

DEEP

FOUNDATIONS

Foundations have been around since the construction of ancient buildings and structures. The Pyramids were probably the most stable of these ancient structures, as they are still standing. The builders of that era had enormous resources of human labor to cut stone, transport, and place one stone on top of another. Unfortunately, manpower, funding, and site conditions constrain us from building the majority of our structures to the magnificence that was available to our Egyptian predecessors.

Our modern engineering community has divided foundations into two categories, shallow and deep. The following articles address two manufacturers' concepts of deep foundations using steel helixes welded to steel pipe or solid bar shafts to be "screwed" into a soil substrate. The terms of "piles", "screw piles", and "helical anchors" may be used interchangeably.

Screw pile load capacity verification is similar to using a "blows per foot" correlation for driven piling. The engineer can rely on correlations between applied torque and depth of penetration, in known soil type-stratifications for a helical tension or compression anchor's ultimate axial load capacity.

Thoughtfully approached, structural engineers can prepare helical anchor layout patterns that will address varied soil conditions encountered during screw pile installation with reasonable assurance that a required anchor pattern's gross capacity can be achieved.

Helical anchors self-test during installation. Geotechnical engineering services are invaluable for real-time verification of ultimate capacities by observing the applied torque and installation depth in known competent soil stratifications. Best-practice procedures demand a structural-geotechnical team effort for critical-installation risk management.

HELICAL FOUNDATIONS...

What an Engineer Needs to Know

By Gary Seider, P.E.

The Basics of a Helical Deep Foundation

A helical foundation consists of at least one helix-shaped steel bearing plate attached to a central steel shaft. The shaft is typically solid steel bar (1½ to 2¼ inches square) or heavy wall pipe (2⅞ to 8 inches in diameter). The helix plates are high-strength steel (6 to 16 inches in diameter, ⅜ or ½ inch thick). Each helix is circular in plan, formed into a screw thread with a defined pitch (typically 3 inches).

Installation is by hydraulic motors mounted to virtually any type of machine. Portable equipment is available for such tight access areas as crawl spaces, basements, and narrow alleyways. Percussion drilling equipment is not used. The five to 25 rpm high-torque motor provides rotational energy and the machine provides crowd (down pressure), necessary for installation. The helical foundation is rotated (screwed) into the ground to advance one pitch distance per revolution. Helical foundations can be fully extendable; so that the helix plates can be installed to any specified bearing depth.

A helical foundation can be used to resist both uplift and compression loads. Installed to proper depth and torque, the helix plates serve as individual bearing elements to support a load. The central shaft, which transmits torque during installation, now transfers axial load to the helix plates. The central steel shaft also provides resistance to axial load via skin friction and to lateral loads via passive earth pressure.

Why Use Helical Foundations?

Low Mobilization Costs: Helical foundations are typically installed with small equipment such as a rubber-tired backhoe. This eliminates the high mobilization costs associated with equipment used to install driven piles, drilled shafts or auger-cast piles. Remote location or difficult access sites also increase mobilization costs, which makes helical foundations a better choice.

Expansive soils: The bearing plates of helical foundations are usually placed below the depth of seasonal moisture variation. The swell force on a shaft

is directly proportional to the surface area contact between the soil and shaft. Since helical foundations have smaller shafts than conventional piles, uplift forces are smaller.

Year-round installation: Helical foundations can be installed in any weather because there is no need for concrete or grout. This allows work to proceed without interruption.

Temporary structures: Helical foundations can be removed by reversing the installation process. During the 2002 Winter Olympic Games in Salt Lake City, helical foundations were used to support temporary grandstands and judging booths at various venues, and the huge information signs that informed visitors about events.

Remedial applications: The largest present day market segment for helical foundations is remedial underpinning. They can supplement or replace existing foundations distressed by differential settlement, cracking, heaving, or general foundation failure. Helical foundations are ideal for remedial work since they can be installed in confined, interior spaces. The work is low-impact with minimal damage to landscaping or disruption to building occupants.

Feasibility Considerations

Loads: Design compression and tension loads for helical foundations range between 12.5 and 50 tons. The soil is generally the limiting factor as the number and size of helical foundations can be varied to suit the application.

