QUICK DESIGN GUIDE

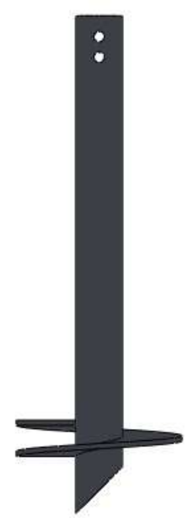
For Screw-Piles and Helical Anchors in Soils
Ver. 1.0

Prepared by

Dr. Alan J. Lutenegger, P.E., F. ASCE

for

International Society for Helical Foundations (ISHF)



INTRODUCTION

This Guide has been prepared by the ***INTERNATIONAL SOCIETY FOR HELICAL FOUNDATIONS*** to provide Engineers with a basic understanding of the current approach to geotechnical design of single-helix and multi-helix Screw-Piles and Helical Anchors. It is intended as an introduction only and does not include all of the details involved in developing a full geotechnical or structural design of helical piles and anchors. **This Guide should be used for preliminary calculations only and applies only to the deep installation of Screw-Piles and Helical Anchors in uniform soils. It is only applicable for design when the depth (D) to the top helical plate is greater than 10 times the diameter (B) of the helical plate and the minimum depth of embedment of the helical plate is 5 ft. The methods described in this Guide provide an estimate of the ULTIMATE capacity; the Engineer must apply an appropriate Factor of Safety to obtain the ALLOWABLE capacity.**

General Bearing Capacity Equation

At the present time, the design of Screw-Piles and Helical Anchors generally follows the traditional theory of General Bearing Capacity used for compression loading of foundations. Terzaghi's general bearing capacity equation for determining ultimate bearing capacity, as given in most Foundation Engineering textbooks is often stated as:

$$q_{ult} = c'N_C + q'N_q + 0.5\gamma'BN\gamma$$

where:

q_{ult} = Ultimate Unit Bearing Capacity
c' = effective cohesion
q' = effective overburden stress = $\gamma'D$
γ' = effective unit weight of soil
D = depth
B = diameter of helix
N_C, N_q, $N\gamma$ = bearing capacity factors

Notes on use of Terzaghi's General Bearing Capacity equation:

1. Because B is considered very small for Screw-Piles and Helical Anchors, relative to most concrete footings, some engineers choose to ignore the term $0.5\gamma'BN\gamma$ in design.

2. In saturated clays under compression loading, Skempton's (1951) Bearing Capacity Factor for shallow round helical plates may also be used:

   $$N_C = 6.0(1 + 0.2D/B) \leq 9.0$$

3. The unit weight of the soil is the total (wet) unit weight if the helical plate is above the water table and the buoyant unit weight if the helical plate is below the water table.

4. For saturated clay soils with $\varphi' = 0$, $N_q = 1.0$; For sands, N_q is a function of friction angle, φ'.

5. **In all cases, for both compression and tension loading, the upper limit of capacity is governed by the mechanical strength of the Screw-Pile or Helical Anchor as provided by the manufacturer**.

Contribution of Shaft to Capacity

Many Screw-Piles and Helical Anchors are manufactured with square central shafts. For these piles/anchors, the contribution of the shaft to the ultimate capacity is **usually ignored** and the total capacity is only calculated from the bearing capacity of the helical plate(s). For Screw-Piles and Helical Anchors with round steel central shafts **the shaft section between plates for multi-helix elements is ignored**, but the shaft above the top plate may be included in design, at least for that section of the shaft in full contact with the soil as discussed in Section 3.

1. DEEP Single-Helix Screw-Piles and Helical Anchors

Deep installations of Screw-Piles and Helical Anchors are generally more common than shallow installations, provided there is sufficient soil depth to perform the installation. The reason is that higher load capacities are generally developed from a deeper installation in the same soil.

