Predicting Helical Pile Capacity

Two of the most common methods for predicting helical pile capacity are the Individual Bearing Method and the Torque Correlation Method. The Individual Bearing Method is rooted in traditional geotechnical methodology, slightly modified with empirical data, and is used to estimate pile capacity during the design phase. The Torque Correlation Method is fully empirical and used to verify capacity during pile installation by correlating the final installation torque to an ultimate pile capacity. Both methods must be used during the design and installation phase of a project to meet the helical pile requirements of the International Building Code.

Individual Bearing Method:

The Individual Bearing Method was first introduced in a research paper by Dr. Samuel Clemence and Bob Hoyt in 1989. The method states that the ultimate pile capacity is equal to the sum of the individual helix plate capacities. For this method, the top helix plate should be embedded at least 5 diameters (5D) below grade for compression loading and up to twelve diameters (12D) below grade for tension loading. The 5D and 12D embedment criteria is required for the pile to act as a deep foundation element and allow use of the deep foundation bearing capacity equation. The helix plates must be spaced at least 3 diameters (3D) above the next lowest plate along the shaft. The 3D spacing is necessary to prevent overlapping of soil stress between the plates, thereby allowing them to act in individual bearing. Skin friction along the shaft is commonly ignored for shaft diameters less than 6 inches which simplifies the methodology. Figure 1 illustrates the load transfer mechanism for the Individual Bearing Method in compression loading.
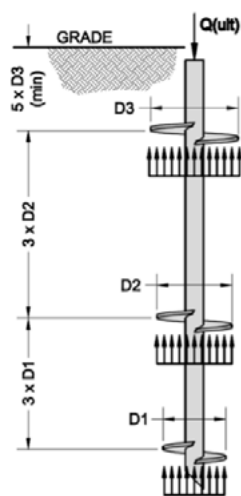

Figure 1: Individual Bearing Method concept

The ultimate capacity of a helical pile using the Individual Bearing Method can be calculated from a modified form of the deep foundation bearing capacity equation:

$$Q_u = \Sigma A_h(cN_c + q'N_q + 0.5_\gamma DN_\gamma)$$

Where,

Q_u = Ultimate pile capacity (lb)

c = Cohesion at the helix depth (lb/ft²)

q' = Effective vertical overburden stress at the helix depth (lb/ft²)

D = Diameter of the helix plate (ft)

A_h = Area of the helix plate (ft²)

N_c, N_q, N_y = Dimensionless bearing capacity factors

The last part of the equation is often ignored in the calculation of end-bearing capacity of deep foundations since this portion of the equation contributes little to the overall pile capacity. With that portion of the equation conservatively ignored, the equation further simplifies to:

$$Q_u = \Sigma A_h(cN_c + q'N_q)$$

Granular Soils: For purely granular (frictional) soils with cohesion = 0, the equation can be rewritten as:

$$Q_u = \Sigma A_h(q'N_q)$$

Bearing capacity factors N_c and N_q are typically provided in foundation design textbooks; however, those values may not be appropriate for use in helical pile design. Research has shown that N_q may not only be a function of the soil friction angle (ø), but also pile embedment depth, pile type and installation method (drilled, driven, etc.). For helical pile design,

Foundation Supportworks recommends N_c and N_q bearing capacity factors calculated by the following equations and shown graphically below. These values of N_c and N_q are slightly lower, and therefore more conservative than the values typically provided in textbooks.

$N_q = 1 + 0.56(12ø)^{ø/54}$

$N_c = (N_q – 1)cotø ≥ 9$

Cohesive Soils: For purely cohesive soils (with $Ø = 0$), $N_c ≈ 9$ and $N_q = 1$. The equation can conservatively be rewritten as:
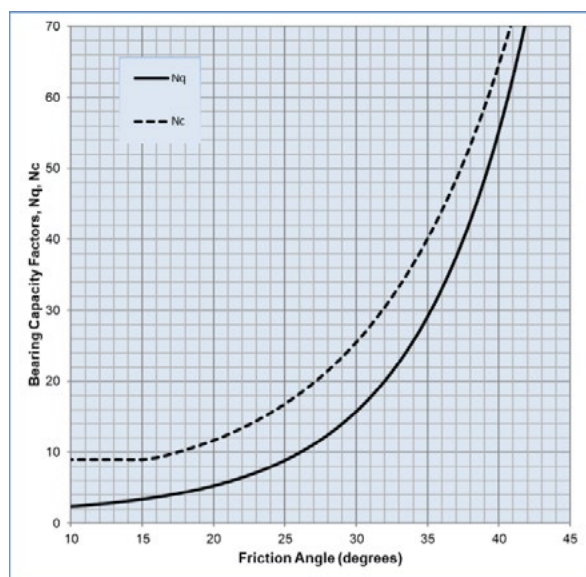
Bearing capacity factors N_q and N_c for helical pile design

