heave, even where there is no dead load.

Any portion of a deep foundation shaft within the active zone of swelling soil is susceptible to an uplift force due to vertical swell pressure. The uplift force magni-tude depends on the coefficient of uplift between the shaft and the soil (see Section 4), and the surface area of the shaft (Nelson and Miller, 1992, p. 130). The uplift force is proportional to the shaft surface area.

As an example, suppose a 1.5 in (38.1 mm) square shaft helical pier were installed through a 30 ft (9.1 m) active zone with a vertical swell pressure of 20,000 psf (960 kPa), a high swelling soil. Using a coefficient of uplift of 0.10 for the smooth steel shaft, the total uplift force on the square shaft helical pier is given by

$$U = (4)(s)(f)(u)(D) \qquad (1)$$

where U = Total uplift force
4 = Number of sides on the square shaft
s = Square shaft size
f = Coefficient of uplift
u = Vertical Swell Pressure
D = Depth of the Active Zone

U = (4)(1.5 in / 12 in / ft)(0.10)(20,000 psf)(30 ft) = 30,000 lbs
(U = (4)(38.1 mm)(0.10)(960 kPa)(9.1 m) ≈ 130 kN)

Through thousands of full-scale load tests, it has been empirically shown that a square shaft helical pier installed to 4,000 ft-lbs (5.4 kN-m) of installation torque has a compression and tension ultimate capacity of 40,000 lbs (180 kN)(Pack, 2004, p. 19). Therefore, even with no dead load, this helical pier has an ultimate uplift capacity of 40,000 lbs (180 kN). The factor of safety, *F.S.*, against heaving of this particular helical pier is

F.S. = 40,000 lbs / 30,000 lbs = 1.3
(*F.S.* = 180 kN / 130 kN ≈ 1.3)

Thus, even with no dead load in a high swelling soil with a deep active zone, this square shaft helical pier will not heave. Experience corroborates this finding. Since 1986 thousands of lightly loaded structures, such as single-story wood frame structures and wood decks, have been founded on square shaft helical piers in swelling soils where little dead load is imposed on the piers. To date, no documented failures or adverse performances of correctly specified and installed square shaft helical piers have occurred.

When the refusal condition is reached (see definition above), the tension capacity cannot be determined by installation torque. Since 1986 it has been empirically shown that in the refusal condition square shaft helical piers do not heave, even with no dead load and even at shallow depths, such as 10 feet (3 m) or less. While the mechanics of the refusal condition for square shaft helical piers warrant study, it is felt by this writer that the combination of findings in this paper (excluding the 4,000 ft-lb (5.4 kN-m) installation torque requirement) all contribute to the performance of square shaft helical piers in the refusal condition. It is recommended that further investigation be undertaken to ascertain the reasons why square shaft helical piers in the refusal condition still perform.

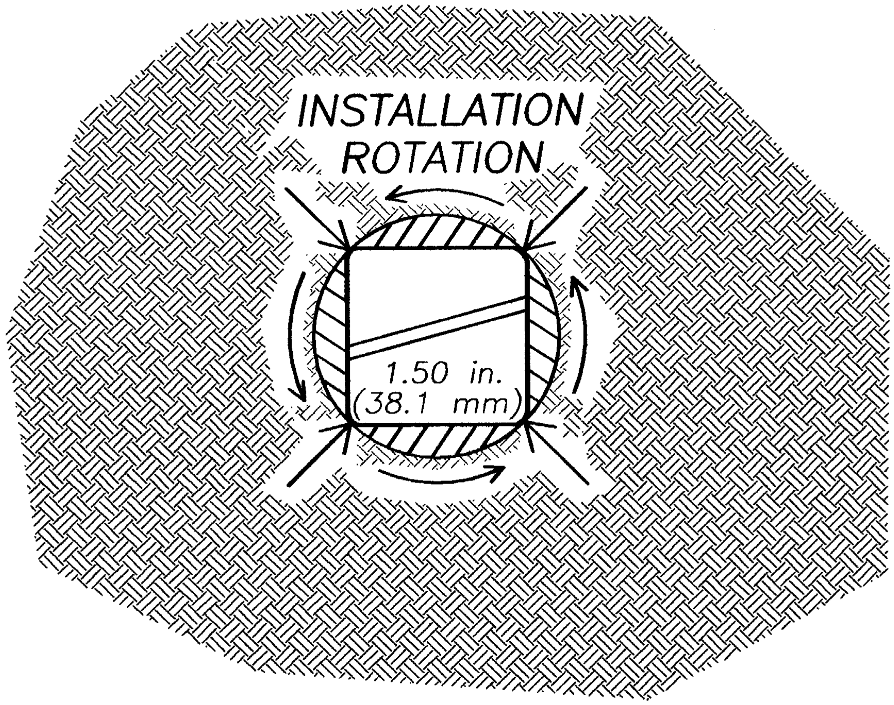
4. The smooth steel shaft surface may reduce uplift forces on the pier.

It has been experimentally determined that the coefficient of uplift between concrete and soil of a drilled cast-in-place concrete pier (caisson) is on the order of 0.15 (Chen, 1988, p. 136). Another estimate of this coefficient ranges from 0.10 to 0.25 (Nelson and Miller, 1992, p. 130). These values were determined for concrete piers that typically have relatively rough surfaces as compared to the smooth steel surface of a square shaft helical pier. Therefore, it stands to reason that the smooth steel sur-face of the square shaft helical pier would have a coefficient of uplift on the low end of the range, perhaps below 0.10. A value of 0.10 was used for Equation (1) above.

Due to the lack of a rough surface, it can be said that total uplift force on square shaft helical piers may be reduced. Quantifying the reduction in uplift force has not been studied but it is expected that some reduction occurs.

5. The square shaft shape may reduce uplift forces on the pier.

Figure 5 shows a cross-section of a 1.50 inch (38.1 mm) square shaft helical pier. It will be noted that, as the shaft is installed, only the rounded corners of the shaft shear the sides of the disturbed zone adjacent to the shaft. Between corners is a zone of soil against the sides of the steel shaft that does not directly impact the shaft. Uplift forces impact the shaft directly on the corners only, not the straight sides between the corners. Between the corners uplift forces from swelling soil must act on the soil in the undisturbed zone between corners then transmit forces through this zone to the shaft. The amount of uplift force reduction has not been studied. However, it stands to reason that some reduction is actually occurring when the geometry of the square shaft is considered.



[Paper No. 1] **Figure 5. Square Shaft Helical Pier Cross-section.**

6. Water does not migrate along the sides of the shaft down to the soil in which the helix is embedded.

There have been no documented cases where water has migrated down the shaft to soil surrounding the helix, even where the helix less than 10 ft (3 m) deep.

Swelling soils swell upon wetting. The very phenomenon that makes swelling soils a challenge for foundation engineers makes them advantageous to square shaft helical piers. As water starts to penetrate along side the square shaft, the presence of swelling soils self-seals any water avenues thus preventing water from migrating down the shaft to soil surrounding the helix.

This finding is corroborated by a study completed between 1995 and 1998 at Colorado State University (Chapel, 1998, p. 107-108). The study found that water did not migrate along the shaft of square shaft helical pier any more than water migrated along the shaft of drilled cast-in-place concrete piers (caissons). Due to lack of natural rainfall, an irrigation system was set up during the last two years of the study to ensure that water was available to migrate. The result of this study is in agreement with field experience in swelling soils.

7. Specifying International Building Code (IBC) and ISO 9001 listed square shaft helical piers ensures the correct material is furnished and installed for swelling soil conditions.

Swelling soils require helical pier shaft and helix material that is sufficiently strong to withstand high installation crowd (compression pressure from the installation equipment) and high installation torque. Specifying IBC listed square shaft helical pier material allows the designer to review the specifications to ascertain whether the material being considered meets the recommended minimum strength requirements given below.

To match the performance standard given in this paper (no failures or adverse performance), shaft steel for 1.50 in (38.1 mm) square shaft should have a minimum 70 ksi (480 Mpa) tensile strength. Shaft steel for 1.75 in (44.5 mm) square shaft should have a minimum 90 ksi (660 Mpa) tensile strength. Helix steel for all square shaft helical piers should have a minimum 80 ksi (550 Mpa) tensile strength. All welds should be certified per American Welding Society guidelines.

The manufacturer of square shaft helical piers should rate their products for ultimate installation torques and ultimate tension and compression capacities. All ratings must be backed by test results.

Square shaft helical piers should be manufactured by an ISO 9001:2000 listed manufacturer. ISO, the International Organization for Standardization headquartered in Geneva, Switzerland, lists companies in 157 nations. According to the ISO website (www.iso.org), "ISO 9001:2000 is one of a family of quality management standards" that "has become an international reference for quality requirements in business to business dealings." ISO 9001:2000 "is concerned with 'quality management'. This means what the organization [manufacturer] does to enhance customer satisfaction by meeting customer and applicable regulatory requirements and continually to improve its performance in this regard." The ISO family of standards represents an international consensus on good management practices with the aim of ensuring that the manufacturer can time and time again deliver the product or services that meet the client's quality requirements.

8. The use of trained and experienced installing contractors ensures that square shaft helical piers are correctly installed in swelling soils.

As in all geotechnical construction, the use of a trained and experienced installing contractor is one of the most important steps that can be taken to ensure a properly performing square shaft helical pier foundation in swelling soils. Trained and experienced contractors know the balance between soil conditions, installation equipment and techniques, and helical pier material to ensure a correct foundation in swelling soils.

Manufacturer certification is not sufficient, in and of itself, to ensure correct installation. Owners and designers should ascertain qualifications by pre-qualifying prospective installing contractors based on specific project experience in swelling soils and longevity in the industry. It is not unusual for installing contractors of square shaft helical piers who are long experienced in swelling soils to guarantee the performance of the foundations they install for both new construction and repair of existing foundations.

Conclusion

Structures in swelling soil regions of Colorado and other swelling soil regions of the world remain stable if founded on correctly specified and installed square shaft helical piers. This is true for new construction and for foundations requiring repair. The underlying principles presented above prove why this is so. Owners, designers and constructors should consider the use of square shaft helical piers wherever swelling soils are encountered.

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5.4.2 Paper No. 2

The following paper is reprinted from Conference Proceedings 2007, 32nd Annual Conference on Deep Foundations, pp. 321-330, October 11-13, 2007, Colorado Springs, Colorado, by the Deep Foundations Institute. This material may be downloaded for personal use only.

DESIGN, SPECIFICATION AND INSTALLATION OF SQUARE SHAFT HELICAL PIERS IN EXPANSIVE SOILS

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The application of square shaft helical piers in expansive soils is a standard of practice in many areas of the United States. Over 20 years of performance monitoring show exceptional performance and economy will result if proper design procedures, specification requirements and installation procedures are followed. This is true for new foundations and the repair of existing foundations, including lightly loaded wood-frame structures on expansive soils. Proper design includes: 1) site geotechnical characterization, 2) pier layout such that each pier is loaded to its maximum design capacity, 3) maximize spans between piers, 4) minimize the number of piers, 5) isolate the structure from the expansive soil with an appropriate void zone below all grade beams, slabs or other components that would otherwise be in soil contact and 6) utilize only single helix piers. Proper specification employs a performance specification that specifies: 1) the design load on each pier with a suitable safety factor, 2) the minimum installation torque, typically 4,000 ft-lbs (5.4 kN-m), or refusal, 3) a minimum pier shaft steel F_y = 70 to 90 ksi (483 to 621 Mpa) and pier helix steel F_y = 80 ksi (552 Mpa), 4) 1.5 to 1.75 inch (38.1 to 44.5 mm) square shafts, 5) smooth shaft surface, 6) the ICC Evaluation Report (ER) number of the manufacturer and 7) the manufacturer ISO 9001 certification for material quality control. Proper installation requires: 1) equipment with sufficient axial compression force (crowd) on the pier shaft so the helix engages the soil and advances to the specified minimum installation torque or refusal, 2) additional specialized techniques for expansive soils and 3) qualified specialty helical pier installation contractors experienced in expansive soils who submit and utilize pier configurations, techniques and equipment that will most effectively and economically meet the specified performance.

INTRODUCTION

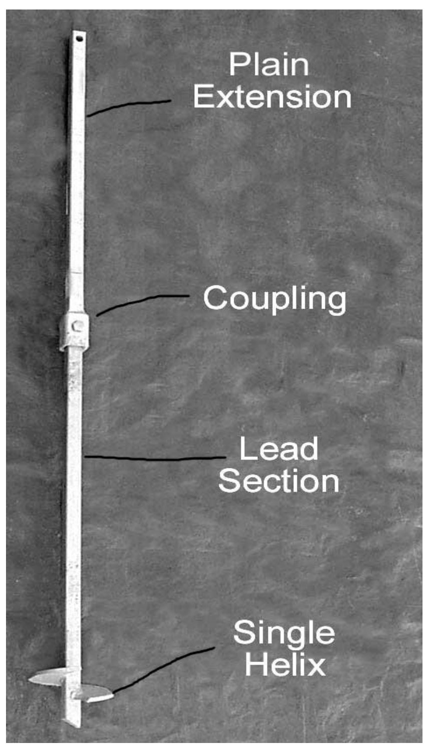
Performance monitoring, ongoing since 1986, proves that any structure founded on properly designed, specified and installed square shaft helical piers in expansive soils of even the highest severity will maintain long-term stability, i.e., will not heave. This includes lightly loaded wood-frame structures. It is true for new foundations and the repair of existing foundations. The underlying principles for this performance are well documented (Hargrave and Thorsten, 1992; Black and Pack, 2001; Pack and McNeill, 2003; Pack, 2006).

Due to exceptional performance, square shaft helical pier applications in expansive soil regions have become common throughout the United States, predominately in the states of Colorado, Montana, Texas, Utah and Wyoming. In most of these areas, the use of square shaft helical piers is a standard of practice.

This paper outlines design, specification and installation procedures and requirements for square shaft helical piers that will result in long-term stable foundations in expansive soils. These practices have been derived primarily through the experience gained since square shaft helical piers began to be installed in the highly expansive clays of the Denver and Front Range areas of Colorado in 1986. Most of the structures that are the result of these methods are light wood-frame residences, the very structures that are the most susceptible to differential heave because of their low dead loads. Large commercial, Industrial, institutional and multiple-story structures in expansive soils have also been successfully designed and constructed using these procedures and requirements.

Brief Description

The square shaft helical piers that are the subject of this paper have shaft dimensions that range from 1.5 inch (38.1 mm) to 1.75 inch (44.5 mm) square. The helix is a split circular steel plate, ⅜ to ½ inch (9.5 to 12.7 mm) thick, stamped in the shape of a helix and welded to the central square shaft (Figure 1). The helix has a leading edge that engages the soil when it is rotated, or screwed, such that an axial thrust is created driving the helix and shaft into the soil. Lead sections typically come in lengths of 3, 5, and 7 feet (0.9, 1.5, and 2.1 m). As the lead section advances farther into the soil, plain shaft extensions are added until the desired depth is reached. Extensions also come in 3, 5, and 7 feet (0.9, 1.5, and 2.1 m) lengths. Shaft sections are typically connected with a bolted connection. Helix diameters typically range from 6 to 14 inches (152 to 356 mm), however, the most common helices used in expansive soils are the 6 and 8 inch (152 and 203 mm). Figure 1 is a photograph of a single helix square shaft helical pier with the different parts labeled.



[Paper No. 2] Figure 1. Single Helix Square Shaft Helical Pier

The helix serves dual purposes: 1) It is the installation tool, i.e., as it is rotated it drives the shaft deeper into the soil. 2) It is the bearing plate for load transfer to the soil.

Typical individual ultimate capacities of the square shaft single helix helical piers that are the subject of this paper range from 50 kips (222 kN) for the 1.5 inch (38.1 mm) shaft to 60 kips (267 kN) for the 1.75 inch (44.5 mm) shaft. A typical factor of safety of 2 (Specification Requirement 1 below) is applied to pier ultimate capacities to determine design capacities.

For new construction, square shaft helical piers are typically installed with specialized hydraulic torque motors mounted to mobile equipment such as backhoes, trackhoes, or any mobile equipment able to carry and power the torque motor. Figure 2 is a photograph of a typical square shaft helical pier installation using a wheeled excavator with the hydraulic torque motor mounted to the excavator boom.

[Paper No. 2] Figure 2. Square Shaft Helical Pier Installation Using a Wheeled Hydraulic Excavator

For a detailed description of square shaft helical piers and installation equipment for new construction and foundation repair, the reader is referred to Pack (2004).

DESIGN PROCEDURES

The design, specification and installation procedures and requirements outlined below are specific to square shaft helical piers in expansive soils; they are not exhaustive for deep foundation design and installation. In addition to the methods presented herein, other techniques pertaining to deep foundations may be applicable.

These procedures and requirements are not necessarily sequential, however, some logically should occur before others.

Design Procedure 1: Site Geotechnical Characterization

The logical first design step is to determine the existence and extent of expansive soils at a site. A detailed discussion of the nature of expansive soils and methods to perform site exploration and characterization is beyond the scope of this paper. For such information, the reader is directed to Chen (1988) and Nelson and Miller (1992) as well as other sources of information available in the literature.

Where site characterization is to be performed, it is recommended that a geotechnical engineer familiar with 1) expansive soils in the area and 2) square shaft helical pier technology be consulted. Experience has shown that unfamiliarity with square shaft helical pier technology in expansive soils can lead to the inappropriate application of other foundation technologies to square shaft helical piers.

For example, in expansive soils, the requirement of a minimum length of pier embedment into the stable formation below the active zone, such as bedrock, does not apply to properly designed, specified and installed square shaft helical piers. To ensure long-term stability, square shaft helical piers typically are installed to a minimum of 4,000 ft-lbs (5.4 kN-m) of installation torque or refusal (see Specification Requirement 2 below). For reasons detailed in Pack (2006), this ensures 1) the helices embed in stable soil below the active zone and 2) piers will maintain long-term stability (not heave). No minimum length of embedment is required.

In contrast, drilled cast-in-place concrete piers (caissons) where installed in expansive soils, are typically socketed a certain minimum length into the stable formation below the active zone to counteract uplift forces. This is due to the concrete pier's large surface area in contact with expansive soil in the active zone. Embedment below the active zone attempts to anchor the concrete pier down and keep it from heaving.

While this practice is appropriate for drilled pier technology, it is not for square shaft helical pier technology and should be avoided. Insistence that square shaft helical piers be installed deeper than necessary causes delays and increased costs.

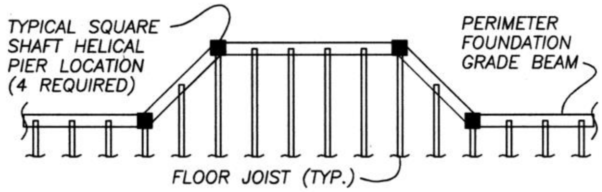
Design Procedure 2: Pier Layout such that Each Pier is Loaded to Its Maximum Design Capacity

Research and monitoring since 1986 have shown that properly designed, specified and installed square shaft helical piers will maintain long-term stability in expansive soils even with no dead load (Chapel, 1998; Pack, 2006). However, in spite of this experience, in expansive soils, loading helical piers to their maximum design capacities is prudent engineering. An additional benefit of this procedure is that it minimizes the number of piers which maximizes economy. Minimizing the number of piers further aids in long term foundation stability in expansive soils by lowering the number of soil/foundation contact points, further described in Design Procedures 3 and 4 below.

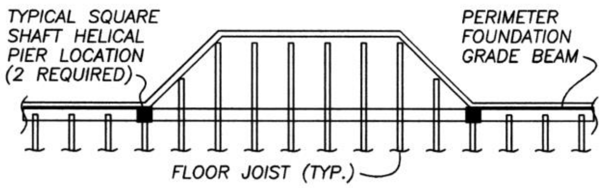
Detailing methods to layout piers such that each is loaded to its maximum design capacity is beyond the scope of this paper. Such information is available in the literature. The structural engineer responsible for the superstructure may defer pier layout and load distribution design to specialty square shaft helical pier contractors or suppliers. The structural engineer must be satisfied specialty contractors or suppliers are qualified to work in expansive soils (See Installation Procedure 3 below).

Experience has shown that there is a tendency of some structural engineers to place more helical piers in the foundation than necessary. Much of this tendency comes from a misperception that square shaft helical piers with such slender shafts may require an added factor of safety beyond what is typical. Testing and decades of experience show this practice is unfounded and may, in fact, add to overall foundation instability in expansive soils.

Structural engineers and architects should work together so the foundation plan lends itself to maximizing pier loads. For example, a residential structure may have a bay window alcove as shown in Figure 3a. Foundation plans frequently call for the perimeter grade beam to follow the plan of the bay. To avoid eccentric loading of the perimeter grade beam, two lightly loaded helical piers are required at the bay outside corners. As shown in Figure 3b, a way to eliminate these two piers is to have the perimeter grade beam continue straight and have the bay alcove floor joists cantilever beyond the perimeter grade beam. By following this concept, the structural engineer and architect work together to maintain architectural aesthetics while maximizing the design load on each pier, minimizing the number of piers and reducing the number of soil/foundation contact points.



[Paper No. 2] Figure 3a. Perimeter Foundation Grade Beam With 4 Square Shaft Helical Piers



[Paper No. 2] Figure 3b. Perimeter Foundation Grade Beam With 2 Square Shaft Helical Piers

Design Procedure 3: Maximize Spans Between Piers

Design Procedures 3, 4 and 5 have identical purposes: 1) Minimize the contact area of the foundation with expansive soil and 2) isolate the foundation, insofar as practical, from the expansive soil. Minimal soil/foundation contact and maximum foundation isolation results in foundation stability because total expansion forces that act on the foundation are minimized. This procedure should be used for new construction and for the repair of existing foundations on expansive soils.

Design Procedure 3 assumes a structural grade beam and raised floor system or a structural slab is used, regardless of the purpose or size of the structure. Spans between piers should first be designed to maximize pier loads (Design Procedure 1 above). Once this criterion is met, then grade beam or slab design proceeds per normal design methods.

Design Procedure 4: Minimize the Number of Piers

It is the author's opinion that the foundation sys-tem best suited to minimize contact with expansive soil consists of 1) perimeter and interior load bearing grade beams (reinforced concrete, steel, glulam, timber, etc.) supported on maximum spaced square shaft helical piers, 2) raised structural floors (reinforced concrete, wood, etc.) over a crawl space, the floors supported by clear-span joists or girders and 3) an appropriate void depth under all grade beams, slabs or other building components between piers that would otherwise be in soil contact (Design Procedure 5 below). In summary, the only soil/foundation contact should be where the helical pier shafts enter the subgrade.

Slabs-on-grade should be avoided in expansive soils. The only exception to this may possibly be for residential garage slabs where 1) the slab is isolated from the surrounding foundation grade beams and 2) the subgrade below the garage slab is prepared appropriately for the specific expansive soil at the site.

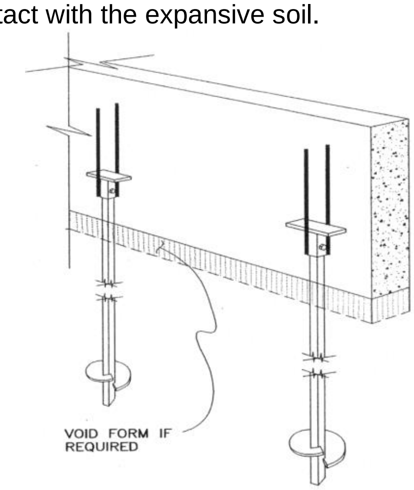
Project Economy: An important side benefit to maximizing spans between piers and minimizing the number of piers is economy. Logically, minimizing the total number of piers in a project promotes economy.

