How to Design Helical Piles per the 2009 International Building Code

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ABSTRACT

Helical piles and anchors have been used in construction applications for more than 150 years. The first recorded use of helical piles was in 1836 by Alexander Mitchell when he used helical piles to underpin the Maplin Sands Lighthouse in England. Helical piles have gained in popularity to the extent they are more frequently used compared to many other deep foundation types in some geographical areas. In the past, helical piles were an interesting alternative that some geotechnical engineers would take into consideration in some special cases. Helical piles are barely mentioned in undergraduate and graduate civil engineering studies. Now helical piles are widely known by most practicing engineers and should be considered an essential part of any foundation course. Even owners and developers are beginning to request helical piles due to their versatility and high capacities in both tension and compression. The International Code Council (ICC) has also taken notice of the growing use of helical piles.

Chapter 18 'Soils and Foundations' of the 2009 International Building Code (IBC) has been completely revised in its entirety in reference to past International Building Codes and includes the addition of helical piles. This paper was written to aid foundation design engineers and specifically discusses how to design helical piles per the 2009 IBC with excerpts and commentary applicable to helical piles. Most of the IBC section excerpts presented in this paper are not new and exist in past IBC codes. This paper has sought to include all the applicable code sections so that the designer will have a better understanding of the design process of helical piles and the intent of the code.

SECTION 1802 - DEFINITIONS

Section 1802.1 defines a helical pile as:

> **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.*

Some of the terms used in this paper may be unfamiliar to the reader, or may be used with a specific meaning not commonly known outside the helical pile industry. In determining the meaning of any term used herein, a definition contained in the following list shall take precedence.

Helix Plate – A round plate formed into a ramped spiral. When rotated into the soil, the helical shape provides thrust along its longitudinal axis thus aiding in pile installation. After installation, the plate transfers axial load into the soil through bearing.

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Lead Section - The first helical pile section installed into the soil consisting of one or more helical plates welded to the pile shaft.
Extension – A pile section without helical plates. Extension(s) are installed after the lead section. Each extension is connected with integral couplings which provide a rigid load transferring connection. Their purpose is to extend the lead section with helical plates to a load bearing stratum.

Helix Driver – A high torque hydraulic motor used to advance (screw) a helical pile into the soil to a load bearing stratum. Depending on the capacity of the helix driver, it may be either hand held or machine operated.

Torque Rating – The maximum torque energy that can be applied to a helical pile during installation into the soil.

Installation Torque – The resistance generated by a helical pile when installed into the soil. The installation resistance is a function of the strength properties of the soil the helical piles are being installed in as well as the shaft geometry of the pile shaft and helical plates.

Crowd – Axial compressive force applied to the head (top) of the helical pile shaft during installation as required to ensure the pile progresses into the ground with each revolution a distance approximately equal to the helix pitch.

Deep Foundation Element – A pier or pile used to transfer structural loads through unstable soils and into a suitable load bearing stratum.

Bearing Stratum – The undisturbed soil layer at any pile excavation location which provides a significant portion of the axial resistance of an installed helical pile bearing on one or more of the pile helical plates.

SECTION 1810 – DEEP FOUNDATIONS

Section 1810 includes all deep foundation elements specifically mentioned in the IBC. Excerpts pertaining to the design criterion of helical piles have been extracted from this section for review and discussion.

> **1810.2.1 Lateral Support.** *Any soil other than fluid soil shall be deemed to afford sufficient lateral support to prevent buckling of deep foundation elements in accordance with accepted engineering practice and the applicable provisions of this code.*
>
> *Where deep foundation elements stand unbraced in air, water or fluid soils, it shall be permitted to consider them laterally supported at a point 5 feet (1542 mm) into stiff soil or 10 feet (3048 mm) into soft soil unless otherwise approved by the building official on the basis of a geotechnical investigation by a registered design professional.*

Traditionally the IBC has used the section for lateral support to define the minimum unbraced length a deep foundation element must be designed for. The first paragraph of Section 1810.2.1 is new in reference to the previous International Building Codes and is somewhat contradictory to Section 1810.2.2 – Stability; which defines a laterally braced deep foundation element.