Soils: Helical foundations can be installed into soils with a blow count (N-value) less than 80 blows/foot of the 2-inch OD sampler per ASTM D-1586. A limitation of screw foundations is they cannot be installed into competent rock or very hard, dense soil greater than about 80 blows/foot.

Design Theory

Several methods exist to design helical foundations and to predict their performance under load. Two of those methods are Bearing capacity and Torque correlation.

Bearing Capacity

The Terzaghi general bearing capacity equation suggests that the total capacity of a helical foundation, either in tension or compression, is equal to the sum of the capacities of each individual helix plate. Calculating the unit bearing capacity of the soil and applying it to the individual helix plate areas determine the helix capacity. The bearing capacity method predicts capacity reasonably well when adequate soil data is available. Soil data is typically provided by the geotechnical report. If soil data is lacking or not available, other design methods are required.

Underpinning application of helical foundations.



Installing helical foundations for structural slab support.

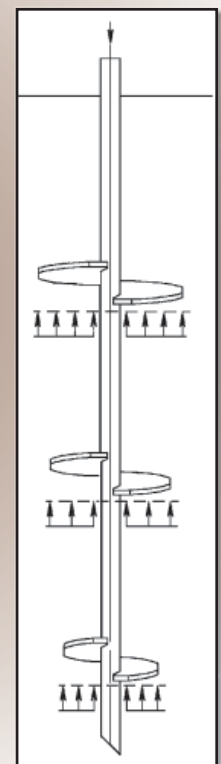


Plate bearing-capacity model.

Torque Correlation

The empirical relationship between installation torque and capacity is considered to be the greatest attribute of helical foundations. The relationship is: As a helical foundation is installed (screwed) into increasingly denser/harder soil, the resistance to installation (called installation energy or torque) will increase. Likewise, the higher the installation torque, the higher the axial capacity of the installed helical foundation. The relationship can be described in the following equation:

$$Q_U = K_t \times T$$

Q_U = Ultimate capacity of screw pile

K_t = Empirical torque factor

T = Average installation torque

The value of K_t may range from 3 to 20 ft, depending on the soil conditions and design parameters (principally the shaft size). For square shaft, it typically ranges from 10 to 20. For pipe shaft, it typically ranges from 3 to 10 ft. Torque monitoring tools provide a good method of production control during installation.

Capacity Verification

The engineer can use the relationship between installation torque and load capacity to establish minimum torque criteria for the installation of production helical foundations. The recommended default values for K_t [10

for square shaft and 7 for 3½ -inch OD pipe shaft] will typically provide conservative results. For large projects, a pre-production load test program can be used to establish the appropriate torque correlation factor (K_t) for the existing project soils.

Other Design Issues

Factor of Safety: For compression loads, a factor of safety of 2 has historically been sufficient to account for the inevitable uncertainties in soil, installation, and manufacture. In some instances, as with tiebacks for earth retention, the factor of safety can be less than 1.5.

Helical Foundation Spacing: The recommended center-to-center spacing between adjacent helical foundations is five times the diameter of the largest helix. The absolute minimum spacing is three diameters. Minimum spacing requirements apply only to the helix plate, which means the central shaft can be battered to obtain adequate spacing.

Design Assistance: For design assistance at any step in the design process, including capacity design, helical foundation selection, corrosion, lateral/buckling concerns, and specifications, contact your local helical foundation installer or distributor. They will either assist you directly, or refer your inquiry to the manufacturer. The Design Algorithm



Earth retention application with helical tiebacks.

flowchart demonstrates the steps involved in the design of a helical foundation.

Bidding

If satisfactory soils information is known about a particular site, the contractor may lump sum bid the helical foundations or anchors, regardless of length. Lump sum bids are popular with owners because the price is known up-front.

The price per foundation with add/deduct bid is typically used when little to no soil information is available. It is probably the most common type of contract. A pre-determined bid length is used, with an add/deduct amount per lineal foot to accommodate variations in subsurface conditions.

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SCREW PILES...

Uses and Considerations

By Richard Schmidt, P.Eng. and Mamdouh Nasr, M.Eng.