1.1 Compression Loading of Screw-Piles in CLAY

Under both compression and tension loading of deep Screw-Piles and Helical Anchors in clay, the ultimate capacity is obtained using the Total Stress Analysis (TSA) and undrained shear strength. In saturated clays with φ' = 0 and $c = s_u$ the bearing capacity equation is often give as:

$$Q_H = A_H(N_C)s_u \qquad [1.1]$$

where:

Q_H = Ultimate Bearing Capacity in Compression
s_u = undrained shear strength
N_C = Bearing Capacity Factor for clays with φ' = 0; for round plates $N_C = 6.0(1 + 0.2D/B) \leq 9$
A_H = Effective area of the helical plate

For deep installations, $N_C = 9$, which gives:

$$Q_H = A_H(9)(s_u) \qquad [1.2]$$

The design steps are:

1. **Determine the design value of undrained strength, s_u, from appropriate lab or field tests;**
2. **Select a Screw-Pile and determine the area of the helical plate;**
3. **Use Equation 1.2 to estimate capacity.**

Note: **In compression, the full cross sectional area of the helical plate is used and there is no reduction of shear strength for installation disturbance.**

Equation 1.2 indicates that the ultimate undrained compression capacity of a single-helix screw-pile increases linearly with the increase in undrained shear strength. This behavior is illustrated for common sizes of single-helix Screw-Piles in clay in Figure 1 which includes only bearing capacity from the helical plate.

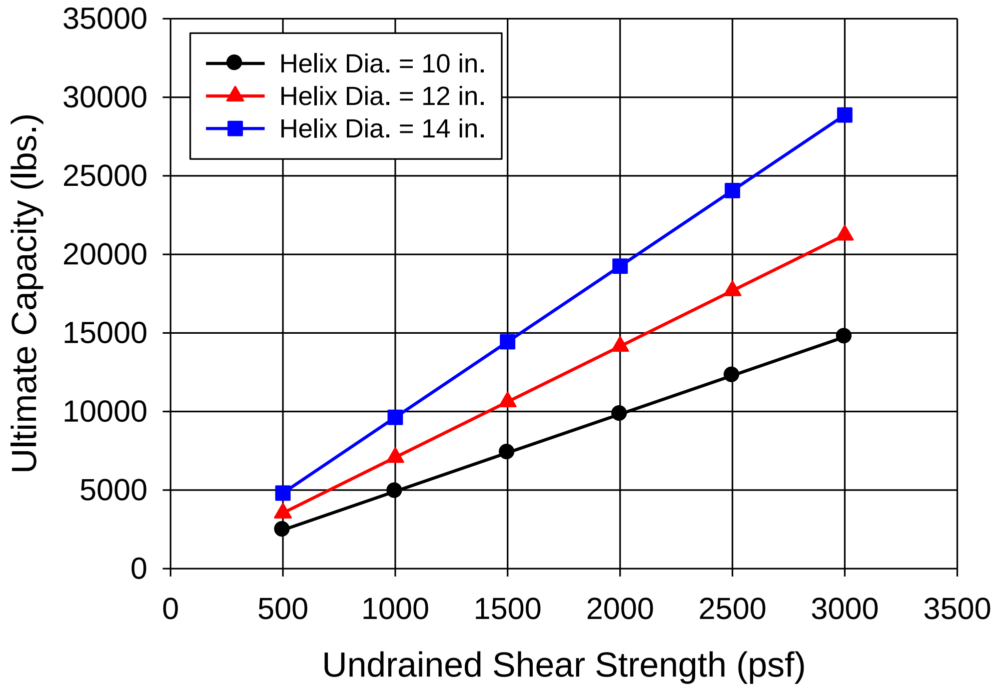


Figure 1. Ultimate Undrained Compression Capacity of Different Diameter Single-Helix Screw-Piles in Clay (ignoring shaft resistance).

1.2 <u>Tension Loading</u> of Helical Anchors in CLAY

For deep installations of Helical Anchors under tension in clay the design is essentially the same as for compression loading of Screw-Piles in clay except that a reduced cross sectional area is used to account for the area of the central shaft and some provision for installation disturbance may be made.