Most engineers interpret the code to mean that deep foundation elements that are not clearly defined as a laterally braced pier or pile must be designed in accordance to the minimum unbraced length as defined in the code. The minimum unbraced length is defined in the second paragraph of Section 1810.2.1.

The first five (5'-0) feet of a pier or pile placed in a stiff soil should be considered unbraced unless the pier or pile is defined as laterally braced in all directions by the IBC in Section 1810.2.2. In a soft soil, the first ten (10'-0) feet is considered unbraced. Most geotechnical engineers classify a soft soil as having an N-value of 4 or less and a stiff soil as having an N-value of 5 or greater.

Most remedial underpinning performed on existing structures will be defined as unbraced deep foundation elements. When a side load bracket or haunch is used to transfer structural loads to a pile or pier, the pile must also be designed to resist the eccentricity. The eccentricity is normally taken as the distance from the vertical face of the footing or bearing wall to the center of the pile.

> **1810.2.2 Stability.** *Deep foundation elements shall be braced to provide lateral stability in all directions. Three or more elements connected to a rigid cap shall be considered braced, provided that the elements are located in radial directions from the centroid of the group not less than 60 degrees (1 rad) apart. A two-element group in a rigid cap shall be considered to be braced along the axis connecting the two elements. Methods used to brace deep foundation elements shall be subject to the approval of the building official.*
>
> *Deep foundation elements supporting walls shall be placed alternately in lines spaced at least 1 foot (305 mm) apart located symmetrically under the center of gravity of the wall load carried, unless effective measures are taken to provide for eccentricity and lateral forces, or the foundation elements are adequately braced to provide for lateral stability.*
>
> **Exceptions:**
>
> 1. **Not included as it pertains to cast-in-place concrete piers only.*
> 2. *A single row of deep foundations without lateral bracing is permitted for one- and two-family dwellings and lightweight construction not exceeding two stories above grade plane or 35 feet (10 668 mm) in building height, provided the centers of the elements are located within the width of the supported wall.*

As previously stated, Section 1810.2.2 defines a fully braced deep foundation element. In previous International Building Codes, the code always preceded the definition of an unbraced foundation element with that of a braced foundation element. The reason for the change in the 2009 IBC is unclear.

> **1810.2.5 Group Effects.** *The analysis shall include group effects on lateral behavior where the center-to-center spacing of deep foundation elements in the direction of lateral force is less than eight times the least horizontal dimension of the element. The analysis shall include group effects on axial behavior where the center-to-center spacing of the deep foundation elements is less than three times the least horizontal dimension of an element.*

Due to the slenderness of the central shaft of a helical pile, the group effect on the minimum horizontal spacing is much larger than the code allows. Industry standards are that a group efficiency analysis must be performed on helical piles with a center-to-center spacing less than three times the largest helical plate diameter of the pile. For example, a helical pile with an 8"-10"-12" helical plate configuration on the lead section must not be spaced closer than three (3'-0) feet center-to-center without performing a group efficiency analysis.

SECTION 1810.3 – DESIGN AND DETAILING

> **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.*

Your local Ram Jack Dealer can provide you with details, mechanical strengths, section properties and torque ratings of all the Ram Jack helical products. This information as well as AutoCAD drawings are available online at www.ramjack.com .

> **1810.3.2.6 Allowable Stresses.** *The allowable stresses for materials used in deep foundation elements shall not exceed those specified in Table 1810.3.2.6.*

TABLE 1810.3.2.6
ALLOWABLE STRESSES FOR MATERIALS USED IN DEEP FOUNDATION ELEMENTS

MATERIAL TYPE AND CONDITION	MAXIMUM ALLOWABLE STRESS[a]
3. Structural steel in compression Helical piles	$0.6\,F_y \leq 0.5\,F_u$
5. Structural steel in tension Helical piles	$0.6\,F_y \leq 0.5\,F_u$

a. F_y is the specified minimum yield stress of structural steel; F_u is the specified minimum tensile stress of structural steel.

All of Ram Jack's central pile shafts are a special manufactured ASTM-A500 Grade C steel and has a minimum yield strength of 65 ksi and a minimum tensile strength of 80 ksi. All the helical plates are manufactured from ASTM-A36 steel plate and have a minimum yield strength of 50 ksi.

