PDHonline Course C513 (1 PDH)

Helical Pile Application and Design

Instructor: Andrew P. Adams, PE

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone & Fax: 703-988-0088
www.PDHonline.org
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Andrew P. Adams, P.E.

COURSE CONTENT

1. Introduction

This course is intended to be a stand-alone course with new prerequisites required. It will be assumed that anyone taking this course is familiar with basic foundation principles and soil mechanics.

A helical pile, as defined by the International Building Code is: *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.*

Other definition of terms associated with helical pile foundations that are not common to most engineers are as follows.

Helical Plate – A steel plate formed into a ramped helix, which acts as a "screw" when placed in the soil. The plate also allows for soil bearing capacity after the pile is installed

Helical Pile Driver – A hydraulic motor used to install helical piles in the soil by screwing the helical plates. The motor can be mounted on a piece or equipment or be hand held. Hand held drivers typically have a much lower installation capacities.

Installation Torque – The torque generated by a helical pile when installed into the soil. This torque is a result of the properties of the soil and the geometry of the pile plates.

Lead Section –The section of the helical pile that is install first, and usually the only section that has helical plates.

Shaft Extension – A section of pile the extends the length, but generally does not have helical plates. Extensions are attached with rigid connections that do not allow for slippage during installation.

Torque Rating – The helical pile's maximum torque energy that is allowed during installation.

2. General Information on Helical Piles

Helical piles, or often called helical piers, are deep foundation elements that consist of a shaft with helical bearing plates. The basic principles of helical pile foundation load resistance are very similar to other deep foundations with regard to their reliance of bearing capacity and friction. However, the shaft diameter on helical piles are usually relatively small, and frictional resistance is usually negligible and omitted when determining the pile capacity.

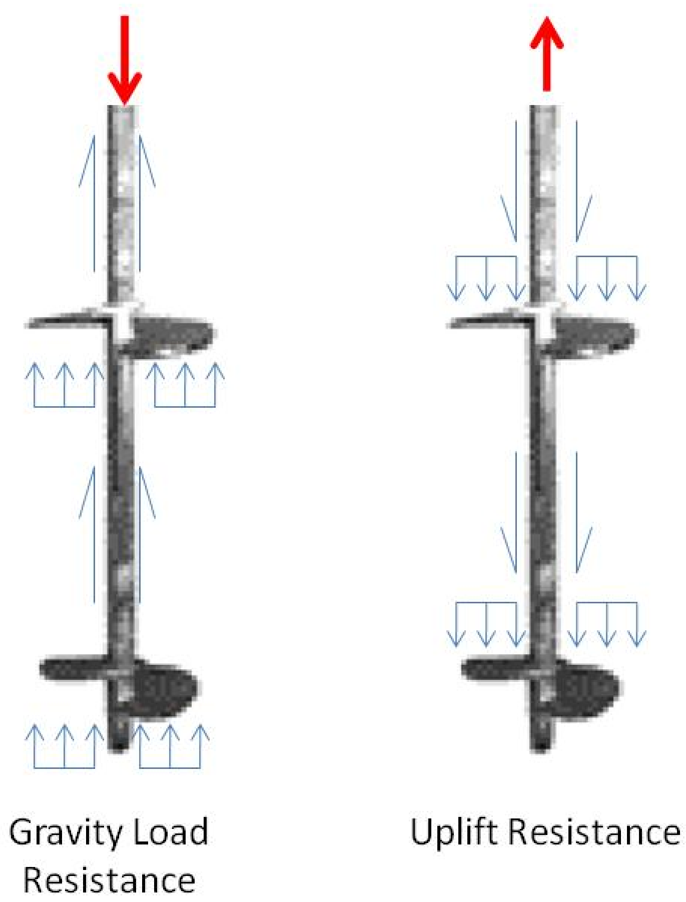

Figure 2: Helical Pile Loading Conditions

3. History of Helical Piles

The first recorded use of helical piles for a foundation was a design by Alexander Mitchell in 1836, and was used for ship moorings off the coasts and habors in England. By 1838, Mitchell used his "screw piles" for the Maple Sands Lighthouse foundation. This foundation concept became widely used in the United States in the 1840s and 1850s for lighthouses along the East Coast and Gulf of Mexico. These foundations were advantages for lighthouse construction because the lighthouses could be placed in remote areas with foundations placed directly into the sea floor.

