CHANCE®

Basic Guidelines for Designing Helical Piers for Underpinning

A. B. CHANCE COMPANY • Centralia, Missouri 65240 U.S.A.

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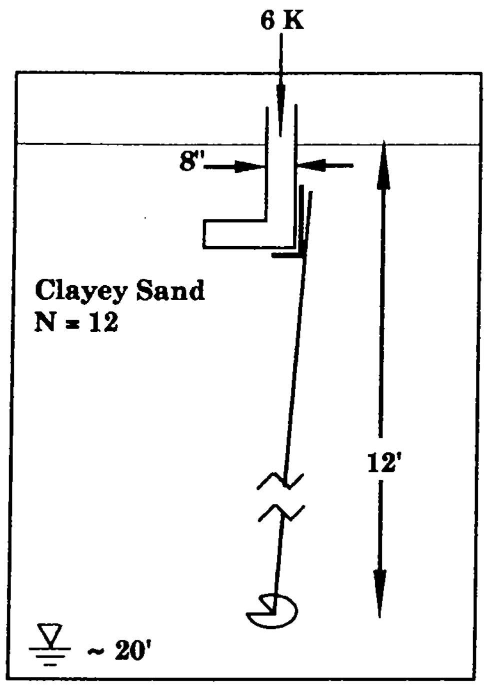
Underpinning — Sample Calculations



Given: 8" thick foundation wall gives a load per pier, 6k.
Soil is clayey silty sand with water table at 20'.
N=12 strata.

I. **Select Helical Plate Size:**
Bearing Capacity Eq, Bulletin 31-8901, pages 2 & 3
$Q = A_h (9c + \bar{q} N_q)$ Try 10" helix
Let c = 1000 PSF; $\varnothing = 30°$; $\gamma = 115$ PCF; Nq= 12.5

$$Q = \frac{10^2 \pi}{4 * 144} (9 * 1000 + 12 * 115 * 12.5)$$

$$= 0.5454 (9{,}000 + 17{,}250) = 14{,}316 \text{ lb.}$$

SF= 14,316 / 6000 = 2.38; OK, use 10" helix.

II. **Check Bending**
Nearly all textbooks on pile foundation maintains bending does not occur. However, make calculations, using the Cummings method as cited by Terzaghi in Theoretical Soil Mechanics, 1943, J. Wiley & Son, pages 361 & 362. Equations (1) & (2).

Method assumes horizontal soil reaction is constant with depth, a conservative assumption for normally consolidated; granular; or overconsolidated soil.

$$m^2 (m + 1)^2 = \frac{d k_h L^4}{\pi^4 EI} \cdots\cdots\cdots\cdots \textbf{Equation 1}$$

where m is number half sine waves; d is shaft width; k_h is horizontal subgrade reaction, L is length, E and I are pile shaft properties.

Let: k_h = 45 pci
L = 12 * 12 = 144 inches
d = 1.5 inches
EI= 30E6 * .4219 = 12.66 E6

$$m^2 (m + 1)^2 = \frac{1.5 * 45 * 144^4}{\pi^4 * 12.66 \text{ E6}} = 23.54$$

By successive approximations, m= 2 (required to be an integer)

Therefore critical buckling load, Q_b is

$$Q_b = \frac{\pi^2 EI}{L^2} (2m^2 + 2m + 1) \cdots\cdots \textbf{Equation 2}$$

$$= \frac{\pi^2 * 12.66\text{E6}}{144^2} (2 * 2^2 + 2 * 2 + 1) = 78{,}334 \text{ lb.}$$

78,334 lb. > > 6,000 lb. applied, OK

Check eccentric load for local buckling, assuming pinned ends (no foundation brackets).

6,000lb. * 8"/ 2 = 24,000 in.-lb.