Design Procedure 5: Isolate the Structure from Expansive Soil with an Appropriate Void Zone

The placement of a void zone or space below grade beams and structural floors that otherwise would be in contact with the soil is a standard of practice in expansive soil areas. Void space gives the expansive soil a place to expand into without impacting the foundation or structure. The thickness of the void space is dependent on the expansion or heave potential of the soil. This determination should be made in consultation with a geotechnical engineer familiar with the site expansive soils.

For example, for new construction, under new concrete members, the void space is typically created with a void form (Figure 4). This is typically a corrugated paper box placed below the forms that is specifically sized for the location. The box is treated to withstand the moist environment and weight of wet concrete until the concrete cures. After the concrete cures, the void form paper gradually disintegrates to create a void below the member.

For retrofit construction, such as in foundation repair, the void space must be excavated so as not to leave the foundation in contact with the expansive soil.



[Paper No. 2] Figure 4. Void Form Below Grade Beam

Design Procedure 6: Utilize Only Single Helix Piers

For reasons documented in Pack (2006) only single helix square shaft helical piers should be used in expansive soils. (See Figure 1) Manufacturer ratings of single helix helical piers should be followed when maximizing design loads per Design Procedure 2 above. It is recommended that pier layout be such that single helix helical piers are used exclusively.

Typical individual ultimate capacities of the square shaft single helix helical piers that are the subject of this paper range from 50 kips (222 kN) for the 1.5 inch (38.1 mm) shaft to 60 kips (267 kN) for the 1.75 inch (44.5 mm) shaft. A typical factor of safety of 2 (Specification Requirement 1 below) is applied to ultimate capacities to determine design capacities.

If pier loads exceeding the capacity of a single helix square shaft helical pier absolutely cannot be avoided, then a double helix helical pier may be used. Experience has shown that where double helix helical piers are required for higher loads, and are installed to installation torques commensurate with those loads, or refusal, they also exhibit long-term stability in expansive soils. Great care should be exercised when using a double helix helical pier in expansive soils because of the ease of installing the pier incorrectly. A qualified specialty installation contractor should be employed. (See Installation Procedure 3 below).

Lead sections with three or more helices should typically never be used in expansive soils unless special circumstances arise. On rare occasions, some expansive soil formations may contain active zones underlain by relatively soft soils that, in order to provide an economical pier, warrant the use of multiple helix lead sections to keep the pier from installing deeper than necessary. Great care must be exercised to ensure all helices are below the active zone. A qualified specialty installation contractor should be employed (Installation Procedure 3 below).

SPECIFICATION REQUIREMENTS

Performance specifications are recommended. They ensure that the project requirements are met at the least cost. They allow qualified specialty installation contractors the most flexibility in bringing to bear the most cost-effective materials, methods and equipment.

Performance specification guidelines are found in Pack (2004). It is the author's experience that the key ingredients to successful foundation construction using a performance specification are 1) a well defined performance specification, 2) timely submittals by the installation contractor, and 3) constant and complete communication between the installation contractor and the engineer-of-record during construction.

Specification Requirement 1: The Design Load on Each Pier with a Suitable Safety Factor

Manufacturers publish the ultimate capacity ratings for their square shaft helical piers. Typical individual ultimate capacities of the square shaft single helix helical piers that are the subject of this paper range from 50 kips (222 kN) for the 1.5 inch (38.1 mm) shaft to 60 kips (267 kN) for the 1.75 inch (44.5 mm) shaft. Multiple helix helical piers will have higher ultimate capacities.

Factors of safety are used in foundation design to take into account uncertainties in soil load bearing capacities. In square shaft helical pier technology, each pier is tested during installation by measuring installation torque or refusal. Therefore, much of the uncertainty in the load carrying capability in the helical pier is alleviated. Thus, lower safety factors are allowed.

In square shaft helical pier technology, the typical factor of safety is 2. Experience over many decades has proven that higher factors of safety are not necessary. This is unlike many foundation systems where higher factors of safety are common. Those safety factors should not be applied to square shaft helical piers.

To arrive at the design capacity, a factor of safety is applied to the ultimate capacity. For example, if a pier has an ultimate capacity of 60 kips (267 kN), the design capacity is calculated by

60 kips(267 kN) / 2 = 30 kips(133 kN) design capacity

It is within the prerogative of the designer to use a lower the factor of safety if the structure warrants it. Safety factors of 1.5 to 1.8 for temporary or non-critical structures are common.

Another circumstance when the factor of safety may be lowered is where the design load is slightly higher than that required for a safety factor of 2. For example, for a permanent structure, if a square shaft helical pier with an ultimate capacity of 50 kips (222 kN) must carry a design load of 26 kips (116 kN), the safety factor would be

50 kips(222 kN) / 26 kips(116 kN) = 1

To use this slightly lower factor of safety, the designer must be confident in the load carrying capability of the soil and in the design loads applied to the structure. Other factors may be present that might affect the decision to lower a factor of safety. Experienced engineers and/or installing contractors should be consulted.

Specification Requirement 2: Minimum Installation Torque, Typically 4,000 ft-lbs (5.4 kN-m), or Refusal

Monitoring and testing since 1986 has proven that the minimum installation torque for square shaft helical piers in expansive soils typically should be 4,000 ft-lbs (5.4 kN-m)(Pack, 2006). This ensures that the helices are below the active zone and the piers will maintain long-term stability. Installation torques down to 3,000 ft-lbs (4.1 kN-m) may be permissible in some situations as long as specific site and structural loading conditions are evaluated. Consultation with a qualified installation contractor is recommended (see Installation Procedure 3 below).

Refusal is the condition when, during installation, the helix encounters soil so dense that, in spite of maximum axial compression force on the shaft (crowd) from the installing equipment, the helix does not engage the soil and advance. Refusal is an indication that the soil is sufficiently dense to provide adequate bearing capacity and ensure the helix is below the active zone.

Monitoring and testing of the refusal condition since 1986 has proven that square shaft helical piers installed to refusal as defined above in expansive soils maintain long-term stability (Pack, 2006).

Minimum Depth: Square shaft helical piers are installed to minimum torques or refusal, not minimum depths, except as follows: In cohesive soils, square shaft helical piers typically have an absolute minimum depth of 5 times the diameter of the largest helix on the lead section. For example, a single 8 inch (203 mm) diameter helix lead section would have a minimum depth of 40 inches (1 m). Or, formations or strata may be identified that, for any number of reasons, the lead section must penetrate. This may constitute a minimum depth deeper than the above 5 diameter rule. These exceptions are rare.

Specification Requirement 3: Minimum pier Shaft and Helix Steel Strengths

The square shaft helical piers that are the subject of this paper have shaft steel F_y = 70 to 90 ksi (483 to 621 Mpa) minimum and pier helix steel F_y = 80 ksi (552 Mpa) minimum. The use of high strength steel has been found to be crucial for long-term stability in expansive soils, primarily to aid in proper installation.

During installation, lower strength helices are susceptible to tearing off the shaft or folding or coning. Any of these occurrences damages the helical pier and renders it ineffective. Lower strength shafts could be susceptible to premature shaft twist breakage prior to achieving the typical 4,000 ft-lbs (5.4 kN-m) minimum installation torque.

None of the aforementioned occurrences are visible from the ground surface. Inexperienced installation contractors may not realize a problem exists. Experience since 1986 shows the use of high strength steels ensures that these circumstances do not occur (Pack, 2006).

Appearance Differences: From manufacturer to manufacturer, all square shaft helical piers essentially look alike. It is difficult for the uninformed to differentiate one manufacturer from another. Some manufacturers will have identifying marks on the shaft. For example, at least one manufacturer stamps on the shaft the source steel mill, heat number, date of manufacture and shaft steel strength. At least one manufacturer stamps a code letter on the helix indicating its steel strength. Others place building code ER numbers on their shafts.

Because of the appearance similarities, the designer should know the identification marks of the various manufacturers. The designer must be able to determine in the field that the helical piers specified show up at the site.

Specification Requirement 4: 1.5 to 1.75 Inch (38.1 to 44.5 mm) Square Shafts

The square shape of the shaft is the optimum for expansive soils for reasons documented in Pack (2006). The square shaft helical piers that are the subject of this paper have square dimensions that range from 1.5 to 1.75 inch (38.1 to 44.5 mm). These sizes of square shafts, monitored and tested since 1986, have proven to provide long-term stability in expansive soils.

In expansive soils, in a perfect world, the absolute optimum deep foundation would have an infinitely thin and infinitely strong shaft with a sufficiently large bearing plate embedded in stable material below the active zone. The infinitely thin shaft could not be affected by expansive soil in the active zone. While this optimum deep foundation is impossible, it is approximated by the square shaft helical piers that are the subject of this paper.

Specification Requirement 5: Smooth Shaft Surface

The square shaft helical piers that are the subject of this paper have smooth steel shaft surfaces. As documented in Pack (2006), the smooth surface results in less friction and adhesion. This may further aid long-term stability in expansive soils.

Specification Requirement 6: The ICC Evaluation Report (ER) Number of the Manufacturer

Specifying that a manufacturer of square shaft helical piers has an International Code Council-Evaluation Report (ICC-ER) Number helps assure the designer that the pier material specified will be what is supplied on the project. ICC Evaluation Service, Inc., (www.icc-es.org) performs evaluations and writes reports for manufacturers' products. These reports contain evaluations and conclusions as to the products' materials and capacities.

It is estimated that there are currently about 50 manufacturers of helical pier material world-wide (Helical Pier World Website, 2007). Not all these manufacturers make square shaft helical piers. Of those that do, not all make the high strength square shaft steel helical piers that are the subject of this paper. An ICC-ER Number certifies what is manufactured. The use of ICC-ER numbers for manufactured products in the construction industry is a standard of practice.

Specification Requirement 7: Manufacturer ISO 9001 Certification for Material Quality Control

Specifying that a manufacturer of square shaft helical pier material has ISO 9001 certification helps assure the designer that the manufacturer is able to consistently manufacture products that will meet the quality, strength and dimensions advertised. The use of ISO 9001 certification for manufactured products is a standard of practice.

ISO is the International Organization for Standardization, headquartered in Geneva, Switzerland, dedicated to assuring quality control. The reader is directed to the ISO web site (www.iso.org) for further information.

INSTALLATION PROCEDURES

Proper installation of square shaft helical piers in expansive soils is crucial. All the forgoing procedures and requirements are of no value if the piers are not installed properly.

Installation Procedure 1: Equipment With Sufficient Axial Compression Force (Crowd)

The amount of axial compression force (crowd) on the pier shaft required during installation must be sufficient to allow the helix to engage the soil and advance to the specified minimum installation torque or refusal. The amount of axial compression force required is dependent upon the soil being penetrated. It is similar to screwing a wood screw into wood. In pine, a wood screw typically installs easily without much compression force applied to the screw driver. However, in oak, higher compression force and increased torque is required to keep the screw advancing.

Similar action is required in soils. The denser the soil, the more axial compression force (crowd) and installation torque must be applied to the pier to keep it advancing. In a perfect world, the helical pier will advance a distance equal to the helix pitch for each revolution, typically 3 inches (76 mm). In actual installations, the advancement length per revolution can vary from less than 0.5 inch (13 mm) up to 3 inches (76 mm). The reason is that different soils and densities will cause the helix installation to proceed differently. In all cases, it has been found by experience that the torque versus ultimate capacity relationship still holds.

Heavier installation machines (Figure 5) in the 30,000 to 40,000 lbs (133 to 178 kN) range are preferred in expansive soils for two reasons: 1) they provide greater crowd and 2) they are faster. Lighter weight machines (Figure 6) in the 8,000 to 15,000 lbs (36 to 67 kN) range, and those in between, are acceptable but slower.

Figure 5 is a photograph of a square shaft helical pier installation in expansive soils. The installing machine is a wheeled hydraulic excavator that weighs about 40,000 lbs (178 kN). This is an ideal installation machine because of its ability to impart high axial compression force (crowd) to the helical pier shaft and it is fast.

Figure 6 is a photograph of a relatively light 8,500 lbs (38 kN) tracked type machine about to install a square shaft helical pier. Although not capable of the high crowed of a heavier machine, it is still capable of installing proper square shaft helical piers in expansive soils.

The lighter the machine, the more important role the operator plays to ensure properly installed piers. Detailed operator instructions for expansive soils are beyond the scope of this paper. A qualified specialty installing contractor should be consulted. See Installation Procedure 3 below.

Installation Torque versus Capacity: Regardless of the installation machine weight and the amount of crowd placed on the pier shaft, the torque versus capacity relationship still holds.

[Paper No. 2] Figure 5. Square Shaft Helical Pier Installation in Expansive Soils.
40,000 lb (178 kN) Machine

[Paper No. 2] Figure 6. Square Shaft Helical Pier Installation. 8,500 lb (38 kN) Machine

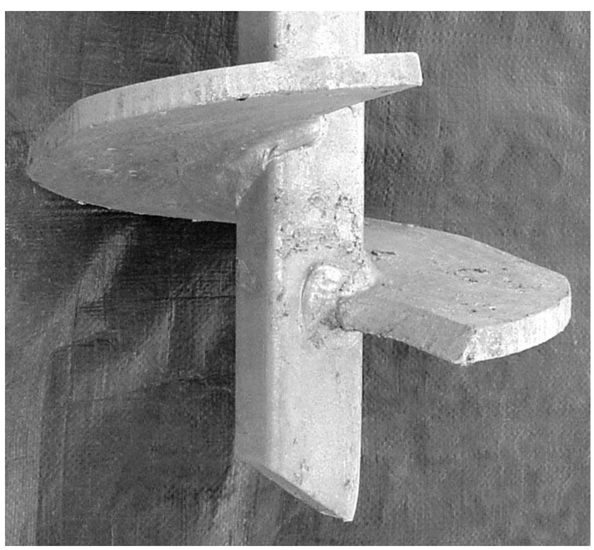
As explained in Hoyt and Clemence (1989), Hargrave and Thorsten (1992) and Pack (2004), there is an empirical relationship between installation torque and ultimate capacity. For the square shaft helical piers that are the subject of this paper, the empirical torque coefficient is 10 ft^{-1} (32.8 m^{-1}). For example, if a square shaft helical pier is installed to 5,000 ft-lbs (6.8 kN-m) of installation torque, the ultimate capacity is

10 ft^{-1} x 5,000 ft-lbs = 50,000 lbs Ult. Capacity
(32.8 m x 6.8 kN-m = 222 kN Ult. Capacity)

Installation Procedure 2: Additional Specialized Techniques for Expansive Soils

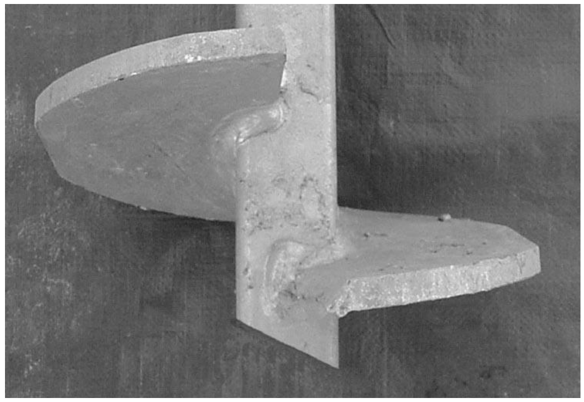
Helix Sizing: To obtain additional helix depth in a dense formation a smaller helix may be used. However, diameters less than 6 inches (152 mm) have an empirical torque coefficient different from the 10 ft^{-1} (32.8 m^{-1}) mentioned in Installation Procedure 1 above and should be avoided. It is permissible to field trim a helix to a smaller diameter.

Bevel the Leading Edge: To obtain additional helix depth in a dense formation, the helix leading edge may be beveled as shown in Figure 7. This may be a factory or field modification.



[Paper No. 2] Figure 7. Helix Beveled Leading Edge

Shorten the Stinger: To obtain additional helix depth in a dense formation, the “stinger”, or portion of the shaft extending below the helix, may be shortened as shown in Figure 8. This is typically a field modification.



[Paper No. 2] Figure 8. Portion of the Shaft Below the Helix, called the “Stinger”, Has Been Shortened

Rock Cut the Leading Edge: To obtain additional helix depth in a dense formation, the leading edge may be modified as shown in Figure 9. This procedure is primarily used in cobble formations but may assist in dense formations as well. This may be a factory or field modification.

[Paper No. 2] Figure 9. Helix Leading Edge Rock Cut

Other techniques exist that are beyond the scope of this paper. Consult qualified specialty square shaft helical pier installation contractors experienced in expansive soils. See Installation Procedure 3 below.

<u>Installation Procedure 3: Qualified Specialty Installation Contractors Experienced in Expansive Soils</u>

As in all geotechnical construction, qualified specialty square shaft helical pier installation contractors experienced with expansive soils will provide the greatest assurance of the long-term foundation stability described in the first paragraph of this paper.

“Qualified” vs. “Certified”: Some manufacturers of square shaft helical piers “certify” contractors to install their piers through training and examination. While manufacturer certification is highly recommended, it should be noted that “certified” does not equate to “qualified”. Manufacturer certification does not qualify a contractor to install square shaft helical piers in expansive soils any more than ground school qualifies a pilot to fly through a hurricane. Specialized training and experience in expansive soils is a requirement.

A potential specialty contractor’s experience and long-term results in expansive soils must be ascertained. Specialty contractors should be pre-qualified by supplying the owner, architect or engineer-of-record their experience in expansive soils. Owners of their past helical pier projects in expansive soils should be contacted to deter-mine long-term results.

In the Specification Requirements portion of this paper, a performance specification is recommended. Experienced and qualified specialty square shaft helical pier installation contractors will submit to the owner or engineer-of-record the materials, procedures and equipment that will most economically meet the performance specification. Such contractors will be familiar with those helical pier lead section configurations best suited for the site conditions. They will be familiar with the necessary installation equipment and installation techniques to install the proper square shaft helical piers that are the subject of this paper.

Submittals: The owner, architect or engineer-of-record should require submittals of all materials, procedures and equipment proposed by the specialty contractor to meet the performance specification. Some specialty contractors offer to provide stamped engineered shop drawings of pier layout and connections within the foundation plan provided by the structural engineer. This allows the structural engineer responsible for the superstructure to concentrate on it while allowing the specialty square shaft helical pier contractor to design the most economical helical pier layout and load transfer devices to meet the requirements of the performance specification.

CONCLUSION

The design procedures, specification requirements and installation procedures for square shaft helical piers discussed in this paper will result in foundations with long-term stability (no heave) in even the most severe expansive soils. Most of the structures that are the result of these procedures and requirements are light wood-frame residences, the very structures that are the most susceptible to differential heave in expansive soils because of their low dead loads. Large commercial, industrial, institutional and multiple-story structures in expansive soils have also been successfully designed and constructed using these methods. Wherever expansive soils are encountered, square shaft helical piers installed per the procedures and requirements outlined in this paper should be considered.

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5.4.3 **Case History 1:** New Foundation on Highly Expansive Clays

In July of 1995 a total of 47 square shaft helical piles were installed for the foundation of a new residential structure. The location is in a neighborhood called “The Preserve,” just west of the Interstate 25 freeway in the town of Greenwood Village about 10 miles (16 kilometers) south of downtown Denver, Colorado, U.S.A.

According to the soil exploration report, two test holes were drilled at the site using a 4 inch (102 mm) diameter continuous flight power auger. The test holes were field logged and samples were obtained for examination, classification and testing in the laboratory. Field testing included penetration test blow counts, i.e., the number of blows required to drive the sampler 12 inches (0.3 m) using a 140 lb (63 kg_f) hammer falling 30 inches (0.76 m). The sampler was a 2 inch (51 mm) I.D. California liner. Laboratory testing included the determination of natural moisture contents, dry unit weights, grain size analysis, liquid and plastic limits, unconfined compressive strength and swell-consolidation characteristics.

The subsurface profile generally consisted of the following:
1 to 6 ft (0.3 to 1.8 m) deep: Man-made fill composed mainly of sandy clay, medium to highly plastic, very stiff, moist to very moist, and brown in color, penetration test blow counts ranging from 20 to 25. Swell-consolidation testing indicated a swell potential of 2.4 percent.

6 to 9 ft (1.8 to 2.7 m) deep: Natural clay that was sandy, medium plastic, very stiff, slightly moist to moist, brown in color and calcareous. Penetration test blow counts ranged from 25 to 45. Swell-consolidation testing indicated a swell potential of 6.2 percent.
9 to 25 ft (2.7 to 7.6 m) deep (the exploration hole was terminated at 25 ft (7.6 m)): Claystone bedrock with penetration test blow counts of 45 at 9 ft (2.7 m), 60 at 13 ft (4 m), and 75 at 25 ft (7.6 m). This claystone was occasionally sandy, highly plastic, hard to very hard, moist, olive brown or gray in color, and occasionally calcareous. Swell-consolidation testing indicated this material was highly expansive with swell potentials ranging from 4.2 to 8.7 percent.

No free groundwater was encountered at the time of exploration drilling.

Of the 47 square shaft helical screw piles installed on the project, 39 were 1.5 inch (38.1 mm) square shaft with installation torques ranging from 3,000 to 5,000 ft-lbs (4.07 to 6.78 kN-m) for design loads ranging from 15,000 to 25,000 lbs (66.7 to 111 kN). All of these piles used a single 8 inch (203 mm) helix on the lead section.

Eight of the helical piles were 1.75 inch (44.5 mm) square shaft with installation torques ranging from 6,000 to 8,000 ft-lbs (8.14 to 10.8 kN-m) for design loads ranging from 30,000 to 40,000 lbs (133 to 178 kN). Four of these piles used a single 8 inch (203 mm) helix on the lead section and four others used an 8 inch-10 inch (203-254 mm) double helix lead section.

All helical piles ranged in depth from 13 to 31.5 feet (4.0 to 9.60 m) with an average depth of 19.4 ft (5.91 m). All piles were installed in two days by a solo hydraulic excavator with the drive head mounted on the boom.

Performance: This foundation has been monitored by the property owners for nearly nine years. As of July, 2019, no helical screw pile movement has been reported to the installation contractor.

5.4.4 **Case History 2:** Underpin of an Existing Failed Foundation on Highly Expansive Clays

In September of 1998 five square shaft helical piles were installed to underpin the failed portion of an existing foundation for a residential structure. The location is in the Ken Caryl Ranch neighborhood of Littleton, Colorado, U.S.A., about 13 miles (21 kilometers) southwest of downtown Denver. The structure, originally constructed in 1978, was founded on 10 ft (3 m) deep straight shaft cast-in-place concrete piers (caissons) 10 in (254 mm) and 12 inch (305 mm) in diameter. The structure is constructed with an approximately 8 ft (2.4 m) deep basement. Soon after original construction was completed the structure began experiencing heave of the basement floor and foundation, cracks in the walls and around the windows, sticky doors and uneven main floor elevations. In the summer of 1998, 5 inches (130 mm) of differential floor elevation was measured throughout the structure. Some remedial work was done during the 1980's, but no underpinning was performed until the five square shaft helical screw piles were installed in 1998.

According to the original soil exploration report written in 1977, two test holes were drilled at the site. The test holes were field logged and samples were obtained for examination, classification and testing in the laboratory. Field testing included penetration test blow counts, i.e., the number of blows required to drive the sampler 12 inches (0.30 m) using a 140 lb (64 kg_f) hammer falling 30 inches (0.76 m). Laboratory testing included the determination of natural moisture contents, dry unit weights, grain size analysis, unconfined compressive strength and swell-consolidation characteristics.