Screw Piles, also known as Screwed, Screw-In, Torque and Helical, Piles, Piers or Anchors consist of a steel center pipe and one or more steel screw flights welded near the toe of pipe and sometimes at intervals along the shaft. Advancement in installation equipment has quickly changed the screw piling industry, from relatively small diameter pipes, 4½-inch and smaller, to 10¾-inch, 12¾-inch and upwards to 36-inch pipes now being screwed into the ground.

Screw piles have been used widely in engineering applications to provide structural stability against axial compression, uplift tension, overturning moment and lateral forces. The structural and geotechnical design of these piles is ever evolving. Many different design methods have been used to design screw piles; two will be discussed:

- Narasimha Rao et al (1993) for the design of screw piles in cohesive soils
- Mitsch and Clemence (1985) for the design of screw piles in cohesionless soils.

Screw piles are becoming a more common structural foundation in everyday construction sites, but really shine where there are problems in terms of poor foundation material and/ or remote locations with limited access.

Screw Pile Uses

Screw Pile installations are performed for a variety of different uses:

Transmission, Forestry, and Communication Towers; Wood and Steel Power Poles; Steel and Wood Frame Building; Small and Medium Commercial Structures; 3-Story Camp Pre-Manufactured Building; Grain, Feed and Sand Hopper-Bottom Bins and Silos; Arch-Ribbed Open Span Structures; New Home Construction; Manufactured Homes; Oilfield Structures: Pumpjacks, Compressors Skids, Pipe Racks, De-Hydrators, Knock-Outs, and Flare Stacks; Pipeline Buoyancy Control; Fall Protection Systems; Lakeshore Docks; Floating Dock Moorings; Boardwalks; Retaining Walls; School Portable Buildings; Truck Scales; Plant and Sub-Station foundations; Garages; Decks; and a variety of other structures.

On some screw pile sites the construction of conventional foundation systems, like bored or driven piles, were precluded due to high water table and difficulty of access for equipment and material.

Screw Pile Sizes & Selection

Table 1 shows available sizes and size ranges for helix to pipe fit. The minimum sizes are the smallest physical sizes that will fit on the pipe, and the maximum are the largest practical sizes available.

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

The critical factors that dictate the helix size are axial load, tension load, torque consideration, installation equipment, soil conditions and pipe shaft size (see Table 2).

Table 2 lists the most common and readily available pipe shaft sizes.

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

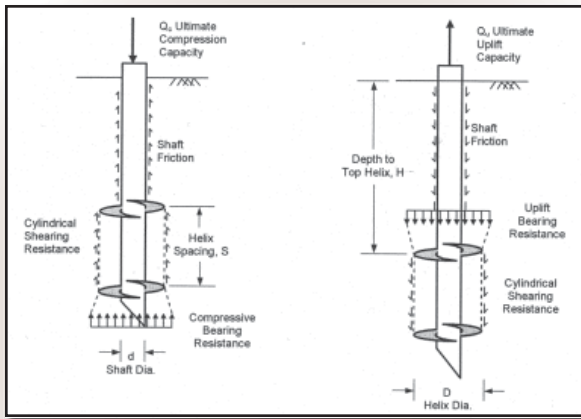
Pipe Shaft Outside Diameter	Common Wall Thickness (Almita common)	Maximum Torque (Ft.Lbs.)	Safe Working Load =.35 A Fy (Lbs.)
2-7/8"	0.217	8,000	34,900
3-1/2"	0.254	11,000	49,900
4-1/2"	0.250, 0.237	21,500 20,400	52,600
5-1/2"	0.275	43,600	71,100
6-5/8"	0.280, 0.250	53,900	87,900
8-5/8"	0.264, 0.322	67,000 81,200	+100,000
10-3/4"	0.365, 0.250	+90,000	+100,000
12-3/4"	0.375, 0.250	+90,000	+100,000

Steps in Pile Selection:

1. Determine applied loads on Pile: Vertical, Lateral, Moments, Safety Factors and Maximum acceptable movement criteria.
2. Determine site specific soils information: Soil Type, Soil Description, Soil Classification, Water Table Levels and Depth of Frost Penetration.
3. Compare soils information with pile load and location information. Pile spacing – is there a group effect among piles?
4. Design Pile – Pile Geometry (The helix diameter and number of helixes are selected based on the soil parameters and the load the pile is designed to support) Select: Pipe Shaft, Helix Diameter and Thickness, Number of Helixes, Embedment Depth, Extension Required? Bolt-On or Welded?
5. Estimate installation torque. The central steel pipe shaft transmits the applied torque during installation and transfers the axial compressive or tensile loads to the helixes during loading.
6. Evaluate Design – Practical? Can designed pile be installed? Do soil conditions allow for installing? Equipment/Power? Possibly repeat Step 4.
7. Calculate ultimate pile capacity and apply Safety Factors (Minimum S.F. = 2.0).