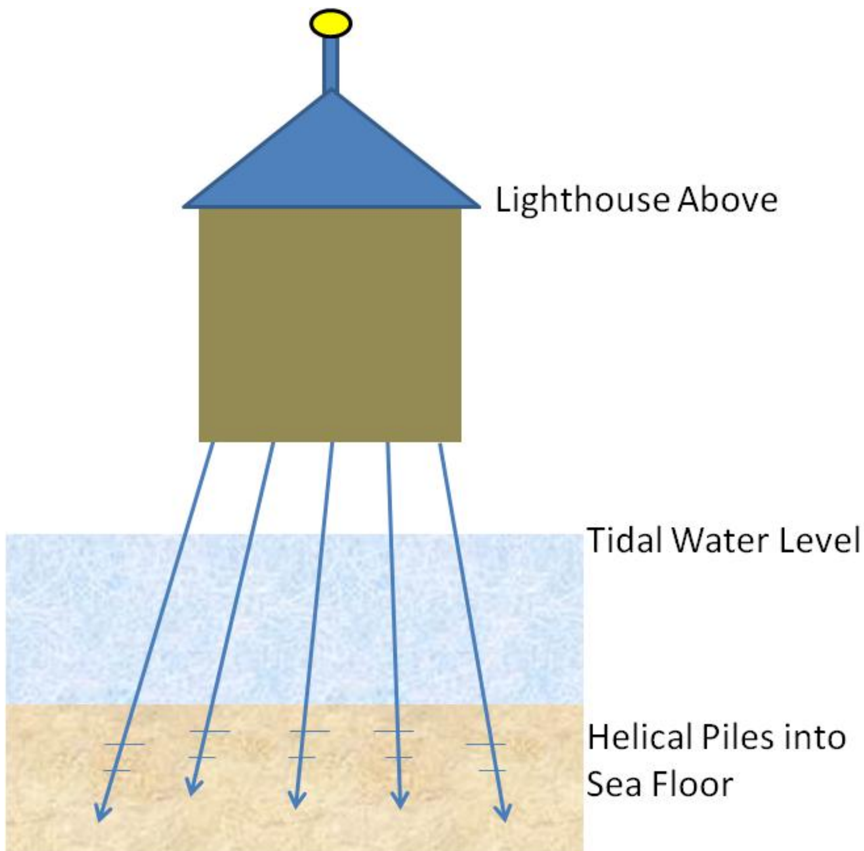

Figure 1: Early Helical Pile Applications (conceptual)

4. Helical Pile Applications

One of the most common applications for helical piles is for foundation underpinning. Underpinning is used as a foundation remediation technique that is usually used to retrofit slab or footing foundations that are no longer performing as designed. When an engineer has determined that the original foundation is failing, helical piers are placed under the existing members and the foundation is stabilized using brackets and lifting apparatuses.

Figure 3: Underpinning Application with Lifting Bracket

Helical piles can also be for new construction foundations. New foundations require the engineer to meet minimum design criteria as outlined in the most current International Building Code (IBC) as well as local jurisdiction requirements. Many helical pile manufacturers have propriety software to assist in the design and detailing of helical foundations.

Helical piers can be placed in the soil to provide both vertical and lateral support when used in conjunction with slab or footing foundations. During new construction, “pile caps” are usually used to tie multiple piers together to resist various load combinations. Along with a main pile, battered piles can be used to resist the lateral loads.