See lab data for 1½" bar, good for 61,167 in. lb. (ultimate)

$$SF = \frac{61}{24} \approx 2.5, \text{ OK}$$

Corrosion: Resistivity of soil > 2000 Ωcm not to be a problem. See Romanoff NBS Cir. 579, 1957, G.P.O.
SOLUTION: Use 10" diameter helix on 1½" x 12' shaft

Basic Theory of Anchor Design

Throughout this discussion we will concern ourselves with the theories of soil mechanics as associated with helical anchor design. The mechanical strength of the anchors will not be considered in this section as we expect anchors with proper strengths to be selected by the engineer at the time of design. For this discussion, we assume the mechanical properties of the anchors are adequate to fully develop the strength of the soil in which they are installed. Although this discussion generally deals with the tension anchor, the design principles are basically the same for either a tension or compression load. The designer simply uses soil strength parameters above or below a helix, depending on the load direction.

Two modes of anchor failure may occur depending on installation depth: One is a shallow failure and the other is a deep failure. Anchors expected or proven to exhibit one or the other of these failures are often referred to as "shallow anchors" or "deep anchors."The terminology "shallow" or "deep" refers to the location of the soil bearing surface with respect to the earth's surface. By definition, a shallow anchor's top helix is installed to a depth equal to as few as three (3) helix diameters. A deep anchor is installed to a depth of as many as eight (8) diameters. A. B. Chance Company uses five (5) diameters as the break between a shallow anchor and a deep anchor. The five (5) diameter depth is the vertical distance from the surface to the nearest helix.

Any time a helical anchor is considered, it should be applied as a deep anchor. A deep anchor has two advantages over a shallow anchor:

1. Provides an increased ultimate capacity.
2. Any failure will manifest as continuous creep of the anchor through the soil (rather than the more catastrophic pull out of a shallow anchor) when the maximum tension load is applied.

The case of the shallow single-helix anchor is relatively simple. One of the earliest methods of determining anchor capacity was the use of the "cone of earth" method. The cone of earth in reference was a solid of revolution with its apex at or below the anchor plate. (This is for the tension case.) In that classical approach, the capacity of the anchor was equal to the weight of the cone of earth plus the friction along the side of the cone.

For the case of a deep single-helix anchor , there is good agreement with the theory that the failure mode will be in bearing. That is, the ultimate bearing capacity of the soil is applied to the projected area of the helix to determine the ultimate theoretical capacity.

Design theory for deep multi-helix anchors does not enjoy complete agreement among those working in the field. Two differing philosophies have evolved from researchers studying the soil mechanisms that control ultimate capacities of multi-helix anchors when an applied load causes soil failure.

One theory is called the "bearing plus cylindrical shear method." This theory suggests that failure occurs when the applied load equals the sum of the bearing capacity of the top or bottom helix (depending on load direction) and the friction resistance of a cylinder of soil with a diameter equal to the average diameter of the remaining helices and a length equal to the distance from the top helix to the bottom helix.

The other theory is called the "bearing capacity method." This theory suggests that the capacity of the anchor is equal to the sum of the capacities of individual helices. The helix capacity is determined by calculating the unit bearing capacity of the soil and applying it to the individual helix area.

A. B. Chance Company believes that the actual mode of failure will depend on specific soil conditions at a given site and the geometry (helix spacing) of the multi- helix anchor lead section. The following illustration helps clarify the comment on geometry.

When helices are spaced quite close (such as within six inches), the theory of bearing capacity plus cylindrical shear is believed to control the design. On the other hand, when helix spacing is great (such as 10 feet), the theory of individual bearing takes control. Based on this illustration, it follows that at some spacing (for given soil conditions) the two theories should give similar results. We believe the two theories may equate when helix spacing is three diameters. Because A. B. Chance Co. manufactures anchors at the three diameter spacing, we feel justified in using the method with which we historically have experienced success. The following reflects the state-of-the-art for determining deep multi-helix anchor capacities as practiced by A. B. Chance Co.

The theoretical method the A. B. Chance Co. uses to evaluate ultimate theoretical capacity for multi- helix anchors is the bearing capacity method. Again, that is the summation of the bearing capacities of all helices. Since the single-helix anchor is the simplest case, we will discuss here only the multi-helix case and expect the reader to reduce it to the single-helix case as needed. Further discussion of theory will deal only with the bearing capacity method, as it is used in the included program and must be understood to some extent by anyone using the program for determining theoretical anchor capacities.