1810.3.3.1.9 Helical Piles. *The allowable axial design load, P_a, of helical piles shall be determined as follows:*

$P_a = 0.5\ P_u$ **(EQUATION 18-4)**

where P_u is the least value of:

1. *Sum of the areas of the helical bearing plates times the ultimate bearing capacity of the soil or rock comprising the bearing stratum.*
2. *Ultimate capacity determined from well-documented correlations with installation torque.*
3. *Ultimate capacity determined from load tests.*
4. *Ultimate axial capacity of pile shaft.*
5. *Ultimate capacity of pile shaft couplings.*
6. *Sum of the ultimate axial capacity of helical bearing plates affixed to pile.*

An explanation and summary of each of the six design criterions required per the IBC for helical pile design have been listed below to better explain the design process and intent of the code.

Item 1 is in reference to the Individual Bearing Method. This method requires prior knowledge of the soil properties at the site via a soils report or boring logs. Please note that most soil reports only report the allowable bearing capacity of a soil or stratum. This allowable capacity normally has a safety factor of two or three applied. Applying another factor of safety of two per the IBC would be extremely conservative.

Typical helical plate sizes are 8”, 10”, 12”, 14” and 16” in diameter. The maximum number of helical plates placed on a single pile is normally set at six (6). The central area of the shaft is typically omitted from the effective area of the helical plate when using the Individual Bearing Method.

Item 2 is in reference to the Torque Correlation Method. The Torque Correlation Method is an empirical method that distinguishes the relationship between helical pile capacity and installation torque and has been widely used since the 1960’s. The process of a helical plate shearing through the soil or weathered bedrock in a circular motion is equivalent to a plate penetrometer test. The method gained notoriety based on the study performed by Hoyt and Clemence (1989)[2]. Their study analyzed 91 helical pile load tests at 24 different sites within

[2] Hoyt, R.M. and Clemence, S.P. 1989. *Uplift Capacity of Helical Anchors in Soil*. Proceedings of the 12th International Conference on Soil Mechanics and Foundation Engineering, Vol. 2 pp. 1019-1022.

various soil types ranging from sand, silt and clay soils. They demonstrated the direct correlation of the installation torque of a helical pile to its ultimate capacity in compression or tension. The common denominator discovered from the study was a parameter referred to as the torque correlation factor, K_t.

The equation is:

$$P_u = K_t T$$

Where:

P_u is the ultimate capacity of the helical pile or anchor [lb (kN)].
K_t is the empirical torque factor of the central shaft of the pile [ft^{-1} (m^{-1})].
T is the final installation torque [ft-lb (m-kN)].

It's important to point out that the tests analyzed by Hoyt and Clemence (1989) were in tension. It was shown in sub-sequential studies that the tension capacity of helical piles was 16 to 33 percent less than the measured compression capacity. The difference is attributed to the fact that the lead helical plate is bearing on relatively undisturbed soil in compression applications. In tension applications, the leading and trailing helical plates are bearing on soil affected by the installation of the helical plates. It has become common practice to use the same torque correlation factor for a helical pile of the same size for tension and compression and ignore the slight increase in compression capacity. This creates a more conservative compression capacity for helical piles when compared to the Individual Bearing Method. Also unlike the Individual Bearing Method, the number of helical plates on a pile is completely independent of the piles capacity based on the Torque Correlation Method.

Ram Jack uses four (4) standard central pile shaft diameters. The recommended default torque correlation factor, K_t, for each diameter is listed in Figure 1.