The subsurface profile generally consisted of the following:
0 to 6 ft (0 to 1.8 m) deep: Plastic clays that were calcareous, stiff and blocky, and ranged in color from weathered gray-brown to weathered orange-gray-brown. Penetration test blow counts ranged from 25 to 40. Swell-consolidation testing indicated highly expansive clay soil with swell potentials ranging from 9.9 to 10.1 percent.

6 to 21 ft (1.8 to 6.4 m) deep: Very dense, slightly weathered claystone bedrock in a blocky high plastic state, becoming denser with depth. Penetration test blow counts ranged from 55 to 75. Swell-consolidation testing indicated highly expansive clay soil with swell potentials ranging from 3.6 to 11.5 percent.

No free groundwater was encountered at the time of exploration drilling.

All five square shaft helical piles installed on the project were 1.5 inch (38.1 mm) square shaft with installation torques ranging from 3,000 to 5,000 ft-lbs (4.07 to 6.78 kN-m) for design loads ranging from 15,000 to 25,000 lbs (66.7 to 111 kN). All of these piles used a single 8 inch (203 mm) helix on the lead section. The piles ranged in depth from 28.5 to 53.5 ft (8.69 to 16.3 m) with an average depth of 41 ft (12.5 m). All piles were installed by hand maneuvered portable installation equipment inside the basement.

Performance: As of March, 2020, no pile movement has been reported to the installation contractor.

5.5 Slenderness Buckling and Soft Soil Conditions

For a more detailed discussion on slenderness buckling see Helical Pile Foundation Design Guide, Deep Foundations Institute, www.dfi.org (2019), p. 42.

HELI-PILE® experience is that soils with Standard Penetration Test (SPT), ASTM D1586, blow counts (N values) of 5 or greater provide sufficient continuous lateral bracing to allow axially loaded compression helical piles to carry their rated ultimate capacities to any depth (Figure 5-1). This is provided there are no shear or bending forces applied to the shaft. There are installations where 1.75-inch RCS (round-corner square solid) shaft helical piles with 50,000 lb (222 kN) design loads have been installed to depths nearly 200 feet (61 m) and are performing as designed. The reason for this is that soil with SPT N values of 5 or greater have sufficient passive or confining lateral pressure to not allow the shafts to buckle under their maximum rated loads. Figure 5-1 depicts such lateral soil support conditions.

The above applies to all HELI-PILE® shaft and helix configurations and takes into account the fact that the helical pile shaft is coupled together. Experience shows couplings have no adverse effect.

Occasionally, during installation a thin annulus is created around the shaft in the upper two to three feet below ground surface due to a slight eccentric rotation of the shaft. This annulus has never affected pile capacity. It is generally filled in with adjacent soil during installation of the helical pile. The annulus need not be filled with grout.

For formations with SPT blow counts less than 5, the interval length of this layer must be checked. If it is a short length, it is probable the length of low braced shaft is short enough that slenderness buckling will not occur. The kl/r ratio must be checked for the interval. If a slenderness buckling issue exists, a helical pile with a larger section modulus, such as a tubular helical pile, may be used (see Figure 5-2). Alternatively, the design load on the pile could be reduced to a low enough value to eliminate slenderness buckling. For soft soil intervals up to 5 feet (1.5 m) thick, usually no slenderness buckling issue exists up to the rated capacities of helical piles of any size.

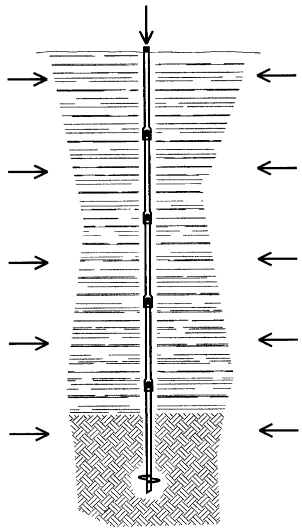


Figure 5-1. Helical Pile with Lateral Soil Support to prevent buckling.

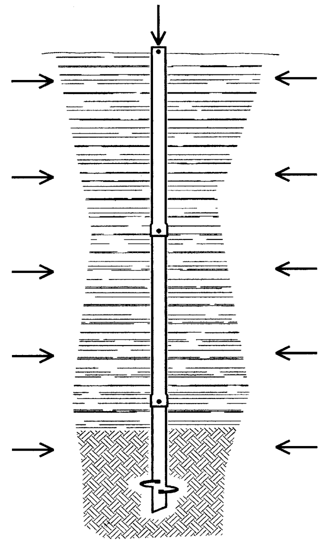


Figure 5-2. Helical Pile with Large Section Modulus to prevent buckling.

Some manufacturers advocate using a grout column surrounding the shaft in lieu of helical piles with a larger section modulus in soft soils. HELI-PILE® feels that such an approach, while technically acceptable, is not cost effective.

To avoid any misunderstanding, it should be said that slenderness buckling is of no concern for pure tension anchors or tiebacks because these members are in tension and not subject to compression loads and slenderness buckling.

5.6 Eccentric Loading on Underpinning, from Mislocation or Other Sources

Eccentric loading on underpinning piles (where the pile centerline is offset from the existing foundation load point), mislocation or other sources may induce a moment in the pile or anchor shaft. Experience has shown that eccentric loading up to 1.5 inches (38.1 mm) may be ignored. In light residential and commercial structures up to 4 inches (102 mm) may be ignored. The 2018 International Building Code, Chapter 18 on deep foundations, allows up to 3 inches (76.2 mm) of mislocation for deep foundations. For large or heavy eccentricities, the pile or anchor should be checked for the resultant moment and combined loading. HELI-PILE® recommends mislocation be specified at 1.5 inches (38.1 mm) maximum. Installation contractors can meet this specification even in rocky, cobbly soil.

5.7 Heavy Load Considerations (e.g., High Rise Structures) using Pile Groups

As with any type of deep foundation, where the design load is greater than the capacity of any single helical pile, a group of two or more piles is used. For instance, a common HELI-PILE® shaft used for heavy foundations is the HPFT438 square HSS shaft. This helical pile typically has an ultimate compression capacity of 150 tons (1,330 kN). If a column design load is, say, 600 tons (5,340 kN), then 8 such helical piles would be required if a factor of safety of 2 were used. This is based on each pile having a design capacity of 75 tons (667 kN). Using high capacity pile groupings, design loads of thousands of tons are supportable.

Through full-scale load testing by HELI-PILE® and others, the minimum axial center to center horizontal spacing of the lead section required to achieve the maximum capacity of each individual helical pile in a group within the bearing formation is three diameters of the largest helix, see Figure 5-3. There is no vertical spacing requirement. For instance, if double helix helical piles were to be used that had a 12-inch (305mm) and a 14-inch (356mm) helix lead section, the minimum horizontal center to center spacing within the bearing formation would be 42 inches (1070mm).

The top of the pile shafts in a group need not meet the minimum horizontal center to center spacing requirement (Figure 5-3), only the helices on the lead sections and subsequent extensions with helices on them, if any, within the bearing formation. By battering the pile shafts up to 5 degrees maximum for full vertical load carrying capability, the tops of the shaft may be confined in a smaller pile cap. Figure 5-3 depicts such a condition where the tops of the helical pile shafts are closer together than the embedded helix lead sections. This reduces pile cap size and economizes foundation costs.

Design of the pile cap, typically performed by the structural engineer, is identical to any multiple-pile cap which distributes load from the structure above to the piles below. Hardware for concrete to steel helical pile load transfer is discussed in Section 5.18.

Recent research indicates the optimum placement of a load transfer device within a concrete pile cap or grade beam is at the midpoint.

Pile caps are also used to transfer lateral loads, such as wind and seismic loads, from the structure to battered helical piles as discussed in Section 5.11. Since helical piles take axial load in both tension and compression, economies can be realized if piles battered up to 45 degrees or more are used to take both lateral tension and compression loads (see Figure 5-7). This is a common practice.

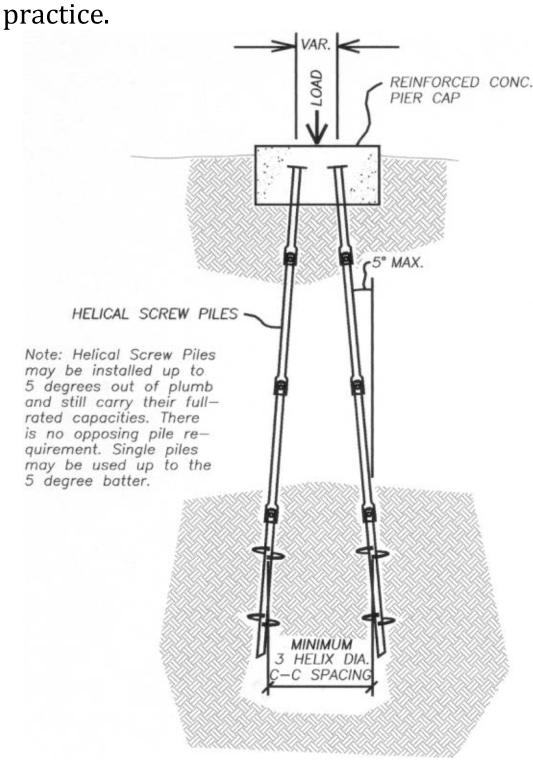


Figure 5-3. Battered Helical Piles for New Foundation

5.8 Refusal Condition in Extremely Dense Soil, Rock and Cobble

The refusal condition occurs when a helical pile or tension anchor does not advance as it is being rotated into the earth, even with high crowd. The reason for the non-advancement of the pile or anchor is the presence of an earth bearing material or other object so dense that the helix does not engage the material and does not advance under the installation rotational or torque force. The bearing material may be bedrock or other competent rock material, heavy cobble, dense coarse gravel, or some other dense material. See Figures 5-4(a) and 5-4(b). Another term used for this refusal condition is "grinding."

Associated with the refusal condition is usually a reduction in installation torque. In this case, it has been empirically found the reduction in torque does not mean a reduction in compression capacity of the pile, even with a multiple-helix pile. The presence of hard earth material usually indicates a very good bearing stratum.

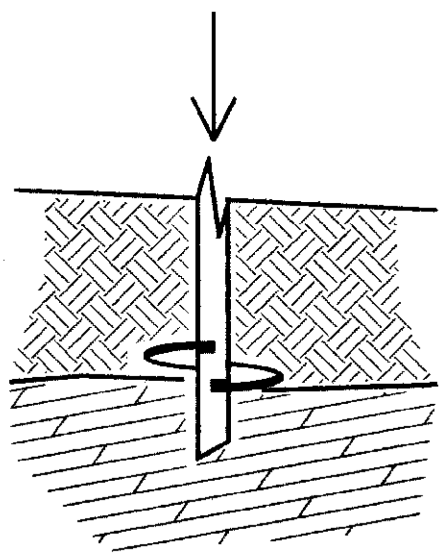


Figure 5-4(a). Refusal Condition in Claystone

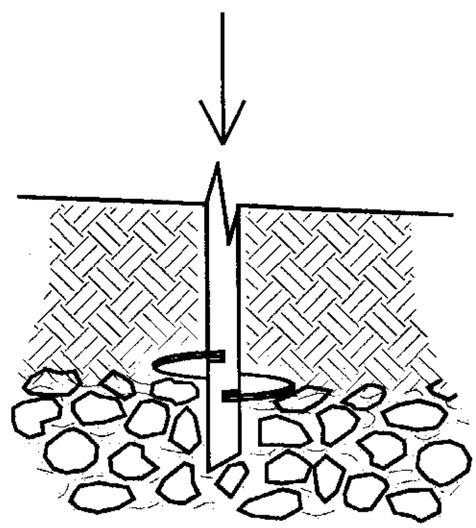


Figure 5-4(b). Refusal Condition in Coarse Gravels

The exact nature of the hard bearing material will dictate whether the helical pile is bearing on the shaft point or on the first helix. In either case, even though unit bearing pressures are high, experience has shown the pressures are within the capacity of the bearing material and the published rated capacities of the piles can be relied upon.

From experience, in most cases it is probable that the pile capacity, even for a single helix pile, is actually greater than HELI-PILE®'s rated capacity. However, because the excess capacity of a single helix or the additional capacity from the other helices is indeterminate unless field tested, one can only rely on the HELI-PILE® published rated capacities. If field testing if performed, test results supersede HELI-PILE® ratings.

Encountering the refusal condition for a helical tension anchor does not mean low tension capacity. It must be remembered that no soils are removed during installation, rather, soil is displaced by the shaft and the helical plates. Soil disturbance may cause some take-up in the anchor zone during initial tensioning. From experience, tension capacity in the refusal condition can be predicted from the installation torque just prior to encountering the refusal condition. Or, tension capacity can be measured with a tension load test as described in Section 3.2.2.

The presence of hard material causing the refusal condition should be correlated with known soil borings or other sources of soil profile knowledge (such as other helical piles installed at the site) to be sure an anomaly in the soil profile has not been encountered and that stable material exists below the pile.

If the hard material consists of a cobble formation, a common practice to assist in penetrating the cobble is to use a helix with a leading edge designed to aid in penetrating such formations. Such a leading edge is shown in Figure 5-5. All HELI-PILE® helices are manufactured this way. Neither the torque vs. capacity relationship nor the rated capacity of the helical pile or anchor is affected by this procedure.

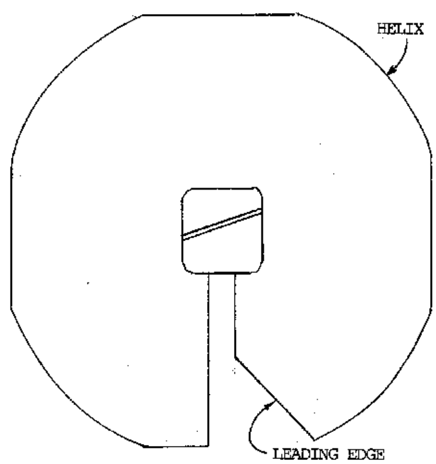


Figure 5-5. Cross-section of a HELI-PILE® Helix Designed for Cobble (Rock Cut)

If cobble conditions are present, the engineer and installing contractor must ensure that the helical piles have sufficient steel and weld strength to not fold or tear during installation. While extremely rare, such folding and tearing is easily detectable during installation by an experienced operator and a replacement pile can be installed. However, prevention is the best policy. Folding and tearing is eliminated by using helical piles with sufficiently high steel strength and thickness to withstand the buffeting of a cobble formation. Because such conditions can be encountered unexpectedly, HELI-PILE® produces all of its helical piles with 80 ksi (552 Mpa) helices that are 0.5 inch (12.7 mm) thick and rock cut as shown in Figure 5-5. This specification, used in conjunction with the leading edge designed as described above, has proven successful in even the densest of cobble formations.

An experienced installation contractor can do things to aid the installation of helical piles in cobble. One tactic is to use a cyclical motion during installation of backing out the pile slightly, perhaps only one revolution of the drive head, then proceeding with the installation. Repeating this action several times can aid in passing the helices through tough cobble conditions. Another tactic is to change the installation angle slightly (up to five degrees out of plumb maximum for vertical piles) to attempt to bypass the obstruction. Another successful tactic is to change the location of the pile slightly. This must be known and approved by the structural engineer. Moving a pile location a few inches, even up to a foot, one way or another within the foundation is usually not a problem. It is important to maintain high compressive pressure (called "crowd") during installation in cobble formations. Other tactics have been tried that are beyond the scope of this book.

The empirical information mentioned above is based on the results of thousands of successful helical pile installations in refusal conditions by HELI-PILE®.

5.9 Shop or Field Modifications

Shop or field reduction of helix diameter is allowed down to a minimum of 6 inches (152 mm) in diameter. Shop or field cutting may affect the galvanizing; however, because of the fact the helix is embedded in tight soil where oxygen is mostly excluded, corrosion protection is not critical. See the Section 5.13 for a more detailed discussion about corrosion.

Occasionally hard near surface sandstone/claystone soils are encountered. It is allowable to modify the pile tip to facilitate installation. For example, the tip bevel may be modified by torching and grinding to streamline it. Other modifications can be done that are beyond the scope of this book.

5.10 Maintaining Shaft Alignment During Installation

In relatively soft or loose cohesive and granular soils, installation rotation of the helix lead section pulls the pile or anchor shaft into the soil. In this case, compressive shaft pressure, or "crowd", is not relied upon as it is for drilled pier installations and always is for driven piles. In this case, because the shaft follows the helix lead section into the formation and is not being driven or pushed, shaft alignment does not change.

In relatively dense cohesive and granular soils and where cobbles or other hard materials exist, because the helical pile or tension anchor is screwed into the formation, not driven or pushed, even where "crowd" is being used, the tendency of the shaft to deflect out of alignment is small. This writer is not aware of any installations where shaft alignment deflection has been detrimental to the load carrying capability of the helical pile or tension anchor.

Rotational forces on a horizontal or nearly horizontal helical tension anchor, such as a tieback, can cause the anchor shaft to occasionally drift slightly off alignment. This is also true with drilled and grouted tension anchors. In this writer's experience, in neither case has the drifting ever presented a capacity or performance concern.

5.11 Lateral Loading including Seismic and Wind Loading

For a more detailed discussion on lateral loading see Helical Pile Foundation Design Guide, Deep Foundations Institute, www.dfi.org (2019), p. 33.

Helical piles and tension anchors are regularly used for seismic and wind loading applications, including in the high seismic zones of California. Pipe racks and other equipment foundations in the oil and gas industry have high lateral loads and bending moments with relatively low axial compression and tension loads. Helical piles are regularly used in such applications. Lateral loads can be taken by the following methods:

5.11.1 Passive Soil Pressure (most cost-effective for taking lateral load)

Passive pressure against the perimeter foundation or grade beams, key interior grade beams, or other structural elements, may be sufficient alone to transfer lateral loads to the soil without using any additional piles. If it is not, helical piles or anchors strategically placed in the foundation will augment the passive pressure resistance. Passive soil pressure should be analyzed in all cases since it is the most economical method of transferring lateral loads to the soil because no additional helical piles for lateral capacity are required.

5.11.2 Diagonally Installed (Battered) Helical Piles and/or Anchors

When passive soil pressure is not sufficient, lateral loads from shear walls or other laterally loaded structural members may be transferred to the soil via strategically placed helical piles installed at appropriate angles off vertical, usually 45 degrees. These members take axial loads in tension as well as compression. (See Figure 5-7, Photos 4-9, 4-17, 4-38, 4-39 and 4-43) Pile layout and load transfer is typically analyzed by the structural engineer.

5.11.3 Larger Helical Pile Shaft

The use of large shaft helical piles may be cost-effective for large lateral loads. See Photo 5-1. The larger piles require larger equipment. A cost analysis between fewer large piles versus more smaller but easier-to-install piles is in order. More smaller piles can be faster, require smaller, easier-to-mobilize equipment and are frequently more cost effective.

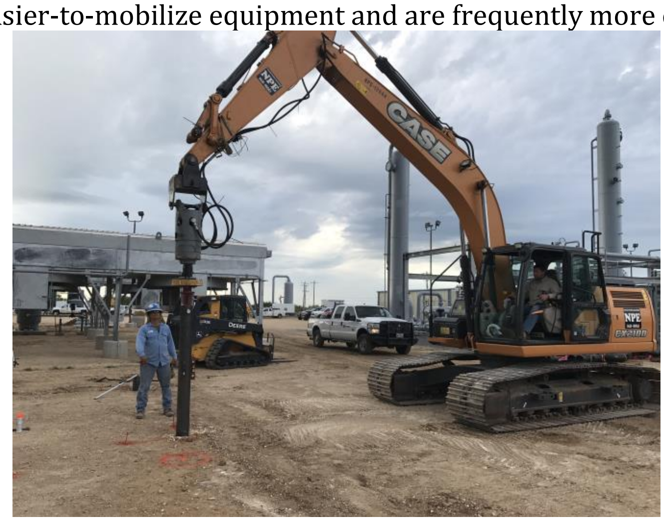


Photo 5-1 Large diameter shaft.

The use of a larger (wider) helical pile shaft in the upper 10 feet (3 m) that transitions to a smaller pile for the vertical load may be sufficient to take the lateral load. See Photo 5-1 and Figure 5-6.

Photo 5-2 HELI-PILE® XL

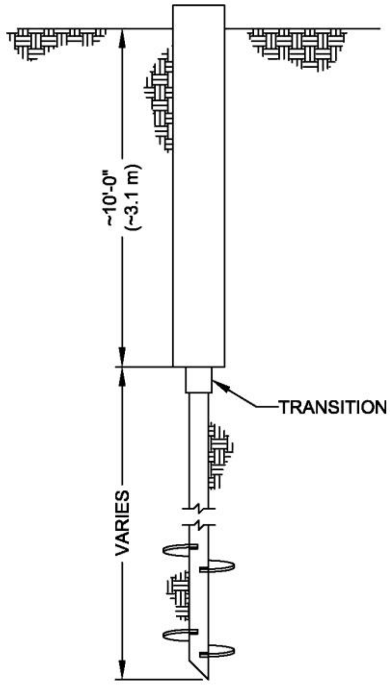


Figure 5-6 (Figure 2-3 Copy)

5.11.4 Lateral Load Testing

Lateral deflection can be determined through full-scale lateral load testing (Photo 5-3) or may be estimated through computer analysis using correct soil parameters. LPILE found at www.ensoftinc.com is an example of such a computer program. Recommended lateral load testing is per ASTM D3966-07. See www.helipile.com for HELI-PILE® lateral load test procedures.

Photo 5-3 Field lateral load test of a helical pile. Test pile at right of photo.

Through computer analysis and full-scale load testing HELI-PILE® has found that lateral deflection is fully dissipated in the upper 10 (3 m) feet depending on actual load and soil profile.

Research shows that computer simulations for lateral deflection typically estimate greater deflection than reality. Field lateral load testing is recommended. Field lateral load testing not only produces actual deflections, but also can verify soil parameter input. Subsequent computer simulations will be more realistic with verified soil input.

5.11.5 Helical Battered Piles as Compression/Tension Members

Seismic and wind generated lateral loads are transferred to the soil through the battered piles strategically placed in grade beams and caps in the foundation. See Figure 5-7. The structural engineer calculates the lateral loads, analyses the foundation for resistance to these loads, then adds strategically placed battered helical piles as appropriate.

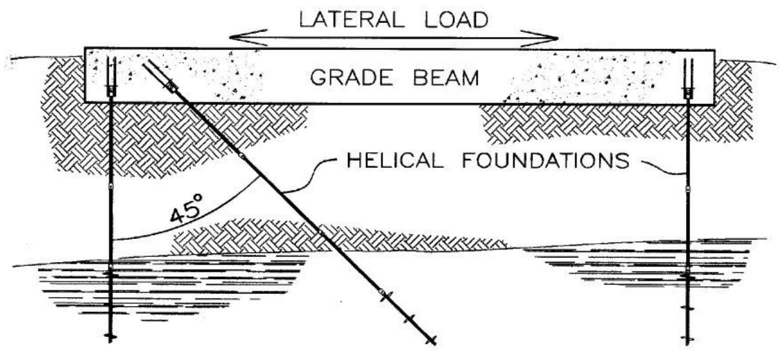


Figure 5-7. Battered Helical Pile for Lateral Loads for New Foundation

As an example, Figure 5-7 shows a helical screw pile battered at 45 degrees. If this pile were installed to 10,000 ft-lbs (13.6 kN-m) of installation torque, it would have an axial tension and compression design capacity of 50,000 lbs (222 kN) with a factor of safety of 2. The lateral load that could be taken by this pile, with a factor of safety of 2, would be cos 45 degrees x 50,000 lbs (222 kN) = 35,400 lb (157 kN). Load transfer of lateral loads from the structure to helical devices uses the same load transfer devices as tiebacks or vertical piers. See Section 5.18.