Ultimate theoretical capacity of a multi-helix anchor equals the sum of all individual helix capacities, see Equation A. To determine the theoretical bearing capacity of each individual helix, use Equation B.

Equation A:

$$Q_t = \Sigma Q_h$$

Where: Q_t = total multi-helix anchor capacity
Q_h = individual helix bearing capacity

Equation B:

$$Q_h = A_h (9c + q N_q) \leq Q_s$$

Where: Q_h = individual helix bearing capacity
A_h = projected helix area
c = soil cohesion
q = effective overburden pressure
N_q = bearing capacity factor (from the graph, next page)
Q_s = upper limit determined by helix strength

A further definition follows for each term in Equation B.

Projected helix area is the area that can be projected on a flat plane perpendicular to the axis of the helix. Because different manufacturers use different processes and procedures in manufacturing and determining the helix sizes, the engineer must attempt to obtain the actual areas from the manufacturer.

The next term in the equation (9c + q Nq) receives extensive discussion below:

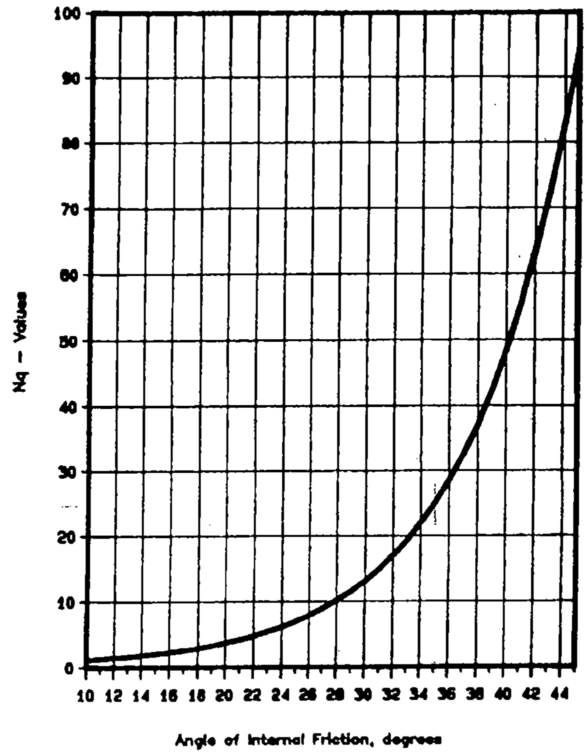
Shear strength of soils is typically characterized by cohesion (c) and friction (Ø) given in degrees. Because c and Ø data typically are not provided in soil test data, Equation B often must have one part of the term in brackets set equal to zero to arrive at an answer. The designation given to soil that derives its shear strength from cohesion is "cohesive" and usually indicates a clay soil. The designation given to soil that derives its shear strength from friction is "non-cohesive" and usually indicates a sand soil. Soil reports often do not contain enough data to assume values for both c and Ø. In such cases, the engineer must decide which soil type is more likely to control failure. That is, determine whether the soil will behave as a clay or as a sand, or which property (cohesion or friction) is most predominant. Once this decision has been made, the appropriate part of the (9c + q N_q) term may be equated to zero, which will allow solution of the equation. This approach generally provides conservative results. When the type of soil behavior expected cannot be determined, calculate for both behaviors and choose the smaller capacity.

As is obvious from Equation B, nine (9) has been chosen as the bearing capacity factor for cohesive soils. The bearing capacity term for cohesionless soils must be determined from the graph, next page. This factor is dependent upon fee (Ø) for its value. The curve is based on Meyerhoff bearing capacity factors for deep foundations and has been empirically modified to reflect the performance of helical anchors. (The conversion from N-values for standard penetration test to fee [Ø] and then to bearing capacity factors for a cohesionless [sand] soil is made automatically in the computer program.)

In all cases, we recommend the use of field testing to verify the accuracy of theoretically predicted anchor capacities.

