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Helical Anchor Geotechnical Design Considerations

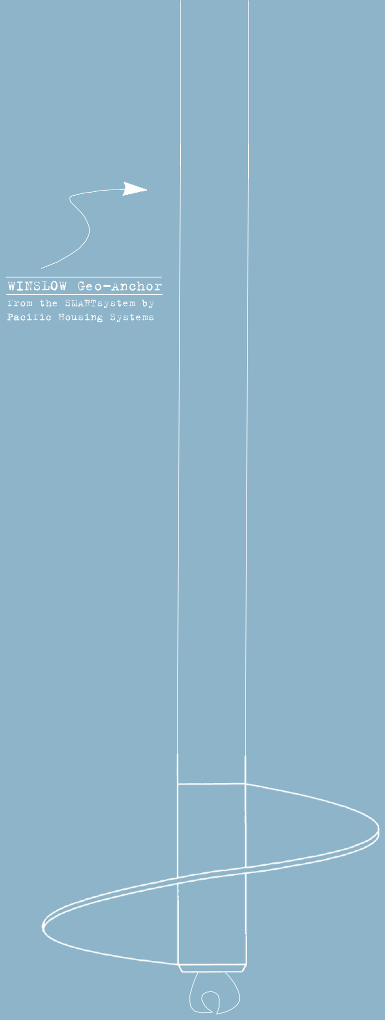
Helical anchor geotechnical design is similar to pile design, where boring logs, including blow count data established from drilled depths below the stress level of the pile, are necessary.

OVERVIEW

In the design of a helical anchor foundation system, the soil properties at various depths at the intended installation site must be taken into consideration. Soil properties are known from the boring logs, inclusive of the standard penetration test blow counts and laboratory test data. The Ultimate Bearing Capacity (Q_f) of the installed helical anchor is the governing factor in the design of this foundation system and depends entirely on the soil properties at the individual helix depths as tempered by blow count information. The Allowable Bearing Capacity (Q_a) is the design bearing strength where a Factor of Safety (F_s) between 1.5 and 3 is generally used.

Initial investigative boring logs, as developed by a Geotechnical Engineer, should include blow count data and laboratory test results, which normally describe the cohesive properties, angle of internal friction, unconfined compressive strengths, and in situ density and moisture content. Values such as internal friction angle and cohesiveness may be interpolated from blow count data, but a certain level of care must be exercised when doing so, especially for silts and clays, because correlations between blow count data and laboratory test data are sometimes on the less conservative side.

After these properties are established, values for bearing capacity factors (N_c and N_q) may be interpreted from Table 3. The spacing of the helix



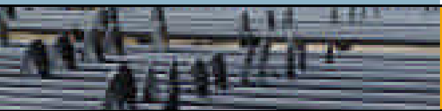
blades on the anchor shaft should be at least three helix diameters apart and should be designed for each helix to be supported in a uniform competent bearing stratum. If this is not possible, each helix capacity should be calculated in accordance with the stratum in which it is supported, which may require additional borings to better define the subsurface conditions.

The design diameter and thickness of the helical anchor hub and helix will depend on the properties of the in situ soil and will have a direct relationship with the Installation Torque (T_i). The number of helices per anchor will also affect installation torque. Where high installation torque values (>15,000 ft-lbs) are required, the yielding shear of the central steel shaft needs to be high enough to maintain structural integrity of the anchor during installation.

A minimum design installation torque value may be established to simplify field installation quality control in normal installations. Proof-load testing of anchors is necessary to provide documented quality control of the system when working in questionable or variable subsoil conditions, or when design loads in excess of 25 kips are specified. The anchors are generally loaded to twice the design dead and live loads, which have already incorporated a safety factor into the anchor capacity calculation. A Hot-Dip Galvanizing (zinc and iron on steal products) treatment is used per ASTM A 123 to protect the steel from oxidizing. Cathodic protection may also be used to prolong the life of the anchor.

ULTIMATE BEARING CAPACITY

As mentioned earlier, the ultimate bearing strength of the soil depends entirely on the soil properties. The Allowable Load (Q_u) is computed by multiplying the area-in-contact of the bearing helix blade with the derived Allowable Bearing Capacity. Equation 1 is the allowable load for one helix:



EQUATION 1. $$Q_u = A[cN_c + p(N_q - 1)] / F_s$$

Where :

- A = Area of helix blade
- c = cohesion of the soil at location of helix
- p = overburden pressure
- N_c = bearing capacity factor for cohesion
- N_q = bearing capacity factor for overburden

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The empirical data included in Table 3 provides values for N_c and N_q, assuming that a value for the angle of internal friction (Φ) has been established. Also, overburden pressure (**p**) is calculated as γ**d** where γ is the effective unit weight of the soil and d is the depth in feet to the helix .