The design steps are:

1. **Determine the design value of undrained strength, s_u, from appropriate lab or field tests;**
2. **Select a Helical Anchor and <u>calculate the net area of the helical plate as the full cross sectional area minus the area of the central shaft</u>;**
3. **Use Equation 1.3 to estimate capacity.**

<u>Note:</u> For tension loading a reduction may be made in the undrained shear strength to account for soil disturbance above the helical plate as a result of installation and may depend on the Sensitivity of the clay. Suggestions for reduction as given below:

Insensitive Clays	**(Sensitivity = 1)**	**No Reduction**
Lightly Sensitive Clays	**(Sensitivity = 2-4)**	**15% Reduction**
Moderately Sensitive Clays	**(Sensitivity = 5-10)**	**25% Reduction**
Sensitive Clays	**(Sensitivity >10)**	**50% Reduction**

1.3 <u>Compression Loading</u> of Screw-Piles in SAND

For deep installations of single-helix Screw-Piles and Helical Anchors in sand the ultimate capacity is obtained using the Effective Stress Analysis (ESA) from:

$Q_H = A_H(\sigma'_{vo} N_q + 0.5\gamma' B N\gamma)$ [1.3]

where:
σ'_{vo} = vertical effective stress at the depth (D) of the helix = $\gamma'D$
N_q and $N\gamma$ = bearing capacity factors
B = Diameter of the helical plate
γ' = effective unit weight of the soil

The bearing capacity factor Nq is usually obtained from values used for determining the end bearing capacity for deep pile foundations. There have been a number of different recommendations for estimating Nq which are available in most foundation engineering textbooks, e.g., Fang & Winterkorn 1983. Difference in Nq values are largely related to the assumptions used in the failure mechanism of deep piles in sand. Figure 2 gives a reasonable chart of Nq values as a function of the friction angle of the soil, φ', that may be used for preliminary design of Screw-Piles and Helical Anchors. The value of Nq in Figure 2 may also be obtained from:

$Nq = 0.5\ (12 \times \varphi')^{\varphi'/54}$ [1.4]

Because the area of the plate is usually small, the contribution of the "width" term of Eq. 1.3 to ultimate capacity is also very small and the width term is often ignored. This reduces Equation 1.3 to:

$Q_H = A_H(\sigma'_{vo} N_q)$ [1.5]

The design steps are:

1. **Estimate or determine the design value of friction angle, φ', from appropriate lab or field tests;**
2. **Estimate the total unit weight of the sand;**
3. **Determine the location of the water table;**
4. **Calculate the effective vertical stress at the depth of the helix;**
5. **Determine the bearing capacity factor, Nq;**
6. **Select a Screw-Pile and calculate the area of the helical plate as the full cross sectional area;**
7. **Use Equation 1.5 to estimate capacity.**

<u>Note:</u> In some sands, the unit end bearing capacity of deep foundations may reach a limiting value.