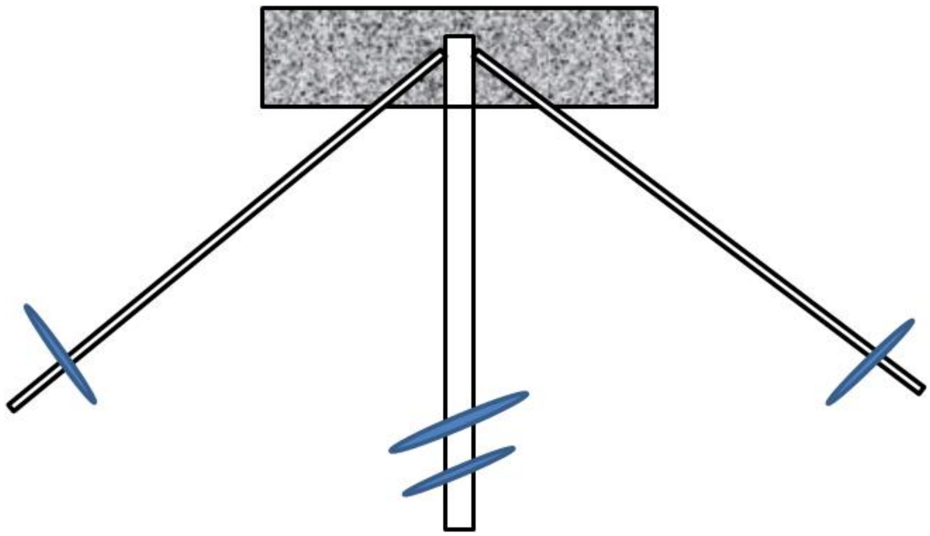

Figure 4: Helical Pile System with Concrete Footing and Batters to Resist Lateral Loads

Tie-backs are also a typical use for helical piles. This application usually uses lower capacity helical piles, and must resist loads in “uplift” rather than bearing. Tie-back helical piles do not fall within building code design requirements for deep foundation designs, but the analysis requirements are similar regardless of application. Tie-backs can be used in new construction or for remediation purposes.

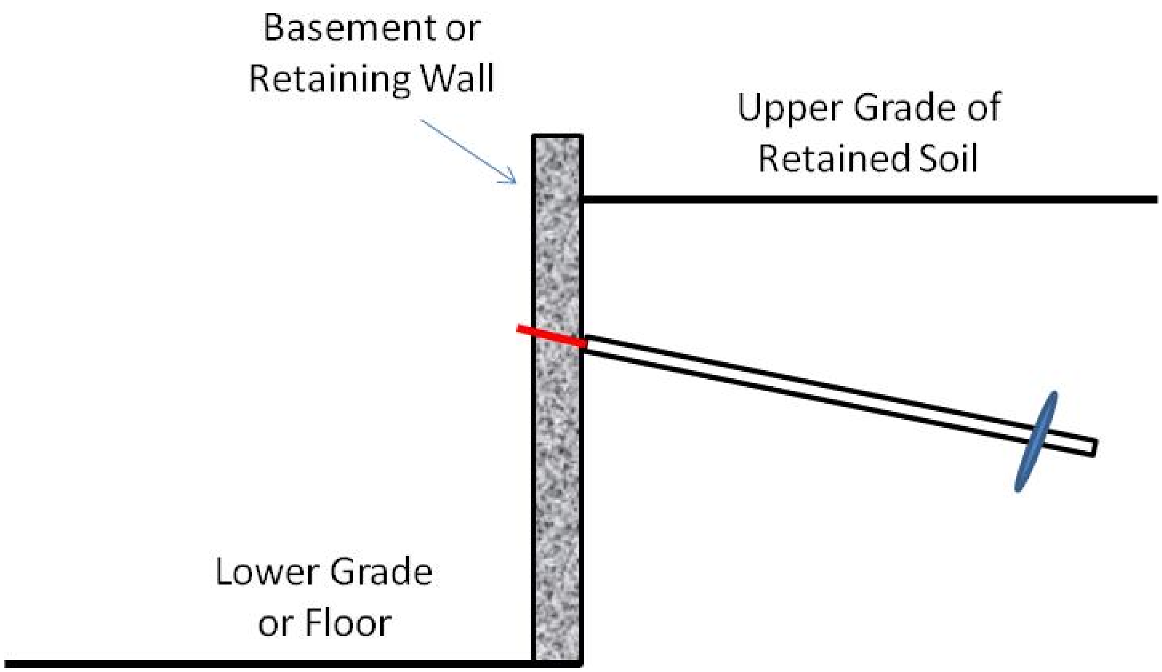

Figure 5: Helical Piles Being Used for Tie-Back Application

5. Types of Helical Piles

Helical piles come in all different shapes, sizes and materials, but the shaft usually defines the helical type. Types of helical pile shafts include square, round, hollow, or solid. There are advantages and disadvantages to using the different types of piles, and the engineer should take the project's design basis, soil conditions and economic feasibility into account when determining the right pile type for a project. When using helical piles in soft soil, round (sometimes called pipe) piles are usually the best pile selection. Solid, square-shaft helical piles are a better selection for more dense soils. Shaft types can also be combined when soil densities change at differing depths, but when combining shaft types, it is best practice to use the stronger type as the lead section.