The use of torque force to install anchors provides an opportunity to monitor each anchor installation. There is a relationship between torque required to place an anchor into the soil and the anchor's capacity under load. The "rule of thumb" is a factor of 10 exists between installation torque and ultimate holding capacity. This factor may be as low as 6 to as high as 20 and normally ranges from 8 to 12. We suggest a factor of 10 be used for the first installation and field test results used to verify or modify the factor.

Bearing Capacity Factor Curve
for
Cohesionless Soils
(N_q vs. Angle of Internal Friction)



Example Problems

Example Problem 1

Given: Soil is homogeneous sand.
$\phi = 30°$
$\gamma = 100$ lb./cu. ft.
Water table @ 15 ft. depth
Anchor catalog number is C150 0007
Installation angle = 45°
Distance from surface to top helix along shaft is 10 ft.
Find: The tension capacity of the given anchor.

<u>Hand solution</u>:
Reduce Equation B in Basic Theory of Anchor Design for sand to obtain the following:

$$Q_h = A_h (\bar{q} N_q)$$

From the graph at the end of Basic Theory of Anchor Design, choose the bearing capacity factor:

$N_q = 13.1$ for phi (Ø) = 30°

Determine the vertical depth to each helix. Remember the helices are spaced 3 diameters apart. So, 8 x 3 = 24 inches and 10 x 3 = 30 inches. The distance to the top helix is given as 10 ft. By multiplying the distance along the shaft by the sin 45°, we obtain the vertical distance to the helices.

d_{12} = 10 x sin 45 = 7.07 ft
d_{10} = 12.5 x sin 45 = 8.84 ft
d_{8} = 14.5 x sin 45 = 10.25 ft

Calculate $\bar{q} = \gamma \times d$ for each helix.

$\bar{q}_{12} = 0.1 \times 7.07 = 0.7$ ksf
$\bar{q}_{10} = 0.1 \times 8.84 = 0.88$ ksf
$\bar{q}_{8} = 0.1 \times 10.25 = 1.02$ ksf

Now determine capacity of each helix using Equation 1 and sum for resulting theoretical ultimate anchor capacity.

$Q_{12} = (111/144) \times 0.7 \times 13.1 = 7.07$ k
$Q_{10} = (76.4/144) \times 0.88 \times 13.1 = 6.12$ k
$Q_{8} = (48.4/144) \times 1.02 \times 13.1 = 4.49$ k
Ultimate theoretical capacity = 17.68 k

Example Problem 2

Given: Soil is homogeneous clay.
c = 2.5 ksf
γ = 100 lb./cu. ft.
Water table at 10 ft. depth
Anchor catalog number is C150 0015
Installation angle = 90°(vertical)
Distance from surface to top helix along shaft is 5 ft.
Find: The compression capacity of the given anchor.

Hand solution:
Reduce Equation B in Basic Theory of Anchor Design for clay to obtain the following:

$$Q_h = A_h (9c)$$

Because of the vertical installation, depth to the helix is 5 ft. (same as the shaft length). Calculate helix capacity, which will be the anchor capacity because it is a single 8-in. helix.

$$Q_t = Q_h = (48.4/144) \times 9 \times 2.5 = 7.56 \text{ kips}$$

Helix Areas

Following are the areas of standard helices manufactured by the A. B. Chance Co.

Helix Size	Helix Area (sq. in.)
6	26.7
8	48,4
10	76.4
12	111.0
14	151.0

A. B. Chance Co. Bulletin 31-8901 contains example problems for tension anchors in both cohesive and cohesionless soils. Tension anchor capacities are calculated by using average soil strength parameters above a given helix. Compression capacities may be calculated similarly, however soil strength parameters should be averaged below a given helix. Average soil strength parameters should be determined for a distance from the helix to approximately three diameters from the helix. The soil strength may often be considered constant for this distance.