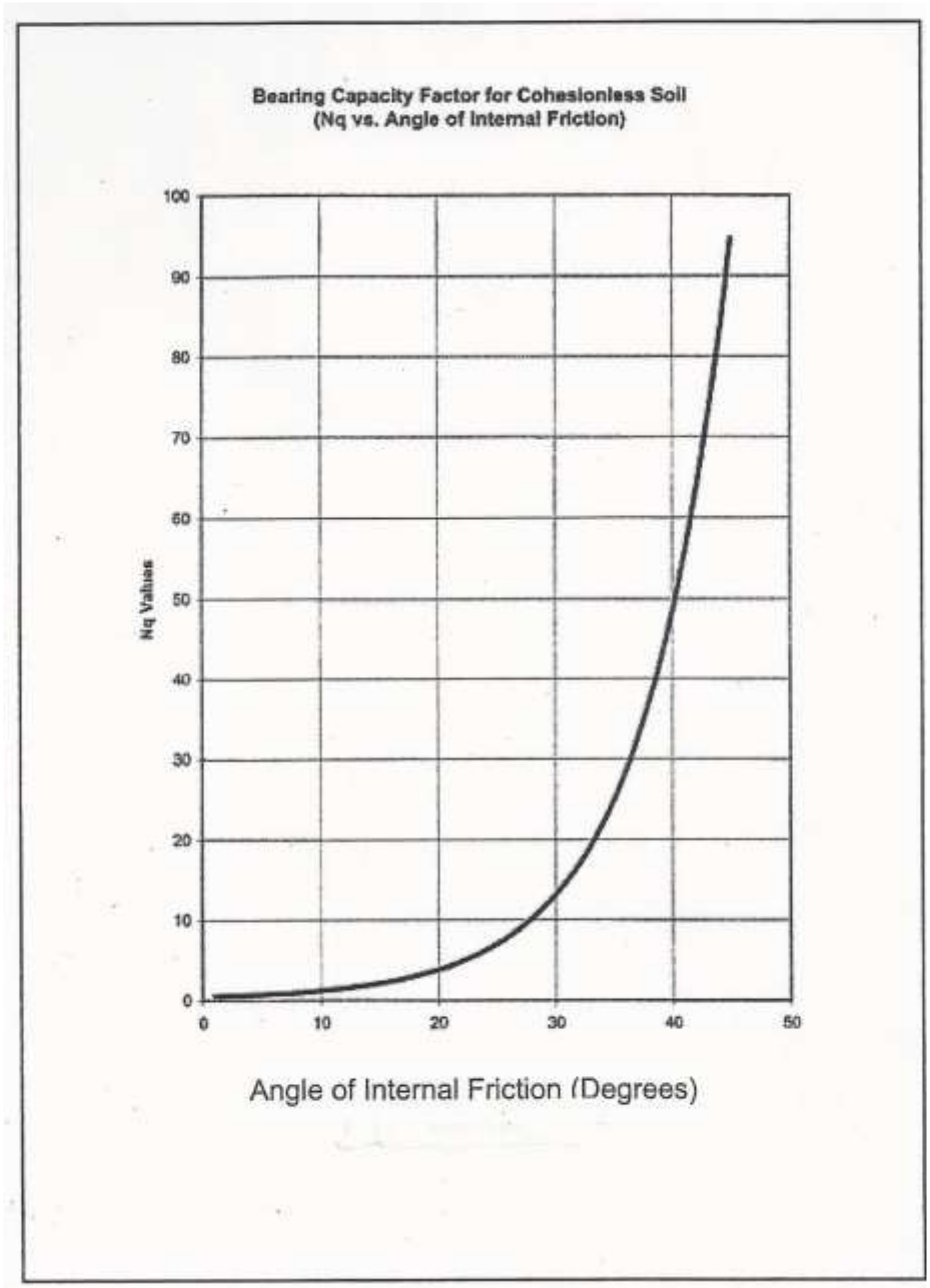


Figure 2. Bearing Capacity Factor Nq for Deep Screw-Piles and Helical Anchors in Sand.

An example of the influence of friction angle on the ultimate capacity of a 12 in. diameter single-helix Screw-Pile in sand under compression loading (ignoring shaft resistance) calculated using Equation 1.5 is shown in Figure 3. The influence of submergence on the calculated ultimate capacity is also shown. The friction angle used in these calculations is the effective stress axisymmetric (triaxial compression) friction angle which is most appropriate for Screw-Piles and Helical Anchors.