Figure 6: Types of Helical Piles

6. Design Considerations

Like all engineering problems, prior to beginning a helical pile design project, the engineer must use the engineering design process as follows:

1. Define the Problem
2. Gather Information
3. Generate Solutions
4. Analyze and Select a Solution
5. Test and Implement the Solution

In some cases, the engineer may determine that a helical foundation is not the best selection for the design, but some factors that are advantageous to using helical piles are:

- Wide range of pile capacity (the average range for manufactured piles is between 5 to 200 kip ultimate capacity)
- A single pile can be used for uplift or gravity loading (tension or compression)
- The construction site can be more confined due to there being no drilling spoils during installation and no vibration during installation
- Can be used to adapt and retrofit almost any foundation
- Most manufacturers provide interlocking pieces that reduce welding and field connections
- Since there is limited site disturbance and most applications do not require concrete, weather does not affect installation procedures.
- In remedial applications, there is usually an economic advantage to helical piles compared to traditional foundation repairs

If a helical pile foundation is selected as the feasible solution for the design, the engineer should design the foundation in accordance with local building official requirements. The International Building Code 2009 (IBC 2009), identifies these requirements for designing helical pile foundations in accordance with Deep Foundation design standards.

1. Geotechnical Investigation
2. Site Classification and Considerations
3. Design Load Analysis
4. Helical Pile Design
   a. Pile Capacity
   b. Lateral Resistance System
   c. Pile Spacing
   d. Un-braced Length of Pile

e. Pile Cap and Connection Requirements

Geotechnical Investigation

For geotechnical investigation, IBC 2009 requires that soil classification be conducted prior to any foundation design. However, the local building official may waive the site geotechnical analysis if satisfactory data is available for adjacent areas. During installation, drilling spoils are not evacuated from the pile holes, so it is difficult to determine the actual soil type around the pile. Fortunately, a helical pile torque reading will assist in determining the pile.

Based on IBC 2009 section on lateral support, the soil information is critical for determining the minimum pile depth. The IBC section on minimum pile depth for deep foundations is contained in section 1810.2.1.

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.

Site Classification and Considerations

Site classification and other considerations are important for determining the design basis. The seismic design category is probably the most important factor when determining the lateral load and code compliance for stability.

Water depth, permafrost, ice lenses and other subsurface conditions should also be evaluated in a design. An important case study for site conditions occurred in Anchorage, Alaska in 2006.

During the site investigation, the engineer of record determined that helical piers supporting a perimeter grade beam would be the best option for the foundation given the potential for active soils under the fill layer. During installation, the foundation contractor installed the helical piles per the engineer's specifications, and proper pile capacities were achieved.