5.12 Cyclical Loading (Seismic Conditions & Machine Foundations)

Lateral oscillating loads from machines or earthquakes are dampened by helical piles due to the slender nature of the shaft. Such performance is difficult to calculate or predict. Anecdotal evidence shows that helical piles perform well under oscillating loads from earthquakes and machinery. Numerous compressors and other types of machinery are founded on helical piles.

Recent full-scale shake table load testing has shown excellent helical pile performance in simulated earthquake loading. Three web sites are recommended:

1. http://nheri.ucsd.edu/projects/2016-helical-piles/(overview of shake table test)
2. http://dx.doi.org/10.1080/19475247.2017.1414108 (paper on seismic behavior)
3. http://doi.org/10.1680/jgeot.18.P.001 (paper on seismic behavior)

Regarding axial performance in cyclical loading, in nearly all soils, tension capacity of a helical pile or tension anchor is nearly the same as compression capacity. Questions arise about soil disturbance as the tension and compression cycles progress. Load testing has shown that when installed to the required torque for a given design load, and using a 2 safety factor, helical piles and anchors maintain their ability to take both compression and tension loads. The challenge to the engineer is to calculate the expected cyclic loads, a task beyond the scope of this design guide.

5.13 Corrosion

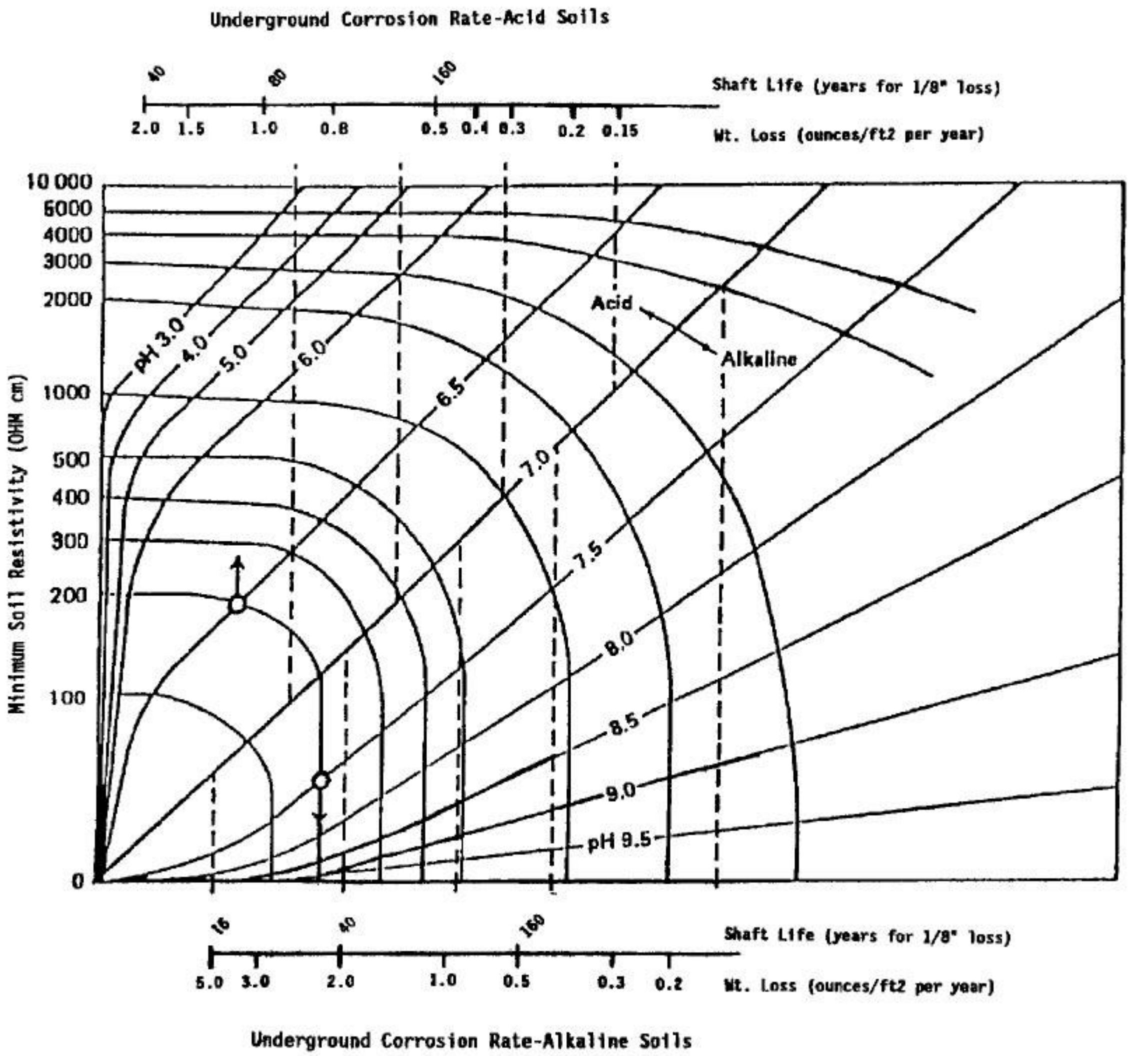
Determination of corrosion rates of bare steel helical piles and anchors is based on the soil pH and soil resistivity. Because there is a possibility that galvanizing will abrade off during installation, all corrosion rate calculations are based on bare steel with no galvanizing or other coating. However, experience shows that galvanizing lengthens shaft service life about 15%.

Figure 5-8 is a corrosion rate nomograph adapted from the 1977 British Corrosion Journal that allows the user to estimate the corrosion rate by knowing the soil pH and resistivity. CAUTION: To avoid misusing the nomograph, use *field* soil pH and resistivity values, not *lab* values. Lab testing procedures that use soil samples with moisture contents higher than field can yield lower resistivities. The soil will appear more corrosive than it actually is. If soil moisture content is low, the corrosion rate will be low. Low field moisture contents equate to low field corrosion rates even if corrosive chemical constituents are present. The helix lead section has a longer life expectancy than the remainder of the shaft, even if the galvanizing is abraded off, because it is embedded in dense soil where oxygen is mostly excluded which causes the corrosion rate to be low. Corrosion rates may be higher near the ground surface, however, in this zone, the shaft extensions are the last to be installed and the galvanizing is intact.

Temporary or permanent shaft wrap of the pile or anchor shaft does not adversely affect the galvanizing by cracking, strain or any other phenomenon.

Experience has shown that corrosion of helical piles and anchors has not been a problem. Life expectancies are typically in the 200-250 year range. However, some soils can be corrosive, testing is required.

Galvanization has been the most reliable method of corrosion protection. HELI-PILE® helical piles and anchors are typically galvanized by electro-deposition in accordance with ASTM B633 which is RoHS compliant. RoHS stands for “Restriction of Hazardous Substances.” Hot-dip galvanizing has come under attack recently due to potential soil contamination with hexavalent chromium.



Examples: pH = 6.7 and resistivity = 700 ohm-cm
Expected life (for 1/8 inch (3.2 mm) shaft loss) is approx. 150 years.

pH = 7.5 and resistivity = 700 ohm-cm
Expected life (for 1/8 inch (3.2 mm) shaft loss) is approx. 140 years.

CAUTION: To avoid misusing this nomograph, use *field* soil pH and resistivity values, not *lab* values. Lab testing procedures that use soil samples with moisture contents higher than field can yield lower resistivities. The soil will appear more corrosive than it actually is. If soil moisture content is low, the corrosion rate will be low. Low field moisture contents equate to low field corrosion rates even if corrosive chemical constituents are present.

Figure 5-8. Corrosion Rate Nomograph Adapted from the British Corrosion Journal, 1977

HELI-PILE® will hot-dip galvanize its material per ASTM A153 or 123 upon request.

On rare occasions if soils of extreme corrosion potential are encountered, methods of cathodic protection are available.

Recent years have seen a movement toward black steel (non-galvanized) helical piles and anchors where corrosion potential is low and pile or anchor life expectancy exceeds the life expectancy of the structure. Today the use of black steel helical piles and helical anchors is common.

5.14 Mechanical Axial Deformation and Permanent Shaft Wrap or Twist

Mechanical axial shortening of helical piles during compression loading or lengthening of helical anchors during tension loading (termed "mechanical axial deformation") comes from shaft axial elastic deformation.

5.14.1 Shaft Axial Elastic Deformation

The equation for shaft axial elastic deformation under load is

$$e = PL/AE \qquad \text{(Eq. 5-1)}$$

where
- e = shaft axial elastic deformation
- P = the load
- L = shaft length
- A = the cross-sectional steel area of the shaft
- E = the modulus of elasticity of steel (29,000 ksi)(200,000 Mpa).

Example: the HPC17 1.75 inch (44.5 mm) shaft has a cross-sectional area of 3.01 in^2 (1,940 mm^2). For a pile that is 26.5 feet (8.08 m) deep under a compression load of 50,000 lbs (222 kN) the shaft elastic shortening, e, would be 0.18 inches (4.6 mm). If the load were increased to 100,000 lbs (445 kN), the shaft elastic shortening would be 0.36 inches (9.1 mm).

5.14.2 Permanent Shaft Wrap or Twist

Another form of shaft deformation is permanent shaft wrap or twist. Visually, this is detected when the shaft looks twisted, kind of like a barber's pole. Permanent shaft wrap occurs when the torque force applied to the shaft exceeds the shaft's torsion elastic limit. A certain amount of shaft wrap is permissible and inevitable under the allowable torque forces. HELI-PILE® helical piles and anchors are rated well within their ranges, far below any failure points. Permanent shaft wrap is a welcomed sight on any helical pile project because of its visual indication of high torque. However, the inspector must be sure the shafts are not being over-torqued. This is accomplished by reviewing installation torque logs.

Visually, for HPC15X or HPC17X solid square shaft only, if the shaft appears to be twisted more than 1 to 1.5 revolutions in any five foot (1.5 m) length, the shaft may have been over-torqued.

Permanent shaft wrap has no affect on galvanizing integrity.

5.15 Water Migration Along the Shaft

Research has shown that where helical piles are installed in expansive clay soils, water migration along the shaft is essentially the same as migration along the sides of drilled shafts (Chapel, Thomas A., "Field Investigation of Helical and Concrete Piers in Expansive Soils," Colorado State University Master's Thesis, 1998.). Since no soil is removed during installation (no hole is created), the helical pile densifies the soil as it passes through. Disturbance of the soil is generally in the form of densification, not the opposite. The expansive nature of clay soil may have a tendency to seal the area surrounding both helical pile shafts and drilled shafts to limit water migration.

Regardless of soil type, expansive or not, experience and research has shown that water tends to not migrate down the shaft to the point where it impacts the tight soils into which the helices have been embedded. To the knowledge of the author, there are no documented cases where water migration along the shaft of a helical pile has adversely affected performance.

5.16 Helix Durability During Installation

This section deals with the durability of the helix or helices as they are being installed. For instance, if a helical pile or tension anchor were being installed into cobble material by a large piece of equipment producing high compression pressure, or "crowd", the helix itself and the weld of the helix to the shaft must be strong enough so the helix will not reverse deflect creating a coned shaped helix or so the helix weld will not sever separating the helix from the shaft.

While rare, detection of such occurrences by an experienced installing contractor is easy. Both circumstances create a disturbance in rotation of the shaft such that the installation operator immediately knows something is wrong and the pile can be removed and inspected.

The remedy is just as easy since another pile can be installed in place of the damaged pile.

HELI-PILE® has found that in heavy cobble and gravel formations, helices made from 0.5 in (12.7 mm) thick 80 ksi (552 Mpa) steel rarely cone and never separate from the shaft. Helices less than 0.5 inch (12.7 mm) thick or less than 80 ksi (552 Mpa) should never be used in cobble or heavy gravel formations due to the very real possibility of coning or severing from the shaft. All HELI-PILE® helices are 0.5 in (12.7 mm) thick and 80 ksi steel (552 Mpa).

In any cobble or heavy gravel formation, the leading edge of all helices should have the modified leading edge (rock cut) as shown in Figure 5-5. HELI-PILE® helices are rock cut.

5.17 Merits of Square Shaft vs. Pipe Shaft

Square shaft helical piles have the advantage of greater torque energy transfer to the helical plates than round pipe shaft. To date, no specific detailed studies have been performed that prove the preceding statement. However, the logic proceeds as follows:

Square shaft is in direct soil contact at the corners only. During installation the soil is disturbed on the flats of the shaft between the corners. It is logical that this action will minimize the shear stress between the shaft side and the soil. Ideally, all torque energy imparted by the torque motor reaches the helical plates. However, a certain amount of torque energy is dissipated along the shaft sides. Because of minimal shear stress along the sides of the square shaft, energy dissipation will be minimized too making more energy reaching the helical plates for embedment in the bearing stratum.

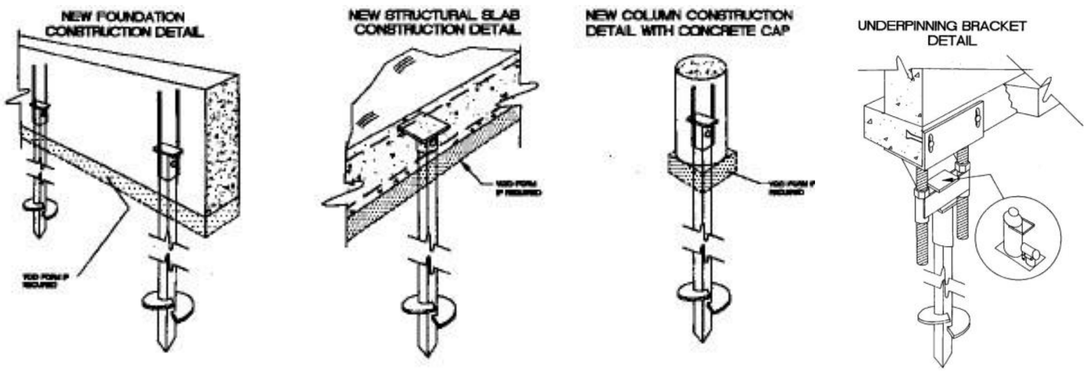
The round pipe shaft is in soil contact around its entire circumference and entire pile length. Even though the magnitude nor the percentage have been quantified, it is the opinion of HELI-PILE® that in some soils more torque energy is dissipated with the round shaft than with the square shaft. In no case is would the reverse be true.

We know of a project where pipe helical piles about 4 inches (102 mm) in diameter were installed to an installation torque thought to be commensurate with the intended loads. The piles were then full-scale load tested and passed. After completion of the structure the piles settled. The investigating geotechnical engineer concluded that the piles were initially transmitting load along the sides of the shaft via friction to the soil. It was felt that a significant portion of the installation torque went into shear along the sides of the shaft. Over time, the shear stresses relaxed through creep and more and more of the load was transferred to helical plates, plates that had not, in fact, been sufficiently embedded into the soil to take the load. The reason is too much installation torque was dissipated along the sides of the shaft and did not reach the helical plates.

Another advantage of the square shaft appears during installation. It is visually easy to detect and monitor permanent shaft wrap or twist in the square shaft helical pile. As noted in the Section 5.14.2, a certain amount of permanent shaft wrap or twist is allowable and desirable. However, too much is not good. Fortunately, with the square shaft, too much shaft wrap is visually easily detectible. It is not so easy to detect it in the round pipe shaft. This inability to visually easily detect permanent shaft wrap can lead to catastrophic failure, such as suddenly weakening or even severing the shaft. Care must be taken during installation to monitor installation torque of the round pipe shaft helical pile.

5.18 Load Transfer Devices

Four representative examples of concrete to pile shaft load transfer devices are shown in Figure 5-9. Each of these devices has been tested and is commonly used for design loads up to 50,000 lbs (222 kN). There are unlimited configurations of load transfer devices that can accomplish the desired load transfer. Several other configurations are shown at www.helipile.com. The configurations shown in Figure 5-9 are in common use and will transfer the rated capacity loads for the various sizes of helical piles. However, the structural engineer has the prerogative to design whatever load transfer device is desired. All the devices shown are typically constructed of ASTM A36 structural steel and Gr 40 or 60 reinforcing steel. If these devices are embedded in concrete, no galvanizing or coating protection for the device itself is required. Contact HELI-PILE® for details. Figure 5-9(a) is a typical new construction bracket embedded in a reinforced concrete grad beam. Figure 5-9(b) is a new structural concrete slab bracket. Figure 5-9(c) is a new construction bracket embedded within a concrete column base. Figure 5-9(d) is an underpinning bracket. Numerous other load transfer devices are available.



(a) (b) (c) (d)

Figure 5-9. Examples of Concrete to Pile Shaft Load Transfer Devices

Photos 5-4 and 5-5 are of equipment and pipe supports used in the oil and gas industry. These supports are vertically adjustable to ensure equipment/pipelines are at the exact design elevation.

Photo 5-4 Adjustable Pipe Supports on HPFT3 Helical Piles

Final depth of a helical pile or anchor depends on the soil profile at each location and the desired installation torque. In some cases the end of the shaft protruding out of the soil must be cut so the load transfer device is at the correct elevation or location. If the bolt hole is cut off, then the load transfer device can be attached by 1) Field drilling a new hole and bolting the load transfer device on, 2) Welding the load transfer device on, 3) Epoxy gluing the load transfer device on, or 4) In the case of the modular helical pile, the square thread bar allows the load transfer device to the screwed on wherever the pile shaft is cut, no drilling, welding, or gluing. See Photos 1-9 and 1-10. In all compression load applications and in most tension load applications, epoxy gluing has never been a problem in this author's experience. In tension load applications a rigid connection is preferred and will preclude gluing. Underpinning brackets do not require any rigid connection such as bolting, welding or gluing unless loads are in tension.

Photo 5-5 Adjustable Equipment/Skid/Pipe Supports on HPFT3 Helical Piles

5.19 AC358 Acceptance Criteria for Helical Pile Systems and Devices

AC358 is a document not in the International Building Code (IBC) and is not a building code for helical piles. It is a helical pile material evaluation tool that is frequently mistaken as part of the IBC.

AC358 is a document prepared by International Code Council (ICC) Evaluation Service (ICC-ES), a subsidiary of ICC, for the evaluation of helical pile systems and devices. It is solely evaluation criteria, not part of the IBC. It is the criteria upon which helical pile systems and devices are evaluated by ICC-ES. Manufacturers can submit their material to ICC-ES for evaluation. Once the material is evaluated, ICC-ES writes an evaluation report listing the strength characteristics of that material. Manufacturers pay ICC-ES for this evaluation and written report. ICC-ES does not accept or reject, it merely evaluates.

The provisions of AC358 are frequently misconstrued to be part of the IBC. They are frequently used in lieu of specifications and drawings normally prepared by registered professional engineers. AC358 was never intended to take the place of plans and specifications prepared by registered professional engineers.

All HELI-PILE® material shop drawings come under the seal (stamp) of a registered professional engineer when requested. Therefore, HELI-PILE® material is not listed under AC358.

AC358 is written for evaluations of helical piles to be used only in Seismic Design Categories A, B, and C. This does not preclude the use of helical piles in Seismic Design Categories D, E, and F. It only means that in D, E, and F, AC358 cannot be used. For D, E, and F a registered professional engineer seal (stamp) must appear on helical pile shop drawings and plans. This is the customary procedure for HELI-PILE® projects, regardless of seismic design category.

5.20 Designing HELI-PILE® Using the 2018 International Building Code

The <u>2018 International Building Code</u> (IBC) is published by the International Code Council (ICC) and is accepted virtually throughout the United States.

Chapter 18 "Soils and Foundations" of the IBC contains provisions for the design of helical pile foundations. The commentary below discusses each helical pile provision in Chapter 18 and references other deep foundation sections that are pertinent to helical piles. IBC sections outside Chapter 18 that pertain to helical piles are also referenced. Not all sections in Chapter 18 are discussed, only those that cover helical piles or are deemed relevant. The reader must be familiar with the actual code language for all IBC sections.

The numbers in **bold** below are sections from the <u>2018 International Building Code</u>.

1802.1 Design basis: This section provides that loading be in accordance with *allowable stress design* (ASD) and the load combinations given in **1605.3**. **1605.3** should be carefully reviewed to be sure the proper load combinations are being considered for the project. Additionally, seismic considerations are covered in **1613**.

202 Definitions: The definition of a helical pile: "Manufactured steel deep foundation element consisting of a central shaft and one or more helical bearing plates. A helical pile is installed by rotating it into the ground. Each helical bearing plate is formed into a screw thread with a uniform defined pitch." Helical piles are defined along with "Deep Foundation," "Drilled Shaft," "Micropile," and "Shallow Foundation" thus placing the helical pile side by side the other common foundation systems in use today. Helical piles are a standard of practice in the United States and are growing in use world-wide.

1803 Geotechnical Investigations: Helical piles are not specifically mentioned in this section. However, the use of the "Helical Screw Test Probe" (Section 4.2 in this design guide) as part of geotechnical investigations would greatly assist in determining depth, capacity, installation time, and ultimately the cost of a helical pile foundation. Use of the test probe would be allowed and welcomed under **1803.5.5 Deep Foundations** wherein several data categories are listed and information is required. The reader is referred to Section 4.2.1, "Helical Screw Test Probe and Helical Test Installations" in this design guide.

1803.5.11 Seismic Design Categories C through F: Any structures constructed in these categories shall have a geotechnical investigation performed that addresses the geologic and seismic hazards listed. There is nothing to prevent helical piles from being used within these seismic zones as long as an evaluation of the geologic and seismic hazards is performed. The hazards include slope instability, liquefaction, total differential settlement, and surface displacement due to faulting, lateral spreading or lateral flow. Liquefaction will be of particular concern considering the slender nature of many types of helical piles and the lack of lateral bracing along the shaft momentarily during a liquefaction event.

(On a side note: AC358, the International Code Council (ICC) acceptance criteria for evaluation of helical piles, excludes helical piles from evaluation for ICC Seismic Design Categories D, E, and F. It does not exclude helical piles from being designed and used in those category areas. Helical piles have been used successfully for decades in Southern and Northern California, Salt Lake City in Northern Utah and other areas of high seismic loading. This just means there will be no evaluation report from ICC for any helical piles to be used in Seismic Design Categories D, E, and F. Helical pile designs in those areas rely solely on the IBC and the design professionals involved.)

1803.5.12 Seismic Design Categories D through F: This section provides additional requirements for the geotechnical investigation in these seismic category areas. Design of helical piles within these categories will be required to account for the provisions given.

For further details about research into helical pile seismic performance please see Section 5.11 herein and Helical Pile Foundation Design Guide, Deep Foundations Institute (2019), p. 36.

1804 Excavation, Grading and Fill: This section does not apply to helical piles.

1805 Dampproofing and Waterproofing: This section does not apply to helical piles.

1806 Presumptive Load-bearing Values of Soils: This section provides presumed load bearing values of soils "unless data to substantiate the use of higher values are submitted and *approved*." A "Helical Test Probe" (Section 2.5.1), "Helical Pile Test Install" (Section 2.5.2), field full-scale load testing (Section 3.2), or a production helical pile installation where torque vs. depth is recorded, along with the torque vs. capacity relationship, will provide data that will override the values given in Table 1806.2. Presumptive load-bearing values are not applied to **1810.3.3.1.9** where axial design load values for helical piles are determined via such methods.