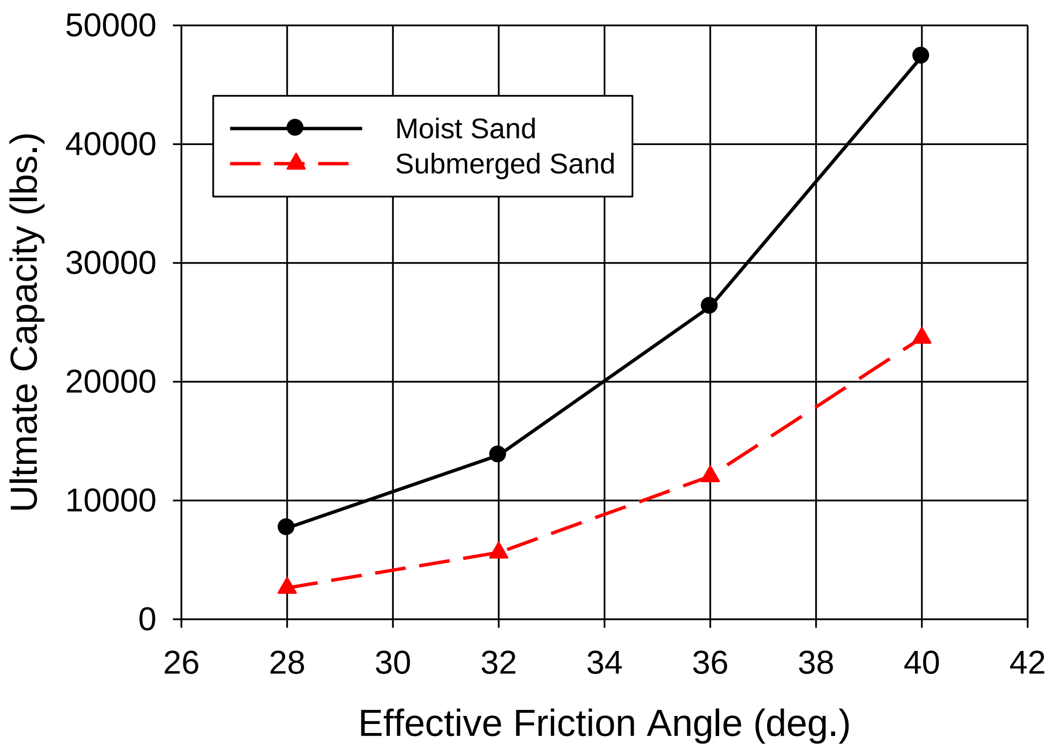


Figure 3. Ultimate Compression Capacity of a 12 in. Diameter Single-Helix Screw-Pile Embedded 10 ft. in Sand with Different Friction Angle (ignoring shaft resistance).

1.4 Tension Loading of Helical Anchors in SAND

The design of deep single-helix Helical Anchors under tension in sands is essentially the same as for compression loading of Screw-Piles in sands.

The design steps are:

1. **Estimate or determine the design value of friction angle, φ', from appropriate lab or field tests;**
2. **Estimate the total unit weight of the sand;**
3. **Determine the location of the water table;**
4. **Calculate the effective vertical stress at the depth of the helix;**
5. **Determine the bearing capacity factor, Nq;**
6. **Select a Helical Anchor and calculate the net area of the helical plate as the cross sectional minus the area of the shaft;**
7. **Use Equation 1.5 to estimate capacity.**

Note: At this time there is very little direct evidence that for single-helix Helical Anchors the shear strength of sands should be reduced to account for installation disturbance in sands, except in cemented sands where the cementation may be affected by installation.

2. DEEP Multi-Helix Screw-Piles and Helical Anchors

The ultimate capacity of deep multi-helix Screw-Piles and Helical Anchors depends on the geometry of the helical section, namely the size and number of helical plates and the spacing between the plates. In the U.S. most manufacturers of Screw-Piles and Helical Anchors produce elements with a helix spacing of 3 times the helix diameter. This spacing is assumed to allow individual plates to develop full capacity with no interaction between plates and the total capacity is often taken as the sum of the capacities from each plate as shown in Figure 4.

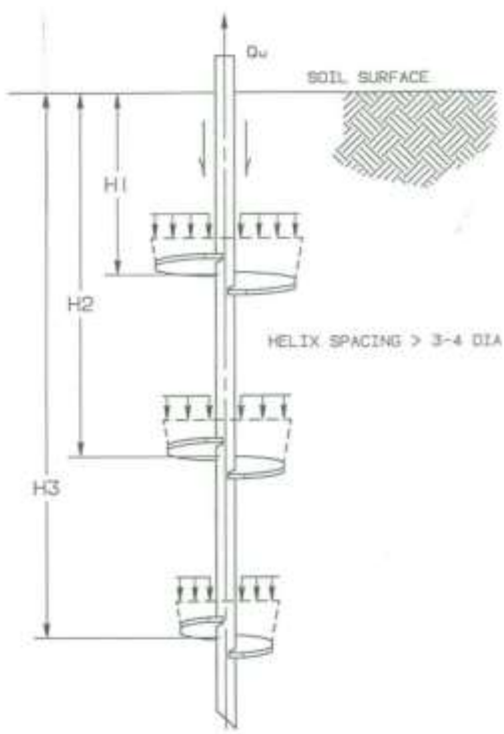


Figure 4. Development of Capacity for Multi-Helix Screw-Piles and Helical Anchors with S/D >3.