Figure 1. TORQUE CORRELATION FACTORS[a]

Pile Diameter	2 3/8"	2 7/8"	3 1/2"	4 1/2"
K_t (default)	10	9	8	7
Torque Rating, T (ft-lb)	4,000	7,000	12,000	21,000
Ultimate Capacity, P_u (lb)	40,000	63,000	96,000	147,000

a. *The structural capacity of the pile must be checked per item 4of Section 1810.3.3.1.9 to ensure it does not govern the limit state of the pile. Ram Jack pile materials are manufactured from specialty materials. Please reference Table A-1 in the appendix for applicable mechanical strengths and section properties.*

Item 3 is in reference to IBC approved load tests. The approved compression load test is ASTM D 1143 *Standard Test Methods for Deep Foundations Under Axial Compressive Load*. The approved tension load test is ASTM D 3689 *Standard Test Methods for Deep Foundations Under Axial Tensile Load*. There are three basic reasons to load test a helical pile:

1) When a project requires a more aggressive design approach. Please note that the default K_t values shown in Figure 1 are conservative and are based on numerous load test analysis. A load test would provide the ultimate load capacity and actual K_t value for the specific project site.

2) Where the design compressive loads are greater than those determined using the allowable stresses specified in Section 1810.3.2.6.

3) Where the design load for any deep foundation element is in doubt.

Item 4 is in reference to the structural axial capacity of the central pile shaft. Standard structural analysis methods should be used which take into account any applicable unbraced length per Section 1802.1 and pile eccentricities. The eccentricity for helical piles used for remedial repairs is normally measured from the vertical face of the wall load or the concrete footer for a column. Ram Jack pile materials are manufactured from specialty materials. Please reference Table A-1 of the appendix for applicable mechanical strengths and section properties.

Item 5 Ram Jack's helical piles couplings are designed to exceed the structural capacity of the central pile shaft based on the Torque Correlation Method. Please reference Figure 1 on page 6 for coupling capacities in tension as well as compression.

Item 6 is in reference to the structural capacity of the helical plate welded to the central shaft of the pile. Table A-2 in the appendix provides a complete list of the strength ratings of each helical plate Ram Jack manufactures based on the plates diameter, thickness and central shaft it is attached to.

1810.3.3.2 Allowable Lateral Load. *Where required by the design, the lateral load capacity of a single deep foundation element or a group thereof shall be determined by an approved method of analysis or by lateral load tests to at least twice the proposed design working load. The resulting allowable load shall not be more than one-half of the load that produces a gross lateral movement of 1 inch (25 mm) at the lower of the top of the foundation element and the ground surface, unless it can be shown that the predicted lateral movement shall cause neither harmful distortion of, nor instability in, the structure, nor cause any element to be loaded beyond its capacity.*

Helical piles are slender deep foundation elements that typically range from 2 3/8" to 4 ½" in diameter. When helical piles are subjected to lateral loads, a lateral load analysis should be performed using a program such as LPILE or equivalent or field tested on the project site as described in Section 1810.3.3.2. When performing an LPILE analysis the geotechnical engineer should provide the soil perimeters (c, Ø, γ and k_s) required to be entered into the software.

When the lateral loads are large there are several methods available to resist the forces. The moment of inertia (stiffness) of the upper portion of the pile can be increased; a pile cap can be

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used to create a couple moment; the piles can be battered or a helical tieback anchor can be connected to the foundation system or vertical helical pile.

1810.3.5.3 Steel. *Steel deep foundation elements shall satisfy the requirements of this section.*

1810.3.5.3.3 Helical piles. *Dimensions of the central shaft and the number, size and thickness of the helical bearing plates shall be sufficient to support the design loads.*

Reference appendix Table A-1 and A-2 for Ram Jack's standard central shaft and helical plate sizes as well as strength and section properties.

1810.3.11 Pile Caps. *Pile caps shall be of reinforced concrete, and shall include all elements to which vertical deep foundation elements are connected, including grade beams and mats. The soil immediately below the pile cap shall not be considered as carrying any vertical load. The tops of the vertical deep foundation elements shall be embedded not less than 3 inches (76 mm) into pile caps and the caps shall extend at least 4 inches (102 mm) beyond the edges of the elements. The tops of the elements shall be cut or chipped back to sound material before capping.*

Section 1810.3.11 applies to all deep foundation elements. The minimum embedment depth of three (3") inches is intended for compression loads only. It's important to point out that where a helical pile is required to resist tension loads or a combination of tension and compression, the embedment depth of the helical pile may need to be increased or applicable nelson studs, weldable deformed bars, concrete anchor bolts or headed studs will be needed to provide a tension connection between the concrete and helical pile. If the depth of the concrete pile cap, grade beam or mat foundation, the embedment depth of the helical pile could be analyzed as a single headed stud per ACI 318 appendix D.