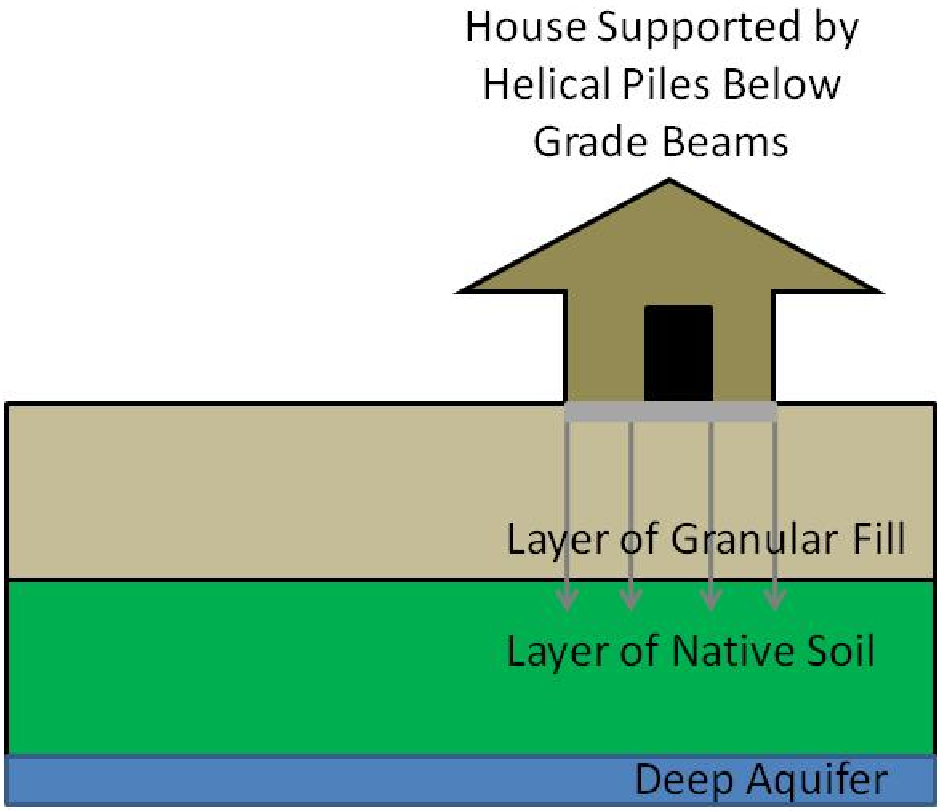

Figure 7: Site Conditions Case Study

Without conducting a proper investigations or consulting an engineer, the home owner installed a well on the property installed a well after the house was constructed. During the well drilling, an artesian well was created, and the home owner did not report any adverse conditions to the foundation engineer or contractor. Within a few months, the house began to settle because the soil around the helical plates began to degrade.

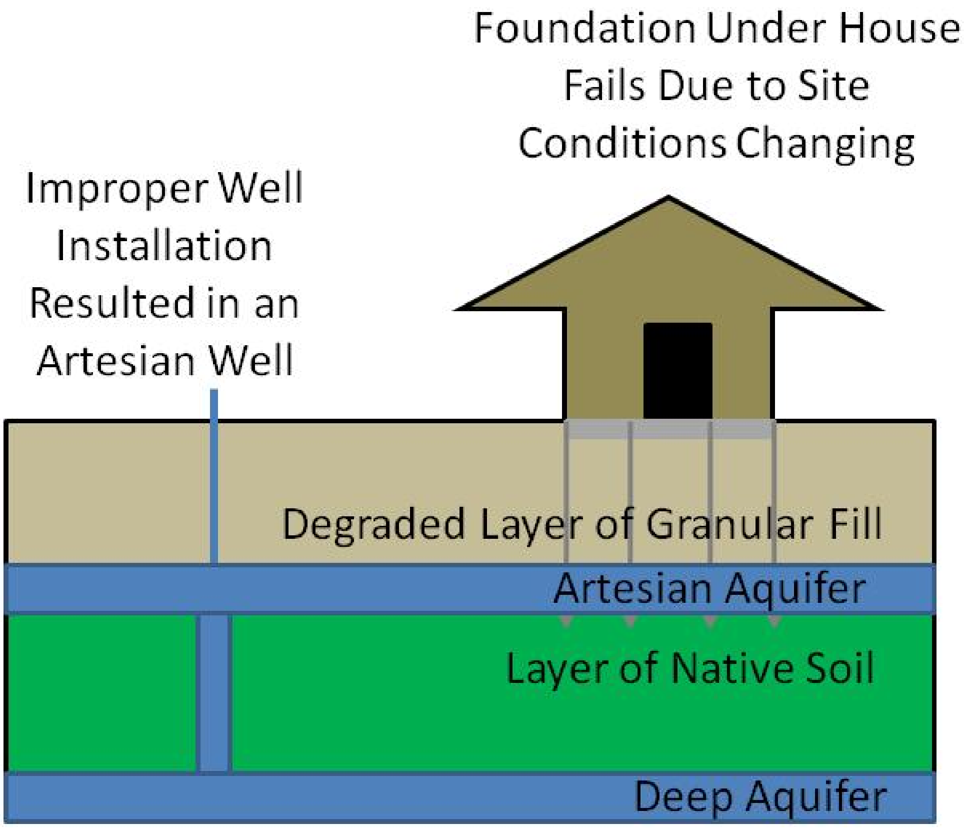

Figure 8: Failed Site Condition Case Study

A site investigation was completed to determine the effect the condition change had on the existing foundation, and building officials and the engineer of record determine a pile foundation to bedrock would be required to remediate the foundation. The home owner and well drilling contractor were found liable for the failure due to installation logs, soil reports and engineering design being consistent with the original site condition.