2.1 Compression and Tension Loading of Multi-Helix Screw-Piles in CLAY

The ultimate capacity of multi-helix Screw-Piles in compression and Helical Anchors in tension with a helix spacing/diameter ration $\geq$ 3 is often taken as the summation of the capacities of the individual plates:

$$Q_M = \Sigma Q_H \qquad [2.1]$$

where:

Q_M = Total Capacity of a Multi-Helix Screw-Pile/Helical Anchor
Q_H = Capacity of an Individual Helix

In clays, some provision may be made for installation disturbance, as previously noted in Section 1.2. In compression, the undisturbed undrained shear strength beneath the lowest helical plate may be used, but the strength between additional plates should be reduced. Skempton (1950) suggested that the average undrained shear strength of the clay between helical plates could be taken as:

$$s_{up} = s_u(und) - [½(s_u(und) - s_u(rem))] \qquad [2.2]$$

where:
s_{up} = undrained shear strength between helical plates
$s_u(und)$ = undisturbed undrained shear strength
$s_u(rem)$ = remolded undrained shear strength

An estimate of the remolded undrained shear strength may be made from an estimate of the Sensitivity.

The design steps are:

1. **Determine the design value of undrained strength, s_u, from appropriate lab or field tests;**
2. **Select a Screw-Pile or Helical Anchor geometry and determine the area of the helical plates;**
3. **For Compression, use the undisturbed undrained shear strength to calculate the bearing capacity of the lowest helical plate using Equation 1.2; use the reduced undrained shear strength to calculate the bearing capacity of the additional helical plates using Equation 1.2; For Tension use the reduced undrained shear strength to calculate the bearing capacity for all helical plates using Equation 1.2; use the net area of helical plates;**
4. **Use Equation 2.1 to estimate total capacity.**

2.2 Compression and Tension Loading of Multi-Helix Screw-Piles and Helical Anchors in SAND

In sands the ultimate capacity of multi-helix Screw-Piles in compression and Helical Anchors in tension with a helix spacing/diameter ration $\geq$ 3 is also traditionally taken as the summation of the capacities of the individual plates:

$$Q_M = \Sigma Q_H \qquad [2.1]$$

where:

Q_M = Total Capacity of a Multi-Helix Screw-Pile/Helical Anchor
Q_H = Capacity of an Individual Helix

The design steps are:

1. **Estimate the design value of friction angle, φ’, from appropriate lab or field tests;**
2. **Estimate the total unit weight of the sand;**
3. **Determine the location of the water table;**
4. **Calculate the effective vertical stress at the depth of the helix;**

5. **Determine the bearing capacity factor, Nq;**
6. **Select a Helical Anchor and calculate the area of the helical plates as appropriate; use the gross area for the lead helical plate in compression and the net area of successive helical plates as the cross sectional minus the area of the shaft; in tension use the net area of all helical plates;**
7. **Use Equation 1.5 to estimate capacity of each helical plate with a capacity reduction as suggested below;**
8. **Use Equation 2.1 to calculate total capacity.**

Note: There is recent evidence that in sands all helical plates of multi-helix configurations do not contribute the same capacity and that the "efficiency" of successive helical plates is diminished as compared to the lead helix. Suggestions for reducing the calculated capacity of individual helical plates for Double-Helix and Triple-Helix Screw-Piles and Helical Anchors are given below:

Lead Helical Plate	**100% Capacity from Eq. 1.5**
2^{nd} Helical Plate	**80% Capacity from Eq. 1.5**
3^{rd} Helical Plate	**60% Capacity from Eq. 1.5**

3. Shaft Resistance of Screw-Piles and Helical Anchors

Screw-Piles and Helical Anchors are available with round steel pipe shafts with diameters ranging from 2 7/8 in. to 12 in and may also be constructed with a grouted shaft. In recent years they have become increasingly popular for use in compression loading for both new construction and upgrading or underpinning of existing structures. Shaft resistance of the section in full contact with the soil can be included in the calculation of total capacity and uses a design approach that is similar to traditional Total Stress and Effective Stress Analysis of other types of deep foundations.