These steps are to be used as a guide in the pile design process; other factors may come into play when designing a screw pile (i.e. seismic considerations, soil chemistry, etc.).

Screw piles, like any other underground steel structure, need special attention paid to corrosion protection. This can be taken into consideration with extra thickness added to the structural required thickness, hot dip galvanization or providing a cathodic protection system; whichever suits the needs and requirements of a specific project.



Screw Pile in Compression and Tension Loading

The steel pipe shaft conforms to ASTM A252, Grade 2 or 3; the Helical Plates conform to CAN/CSA-G40.21-M, ASTM A36 or 44W; and the welding conforms to CSA W59.1 and Almita Manufacturing Ltd. is W47.1 with the Canadian Welding Bureau (CWB).

Disadvantages and Limitation in Use of Screw Piles

Soils which are not conducive to screw piles: Shales, Sandstone, Siltstone, very Rocky Soil with few fines (ie. Pit-Run Gravel), Compacted and Frozen Saturated Soil, Soil that is Dense, Stiff or Hard with Cobbles or Boulders, and Bedrock. (Even though these are problematic soils, remedies can be found for most soil types and load cases).

Advantages over Driven and Bored Piles

- Screw Piling rigs can reach up to 25 ft. in front of rig
- Install Rig can reach over fences/walls/berms/obstacles
- Work above eaves/roof with extensions
- Work on slopes
- Varying sizes of equipment for working inside buildings
- Light-weight installing equipment which allows work in poor site access locales
- Work in close proximity to buildings
- Little noise and/or vibration on sensitive sites
- Minimal tailings – Less site cleanup
- Structural load can be applied immediately after installation

Load Transfer Mechanism

During loading, the force applied to the pile is transferred to the surrounding soil. Thus, the ultimate capacity of the pile is dependant upon the strength of the soil. Soils derive their strength and ultimately their load capacity from several characteristics like the internal friction angle ϕ , the adhesion factor α , the effective unit weight of the soil γ and the undrained shear strength of the soil S_u . Part of the load will be transferred to the soil through the pile shaft (adhesion between shaft and soil) and part will be through the helix (bearing). If there is more than one helix, the last part will be transferred to the soil through the cohesion between the column of soil between the helixes and the surrounding soil. Especially in clayey soils, when the piles are subjected to uplift, a suction force will also be present (which increases the pile uplift capacity).

The Geotechnical Engineer will decide the pile shaft diameter, shaft length, helix diameter as well as helix depth, while the Structural Engineer will design the required pile shaft wall thickness to withstand the design load, the torque required for installation, the helix (or helixes) thickness and the welding size.

Design of Double Helixes Screw Piles in Cohesive Soils (Uplift)

$$Q_U = (N_U * S_U + \gamma * H) * \Pi/4 * (D^2 - d^2)$$

$$Q_{SHAFT} = \alpha * S_U * \Pi * d * H_{EFF}$$

$$Q_{HELIX} = Sf * S_U * \Pi * D * L$$

$$Q_{ULT} = Q_U + Q_{SHAFT} + Q_{HELIX}$$

Where

Q_{ULT} = Total Ultimate Pile Capacity

Q_U = Ultimate Uplift Bearing Load

Q_{SHAFT} = Ultimate Shaft Resistance

Q_{HELIX} = Ultimate Interhelix Resistance

N_U = Uplift End Bearing Factor for Clay (= 9 for $H/D > 4$; Narasimha Rao et al, 1991)

S_U = Undrained Shear Strength of Soil

γ = Effective Unit Weight of Soil

H = Depth to the top Helix

D = Helix Diameter

d = Shaft Diameter

α = Adhesion Factor (= 0.4 in Soft to Stiff Clay; Tomlinson 1994)