In a system with multiple helices per anchor, each helix must be accounted for separately. In this instance, the equation for allowable load (Q_u) is:

EQUATION 2. $$Q_u = \sum \{ A_i [c_i N_{ci} + p_i (N_{qi} - 1)] \} / F_s$$

Installation torque (T_i) is a useful indication of the ultimate load capacity of the installed helical anchor. The Quality Control Engineer records the torque vs. depth data in the field, and from this information the ultimate anchor capacity can be confirmed. The empirical equation for this is:

EQUATION 3. $$Q_u = KT$$

Where: K=Installation torque-capacity ratio
T=the final installation torque, ft-lbs.

K is a value that ranges from 3 to 20 and is empirically derived by the anchor manufacturer. The **K**-value for a 3-1/2 inch diameter central pipe column can range from approximately 4/ft to 7/ft.

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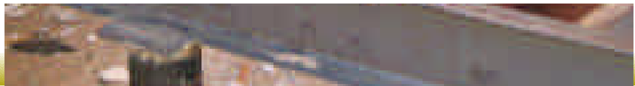


The following Table illustrates approximate bearing strengths of soils:

TABLE 1

APPROXIMATE SOIL BEARING STRENGTH (lb/ft2) FOR SOIL CLASSIFICATIONS

Cohesive Soil Characteristics	Standard Penetrometer Value N1	Screw Type Soil Probe Value (in-lb)	Max Unconfined Soil Compression Strength (lb/ft2)
Very Soft	0-2	0-35	512
Soft	2-4	36-75	1024
Medium	4-7	76-135	2048
Stiff	7-14	136-235	4096
Very Stiff	14-27	236-440	8192
Hard	27-50	over 440	over 8192

(Earth Anchoring System, Engineering Manual, 2000)

As the soil bearing capacity decreases, the need for a larger helix area increases. For the design of the anchor itself actually failing under an eccentric load, the resultant forces acting on the bearing helix create a larger moment as the helix diameter increases and therefore decreases the overall capacity of the anchor itself. Other equations are sometimes used in the design of anchors, but the most accepted equations used are 1, 2, and 3.

TABLE 2

APPROXIMATE RELATION BETWEEN N AND Φ FOR COHESIONLESS SOIL

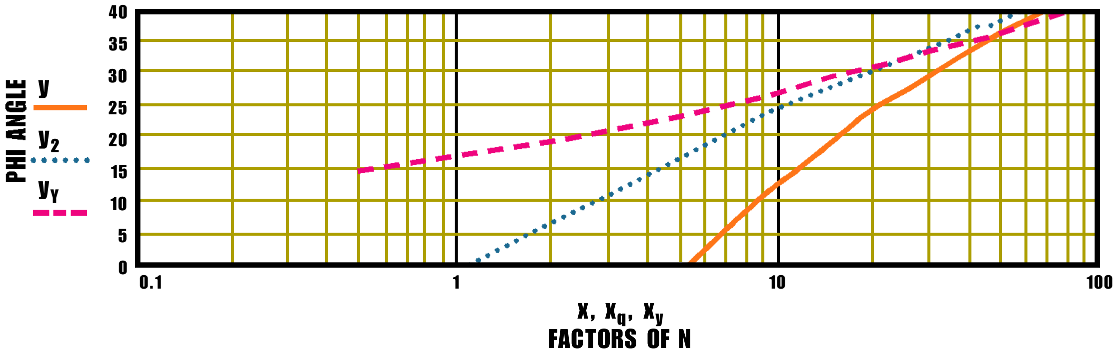
Value of N	Classification of Soil	Approx Value
10	Loose	30±
20	Medium Dense	32±
30	Medium Dense to Dense	35±
40	Dense	38±
50	Very Dense	40±
60	Very Dense	42±

(Essentials of Soil Mechanics and Foundations, McCarthy, 1988)