1807 Foundation Walls, Retaining Walls and Embedded Posts and Poles: This section does not contain provisions specific to helical piles. However, helical piles and tension anchors are used with all these structures. **1807.1** states that any of these structures built on a deep foundation must have the foundation designed in accordance with **1808** which, in turn, references **1810** which contains provisions for helical piles and tension anchors. See **1808.1** below.

1808 Foundations: These are general requirements for all foundations.

1808.1 General: "Deep foundations shall satisfy the requirements of Section **1810**." Section **1810** contains provisions for helical piles. Many of those provisions would apply to helical tension anchors as well.

1808.2 Design for capacity and settlement: Using the torque vs. capacity relationship (Section 3.1) with the appropriate safety factor, typically 2, ensures the soil bearing capacity is not exceeded and that differential settlement is minimized. See Section 3.4 for a discussion of safety factors.

1808.3.1 Seismic overturning: Helical piles and anchors are increasingly being used for seismic applications. They are allowed in all seismic design categories in any geographical location, including California. They can be sized and placed for seismic overturning applications.

1808.4 Vibratory loads: See Section 5.11. Helical piles are used in vibratory conditions. Slender helical piles have excellent damping characteristics.

1808.5 Shifting or moving soils: Using the torque vs. capacity relationship (Section 3.1) ensures helical piles are installed below any active zones or other zones of instability.

1808.6 Design for expansive soils: For assistance in this portion of the IBC the reader is directed to "Expansive Clay Soils (with two Case Histories)", Section 5.4. Helical pile performance excels in expansive soils.

1808.8 Concrete foundations: Most load distribution members used in conjunction with helical piles are made of concrete such as group pile caps, foundation walls, column bases supported by helical piles, etc. Therefore, many provisions of this section will apply to the overall design of helical pile foundations.

1809 Shallow Foundations: Only **1809.5 Frost protection** applies to helical piles. Most building officials have allowed the fact that helical piles extend below frost depth to satisfy the requirement that a foundation wall be founded at a depth below frost depth for frost protection. This allows the bottom of foundation walls to be constructed at grade with no need to excavate a trench. It is recommended that void form be used under all concrete structures in similar fashion to expansive soil sites in order to accommodate frost heave.

1810 Deep Foundations: This is the meat of IBC Chapter 18. It deals specifically with helical piles along with the other types of deep foundations.

1810.1 General: This section deals with provisions that apply to all deep foundations.

1810.2.1 Lateral support: This section deals with lateral support for slenderness buckling purposes. This section states "any soil other than fluid soil shall be deemed to afford sufficient lateral support to prevent buckling of deep foundation elements…." A fluid soil is defined in ICC AC358 (2017) as a soil with Standard Penetration Test (SPT)(ASTM D1586) blow count (N value) of 0. AC358 also defines soft soil as having N values between 0 and 4 and firm soil having N values of 5 and greater. As pointed out in Section 5.5 herein, "Slenderness Buckling and Soft Soil Conditions," HELI-PILE® adheres to the standard that soils with N values of 5 or greater provide sufficient lateral support to preclude slenderness buckling for compression loads up to the rated capacity of the helical pile to any depth. Methods exist for soils with N values less than 5, see Section 5.5.

1810.2.2 Stability: As with all deep foundations, helical piles must be braced to provide lateral stability in all directions. One exception is for one and two-family dwellings and lightweight construction not exceeding two stories above grade plane or 35 feet (10.7 m) in building height, provided that the centers of the elements are located within the width of the supported wall.

1810.2.3 Settlement: For settlement analysis please refer to herein Section 5.2 "Predicted Settlement and Long-term Creep."

18.2.4 Lateral Loads: Computer programs, such as LPILE and HelixPile, analyze the non-linear interaction of the helical pile shaft and soil. See Section 2.8 "Software."

1810.2.4.1 Seismic Design Categories D through F: Helical piles must be designed and constructed to withstand maximum imposed curvatures from earthquake ground motions and structure response as described in this section. Typically, lateral loads imposed by earthquakes are determined by the structural engineer. Given those loads, the helical pile can be analyzed by a computer program where the soil profile is input and pile response is predicted. Maximum curvature is determined by comparing lateral deflections and imposed bending moments. Where either maximum lateral deflection or maximum bending moment for a particular helical pile shaft is exceeded, then the shaft size must be altered and re-analyzed. With this incremental analysis, the maximum imposed curvature requirement of this section will be met. Alternatively, some computer programs may be able to determine directly the correct helical pile shaft size given the imposed loads and the soil profile. LPILE and HelixPile are available computer programs. Others may be available.

1810.2.5 Group effects: If pile center-to-center spacing is less than 3 times the diameter of the largest helix then group effects may be ignored. For battered piles the center-to-center spacing must be measured at the ground depth of the piles, not the spacing of the tops of the piles at grade. See Section 5.6 "Heavy Load Considerations (e.g., high rise structures) using Pile Groups." If center-to-center spacing is less than 3 diameters of the largest helix then a reduction factor may need to be considered. Please see 5.5.2 of Helical Pile Design Guide, p. 37, Deep Foundations Institute (2019). This publication is available www.dfi.org.

1810.3.1.5 Helical Piles: "Helical piles shall be designed and manufactured in accordance with accepted engineering practice to resist all stresses induced by installation into the ground and service loads." The information in this design guide should help in satisfying the requirements of this section. If it does not, please inform HELI-PILE® what areas need amplification and coverage.

1810.3.2.5 Protection of materials: This section covers material corrosion protection. As stated in Section 5.12, "Corrosion," all HELI-PILE® helical piles are galvanized per ASTM B633 or ASTM A153 (upon request). These galvanizing specifications satisfy this section.

1810.3.1.3 Mislocation: The IBC allows up to 3 inches (76.2 mm) of mislocation. HELI-PILE® recommends mislocation be specified at 1.5 inches (38.1 mm) maximum. Installation contractors can meet this specification even in rocky, cobbly soil. (From a combined loading standpoint, experience has shown that moments induced in the pile shaft due to eccentric loading up to 1.5 inches (38.1 mm) may be ignored. In light residential and commercial structures up to 4 inches (102 mm) may be ignored.)

1810.3.2.6 Allowable Stresses: This section refers to Table 1810.3.2.6 wherein helical piles are called out in the box 3, Steel in compression and the box 5, Steel in tension. In each case, the allowable stresses are identical: 0.6 $F_y \leq 0.5\ F_u$. This means the maximum allowable stress is 0.6 F_y, as long as it is less than or equal to 0.5 F_u. F_y is the specified minimum yield stress, F_u is the specified minimum tensile stress. For HELI-PILE® solid steel square shaft helical piles, minimum F_y = 90 ksi (621 MPa) and minimum F_u = 120 ksi (827 Mpa). Therefore, maximum allowable stress is 0.6(90 ksi) = 54 ksi (0.6(621 MPa) = 372 MPa) which is less than 0.5(120 ksi) = 60 ksi (0.5(827 MPa) = 414 MPa). For HELI-PILE® tubular helical piles, minimum F_y = 60 ksi (414 MPa) and minimum F_u = 69 ksi (476 MPa). Therefore, maximum allowable stress is 0.5(69 ksi) = 34.5 ksi (0.6(476 MPa) = 238 MPa) which is less than 0.6(60 ksi) = 36 ksi (0.6(414 MPa) = 248 MPa).

1810.3.2.8 Justification of higher allowable stresses: Higher stresses are allowed if they can be justified through soil investigation and load testing under the direct supervision of a registered design professional knowledgeable in the field of soil mechanics and deep foundations. A report must be submitted to the building official with justification.

1810.3.3 Determination of allowable loads: This section sets forth the method to determine the allowable helical pile loads via approved formulas and load testing or method of analysis. In addition, provisions are given for single pile uplift capacity and pile group uplift capacity (**1810.3.3.1.5** and **1810.3.3.1.6**). **1810.3.3.1.7** and **1810.3.3.1.9** specify the use of a 2 safety factor.

1810.3.3.1.9 Helical piles: This section provides for determination of the allowable axial design load using a 2 safety factor (Equation 18-4). This section applies to tension as well as compression. The axial design load P_a is the least value of the six given methods to determine axial load. Interpretation of these six methods is subject to controversy. For example, in the judgment of the author, Method 3, "ultimate capacity determined from load tests" should be incontrovertible. What is better than an on-site full-scale load test? When compared to Method 1, "the sum of the areas of the helical bearing plates times the ultimate bearing capacity of the soil or rock comprising the bearing stratum," great disparity could ensue if the method of determining the soil bearing capacity is conservative. Needless costs could be suffered if good engineering judgment is not exercised with this section.

HELI-PILE® relies on Methods 2 and 3. Soils almost always dictate helical pile capacity rather than mechanical capacity of the steel, including shaft, couplings, and helices. An exception is in a hard formation such as cobble or rock. For more information, please see herein Section 5.7 "Refusal Condition in Extremely Dense Soil, Rock and Cobble."

1810.3.3.2 Allowable lateral load: This section provides methods for acceptable lateral load determination for a single pile and a pile group. Helical piles require lateral load determination just as any other deep foundation system.

1810.3.4 Subsiding soils: This section provides for the determination of any downdrag forces that helical piles may experience. The typical advantage of helical piles is their slenderness (low surface area). Thus, downdrag forces, if they exist, are lessened.

1810.3.5 Dimensions of deep foundation elements: Dimensions of helical piles are addressed in **1810.3.5.3.5** wherein it is stated, "Dimensions of the central shaft and the number, size and thickness of helical bearing plates shall be sufficient to support the design loads."

1810.3.11 Pile caps: The design of the pile cap or load transfer device is governed by this section. Minimum cap dimensions are specified. In addition, pile cap design in Seismic Design Categories C through F is given. It should be repeated that none of the provisions in this subcategory preclude the use of helical piles in the highest of seismic areas, only that the design be carried out as specified.

1810.4 Installation: Various provisions for installation are give that apply to all deep foundation systems. **1810.4.11** states: "Helical piles shall be installed to specified embedment depth and torsional resistance criteria as determined by a *registered design professional*. The torque applied during installation shall not exceed the maximum allowable installation torque for the helical pile."

1810.4.12 Special inspection: This section states: "*Special inspections* in accordance with Section **1705.9** shall be provided for helical piles." **1704.9** states: "*Continuous special inspections* shall be performed continuously during installation of helical pile foundations. The information recorded shall included installation equipment used, pile dimensions, tip elevations, final depth, final installation torque and other pertinent installation data as required by the *registered design professional in responsible charge*. The *approved* geotechnical report and the *construction documents* prepared by the *registered design professional* shall be used to determine compliance."

It should be noted that many jurisdictions entirely or partially wave **1810.4.12 Special inspection** if a certified HELI-PILE® installation contractor is doing the work and provides installation logs.

Combined Axial and Lateral Loading: IBC Chapter 18 is silent on this subject, however, it is recommended that all helical pile shafts be designed for this. See Section 2.3.

5.21 Design Responsibility

Design responsibility for helical piles and anchors is typically taken by the project structural engineer-of-record who designs, specifies, and seals or stamps the project drawings. Alternatively, the project geotechnical engineer-of-record may take responsibility for helical piles and anchors and seal the project drawings for them only. This assumes the structural and geotechnical engineers are qualified to do so.

As another alternative, the helical pile or anchor manufacturer or installation contractor may have licensed professional engineers on staff or on retainer to take design responsibility and seal the foundation drawings. Or another qualified licensed professional may be hired.

END OF SECTION 5

SECTION 6. APPLICATIONS

6.1 Applications of HELI-PILE® Technology

The list of applications of HELI-PILE® technology is endless. The list includes, but is not limited to, the following commercial, industrial, institutional, and residential applications. For photos of several types of projects, please see Sections 6-2 through 6.5. For installation equipment photos, please see Section 4.

- ◆ Permanent new structural foundations under continuous foundation grade beams or column bases, compression and/or tension loads. Typical ultimate capacities for single piles can range from 35 tons (311 kN) to 300 tons (2,670 kN) and higher. In pile groups, column design loads of 2,000 tons (17,800 kN) and higher can be supported. Examples of this application would be for new single and multiple-story buildings, including high-rise structures, bridges, residences, industrial facilities including skid foundations and pipe rack foundations.
- ◆ Permanent battered piles to take lateral loads including wind and seismic. Lateral loads are taken as axial compression and/or tension loads. Examples of this application would be those listed immediately above but also including sound walls, water towers, communications towers, bill boards, pipe racks, etc.
- ◆ Permanent new structural foundations under new concrete slabs.
- ◆ Permanent retrofit foundations in existing structures and additions where new loads are being added to the structure. An example would be where a new mezzanine level is being added inside a building or where new, larger and heavier machines are being installed in a factory.
- ◆ Permanent retrofit structural foundations under existing concrete slabs.
- ◆ Permanent retrofit foundations for seismic upgrade purposes.
- ◆ Permanent new foundations under heavy artwork such as sculpture.
- ◆ Permanent underpinning of any settled or heaved existing foundations, heavily or lightly loaded. A steel bracket is used to transfer existing loads from the structure to the new helical screw piles.
- ◆ Underpinning for permanent or temporary structural shoring, primarily vertical axial compression loading.
- ◆ Machine foundations including heavy compressors.
- ◆ New foundations in tight access or inaccessible areas.
- ◆ Underpinning in tight access or inaccessible areas, primarily vertical axial compression loading.
- ◆ New foundations in hazardous or environmentally sensitive areas where no drill spoils are desired.
- ◆ All locations where drilled or driven piles are specified.
- ◆ Tiebacks for permanent retaining walls constructed of any materials such as cast-in-place concrete, shotcrete, gunite, soldier beams and wood or concrete lagging, railroad ties, etc.
- ◆ Permanent tension hold-downs for wind and seismic loads.
- ◆ Tiebacks for permanent or temporary shoring.
- ◆ Anywhere where lateral loads must be resisted.
- ◆ All locations where grouted tiebacks are specified and the anchor zone is not in competent rock.

The helical pile and tension anchor is a deep foundation element that has attained standard of practice status in the United States and expanded use abroad. The International Building Code, starting with the 2009 edition and continuing with the 2018 edition, attests to this fact (see Section 5.19). The photos below partially illustrate the unlimited scope of structures that are founded on helical piles and anchors.

6.2 Examples of New Structures Designed and Constructed on Helical Piles

Photo 6-1 New multiple-story commercial structure designed and constructed on helical piles.

Photo 6-2 New multiple-story commercial structure designed and constructed on helical piles.

Photo 6-3 New condominium structure in a resort area designed and constructed on helical piles.

Photo 6-4 New multiple-story commercial structure designed and constructed on helical piles.

Photo 6-5 New multiple-story commercial structure designed and constructed on helical piles.

Photo 6-6 New church building designed and constructed on helical piles.

Photo 6-7 New office building designed and constructed on helical piles.

Photo 6-8 New multiple-story commercial structure designed and constructed on helical piles.

Photo 6-9 New natural gas compressor station designed and constructed on helical piles.

Photo 6-10 New natural gas facility designed and constructed on helical piles.

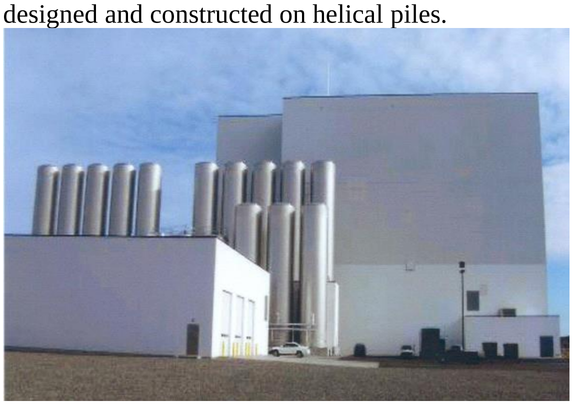


Photo 6-11 New Industrial facility, all structures, including tanks, designed and built on helical piles.

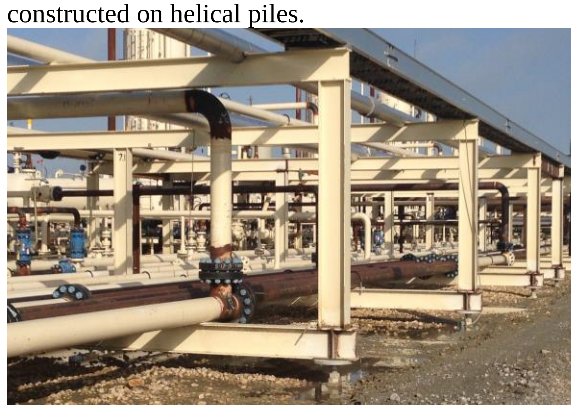


Photo 6-12 Pipe rack with high lateral loads and moments designed and constructed on helical piles.

Photo 6-13 Compressors designed and constructed on helical piles with their high damping ratios.

Photo 6-14 New gasoline pump facility. All structures designed and constructed on helical piles.

Photo 6-15 New large grain elevator facility designed and constructed on helical piles.

Photo 6-16 New annex to historical structure designed and constructed on helical piles.

Photo 6-17 New residential structure designed and constructed on helical piles.

Photo 6-18 New residential structure designed and constructed on helical piles.

Photo 6-19 New residential condominium structure designed and constructed on helical piles.

Photo 6-20 New residential structure designed and constructed on helical piles.

Photo 6-21 New residential structure designed and constructed on helical piles.

Photo 6-22 New residential condominium structure designed and built on helical piles.

Photo 6-23 New residential structure designed and constructed on helical piles.

Photo 6-24 New residential structure designed and constructed on helical piles.

6.3 Examples of Existing Structures Underpinned with Helical Piles

<u>Photo 6-25</u> Existing building with settled foundation underpinned and stabilized with helical piles.

<u>Photo 6-26</u> Existing residence with settled foundation underpinned/stabilized with helical piles.

<u>Photo 6-27</u> Existing residence with 18 inches differential heave in expansive soil underpinned, stabilized, and re-leveled on helical piles.

<u>Photo 6-28</u> The existing nine-story structure was underpinned and shored with helical piles.

<u>Photo 6-29</u> Existing residence with settled foundation underpinned and stabilized with helical piles.

<u>Photo 6-30</u> Existing building with settled foundation underpinned and stabilized with helical piles.

<u>Photo 6-31</u> Existing rubble foundation under this historic structure replaced using helical piles.

<u>Photo 6-32</u> Existing building still under construction settled. Foundation underpinned and stabilized with helical piles.

6.4 Examples of New Bridges and Boardwalks Designed & Built on Helical Piles

Photo 6-33 New reinforced concrete multi-lane bridge with abutments supported on helical piles and helical tiebacks.

Photo 6-34 New reinforced concrete multi-lane bridge with abutments supported on helical piles and helical tiebacks.

Photo 6-35 New steel bridge with abutments supported on helical piles and helical tiebacks.

Photo 6-36 New pedestrian bridge with abutments supported on helical piles.

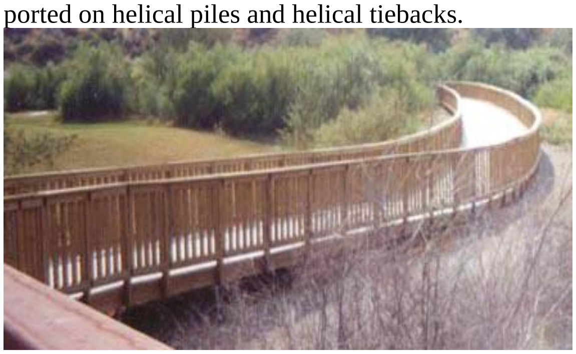


Photo 6-37 New boardwalk in marsh wetland supported on helical piles.

Photo 6-38 New golf cart/pedestrian/vehicle bridge in marsh wetland supported on helical piles.

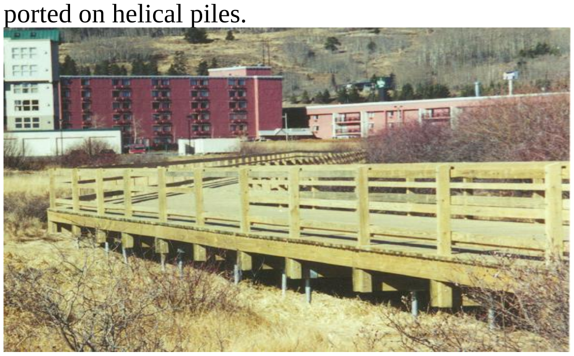


Photo 6-39 New boardwalk in marsh wetland supported on helical piles.

Photo 6-40 New fishing pier supported on helical piles.

6.5 Examples of Helical Tension Anchors used as Tiebacks and Soil Nails

Photo 6-41 New rock faced retaining wall using helical tension anchors as tiebacks.

Photo 6-42 New reinforced concrete retaining wall using helical tension anchors as tiebacks.

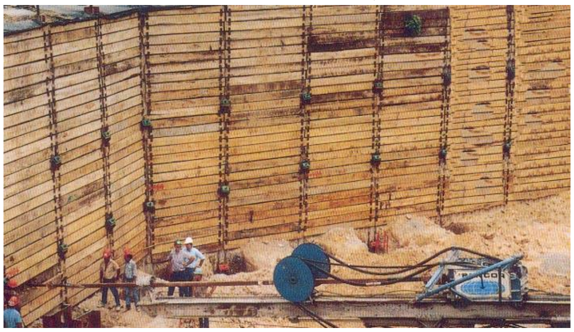


Photo 6-43 New soldier beam and wood lagging shoring wall using helical anchors as tiebacks.

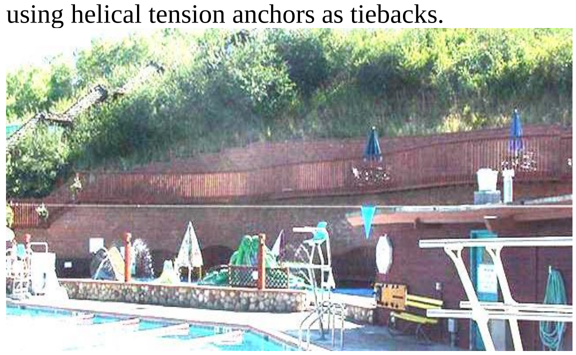


Photo 6-44 New reinforced concrete retaining wall using helical tension anchors as tiebacks.

Photo 6-45 New pre-engineered shoring panel shoring wall using helical tension anchors as tiebacks.

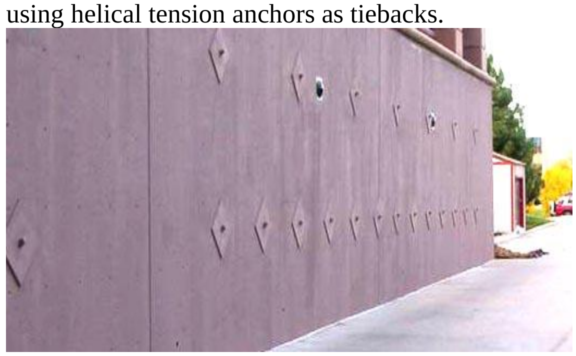


Photo 6-46 Existing foundation/retaining wall laterally supported with helical anchors as tiebacks.

Photo 6-47 New retaining wall under construction using helical tension anchors as soil nails.

Photo 6-48 New pre-engineered shoring panel shoring wall using helical tension anchors as tiebacks.