Figure 9: Foundation Condition after Subsurface Failure

Design Load Analysis

Design loads for helical pile foundations will not vary from standard design loads. The engineer will have to account for all load combinations outlined in ASCE 7 or the most current edition of building codes (usually IBC).

Based on the IBC, determining the pile axial load is as follows.

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.

Due to lateral loading, certain provisions must be addressed to adhere to the

International Building Code. This may vary from other design standards, and is noted as follows.

1810.3.3.2 Allowable Lateral Load. *Where required by the design, the lateral load capacity of a single deep foundation element* [Helical Pile] *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 Pile Design

When determining the proper pile to use for an application, the pile capacity must be determined. There are two ways to determine the installed bearing capacity of a helical pile. The first is by using Terzaghi Bearing equations:

$$Q_u = A_h q_u = \sum A_h (cN_c + q_v N_q)$$

$A_h = helix\ plate\ area$
$c = soil\ cohesion$
$q_v = overburden\ stress$

$N_q\ and\ N_{qc} = Meyerhof\ bearing\ factors$

The second, and most common, method is the Torque Correlation Method. The Torque Correlation Method uses the torque required to install a pile to empirically determine the ultimate capacity of a pile.

$Q_u = K_t T$
$K_t = Helix\ Torque\ Factor\ (ft^{-1})$
$T = Torque\ (ft \cdot lb)$

K_t is a factor that is usually determined by and provided by the manufacturer of the helical pile system based on third party testing. These values will vary based on the helical plate size, the number of plates, the shaft size and other factors. The installation contractor should ensure that the torque required for reaching capacity does not exceed the manufacturer's limits for the pile.

Along with the axial capacity, a lateral system must be designed for each pile location or for the building system. The IBC requires lateral stability as outline in section 1810.2.2 for deep foundations.

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.

Figure 4 above illustrates the general concept for lateral resistance for a single pile cap. Some provisions allow for a batter system to be used on building corners or in varying numbers if the lateral loads are small, the pile foundation elements are sufficiently connected, and the site conditions are favorable. This is subject to building official review, and may not always be permissible.

Pile spacing is also an important factor to ensure proper performance. The basic principles for pile spacing remain the same throughout deep foundations, a three diameter center-to center spacing is required, and is determined by the largest plate diameter for a helical pile. For example: if a helical pile has a 2 inch round shaft with an 8" – 10" configuration, the piles must have a minimum of 30" center to center spacing.

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.*

For an unbraced pile length, helical piles must have a minimum embedment before they can be considered to be unsupported until they are placed a minimum of 5' into stiff soil or 10' into soft soil. So, if a contractor is using the Torque Correlation Method to determine a piles capacity, they must have a minimum embedment of either 5' or 10' regardless of torque value. Though, it is very uncommon to reach torque capacities at such shallow depths, a pilot hole may be drilled to ensure penetration of the minimum depth.

Many manufacturers have products that allow for expedient remediation and installation. Among these products are lifting brackets, pre-fabricated pile caps, and foundation "grillage". The design engineer should check with local building officials for compliance of these products or request third party testing data from the manufacturer. However, for standard helical pile installation, code requirements specify a concrete pile cap.

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.*

These pile cap perimeters are for compression (i.e. gravity) loads only. For lateral and uplift loads the pile caps should be designed per applicable codes and regulations. Reinforcement, anchor bolts and studs may be required to ensure sufficient connection, but some applications may allow for the helical pile to be analyzed as a single headed stud per appendix D of ACI 318.

7. Summary

Though helical piles have been used in the construction industry for many years, code requirements have just recently began addressing the specific applications of helical piles. This course was designed to give a brief overview of helical piles as deep foundation members. Some code requirements and calculation requirements were addressed to provide an initial understanding of helical pile design. This course should not be used as a design guide, and the engineer should contact the helical pile manufacturer to ensure their compliance with minimum code requirements.