H_{EFF} = Effective Height

Sf = Spacing Ratio Factor

L = Distance between Top and Bottom Helixes

The value of Sf was believed to be 1 if $S/L \leq 1.5$ (Narasimha et al 1993), but after extensive tests done by Almita and University of Alberta they proved, for Alberta soils, this factor = 1 if $S/L \leq 3$ (Almita 2002)

Effective Height H_{EFF}

Narasimha et al, 1993, stated that there was an ineffective length of the pile shaft that could be mobilized. They assumed the soil above the top helix mobilized in uplift could be evaluated similar to that below a deep foundation in bearing. Zeevaert, 1983, had shown that the failure zone extends over a depth of almost twice diameter below the tip of pile loaded in compression.

H_{EFF} can be simply assumed to be $(H - 2 * D)$ for a long pile with no tension cracks and no frost zone.

Design of Double Helixes Screw Piles in Cohesionless Soils (Uplift)

$$Q_U = ((Fq^*) * H + \gamma * H) * \Pi/4 * (D^2 - d^2)$$

$$Q_{HELIX} = 1/2 * \Pi * Da * \gamma * (H_2^2 - H^2) * K_U * \tan \phi$$

$$Q_{SHAFT} = Ps * H * 1/2 * \gamma * H * K_U * \tan \phi$$

(Das 1990)

$$Q_{ULT} = Q_U + Q_{SHAFT} + Q_{HELIX}$$

Where

Q_{ULT} = Total Ultimate Pile Capacity

Q_U = Ultimate Uplift Bearing Load

Q_{SHAFT} = Ultimate Shaft Resistance

Q_{HELIX} = Ultimate Interhelix Resistance

Fq^* = Breakout Factor

H = Depth to Top Helix

γ = Effective Soil Unit Weight

D = Top Helix Diameter

d = Shaft Diameter

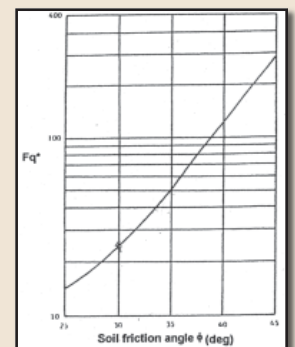
Da = Average Helix Diameter

H_2 = Depth to Bottom Helix

ϕ = Sand Friction Angle

K_U = Coefficient of Lateral Earth Pressure in Uplift for Sand (Mitsch and Clemence, 1985)

Ps = Perimeter of the Screw pile shaft.



Variation of Breakout Factor with Embedment Depth for Deep Anchor

TABLE 3	
Values for the Modulus of Subgrade Reaction for Lateral Loads on Piles in Cohesive Soils	
Loading Conditions	Modulus of Subgrade Reaction (MN/m ³)
Sustained Lateral Loads	(7 / D*)
Cyclical Lateral Loads	(5 / D*)
Transient Lateral Loads	(9 / D*)

*D = Pile Diameter (m)
The above values are applicable to lateral displacements of 6mm or less at the ground line.

Design of Screw piles for Lateral Loads in Cohesive Soils

Using Broms Method

$$\beta = (K * d / (4 * E_{PILE} * I_{PILE}))^{1/4}$$

Where

K = Modulus of Subgrade Reaction

d = Pile Shaft Diameter

E_{PILE} = Elastic Modulus of Pile

I_{PILE} = Moment Of Inertia of the Pile Section

Using that in chart (see figure top right)

Where

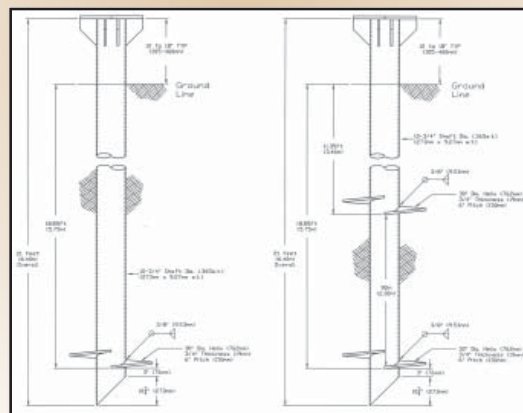
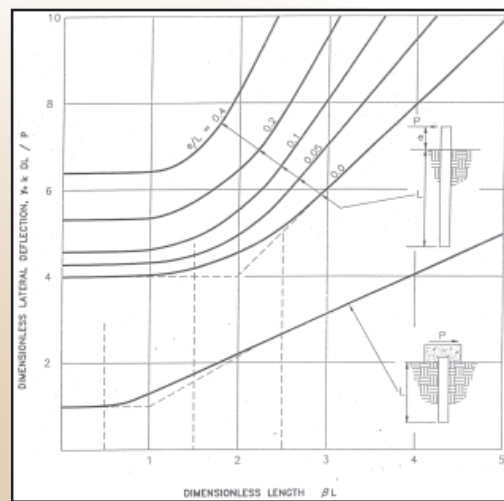
L = Pile Length