3.1 Steel Pipe and Grouted Shaft Resistance in Clay φ' = 0

In clays, the shaft resistance developed by round shaft and grouted shaft Screw-Piles and Helical Anchors is considered in much the same way as shaft resistance for driven piles. This traditional approach is used for many driven piles in clays and uses a percentage of the undrained shear strength of the clay for side resistance. This is the Total Stress (undrained) or "Alpha" method in which:

$$f_S = \alpha\, s_u \qquad [3.1]$$

where:

f_S = Unit Side Resistance
α = Adhesion Factor
s_u = Undisturbed Undrained Shear Strength of the Clay

The value of α is usually obtained from any one of a number of published charts and is often related to the absolute value of the undisturbed undrained shear strength of the clay.

Suggested values of α for steel piles based on the undisturbed undrained shear strength and given by the American Petroleum Institute (API) may also be used in which:

for $s_u < 500$ psf; $\alpha = 1.0$

for $s_u > 1500$ psf; $\alpha = 0.5$

for 500 psf $< s_u <$ 1500 psf; α varies linearly between 1.0 and 0.5

The total shaft resistance is then obtained from:

$Q_S = (f_S)(\pi)(d)(L)$ [3.2]

where:

Q_S = Total Shaft Resistance
d = Diameter of Central Shaft
L = Length of Round Shaft in Contact with Soil

The shaft resistance should **only be calculated for the portion of the shaft length that is in full contact with the soil**. This will depend on the length of the lead section and on the design of the couplings between the extension sections. For example, flanged and bolted connections generally create a cavity between the shaft and the soil as the pile or anchor is rotated during installation. Generally, the length of the central shaft above these connections is not considered to develop shaft resistance.

3.2 Steel Pipe Shaft Resistance in Sands

The shaft resistance of steel displacement pipe piles in coarse-grained soils, such as sands and mixed soils is more complex than in clays but can still be estimated using traditional deep foundation analyses. For preliminary design, the Department of Navy Design Manual DM-7 gives a simplified method for estimating the unit side resistance for straight shaft steel piles in sands. The value of f_S is related to the friction angle of the soil, φ', and the effective vertical stress, σ'_{VO}, as given in Table 4.

Table 4. Values of Unit Side Resistance for Steel Piles in Sand. (from Navy Manual DM-7)

σ'_{VO} (psf)	Friction Angle of Soil φ'				
	20	25	30	35	40
	Unit Side Resistance f_S (psf)				
500	137	175	217	263	315
1000	273	350	433	525	629
1500	410	524	650	788	944
2000	546	700	866	1050	1259
2500	683	875	1082	1313	1574
3000	819	1049	1300	1575	1888
3500	956	1244	1516	1838	2203
4000	1092	1399	1732	2101	2517

3.3 Grouted Shaft Resistance in Sands

Screw-Piles and Helical Anchors may be constructed using a lead helical section followed by a grouted shaft. The grouted shaft consists of cement grout placed under gravity around the central shaft. The grouted shaft can act much like a bored pile and develop considerable side resistance in some soils. The design of the lead helical section is the same as a nongrouted shaft using the appropriate procedures previously described. For preliminary design the simple approach according to the Navy Design Manual DM-7, previously described in Section 3.2 may be used to estimate side resistance of grouted shafts. Values of unit side resistance for smooth concrete piles are given in Table 5.

Table 5. Values of Unit Side Resistance for Smooth Concrete Piles in Sand. (from Navy Manual DM-7)

σ'_{VO} (psf)	Friction Angle of Soil φ'				
	20	25	30	35	40
	Unit Side Resistance f_S (psf)				
500	182	233	289	350	420
1000	364	466	577	700	839
1500	546	699	866	1050	1259
2000	728	933	1155	1400	1678
2500	910	1166	1443	1751	2098
3000	1092	1399	1732	2100	2517
3500	1274	1632	2021	2451	2937
4000	1456	1865	2309	2801	3356

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Skempton, A.W., 1950. discussion of The Bearing Capacity of Screw Piles and Screwcrete Cylinders. Journal of the Institution of Civil Engineers – London, Vol. 34, No. 5, pp. 76-81.

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