Mechanical Properties

Pier Family	Max. Tensile Capacity, kips	Max. Compressive Capacity, kips	Max. Bracket Capacity, kips
1½SS	70	70	40
1¾SS	100	100	60
HS	100	100	60

The Theory of Torque vs. Anchor Capacity

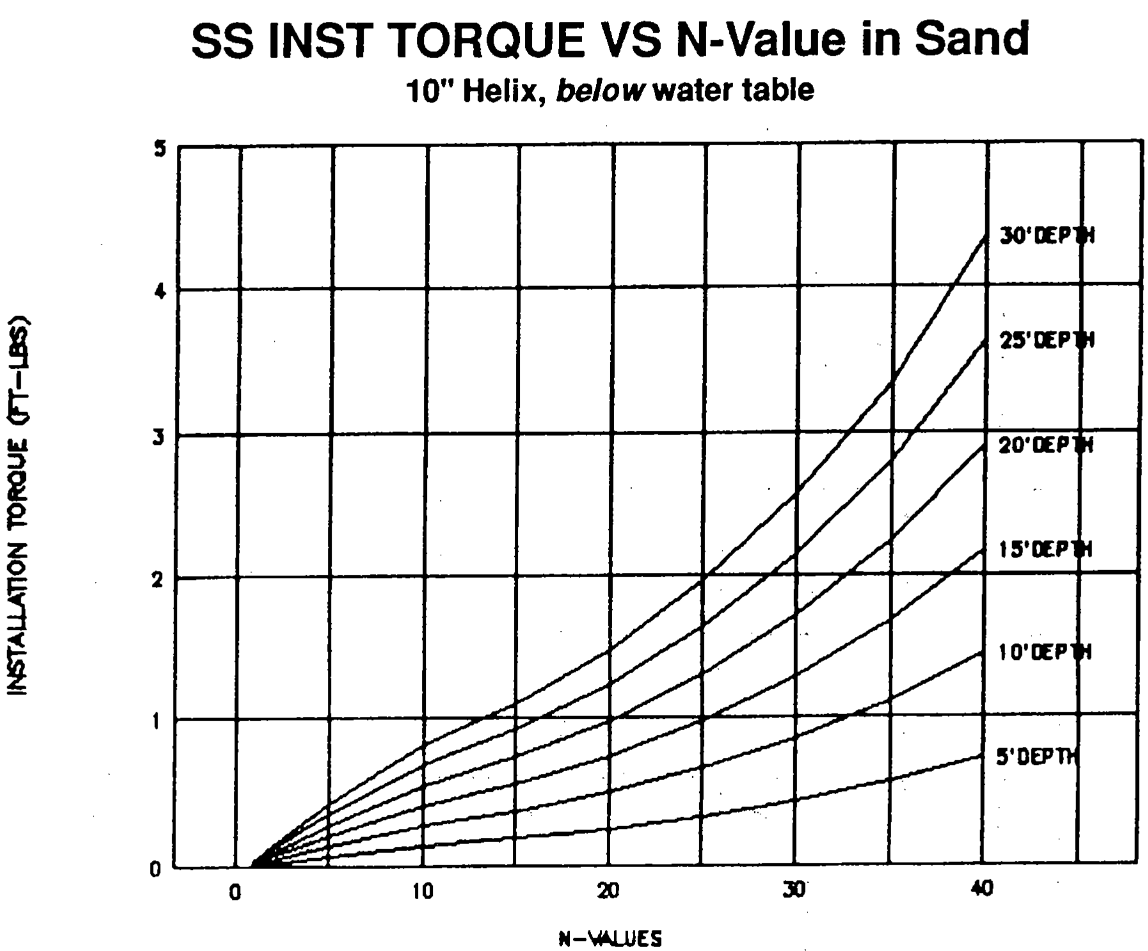
The theory that the amount of torsional force required to install a helical anchor relates to the ultimate capacity of the anchor in tension or compression has long been promoted by the A. B. Chance Co. Precise definition of the relationship for all possible variables remain to be identified. However, simple empirical relationships do exist and have been used for a number of years. Recommended reading on the subject may be found in the paper "Uplift Capacity of Helical Anchors in Soil" by R. M. Hoyt and S.P. Clemence (Bulletin 2-9001). In this paper the formula for the torque/anchor capacity relationship is given as:

$$Q_u = K_t \times T$$

where q_u = ultimate uplift capacity
K_t = empirical torque factor (ft^{-1})
T = average installation torque (ft.-lb.)