END OF SECTION 6

SECTION 7. HELICAL TIEBACKS & SOIL NAILS

7.1 Helical Tiebacks

Helical tiebacks are devices used in a tension mode to support an earth retention structure or provide lateral resistance for a building foundation or other structure. See photographs in Section 6.5. Helical tiebacks can be used for retaining walls, basement walls, excavation shoring, etc., the same as any type of tieback. Because no concrete or grout is used nor is any soil excavated, they can be installed at any angle, even up from the horizontal. They can be tensioned to the design load immediately because there is no concrete or grout cure time.

Helical tieback capacities are determined identically to vertical helical piles using the torque vs. capacity method discussed in Section 3. For typical load transfer, a modular Terminator or other threaded adapter is attached to the anchor shaft and to the retaining structure with a plate and nut. Other load transfer mechanisms are available as outlined below.

Other tension anchors, such as structural hold downs, are designed and installed just like tiebacks except in a vertical orientation.

Figure 7-1 shows a reinforced concrete retaining wall founded on vertical helical piles and laterally restrained by helical tiebacks.

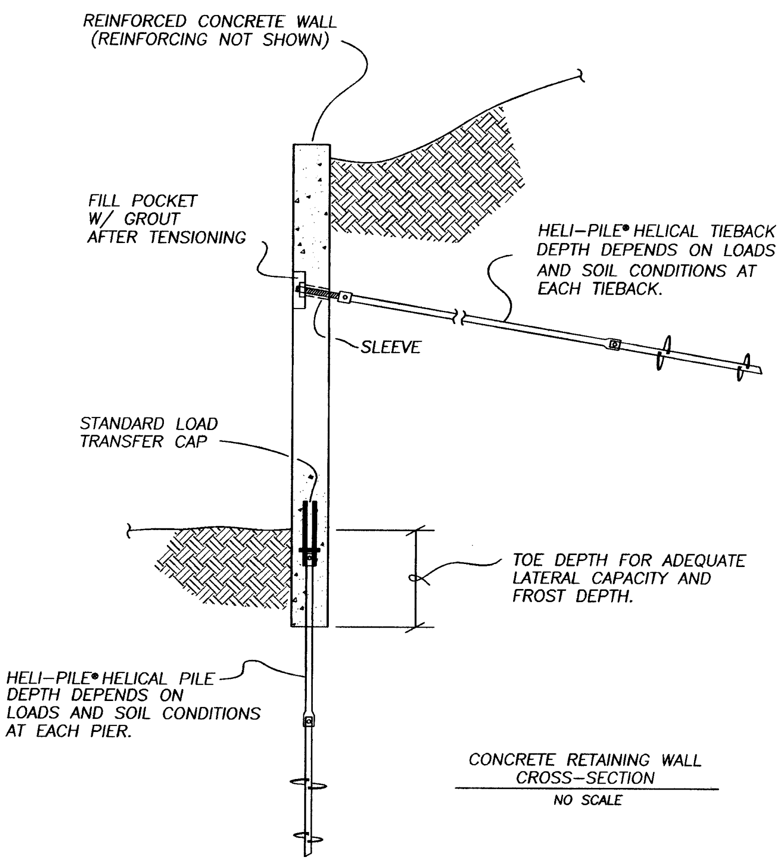


Figure 7-1. Retaining Wall with Helical Screw Piles and Helical Tiebacks

The repair of existing deflected (leaning) retaining walls can be done as shown in Figures 7-2 and 7-3.

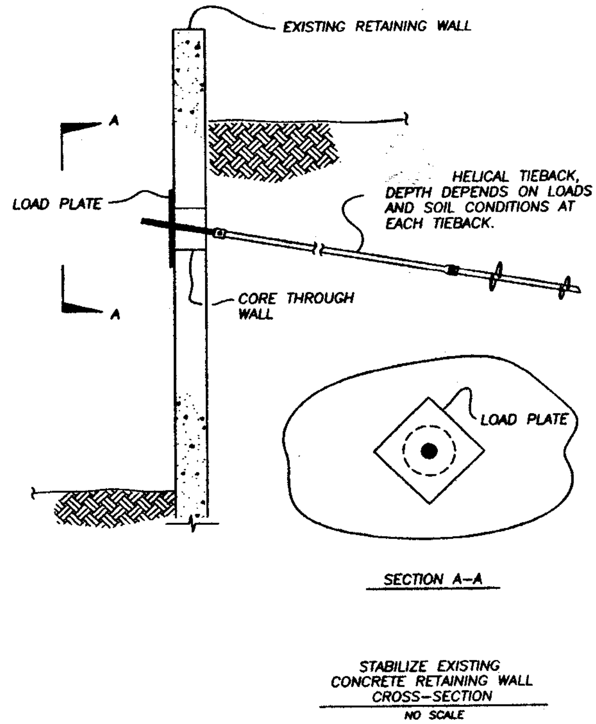


Figure 7-2. Retaining Wall Repair using Helical Tieback and Load Plate

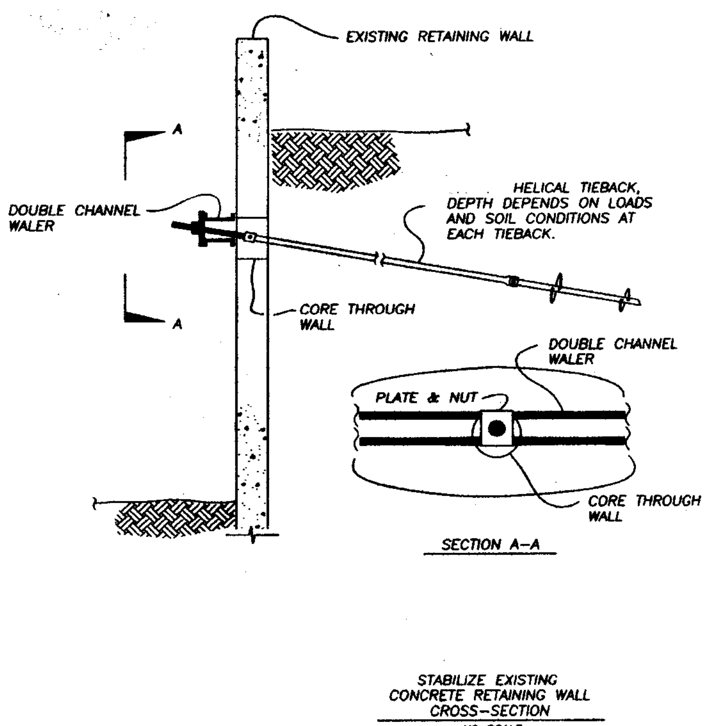


Figure 7-3. Retaining Wall Repair using Helical Tieback and Double Channel Waler

Figure 7-4 shows a large typical shoring panel (load plate) using a helical tension anchor as a tieback. See Photos 6-45 and 6-48. The great advantage of using helical tiebacks in shoring applications is that no concrete is introduced into the ground, thus, no waiting for cure time.

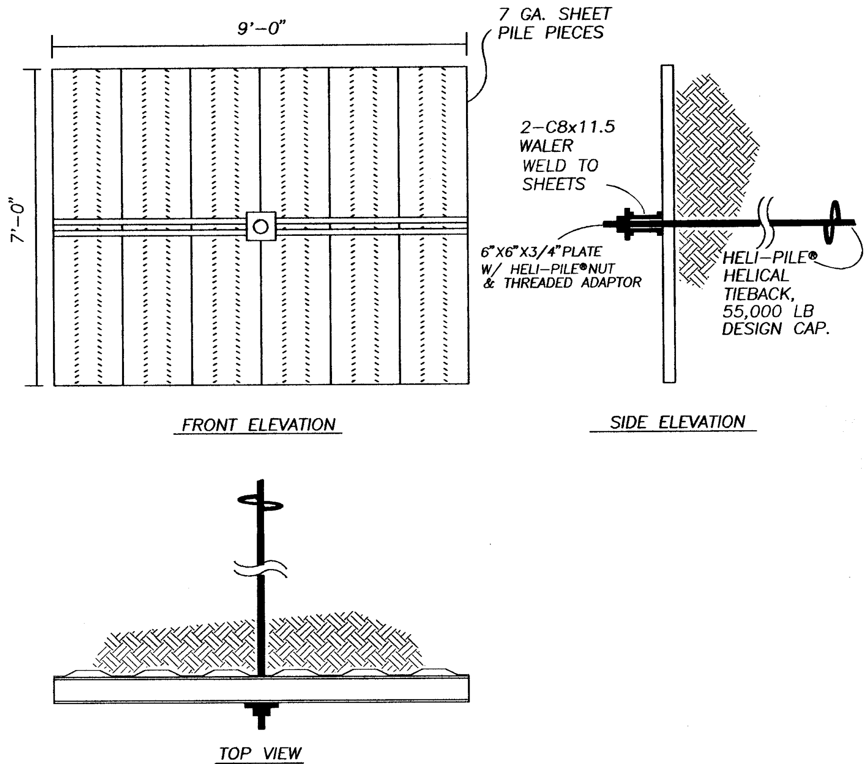


Figure 7-4. Example of Shoring Panels using Helical Tension Anchors as Tiebacks (See Photos 6-45 and 6-48 to see this shoring panel in place in shoring walls.

Figure 7-5 shows the use of vertical compression loaded helical piles to support the bridge abutment and helical tension anchors as tiebacks to provide lateral support. For a photographic example of this concept see Photos 6-33 and 6-34.

For more detailed information please see Helical Piles, A Practical Guide to Design and Installation, Perko (2009), Chapter 13.

7.2 Helical Soil Nails

Developments in soil nail technology have made this system of earth retention popular for excavation shoring, slope stability, and retaining walls. This is a cost-effective method of ground reinforcement for earth retention without excavating. See Photo 6-47 for an example of a helical soil nail wall.

A helical soil nail is installed identically to a tieback. However, the philosophy of earth retention is not the same as a tieback. A detailed discussion of the differences is beyond the scope of this volume. Generally, the purpose of helical soil nails is to bind a soil mass together to create a large gravity retaining wall. Figure 7-6 shows how the presence of the nails creates a gravity retaining wall essentially the size of the height H and the length of the helical soil nails.

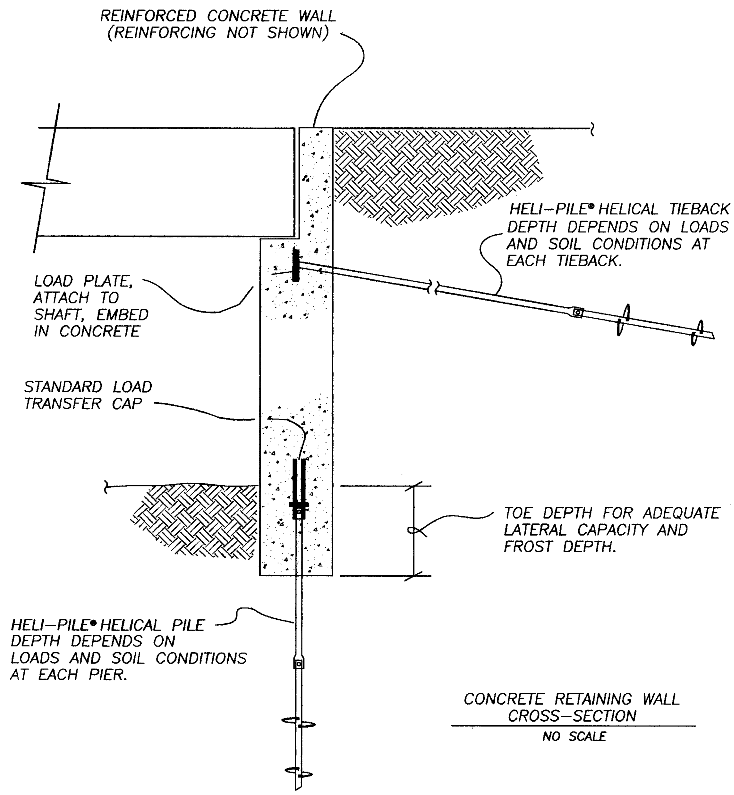


Figure 7-5. Vertical Helical Piles and Helical Tension Anchors as Tiebacks for Bridge Abutment (See Photos 6-33 and 6-34)

The helical soil nail consists of helices attached at regular intervals to the entire shaft, including extensions (see Figure 7-6). The result is a helical device with helices spread along the entire length of shaft. The common helical soil nail is a 7 ft (2.1 m) lead or extension with 8-inch (203 mm) diameter helices spaced at 30-inch (760 mm) intervals along the shaft. The 7 ft (2.1 m) lead section plus any number of 7 ft (2.1 m) extensions can result in a soil screw installed to any length.

Soil screw capacity is determined in the identical manner as tiebacks or piers. However, large soil screw tension capacities are not required because of the way they are used. Soil screws are installed to depth, not torque. Usually, a small tension capacity is all that is required. Figure 7-6 shows a typical helical soil nail installation with typical dimensions. The specific soil conditions will dictate what actual spacing and helical soil nail length to use.

A detailed discussion on helical soil nail design is beyond the scope of this book. For detailed information please see Helical Piles, A Practical Guide to Design and Installation, Perko (2009), Chapter 13.

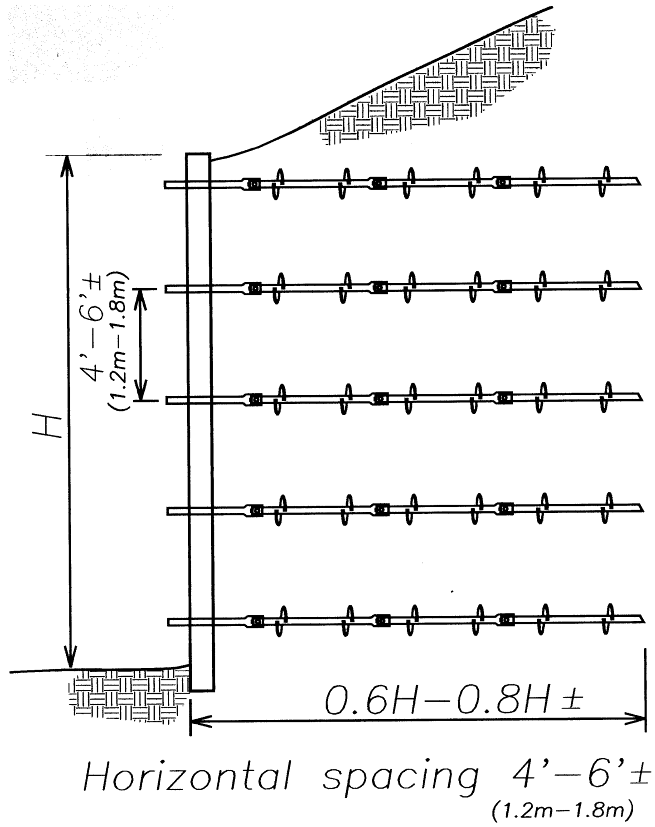


Figure 7-6. Cross-section of Helical Soil Nail Wall with Typical Dimensions

END OF SECTION 7

SECTION 8. SAMPLE SPECIFICATIONS

These sample specifications are for square solid shaft and square tubular HELI-PILEs®. These specifications can be adapted for other sizes.

A performance specification is preferred to a product specific specification. This is best accomplished as follows: the designer specifies the performance criteria: 1) pile or anchor location, 2) design loads and 3) minimum depth on the drawings, and 4) provides site soil data. This information is given to all qualified installing contractors bidding the project. All qualified installing contractors bidding the project, or just the successful qualified installing contractor, at the designer's discretion, then submit to the designer for approval the helical piles or tension anchors proposed that will meet the performance criteria. It is expected that all qualified installing contractors will propose helical pile or tension anchor material that will most economically meet the designer's performance criteria.

Specifications should be flexible by allowing the installing contractor to propose several helical lead section configurations that will meet the performance criteria during the course of installation work, subject to the approval of the designer. This reduces field down-time and improves the schedule.

The sample specifications presented below allow for the performance specification of size, shape, and depth of helical piles and tension anchors while detailing material quality, manufacturer, building code listing, and installation procedure, etc.

Three sample specifications are presented below:

8.1 Simplified HELI-PILE® Helical Pile (or Tieback) Specification

This is the preferred specification wherever possible. It serves well on drawings or in a specification package.

HELI-PILE® ROUND CORNER SOLID STEEL SHAFT
SIMPLIFIED SPECIFICATION

Helical piles shall be manufactured by HELI-PILE®, Denver, Colorado, USA.

HELI-PILE® helical piles shall be installed by an authorized HELI-PILE® installing contractor who has satisfied the certification requirements relating to the technical aspects of the product and the ascribed installation techniques. Proof of current certification by HELI-PILE® must be provided.

A. All work as described herein shall be performed in accordance with all applicable safety codes in effect at the time of installation.
B. HELI-PILE® helical piles shall be designed in accordance with the helical pile provisions of the 2018 International Building Code.
C. The helical lead sections and extensions shall be solid steel, rounded corner square shaft configuration, with one or more helical bearing plates welded to the shaft.
D. All pile steel shall be corrosion protected by galvanization per ASTM B633 or ASTM A153 per Owner.

E. Installation units shall consist of a rotary type torque motor with forward and reverse capabilities. These units shall be either electrically or hydraulically powered.
F. Installation units shall be capable of developing the minimum torque as required.
G. Installation units shall be capable of positioning the HELI-PILE® helical pile at the proper installation angle. This angle may vary between vertical and 5 degrees depending upon application and type of load transfer device specified or required.
H. Installation torque shall be monitored throughout the installation process.
I. HELI-PILE® helical piles shall be installed to the minimum torque value required to provide the load capacities shown on the plans.
J. The appropriate steel underpinning bracket or new construction load transfer device shall be used.
K. Appropriate HELI-PILE® helical pile selection will consider load plus safety factor (which may be specified on the plans), soil parameters and the installation torque versus capacity equation as per the installation unit manufacturer's recommendations.

END OF SPECIFICATION

8.2 Extended HELI-PILE® Helical Pile (or Tieback) Round Corner Square Solid Steel Shaft Specification Organized in Accordance with CSI

SECTION __________ HELI-PILE® SOLID STEEL SHAFT HELICAL PILES

PART 1: GENERAL

1.1 DESCRIPTION:

1. The work of this section consists of furnishing and installing HELI-PILE® steel helical piles, Denver, Colorado.

2. HELI-PILE® steel helical piles shall be designed and installed to resist the unfactored design loads as shown on Sheet S-__. The geotechnical report ________ for the site dated by _________ is included in this project manual as specification section ______.

3. Related Work Specified Elsewhere:

1.2 QUALITY ASSURANCE

1. HELI-PILE® helical piles shall be designed in accordance with the helical pile provisions of the 2018 International Building Code.

2. Installer Qualifications: Installation shall be done by a HELI-PILE® authorized installation contractor. Proof of current certification with HELI-PILE® shall be submitted to the Owner prior to starting installation.

3. A qualified inspector shall be present during HELI-PILE® installation in accordance with the local building code.

4. Welding: Meet requirements of AWS "Structural Welding Code," D1.1, latest edition. All welders shall be AWS certified.

1.3 SUBMITTALS

1. Submit shop drawings indicating shaft and helix sizes, and include manufacturer's catalog cut and data sheets.

PART 2: PRODUCTS

2.1 MATERIAL

1. Pier Shafts (Lead Section and Extensions):

    1. The 1.5 inch (38.1 mm) round cornered square (RCS) solid steel shafts shall conform to the general requirements of ASTM A29 and the following descriptions:

        High strength low alloy (HSLA), low to medium carbon steel grade (similar to ASTM 1530) with improved strength due to fine grain size and structure having a torsional strength rating of 7,000 ft.-lbs (9.49 kN-m)(968 kg_f-m).

    2. The 1.75 inch (44.5 mm) round cornered square (RCS) solid steel shafts shall conform to the general requirements of ASTM A29 and the following descriptions:

        High strength low alloy (HSLA), low to medium carbon steel grade (similar to AISI 1530) with improved strength due to fine grain size and structure having a torsional strength rating of 11,000 ft.-lbs (13.6 kN-m)(1,380 kg_f-m).

2. Helices: Carbon steel sheet, strip, or plate formed on matching metal dies to true helical shape and shall conform to the following ASTM specifications:

    1. 7,000 ft-lbs.(9.49 kN-m)(968 kg_f-m) 1.5 inch (38.1 mm) Piers: ASTM A656 Grade 80 0.5 inch (12.7 mm) thick.
    2. 10,000 ft.-lbs.(13.6 kN-m)(1,380 kg_f-m) 1.75 (44.5 mm) inch Piers: ASTM A656 Grade 80, 0.5 inch (12.7 mm) thick.
    3. All helix leading edges shall be rock cut at 45 degrees and sharpened.

4. Bolts: The sizes and types of bolts used to connect the Helical Pier® extensions to lead sections or another extension shall conform to the following ASTM specifications:

    1. 1.5 inch (38.1 mm) Helical Piers®: 0.75 inch (19.1 mm) diameter bolt per ASTM A449.
    2. 1.75 inch (44.5 mm) Helical Piers®: 0.875 inch (22.2 mm) diameter bolt per ASTM A193 Grade B7.

5. Couplings: Couplings shall be cold-forged welded to the shaft.

6. Finish: All material shall be galvanized per ASTM B633 or ASTM A153 per Owner.

PART 3: EXECUTION

3.1 EQUIPMENT:

1. Installation Equipment:

    1. Shall be a rotary type motor with equal forward and reverse torque capabilities. This equipment shall be capable of continual adjustment of the torque drive unit's revolutions per minute (RPM's) during installation. Percussion drilling equipment will not be allowed.

    2. Shall be capable of applying installation torque equal to the torque required to meet the pier loads.

    3. Equipment shall be capable of applying axial compression (crowd) pressure and torque simultaneously.

2. Torque Monitoring Devices:

    1. The torque being applied by the installing units shall be monitored throughout the installation by the installer. The torque monitoring device shall either be a part of the installing unit or an independent device in-line with the installing unit. Calibration for either unit shall be available for review by the Owner.

3.2 INSTALLATION PROCEDURES:

1. Advancing Sections:

    1. Engage and advance the HELI-PILE® sections in a smooth, continuous manner with the rate of pier rotation in the range of 5 to 35 RPM.

    2. Apply sufficient axial compression (crowd) pressure to uniformly advance the helical sections to approximately 3-inches (76.2 mm) per revolution. The rate of rotation and magnitude of crowd pressure must be adjusted for different soil conditions and depths in order to maintain the penetration rate.

    3. If the helical section ceases to advance, refusal will have been reached and the installation shall be terminated.

2. Termination Criteria:

    1. The torque as measured during the installation shall not exceed the torsional strength rating of the steel helical lead and extension sections.

2. The minimum depth criteria indicated on the Drawings must be satisfied prior to terminating the HELI-PILE® steel helical pile.

3. The top helix is to be located not less than five (5) feet (1.5 m) below the grade elevation unless otherwise approved by the Owner.

4. If the torsional strength rating of the pier and/or installing unit has been reached prior to satisfying the minimum depth required, the installing contractor shall have the following options:

    a. Terminate the installation at the depth obtained with the approval of the Owner, or,

    b. Remove the existing pier and install a pier with smaller and/or fewer helices. This revised pier shall be terminated deeper than the terminating depth of the original pier as directed by the Owner.

5. In the event the minimum installation torque is not achieved at minimum depth, the Contractor shall install the foundation deeper using additional plain extension sections.