Y₀ = Pile Head Movement

P = Horizontal Load

And according to the maximum allowed Head movement, the ultimate pile Horizontal load can be determined.

For a full size version of graphics visit www.structuremag.org.



Compression and Tension Screw Piles

Summary of Actual Large Capacity Screw Pile Load Tests

Besides the many tests Almita has performed in conjunction with the University of Alberta on Screw piles, two Large Capacity pile load tests on Screw piles were done. The results are presented below:

1. Ruth Lake Project - Fort McMurray, Alberta, Canada

Soil Description

- 0 – 2 feet (Top Soil)
- 2 – 8 feet (Clay)
- 8 – 20 feet (Clay Till)

Pile Description

Two piles were used for testing to failure (Compression, Tension and Lateral tests were done for each pile type).

Test results summary

Please refer to Tables 4 & 5 for ultimate design loads and actual test load for all tested piles.

2. Dover Substation Project - Fort McMurray, Alberta, Canada

Soil Description

- 0 – 4 feet (Sand- Medium dense)
- 4 – 8 feet (Clay Till)
- 8 – 20 feet (Sand- Dense)

Pile Description

Pile Diameter = 16 inches, Length = 16 feet, with single Helix diameter = 30 inches. This pile was proposed to have a safe working tension load of 92.2 Kips. The pile was tested (Tension) to 224.8 Kips (2.5 Working load) then unloaded to zero, then reloaded with the intention to go to failure but due to test Jack limitation test was ceased at 404.7 Kips.

Test results summary

The first load cycle showed 0.787 inches total upward movement (0.630 inches when unloaded to Zero Load).

The second load cycle showed 1.339 inches total upward movement (1.102 inches when unloaded to Zero Load).

Pile Shaft ultimate resistance = 224.8 Kips (Van Weele, 1957)

Pile expected Ultimate resistance = 719.4 Kips (Mayerhof, 1968)■

TABLE 4				
Comparison of Predicted and Measured Axial Pile Capacities				
Pile Type and Loading Condition	Measured Load at Percent Total Displacement * (kN)		Interpreted Ultimate Capacity (kN) from Load Test	Predicted Ultimate Capacity (kN)
	@ 1% Helix Diameter	@ 2% Helix Diameter		
Single Helix Compression	369 (83Kips)	522 (117Kips)	1010 (227Kips)	980 (220Kips)
Double Helix Compression	462 (104Kips)	671 (151Kips)	1369 (308Kips)	1305 (293Kips)
Single Helix Tension	334 (75Kips)	471 (106Kips)	809 (182Kips)	800 (180Kips)
Double Helix Tension	547 (123Kips)	717 (161Kips)	1307 (294Kips)	1030 (232Kips)

TABLE 5			
Comparison of Predicted and Measured Lateral Loads			
Pile Type and Loading Condition	Measured Lateral Load at Specified Displacement near Ground-Line (kN)		Predicted Sustained Load @ 6mm (kN)
	@ 6mm (.236") Displacement	@ 12mm (.472") Displacement	
Single Helix Lateral	24 (5.4Kips)	39 (8.8Kips)	35 (7.9Kips)
Double Helix Lateral	25 (5.6Kips)	37 (8.3Kips)	35 (7.9Kips)

Richard Schmidt, P.Eng., serves as the Engineering Manager for Almita Manufacturing, Ltd., Alberta, Canada. Mamdouh Nasr, M.Eng., is a Geotechnical Engineer with Almita. www.almita.com

An expanded version of Deep Foundations, including additional figures, can be found online at www.structuremag.org.