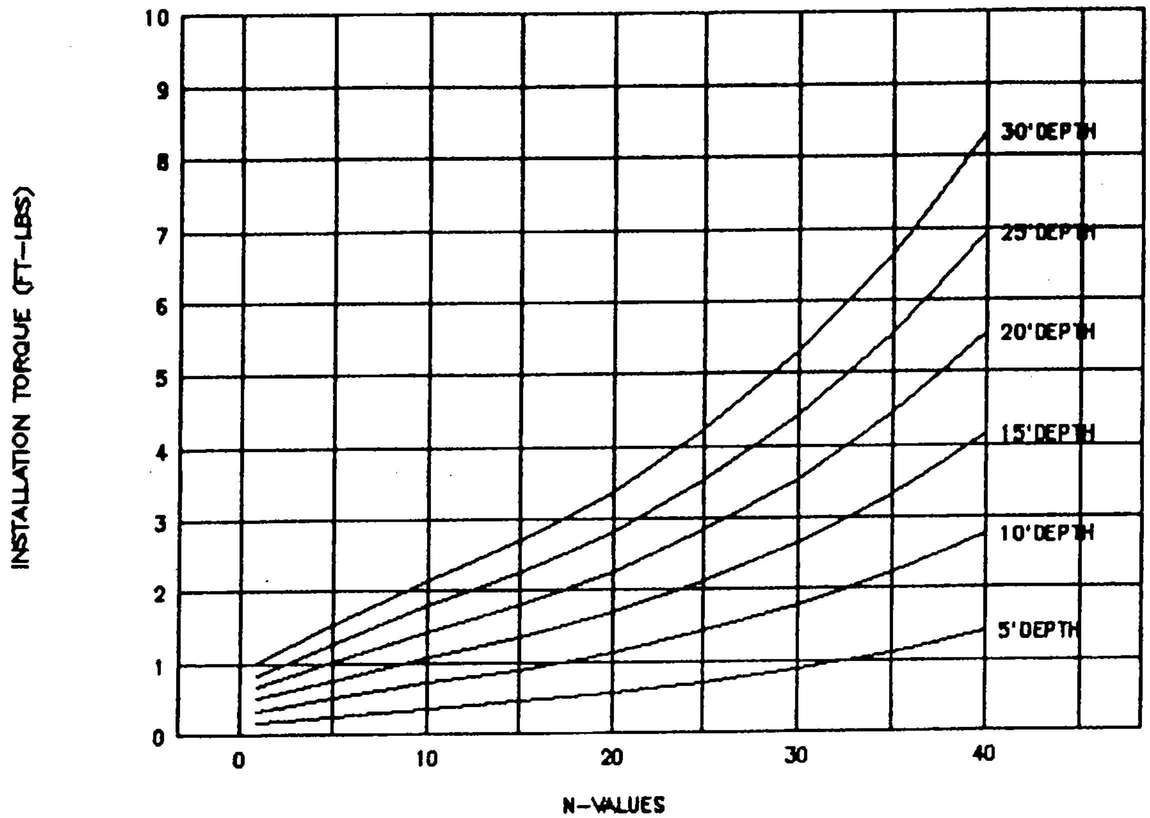
For the SS anchors being discussed herein, the value for K_t is 10. This value may be used for either tension of compression anchors.

Graphs have been prepared for use with this discussion. A single ten inch helix was used at various depths for both cohesive and cohesionless soils. Two graphs are required for cohesionless soils as the position of the water table effects both the installation torque and the ultimate capacity of the anchor directly as it causes change in the effective unit weight of the soil. One graph is provided for cohesive soil as the factor effecting the installation torque of an anchor is the soil strength or cohesion. All graphs present the variation of installation torque with respect to N-values or SPT results indicating the insitu soil strength. It is believed that the graphs are simple enough to be self explanatory.



SS INST TORQUE VS N-Value in Sand

10" Helix, *above* water table



SS INST TORQUE VS N-Value in Clay

10" Helix