6. The minimum specified installation torque shall have been met when the measured installation torque meets or exceeds the minimum specified installation torque in two successive readings of the measuring device, unless otherwise specified by the Owner.

7. The installer shall keep a written installation record for each HELI-PILE®. This record shall include the following information as a minimum:

    a. Project name and location.
    b. Name of authorized and certified dealer and installer.
    c. Name of installer's foreman or representative witnessing the installation.
    d. Date of installation.
    e. Location of each helical pile.
    f. Description of lead section including number and diameter of helices and extensions used.
    g. Overall depth of installation from a known reference point.
    h. Installation torque at termination of pier.
    i. Load transfer device

END OF SPECIFICATION

8.3 EXTENDED HELI-PILE® HELICAL PILE STEEL TUBULAR SHAFT SPECIFICATION ORGANIZED IN ACCORDANCE WITH CSI

SECTION ________ HELI-PILE® STEEL TUBULAR HELICAL PILES

PART 1: GENERAL

1.1 DESCRIPTION:

1. The work of this section consists of furnishing and installing HELI-PILE® steel tubular helical piles manufactured by HELI-PILE®, Denver, Colorado.

2. HELI-PILE® steel tubular helical piles shall be designed and installed to resist the unfactored design loads as shown on Sheet S-__. The geotechnical report ____ for the site dated ____ by _____ is included in this project manual as specification section _____.

3. Related Work Specified Elsewhere:

1.2 QUALITY ASSURANCE

1. HELI-PILE® helical piles shall be designed in accordance with the helical pile provisions of the <u>2018 International Building Code</u>.

2. Installer Qualifications: Installation shall be done by a HELI-PILE® authorized installation contractor. Proof of current certification with HELI-PILE® shall be submitted to the Owner prior to starting installation.

3. A qualified inspector shall be present during HELI-PILE® installation in accordance with the local building code.

4. Welding: Meet requirements of AWS "Structural Welding Code," D1.1, latest edition. All welders shall be AWS certified.

1.3 SUBMITTALS

1. Submit shop drawings indicating shaft and helix sizes, and include manufacturer's catalog cut and data sheets.

PART 2: PRODUCTS

2.1 MATERIAL

1. Pier Shafts (Lead Section and Extensions):

    1. HPFT25, 2.5 inch (63.5 mm) with 0.25 inch (6.35 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 7,000 ft-lbs (9.49 kN-m).

2. HPFT3, 3 inch (76.2 mm) with 0.25 inch (6.35 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 11,000 ft-lbs (14.9 kN-m).

3. HPFT331, 3 inch (76.2 mm) with 0.313 inch (7.95 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 15,000 ft-lbs (20.3 kN-m).

4. HPFT4, 4 inch (102 mm) with 0.5 inch (12.7 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 30,000+ ft-lbs (40.7+ kN-m).

5. HPFT425, 4 inch (102 mm) with 0.25 inch (6.35 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 20,000 ft-lbs (27.1 kN-m).

6. HPFT438, 4 inch (102 mm) with 0.375 inch (9.53 mm) wall, tubular steel shafts shall conform to the requirements of ASTM A500 Gr B with minimum F_y = 60 ksi and torsional strength rating of 30,000 ft-lbs (40.7 kN-m).

3. Helices: Carbon steel sheet, strip, or plate formed on matching metal dies to true helical shape and shall conform to ASTM A656 Gr 80 Type 7 specifications, 0.5 inch (12.7 mm) thick with the leading edge rock cut at 45 degrees and sharpened.

4. Bolts: The sizes and types of bolts used to connect the Helical Pier® extensions to lead sections or another extension shall conform to the following ASTM specifications:

   1. 2.5 inch (63.5 mm): 0.75 inch (19.1 mm) diameter bolt per SAE J429 Gr 5 steel (Fy = 120 ksi (827 MPa)) or equivalent.
   2. 3 inch (76.2 mm): 0.875 inch (22.2 mm) diameter bolt per SAE J429 Gr 5 steel (Fy = 120 ksi (827 MPa)) or equivalent.
   3. 4 inch (102 mm): 1.25 inch (31.8 mm) diameter bolt per SAE J429 Gr 5 steel (Fy = 120 ksi (827 MPa)) or equivalent.

5. Couplings: Couplings shall be cold-forged welded to the shaft.

6. Finish: All material shall be galvanized per ASTM B633 or ASTM A153 per Owner.

PART 3: EXECUTION

3.1 EQUIPMENT:

1. Installation Equipment:

1. Shall be a rotary type motor with equal forward and reverse torque capabilities. This equipment shall be capable of continual adjustment of the torque drive unit's revolutions per minute (RPM's) during installation. Percussion drilling equipment will not be allowed.

2. Shall be capable of applying installation torque equal to the torque required to meet the pier loads.

3. Equipment shall be capable of applying axial compression (crowd) pressure and torque simultaneously.

2. Torque Monitoring Devices:

1. The torque being applied by the installing units shall be monitored throughout the installation by the installer. The torque monitoring device shall either be a part of the installing unit or an independent device in-line with the installing unit. Calibration for either unit shall be available for review by the Owner.

3.2 INSTALLATION PROCEDURES:

1. Advancing Sections:

1. Engage and advance the HELI-PILE® sections in a smooth, continuous manner with the rate of pier rotation in the range of 5 to 35 RPM.

2. Apply sufficient axial compression (crowd) pressure to uniformly advance the helical sections to approximately 3-inches (76.2 mm) per revolution. The rate of rotation and magnitude of crowd pressure must be adjusted for different soil conditions and depths in order to maintain the penetration rate.

3. If the helical section ceases to advance, refusal will have been reached and the installation shall be terminated.

2. Termination Criteria:

   1. The torque as measured during the installation shall not exceed the torsional strength rating of the steel helical lead and extension sections.

   2. The minimum depth criteria indicated on the Drawings must be satisfied prior to terminating the HELI-PILE® steel helical pile.

   3. The top helix is to be located not less than five (5) feet (1.5 m) below the grade elevation unless otherwise approved by the Owner

   4. If the torsional strength rating of the pier and/or installing unit has been reached prior to satisfying the minimum depth required, the installing contractor shall have the following options:

      a. Terminate the installation at the depth obtained with the approval of the Owner, or,

      b. Remove the existing pier and install a pier with smaller and/or fewer helices. This revised pier shall be terminated deeper than the terminating depth of the original pier as directed by the Owner.

   5. In the event the minimum installation torque is not achieved at minimum depth, the Contractor shall install the foundation deeper using additional plain extension sections.

   6. The minimum specified installation torque shall have been met when the measured installation torque meets or exceeds the minimum specified installation torque in two successive readings of the measuring device, unless otherwise specified by the Owner.

   7. The installer shall keep a written installation record for each HELI-PILE®. This record shall include the following information as a minimum:

      a. Project name and location.
      b. Name of authorized and certified dealer and installer.
      c. Name of installer's foreman or representative witnessing the installation.
      d. Date of installation.
      e. Location of each helical pile.
      f. Description of lead section including number and diameter of helices and extensions used.
      g. Overall depth of installation from a known reference point.
      h. Installation torque at termination of pier.
      i. Load transfer device

END OF SPECIFICATION

END OF SECTION 8

SECTION 9. QUALITY CONTROL, INSPECTION & PERFORMANCE MONITORING

This section is adapted from the paper by John S. Pack, P.E., entitled, "Helical Foundations and Tiebacks: Quality Control, Inspection and Performance Monitoring," published in Deep Foundations Institute 28th Annual Conference on Deep Foundations, Deep Foundations Institute Conference Proceedings, October 22-24, 2003, Miami Beach, Florida, pp. 271-284. This section is designed as a stand-alone field inspection manual for helical piles and tension anchors. Therefore, there is some repetition of material already presented above. This section has been updated for this edition.

9.1 Introduction

Helical piles and tiebacks are a several hundred million dollars per year segment of the deep foundation industry that is expected to continue rapid growth. The driving forces behind this growth include 1) An excellent performance record over nearly 30 years of monitoring and 2) Cost competitiveness with its deep foundation cousins: drilled shafts, driven piles and grouted micro-piles. In addition, inclusion of helical piles in the 2018 International Building Code has spurred acceptance in the engineering and construction community. Specified projects ranging from heavily loaded new foundations under high-rise structures down to lightly loaded residential structures are common. Helical piles and tiebacks are now a standard practice for deep foundations and earth retention projects in many parts of the United States, Canada, and elsewhere in the world.

As the use of helical piles and tiebacks accelerates, local building departments and consulting engineers are being called upon in greater numbers to provide quality control, inspection and performance monitoring services for these projects. Also, there is a high demand for manufacturers, distributors, and installation contractors to police their own products and services to ensure the highest quality and performance for helical piles and tiebacks.

While guidance on design and installation techniques is readily available in the literature, detailed information on quality control, inspection and performance monitoring is lacking. This section is an attempt to fill the void. It is based on the experience of the engineers and constructors at D & B Drilling, Inc., Engineering Contractors, and I.M.R., Inc., both of Denver, Colorado, U.S.A., who, since 1986, have directly installed or been involved in the installation of nearly 200,000 individual helical screw piles and tiebacks in a myriad of soil conditions with all types of structures. Specific techniques for quality control, inspection and performance monitoring have been developed that are presented herein.

9.2 Brief Description

For a detailed description of helical piles and tiebacks, please refer to the other sections in this book or literature available from the various manufacturers of helical pile and tieback material. This section assumes some prior familiarity with helical piles and tiebacks and only briefly describes them as a refresher for the reader.

Helical piles are also referred to as "helical piers," "helical foundations," "helical anchors", "helix piers," "helix piles," "helical screw piles" etc. These terms typically refer to the helical pile used primarily as a compression or tension member under a structure where the loads are usually, but not always, vertical. Sometimes the loads are lateral, especially for wind and seismic loading. Helical tiebacks, on the other hand, are the identical type of device that are used solely in a tension mode for earth retention structures. Figure 9-1 depicts helical piles supporting vertical compression loads and lateral loads (wind or seismic, tension or compression). Figure 9-2 depicts a helical tieback supporting lateral soil loads imposed on a retaining wall.

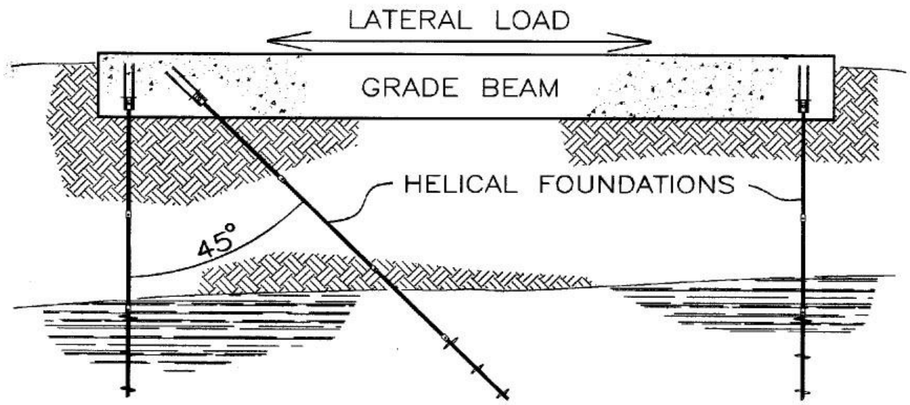


Figure 9-1. Helical Piles Under a Structure

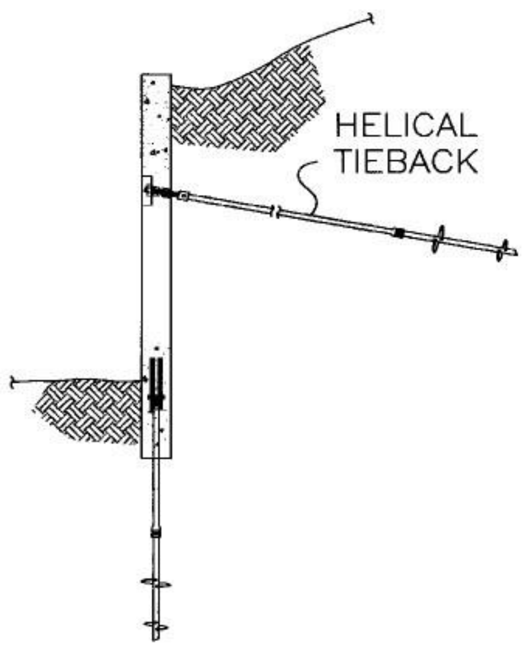


Figure 9-2. Helical Tieback in Retaining Wall

A helical pile or tieback is comprised of one or more circular steel plates split along one radial line and welded to a central solid steel square or pipe shaft, sometimes called a hub. Each plate is shaped in the form of a helix with a leading and trailing edge such that when torsional rotation force (torque) is applied to the central shaft the helix engages the soil and is driven axially into the soil (see helix in Photo 9-10). The helical pile or tieback is installed in segments typically ranging from 3 to 10 feet (1 to 3 m) long. The first segment to engage the soil is called the "lead section" with subsequent segments called "extensions." Extensions may or may not have helices welded to them. Figure 9-1 depicts helical piles with three helices welded to the lead section and various plain extensions. Figure 9-2 depicts a helical tieback with two helices welded to the lead section and two plain extensions; the concrete retaining wall is supported by a vertical helical pile with two helices on the lead section and one plain extension.

Each lead section and extension is typically connected by a bolted coupling (see Photo 9-7).

Helical piles and tiebacks use solid steel square bars, square hollow tubes and round pipe for the central shaft. Most manufacturers galvanize their material for corrosion protection (more on this below).

Torque is applied to the helical pile or tieback typically by a hydraulically powered torque drive head mounted to the boom of mobile equipment such as skid-steers or backhoes or mounted on hand-carried equipment. Photograph 9-1 is of a helical screw pile installation using the hydraulic torque drive head mounted on a backhoe boom. Photograph 9-2 is of a helical tieback installation using a torque drive head but in a near horizontal orientation. Photograph 9-5 is a helical tieback installation at a difficult access site using a torque drive head mounted on hand carried equipment.

Photo 9-1 Installation with hydraulic drive head mounted on a backhoe boom.

Photo 9-2 Helical tieback installation with drive head mounted on a skid-steer machine.

9.3 Applications

It is important for inspecting and quality control personnel to know some of the profusion of applications of helical piles and tiebacks. Photograph 9-3 is of a multiple-story structure designed and constructed on helical piles. The use of helical piles for new foundations for heavily loaded structures is expanding (Pack, John S. (2000). "Design of Helical Piles for Heavily Loaded Structures," ASCE Geotechnical Special Publication Number 100: 353-367). Photograph 9-4 is of a new residential structure designed and constructed on helical piles. Other applications include, but are not limited to:

Helical Pile Applications:

1. Permanent new structural foundations under continuous foundation grade beams or column bases, compression and/or tension loads. Typical ultimate capacities for single helical screw piles range from 50,000 to over 200,000 lbs. (222 to 890 kN). In pile groups, column design loads of 2,000,000 lbs. (8,900 kN) or larger can be supported. Examples of this application would be for single and multiple story buildings, including high-rise structures, new homes and bridges.
2. Permanent battered helical piles to take lateral loads including wind and seismic. Lateral loads are taken as axial compression and/or tension loads. Examples of this application would be those listed in Item 1 above but also including sound walls, bill boards, water towers, etc.
3. Permanent new structural foundations under new concrete slabs.
4. Permanent retrofit foundations in existing structures and additions where new loads are being added to the structure. An example would be where a new mezzanine level is being added inside a building or where new, larger and heavier machines are being installed in an existing factory.
5. Permanent retrofit structural foundations under existing concrete slabs.
6. Permanent retrofit foundations for seismic upgrade purposes.
7. Permanent new foundations under heavy artwork and sculpture.
8. Permanent underpinning of settled or heaved foundations. A steel bracket is used to transfer existing loads from the structure to the helical foundation.
9. Underpinning for permanent or temporary structural shoring, primarily vertical axial compression loading.

Photo 9-3 Multiple-story bldg on helicals.

Photo 9-4 Residential struct. on helicals.

10. Permanent tension hold downs for wind and seismic loads.
11. Machine foundations.
12. Hazardous waste sites where excavation soil or drill spoils are undesirable.
13. New foundations in tight access or inaccessible areas, including boardwalks.
14. Underpinning in tight access or inaccessible areas, primarily vertical axial compression loading.
15. All locations where drilled piers, driven piles or grouted micro-piles are specified.

Helical Tieback Applications:

1. Permanent retaining walls constructed of any materials such as cast-in-place concrete, shotcrete, gunite, soldier beams and wood or concrete lagging, railroad ties, etc.
2. Temporary or permanent shoring.
3. Anywhere where lateral loads must be resisted.
4. All locations where grouted tiebacks are specified and the anchor zone is not in solid rock.

Photograph 9-5 is of a helical tieback installation to repair a low retaining wall in a residential neighborhood. It is being installed with hand-carried equipment. Photograph 9-6 is of an excavation shoring project using helical tiebacks with pre-engineered and pre-fabricated steel shoring panels.

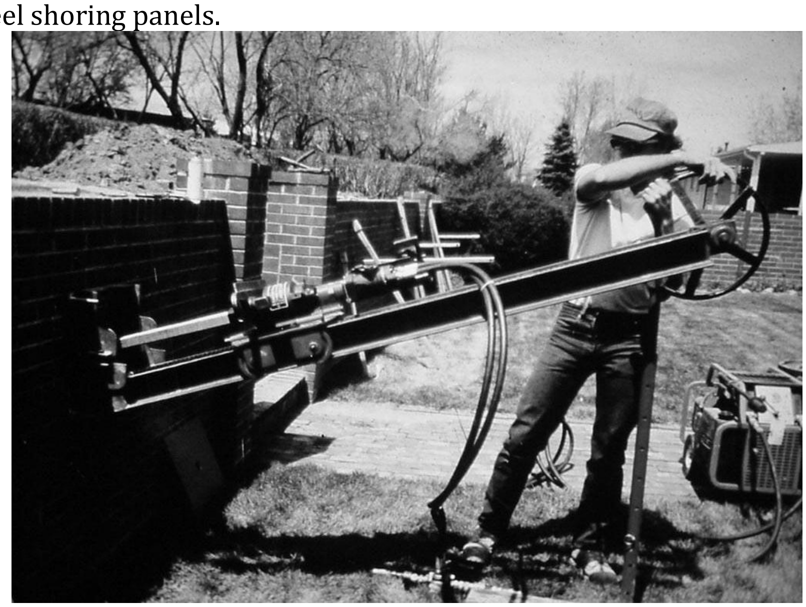


Photo 9-5 Helical tieback in low retaining wall using hand-carried equipment.

Photo 9-6 Excavation shoring using helical tiebacks and pre-engineered shoring panels.

9.4 Design Responsibility

Design responsibility for helical piles and tension anchors is typically taken by the project structural engineer-of-record who designs, specifies, and seals or stamps the project drawings. Alternatively, the project geotechnical engineer-of-record may take responsibility for helical piles and anchors and seal the project drawings for them only. This assumes the structural and geotechnical engineers are qualified to do so.

If neither the structural nor geotechnical engineer-of-record is qualified to take design responsibility specifically for helical piles or tension anchors, another qualified licensed professional engineer may be hired to do so.

In some cases, the helical pile and tension anchor installation contractor may have engineers on staff who are licensed in the project's jurisdiction and are able to design, specify and seal shop drawings for helical piles and tension anchors. These shop drawings are then submitted to the project engineer-of-record and become part of the sealed and approved project documents.

Many jurisdictions require no specific design analysis or engineer's seal for helical piles or tension anchors where the manufacturer is building code listed and the installation contractor is certified by the manufacturer to install its helical piles or anchors. In this case, the designer calls out on the project drawings the manufacturer's published building code evaluation report numbers, catalog numbers or other published descriptions of the helical devices desired and states that they must be installed in accordance with the manufacturer's instructions.

9.5 Quality Control Philosophy

The approach to quality control, inspection and performance monitoring of helical piles and tiebacks is no different than any other type of deep foundation or tieback: layout, penetration into the correct soil formation, capacity, and load transfer from the structure to the pile or tieback are basic. Only some specialized details as covered herein should be added in the inspection process. Performance monitoring techniques are identical to those used for any type of deep foundation or tieback.

Therefore, the inspector who is already familiar with quality control, quality assurance, inspection and performance monitoring of other types of deep foundations and tiebacks is already nearly prepared to deal with helical piles and tiebacks. One must learn only a few specialized techniques and terminology as presented herein to be fully prepared.

9.6 Procedures Prior to Field Work

Underpinning vs. New Foundations

"Underpinning" refers to the installation of helical piles under existing structures for the purposes of stabilizing and re-leveling the structures. "New foundations" refers to the installation of helical piles and tiebacks for new structures. Quality control, inspection and performance monitoring techniques are identical for both. Correct layout, penetration into the correct soil formation, capacity, and load transfer from the structure itself to the helical pile or tieback are central to successful performance.

2018 International Building Code

The recently published 2018 International Building Code contains requirements for helical piles. It is recommended that all helical pile projects be designed in accordance with this code. For assistance on using this code, please refer to Section 5.20.

Manufacturing Process and Quality Control During Manufacture

Quality control and inspection personnel should ascertain the method of manufacture. Such methods will have a direct bearing on the quality and performance of the installed helical pile or tieback.

All manufacturers of helical piles and tension anchors obtain the shaft and helix material from outside steel suppliers. Manufacturers should keep records of the steel supplier, steel strength, and heat number. Thus, if a problem occurs in material, the original component supplier can be contacted to prevent further problems.

All welded connections should be shop welded by certified welders to American Welding Society standards and to the correct strengths required for the helical pile or tieback factory rated capacities. All manufacturers should provide proof of weld certification and weld strength upon request.

Couplings are typically constructed by a cold-forged welded process (Photo 9-7), a modular keyed and locked process (Photo 9-8), or a hot-forged upset process (Photo 9-9).

The manufacturer should certify the coupling (and bolt, where used) is of correct steel strength and size to meet the factory rated capacity of the helical pile or tieback in both axial tension and compression loads and for installation torque transfer.

Photo 9-7
Cold-forged welded

Photo 9-8
Modular keyed and locked

Photo 9-9
Hot-forged Upset

Photo 9-10 Helix welded to the central shaft

The weld of the helix to the shaft is a critical element. The manufacturer must be able to certify this weld is compatible with the intended rated capacity of the helical pile. The helix must be able to withstand forces imposed upon it during installation, especially in dense soil and/or cobbles. Photograph 9-10 is of a typical helix welded to the shaft. Note the leading (lower) and trailing (upper) edges indicating clockwise installation. Photograph 9-10 shows an essentially straight leading edge with a beveled "rock cut." However, some manufacturers prefer a straight or rounded leading edge. Some field conditions may necessitate modifying a portion of the leading edge as shown in Figure 9-3 below to aid installation in cobble formations, although the helix shown above in Photo 9-10 is manufactured with the cut already on the leading edge by HELI-PILE®.

Material and Installation Specifications

Most manufacturers have developed specifications for their particular helical pile or tieback. Outside organizations such as Spec-Data® and Manu-Spec®, both of the Construction Specifications Institute, have been hired by some manufacturers to assist in developing specifications.

Specifications should include all components of the helical pile or tieback and installation requirements. Alternatively, specifications may call out manufacturers' names and their respective catalog numbers. Building code evaluation report numbers should be included.

Upon review of the various manufacturers' specifications, it will be noted that between manufacturers helical pile and tieback material is not equal, even if it has an equal visual appearance. Engineers and quality control and inspection personnel should familiarize themselves with the respective specifications and make their own evaluations as to the suitability of a particular manufacturer's material for their project.