$Q_u = ΣA_h(9c)$

Torque Correlation Method:

The Torque Correlation Method is a well-documented and accepted method for verifying helical pile capacity during installation. In simple terms, the torsional resistance generated during helical pile installation is a measure of soil shear strength and can be related to the ultimate capacity of the pile with the following equation:

$Q_u = K_t \times T$

Where,

K_t = Empirical torque correlation factor (ft-1)

T = Final installation torque (ft-lb)

The International Code Council Evaluation Services (ICC-ES) designates specific helical shaft sizes as conforming products to allow use of the published torque correlation factors in the *Acceptance Criteria for Helical Pile Systems and Devices* (AC358). Specifically, square shaft diameters between 1.5 x 1.5 and 3.0 x 3.0 inches and round shaft outer diameters between 2.125 to 4.5 inches are considered conforming. The acceptance criteria include the following default torque correlations for specific shaft geometry and sizes:

• 1.5 and 1.75-inch solid square shaft $K_t = 10$ ft-1

• 2.875-inch outside diameter round shaft $K_t = 9$ ft-1

• 3.0-inch outside diameter round shaft $K_t = 8$ ft-1

• 3.5-inch outside diameter round shaft $K_t = 7$ ft-1

If a shaft size is outside of these diameters but still within the limits of the conforming product sizes, the following equation is published in AC358 to determine the appropriate torque correlation factor. The results of the equation must be rounded down to the nearest 0.5 ft-1.

$Kt = 22.285(d_{eff})^{-0.9195}$

Where,

d_{eff} = the outer diameter of a pipe shaft or the diagonal distance between opposite corners of a square shaft (in)

For example, a 2.0-inch square shaft would be within the limits of AC358 conforming product and have a Kt value of 8.5 ft-1 based on the above equation.

Like other deep foundation alternatives, there are many factors to consider in designing a helical pile foundation. Foundation Supportworks recommends that helical pile design be completed by an experienced geotechnical engineer or other qualified design professional. Please consult the Foundation Supportworks Technical Manual for additional information.

DON DEARDORFF, SENIOR APPLICATION ENGINEER

Project: **Admission Center Addition**
Location: **De Pere, WI**
Pile Installer: **Foundation Supportworks of Wisconsin**

Challenge: St. Norbert College planned a $1,175,000 addition and renovation to their existing admission center. The addition consisted of a 60-foot diameter rotunda to be supported on deep pile foundations and grade beams. A small area of the addition included a stairwell to connect the main floor of the rotunda to the basement level of the existing building. The bottoms of the grade beams stepped up from below the basement level to 4 feet below grade for frost protection. The geotechnical investigation included the advancement of three soil borings, with one boring located in the area of the rotunda addition. The soil profile observed at this location consisted of about 5 feet of uncontrolled fill underlain by soft to medium stiff clay to approximately 20 feet. Very stiff to hard clay was then encountered from 20 to 27 feet and was underlain by soft clay with an SPT N-value of 4 blows per foot. This soft clay layer continued to the termination of boring depth at 30 feet.

A helical test probe was performed to further characterize the thickness of the very stiff to hard clay stratum and the soil conditions below the bottom of the boring. The helical test probe identified relatively soft soils from the bottom of the test boring to a depth of at least 42 feet. The deep foundation option would therefore bear within the very stiff to hard clay from 20 to 27 feet or likely extend to depths exceeding 42 feet.

Solution: Helical piles were selected as the ideal option, since the helix plate size and spacing could be designed to bear in the very stiff to hard clay layer, they were a cost-effective option to support the design working load of 15 kips and torque could be monitored during installation as a verification of capacity. A full-scale compression load test was performed to document the load to deflection characteristics prior to installation of production piles.

The test pile consisted of a Model 287 (2.875-inch OD by 0.203-inch wall) helical pile with a 12"-14" double-helix lead section installed to a tip depth of 25 feet. The load test confirmed an ultimate capacity of 52 kips at a net deflection of 10 percent of the average helix diameter. Total deflection, including elastic compression, was 0.13-inch at the design working load. Based on the successful results of the load test, the project moved forward with the installation of 28 production piles, similar in configuration, depth and installation torque as the test pile. A skid steer on rubber tracks was used to install the piles, due to the wet, slick ground conditions and the congested working space. The load test and installation of the production piles were completed within one week.

Load test arrangement

Helical piles advanced; congested working space

Piles in stepped grade beam

Pile caps tack-welded to shafts

Column rebar installed