1810.4.11 Helical piles. *Helical piles shall be installed to the 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 of the helical pile.*

The torque ratings of Ram Jack's helical piles can be found appendix Table A-1.

1810.4.12 Special inspection. *Special inspections in accordance with Sections 1704.8 and 1704.9 shall be provided for driven and cast-in-place deep foundation elements, respectively. Special inspections in accordance with Section 1704.10 shall be provides for helical piles.*

1704.10 Helical pile foundations. *Special inspections shall be performed continuously during installation of helical pile foundations. The information recorded shall include 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.*

Per Section 1704.1 item 3 under exceptions, *"Unless otherwise required by the building official, special inspections are not required for Group U occupancies that are accessory to a residential occupancy including, but not limited to, those listed in Section 312.1."*

SECTION 312 UTILITY AND MISCELLANEOUS GROUP U

312.1 General. *Buildings and structures of an accessory character and miscellaneous structures not classified in any specific occupancy shall be constructed, equipped and maintained to conform to the requirements of this code commensurate with the fire and life hazard incidental to their occupancy. Group U shall include, but not be limited to, the following:*

Agriculture buildings
Aircraft hangers, accessory to a one- or two-family residence (see Section 412.5)
Barns
Carports
Fences more than 6 feet (1829 mm) high
Grain silos, accessory to a residential occupancy
Greenhouses
Livestock shelters
Private garages
Retaining walls
Sheds
Stables
Tanks
Towers

This concludes this document. Please feel free to contact your local Ram Jack Dealer for any technical assistance when designing a deep foundation system with helical piles.

APPENDIX

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TABLE A-1. RAM JACK HELICAL PILE/ANCHOR SIZES AND PROPERTIES

Central Pile Shaft	2 3/8”	2 7/8”	3 1/2”	4 1/2”
Weight (lb/ft)	4.43	7.00	8.67	19.0
Outside Diameter (in)	2.375	2.875	3.500	4.500
Inside Diameter (in)	1.995	2.441	2.992	3.624
Wall Thickness, t (in)	0.190	0.217	0.254	0.438
Cross-Sectional Area, A (in^2)	1.304	1.812	2.590	5.589
Yield Strength, F_y (ksi)	65.0	65.0	65.0	65.0
Tensile Strength, F_u (ksi)	80.0	80.0	80.0	80.0
Moment of Inertia, I (in^4)	0.784	1.611	3.432	11.66
Elastic Section Modulus, S (in^3)	0.660	1.121	1.961	5.183
Plastic Section Modulus, Z (in^3)	0.909	1.536	2.682	7.255
Radius of Gyration, r (in)	0.775	0.923	1.151	1.445
Torsional Constant, J (in^4)	1.568	3.222	6.865	23.320
Torsional Yield Moment (ft-lb)	4,130	7,800	12,100	23,000
Torsional Plastic Moment (ft-lb)	4,470	8,500	13,000	25,200
Default Torque Correlation Factor, K_t (ft^{-1})	10	9	8	7
Ram Jack Torque Rating (ft-lb)	4,000	7,000	12,000	21,000

TABLE A-2. RAM JACK HELICAL PLATE LOAD DIAMETERS AND LOAD RATINGS

Helical Plate (in)	**Central Pile Shaft** (in)	**Effective Area** (ft^2)	**Plate Thickness** (in)	**Maximum Allowable Load Rating** (lbs)
8	2 3/8	0.318	3/8	47,500
10		0.515		43,500
12		0.755		37,500
8	2 7/8	0.304	3/8	73,000
10		0.500		64,000
12		0.740		47,400
12		0.740	1/2	70,500
14		1.02		58,500
16		1.35		50,000
8	3 1/2	0.283	3/8	65,000
10		0.479		51,000
12		0.719		44,500
12		0.719	1/2	80,500
14		1.00		67,000
16		1.33		64,500
10	4 1/2	0.435	1/2	117,000
12		0.675		94,500
14		0.959		83,000
16		1.290		76,000

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