Sample helical pile and tieback specifications are presented in Section 8.

Galvanization

It will be noted in the sample specifications given in Section 8 that galvanizing in accordance with ASTM B633 or A153 per Owner is specified. Proof of the galvanization process should be supplied by the manufacturer upon request.

Other corrosion protection coatings, such as hot-dip galvanizing per ASTM A153 or no coating whatsoever, as approved by the designer, are allowed and occasionally specified.

Installation Contractor Certification

The installation contractor should be required to show proof of certification to install the specified manufacturer's helical pile or tieback material if such is required by the manufacturer or the specification. Certification is confirmation that the installation contractor is trained and familiar with the installation of that manufacturer's material. Certification acknowledges the contractor has specialized knowledge beyond what is required for general construction. In addition to certification, the installation contractor should show project experience or, if new in the business, show that qualified personnel, either from the distributor or manufacturer, will be present for part, if not all, of the project.

Proof of certification is usually in the form of a pocket certificate card bearing the manufacturer's name, contractor's name, date of certificate expiration and the signature of the manufacturer's representative certifying the installation contractor is trained and qualified to install their helical piles or tiebacks.

It is recommended that, in addition to initial certification, the installation contractor be re-trained and re-certified at least every two years.

9.7 Procedures During Field Work

Field Layout

Field layout of helical piles and tiebacks may be performed by the design engineer, his or her representative, the general contractor, or the helical screw pile installation contractor. As on any project, quality control and inspection personnel must check layout work to ensure the piles or tiebacks are properly located.

At commencement of installation, it is important to maintain precise pile or tieback location. In most cases, however, especially if the designer has accounted for slight mislocation (±0.5 inch (±12.7 mm)), this is not a problem. If the mislocation is large, the engineer may need to know.

Experienced installation contractors have ways of ensuring alignment during installation. The more cobbly the formation, the more difficult it is to hold alignment during installation; the shaft can have a tendency to "walk" off its original location. Procedures have been developed to keep the shaft in place at commencement and while it is being installed. Experienced installation contractors should be consulted about such procedures.

Installation Requirements and Procedures

Installation Torque Measurement:

Helical piles and tiebacks are typically installed with hydraulic torque drive heads mounted to mobile equipment such as the boom of a backhoe or skid-steer type machine (see Photographs 11-1 and 11-2) or hand-carried equipment (see Photograph 11-5). Also, please see the "IMR Installation Equipment Photographs" pages 2-7 through 2-12 in SECTION 2. PHOTOS at the beginning of this book. Other types of installation equipment are acceptable as long as they can impart the necessary torque to the helical pile or tieback shaft.

Installation torque is a direct measurement of helical screw pile or tieback capacity (see Section 3). It is an indicator that the pile or tieback has penetrated the correct soil formation. Therefore, it is important that accurate torque measurements be made.

There are three ways to measure installation torque:

1. A mechanical device can be inserted between the installation torque drive head and the helical pile or tieback shaft. The most common device is called a "shear pin torque indicator." Photograph 11-11 is of a shear pin torque indicator. It utilizes short steel pins inserted in holes spaced around the circumference of a transversely split free-spinning cylinder. The holes penetrate the two halves of the cylinder such that when pins are inserted free-spinning cannot occur until the pins are sheared. The more pins inserted, the more force, or torque, is required to shear the pins.

Photo 9-11 Shear-pin torque indicator (limiter).

The shear pin torque indicator shown in Photo 11-11 has holes for 20 pins. For this particular device, each pin is worth 500 ft-lbs (0.68 kN-m) of installation torque. Therefore, if pins were inserted in all 20 holes simultaneously, it would require 10,000 ft-lbs (13.6 kN-m) of installation torque to shear all 20 pins.

In a typical helical pile or tieback installation, the procedure is to insert the number of pins required to measure the desired installation torque. Once the pins shear, the shear-pin torque indicator is loaded with a fresh set of pins and they are sheared again. Therefore, by shearing pins two times in immediate succession, one is assured that a correct and not false torque reading is obtained.

2. The second way is an electronic torque monitor. It is placed in the same location as the shear pin torque indicator. It has an electronic read-out that can be picked up by a smart phone.

3. The third way to measure installation torque is by reading torque directly from the installation device. In the case of a hydraulic torque drive head, there is a direct relationship between installation torque and the pressure drop across the motor. Most drive head manufacturers publish charts of output torque vs. hydraulic pressure drop.

As opposed to using published charts, sometimes precise torque vs. pressure measurements are not possible due to motor wear, weather conditions, and high hydraulic oil temperature. However, the torque vs. pressure relationship may be calibrated using the shear-pin torque indicator. This is done by reading the system pressure gauge at the moment pins are sheared and correlating the torque to the pressure. This method is used regularly on projects where it will be time consuming to use the shear-pin torque indicator on every pile or tieback. One merely correlates torque vs. pressure from time to time with the shear-pin torque indicator while the majority of piles or tiebacks are install-led by determining installation torque from reading the calibrated system pressure gauge.

Refusal

Refusal occurs when the helical pile or tieback does not advance further into the soil as it is rotated due to encountering hard earth material. Many helical piles are installed to this condition as this is usually an indicator of high compression load capacity. Low installation torque values occasionally accompany the refusal condition. This does not mean low compression capacity. Determination of the adequacy of the refusal condition should be made by the engineers involved in consultation with the installation contractor. Inspectors need to be aware that refusal is a common occurrence. See Section 5.7 for a detailed discussion of refusal.

Permanent Shaft Wrap or Twist

Most helical pile and tieback shafts are designed to undergo permanent shaft wrap or twist as the installation torque increases to the maximum factory rating. This occurrence is normal, acceptable, and is a visual indicator of high installation torque. However, the degree of permanent shaft wrap is not used as a precise measure of torque. Do not exceed the published maximum torque ratings for all helical pile shafts. For HPC15X and HPC17 solid square shaft, to avoid damaging the shaft, permanent shaft wrap should never exceed 1.5 revolutions in any five-foot (1.5 m) length. Permanent shaft wrap does not adversely affect galvanizing.

Field Observations and Installation Log

To assist the field inspector in recording accurate site observations during the installation of helical piles and tiebacks, an installation log should be kept and recorded by the inspector. The log should contain the field observation data listed in Section 3.2.2.7 of the sample extended specification given in Section 8. These items include, but are not necessarily limited to: a) Project name and location, b) Name of authorized and certified dealer and installer, c) Name of installer's foremen or representative witnessing the installation, d) Date of installation, e) Location of helical pile or tieback, f) Description of lead section including number and diameter of helices and extensions used, g) Overall depth of installation from a known reference point, h) Installation torque at termination of pile or tieback and i) Load transfer device. In addition, the pile or tieback field layout locations should be verified and recorded by the inspector.

Field Modifications

Shaft Field Modification: Helical pile and tieback depth will equal the depth of the soil formation where the desired installation torque will be reached. Because this depth is usually not exactly predictable, the top of the shaft left protruding above grade may not be at the correct elevation or position to attach to the structure properly. This necessitates cutting the shaft to the correct elevation or length. If the shaft is cut for a new foundation, it may then be necessary to drill a new hole in the shaft to bolt on the load transfer device, or the device must be epoxy glued or welded onto the shaft, depending on the specification. For underpinning, typically no rigid connection to an underpinning bracket is required because structure dead load is sufficient to keep the underpinning bracket rigid and in place.

Helix Field Modifications: It is allowable to reduce helix diameter in the field. Example: A 10 inch (254 mm) diameter helix may be reduced in diameter to 8 or 6 inches (203 or 152 mm) if the pile or tieback must penetrate into a denser formation than anticipated. The helix diameter should not be reduced below 6 inches (152 mm). For cobble conditions, the leading edge of the helix may be modified as shown in Figure 9-3 to ease penetration into the formation. Figure 9-3 shows a cross-section of the shaft and the helix where the leading edge has been modified, termed a "rock cut," for cobble conditions. HELI-PILE® produces all of its helices in this shape in the factory.

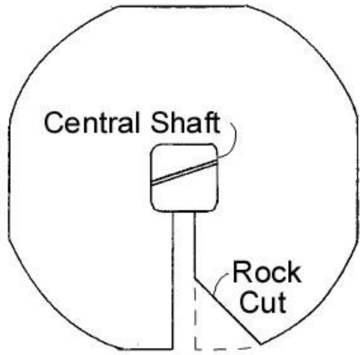


Figure 9-3. Shaft Cross Section, Rock Cut on Helix

<u>Load Transfer Devices</u>

Load transfer devices transfer structural loads to the helical pile or tieback shaft. These devices are typically designed by the structural engineer. They bolt, weld, epoxy glue to or slide over the end of the helical pile or tieback shaft. Figure 9-4 shows two load transfer devices used for new construction attached to the top of helical piles embedded in a new reinforced concrete grade beam (reinforcing not shown for clarity). Tiebacks typically transfer load via a threaded rod adapter with load plate and nut. For further load transfer device information, please see "Load Transfer Devices" under Section 5.18.

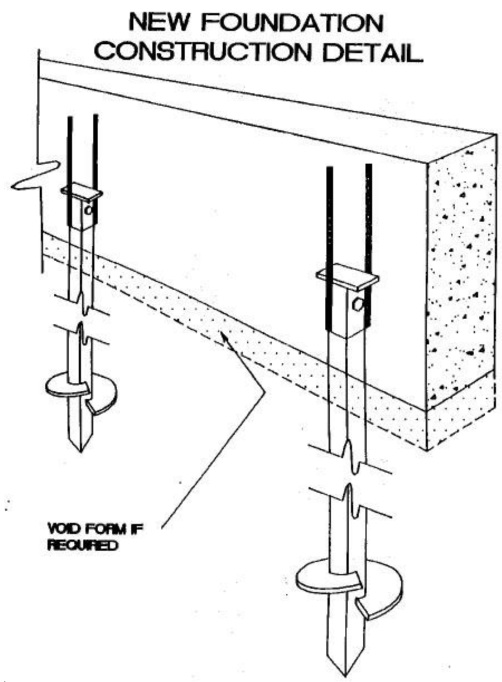


Figure 9-4. New Construction Bracket Embedded within a Reinforced Concrete Grade Beam

Figure 9-5 shows a load transfer device used for underpinning an existing foundation. In this particular bracket, a bottle jack is temporarily inserted in the bracket to allow the existing concrete foundation to be raised for re-leveling purposes.

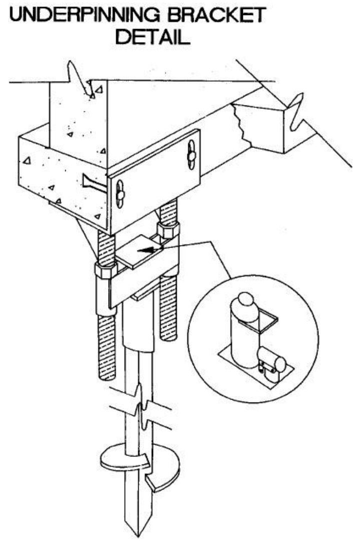


Figure 9-5. Underpinning Bracket used with Existing Foundations

Building Code and Specification Compliance and Special Inspection

As with any construction project, quality control and inspection personnel must be familiar with the building code having jurisdiction and the project specification. Prior to helical foundation or tieback installation, plan check personnel should review construction drawings and calculations for compliance. During installation, inspection personnel must check field materials and construction activities for compliance. Special inspection may be required. For the most part, the field inspection requirements are similar to those indicated in the sample extended specifications given in Section 8. These items include, but are not necessarily limited to: a) Project name and location, b) Name of authorized and certified dealer and installer, c) Name of installer's foremen or representative witnessing the installation, d) Date of installation, e) Location of helical pile or tieback, f) Description of lead section including number and diameter of helices and extensions used, g) Overall depth of installation from a known reference point, h) Installation torque at termination of pile or tieback and i) Load transfer device. In addition, the pile or tieback field layout locations should be verified and recorded by the inspector.

9.8 Performance Monitoring

Field Survey

Performance monitoring of helical piles and tiebacks is identical to the performance monitoring of any foundation or tieback system.

Since the purpose of the structural foundation is to provide a stable base upon which structural loads are transferred to the soil, performance monitoring measures the ability of the foundation to perform this purpose over the period of time of interest.

The key to effective performance monitoring of any foundation system used for the repair of existing failed foundations or for new construction is to first obtain the base data. Base data usually includes elevations of floors or other prominent points of the structure measured at the time of project completion. The points used must be accessible such that subsequent elevations can be measured from time to time throughout the monitoring period.

Many devices are available to perform floor elevation surveys such as a water manometer, surveyor's level and rod and a commercial device called a "Ziplevel®", a self-contained elevation measurement device accurate to 0.1 inch (2.5 mm) that can be operated by one man even in a building with doors, walls, and corners. (See www.ziplevel.com)

An example of the results of a floor elevation survey in a residential structure is shown in Figure 9-6, the floor plan of an existing building with elevations indicated at certain points. In subsequent years further surveys can be run to verify that the foundation continues to remain stable. This method is adaptable to any project.

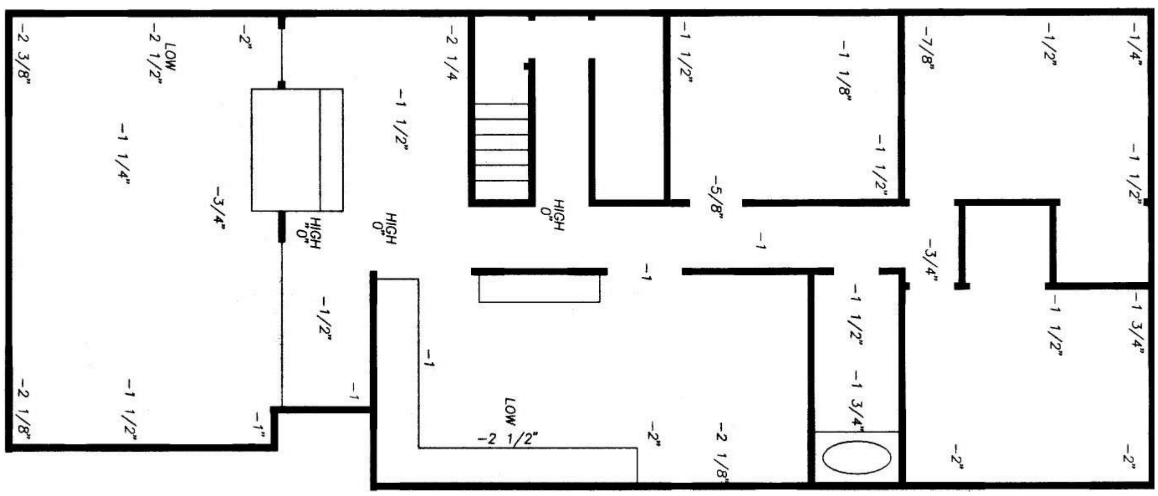


Figure 9-6. Sample Floor Level Survey for Base Data

Visual Monitoring

The most common method of performance monitoring is through visual observation. The most common observations made in new structures and existing repaired structures include, but are not limit to:

Buildings

Observe that:

1. Floors remain level.
2. Cracks in interior floors, walls, and ceilings remain the same size and do not reappear.
3. Cracks in exterior walls remain the same size and do not reappear.
4. Doors continue to fully open or close.
5. Doors continue to not swing open or closed.
6. Windows continue to fully open or close.
7. Cracks I foundation walls remain the same size and do not reappear.
8. Gaps under walls or between concrete porches and walks and the building wall remain the same size and do not reappear.

Earth Retention Structures
Observe that:
1. Retaining wall remains plumb.
2. Cracks in the retaining wall remain the same size and do not reappear.
3. Wall does not settle or heave.
4. There is no subsidence of soil behind the wall.

Cracks in walls, ceilings, floors, etc., can be monitored over time using crack measuring devices available from most engineering supply companies.

9.9 Example of a Step by Step Quality Control, Inspection and Performance Monitoring Program

A new three-story office building is to be constructed in an office park. The building is designed with a helical pile deep foundation in a city where the 2018 International Building Code (IBC) governs. The building was designed by a local architect who enlisted the services of local consulting geotechnical and structural engineers. The foundation plan containing the helical screw pile design is prepared by the structural engineer and bears his/her professional engineer stamp. The building permit was issued by the city where the building is located.

The helical screw piles are to be installed by "John Doe Foundation Company," a company licensed in the state to do helical pile work.

A step by step quality control, inspection and performance monitoring program for this project is given below:

1. Who is inspecting this helical screw pile installation?
Inspection is being provided by a consulting engineering firm specializing in construction inspection who is also designated as a "special inspector" per the IBC and the city building official.

2. Are the geotechnical and structural engineers involved with any inspection on this project as related to the helical piles?
Yes, but on an intermittent basis. The primary responsibility for inspection is with the inspection firm.

3. What helical screw piles are to be used?
The helical piles to be used in this building have been designed in accordance with the provisions of the 2018 International Building Code. The structural engineer has submitted shop drawings proving the manufacturer meets the project specification for helical screw piles.

4. What quality control programs are followed by the manufacturer to ensure a high-quality product?
All welders are AWS certified. Shop drawings indicate the helical pile steel meets the project specifications.

5. <u>What are the specific project requirements: helical pile sizes, torque requirements, layout, load transfer devices, etc.?</u>
The drawings and specification prepared by the consulting engineers indicate the general family of helical screw piles to be used and their specific material identifiers (see sample specification in the Section 8), design load for each pile, factor of safety to be used (typically 2), installation torque, layout and load transfer device. The specification requires the installation contractor to submit to the engineer specifics on what material he will install that will meet the engineer's specification, i.e., description of helical piles, catalog numbers, size and number of helices, size of shaft, etc. A written description or shop drawing with this information must be submitted to the engineer for approval.

The owner's surveyor is responsible for helical pile layout.

6. <u>Who has design responsibility for the helical piles themselves?</u>
The structural engineer-of-record is qualified to design and specify helical piles. His professional stamp appears on the drawings. If the structural engineer had not felt qualified, the soil engineer or a qualified engineer hired by the installation contractor or the manufacturer could stamp the drawings.

7. <u>Is John Doe Foundation Company qualified?</u>
The installation contractor is certified by the helical pile manufacturer to be qualified as evidenced by the certification card.

8. <u>When John Doe Foundation Company shows up to install the helical piles, is the correct material being brought on-site?</u>
The helical pile material has a visual appearance of galvanization. Most important, it is marked with the manufacturer's identification mark or code identifying it as the correct material. The dimensions of the material are verified to meet the specification. Therefore, the correct material is on-site.

9. <u>Is the correct installation equipment being utilized by John Doe Foundation Company?</u>
Being a certified installation contractor, it can be assumed the correct installation equipment for the helical pile material specified is to be used and that the equipment meets the project specification. However, the equipment should be observed during installation to verify it meets the specification and the installation procedures meet the specification.

10. <u>Is the shear-pin torque indicator prepared for measuring installation torque?</u>
Yes.

11. <u>Is the installation log ready for use?</u>
The installation log designed as described above under "Field Observations and Installation Log" is prepared for recording the pile lead section description, number of extensions and extension description, pile total depth, load transfer bracket or device, etc., for each helical pile installed.

12. <u>Is the helical pile layout correct?</u>
The owner's surveyor is responsible for the field layout of the helical screw piles. However, just prior to commencement of each helical pile installation, the field layout is observed and compared to the construction drawings to be reasonably sure the layout looks correct.

13. During installation, are all parameters being recorded as given on the log?
All parameters are being recorded.

14. Are the specified parameters being reached?
Yes, as shown by observation and recorded from the shear-pin torque indicator or pressure gauge on the hydraulic drive head calibrated by the shear-pin torque indicator.

15. Is permanent shaft wrap occurring?
Yes, but it is within the limits indicated by the manufacturer.

16. Are load transfer devices being installed as specified?
Yes.

17. Is special inspection being done if required?
Yes, the inspector is a certified IBC inspector.

18. Who will "sign off" on the helical piles after completion of the project as required by the city?
The structural engineer-of-record signs off on the helical piles as the original designer.

19. Who is responsible for performance monitoring?
The owner has contracted with the inspection firm to do the performance monitoring.

20. How is the performance monitoring base data being procured?
A level survey will be performed where the elevation of certain points will be measured and recorded. It has been determined that points on the main floor throughout the building are best. Therefore, a floor level survey will be performed immediately upon completion of the project.

21. How will performance over time be measured?
A new floor level survey will be performed six months after completion of the project. The owner will then decide when to do the next survey, if at all, based on the results of the new floor level survey and advice from the geotechnical and structural engineers of record.

9.10 Conclusion to Quality Control, Inspection & Performance Monitoring

Quality control, inspection and performance monitoring for HELI-PILE® helical piles and tiebacks is a straight-forward process easily learned and executed. Most of the process is identical to all deep foundation and tieback construction projects, only a few procedures are unique to the helical pile and tieback industry. The information contained in this section will allow all design and construction professionals to properly and accurately perform the quality control, inspection and performance monitoring function.

END OF SECTION 9

SECTION 10. CONTRACTS

Helical pile contracts are organized similarly to those of drilled shafts, except they are written to furnish and install material. If much sub-surface information is known about a particular site, especially the results of helical pile test installs, the contractor may lump sum bid the piles or tiebacks, regardless of depth. If there is not sufficient sub-surface information available, the contractor may bid each pile or tieback on a per foot basis of installed pile or tieback. However, the most common contract calls for a base depth plus an overrun of a certain number of dollars per foot deeper than the base depth.

It should be emphasized that, as in all geotechnical construction, the more that is known about a site, the more economical the project will be. Sub-surface soil investigations, especially where test helical piles or tiebacks have been installed, are welcomed.

SECTION 11. COSTS

The existence of thousands of specialty helical pile contractors in business throughout the world attests to the fact that helical piles are competitive with other types of deep foundations. This is true for new foundations, including heavily loaded foundations, as well as the repair of existing foundations.

It is impossible to delineate representative costs herein because, as any experienced geotechnical engineer and/or contractor knows, each site is so different, each case so unique, it is impractical to give “rules of thumb” or even representative guidelines. Local specialty contractors are willing and able to provide estimates. In preparing engineer’s estimates, these local specialty contractors should be contacted directly. Local specialty contractors know the soils in a particular area which allows them to give responsive bids and estimates. HELI-PILE® has many such installation contractors throughout the country.

SECTION 12. CONCLUSION

HELI-PILE® helical piles and anchors are viable and accepted deep foundations and anchors for the construction of new and the repair of heavy and lightly loaded structures and earth retention, respectively. The design methodology for helical piles and anchors is similar to the design methodology for any deep foundation or tension anchor system. Proper placement of vertical and, when needed, battered helical piles allows all vertical and lateral loads to be transferred from the structure to the soil. The designer must utilize the data provided by a soil investigation to check the helical piles for minimum depth, minimum installation torque requirements, load capacity, slenderness buckling, and corrosion. By following the straight-forward procedures presented herein, the designer can design an economical and rapidly installed deep foundation or anchor system.

Whenever soil conditions at a particular site suggest that a deep foundation system or earth retention system should be considered, the wise design professional should consider helical piles and anchors along with the other deep foundation and anchor alternatives available. So long as all technical requirements of the project are met, the economics and schedule requirements and constraints should dictate which foundation system is selected.

END OF SECTIONS 10, 11 & 12

HELI-PILE®

SIMPLIFIED DESIGN AND INSPECTION GUIDE
March 2020

NOTES