N is the number of blows/ft using Std. Penetrometer Test

TABLE 3

SOIL BEARING VALUES N_C N_Q AND N_γ RELATING TO INTERNAL FRICTION VALUES OF SOIL



SLENDERNESS RATIO kl/r

As the unsupported section of a column or pier increases when depths of loose or soft soils are penetrated to embed the helix blades into a competent bearing layer, the buckling failure of the upper shaft must become a consideration. The slenderness ratio is defined as **kL/r**, where **kL** is the effective length of the unsupported section of the member and **r** is the radius of gyration. A failure in a pier or column will occur when the yield strength of the member is exceeded. Generally, a failure will occur in the bearing soil well before the anchor itself. Also, a failure due to buckling will occur in a column without proper lateral support long before the yield strength of the column is reached. In instances where the anchor is installed in stiff to dense subsurface material and the anchor is braced within a conventional footing or raised structural floor, buckling does not need to be considered, and the lateral earth pressure is generally adequate for lateral bracing. The greatest allowable slenderness ratio, known as the critical slenderness ratio, needs to be considered when the column support extends out of the surface of the bearing material a significant length. A common **kL/r** value is 200.

SHEAR CAPACITY

During the geotechnical design of the anchor using existing site soil characteristics, Allowable Bearing Capacity ($Q_{\mathbf{u}}$), maximum allowable torque ($T_{\mathbf{all}}$), and a corresponding installation torque ($T_{\mathbf{i}}$) are determined. The installation torque may have a broad range depending on the variable loadings required for the helical anchor. If the anchor is to be installed in dense soils with high cohesive and high internal friction properties, the following equation must be considered to protect the structural integrity of the pipe.

EQUATION 4. $$T_{all} = \frac{\tau_{max} J}{C_2},$$

Where: $T_i \leq T_{all}$,

$J = \frac{\pi}{2}(c_2^4 - c_1^4)$,

and:

τ_{max} = yielding stress

T_i = installation torque

c_2 = outside diameter of hub

c_1 = inside diameter of hub

J = polar moment of inertia

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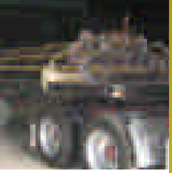

A balance between the number of helix blades and blade diameters, thickness of the anchor hub, soil parameters, and installation torque should be configured to ensure that: (1) the anchor is capable of supporting the designed loads, and (2) the anchor's yielding stress is not reached during installation.

PROOF-LOAD TESTING

Purpose: Axial load tests are a Quality Control method used on pile or anchor supports.

General Application: Projects where loads in excess of 25 kips are used, to ensure anchor embedment into competent bearing material, and that the anchors have the ability to withstand the dead load plus live load as designed for the structure, without shear failure and/or excessive settlement. This test is aso useful for determining the maximum movement for uplift, using test values from uplift design.

Procedure: A steel I-beam, capable of resisting deflection during the loading sequence, is placed across three anchors in a line. The beam is then fixed to the outside two tension anchors. A load cell is placed on the center anchor and a hydraulic jack, capable of applying the desired load, is placed on the load cell and a 5 kip seating load is applied. The applied force is measured by the strain gauges in the load cell, and recorded by an electronic readout device. Measurements of the three anchors' vertical heights are read and recorded; the horizontal distance from anchor to anchor is also recorded to calculate the uplift forces on the two outside anchors. The load is increased to meet the design load for the compression anchor and the force is applied to the anchor for a period of one-half hour. Measurements are again taken and the vertical movement of the anchor is recorded. The load is then increased to twice the design load and this load is applied for at least one hour at which time the measurements are again recorded and the vertical movement noted. The force may then be removed. The allowable movement may vary, but is generally specified as not to exceed 1/2". Where settlement is an issue, the load can be held for 48 hours to verify the impact of a longer duration load cycle. Ten percent of the anchors are typically tested for quality control purposes for critical structures, with a minimum of 3 anchors tested for converted structures (refer to the Project Geotechnical Engineer and ASTM D 1143-81,"Standard Test Method For Piles Under Static Axial Compression Load" for further possible site specific requirements).

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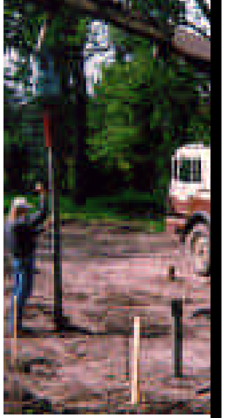

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