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Housing & Building
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LARGE CAPACITY SCREW PILES

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ABSTRACT : Results of field investigations of compressive, uplift and lateral capacity of screw piles in clay and sand is presented. The field study included 3 compressive tests, 3 uplift tests and 2 lateral tests of full-scale screw piles. Methods for estimating pile ultimate capacities were based on:

- Narasimha Rao et al (1991) for the design of screw piles in cohesive soils
- Mitsch and Clemence (1985) for the design of screw piles in cohesionless soils.
- Broms' method (1964) for the Lateral load design

Our design parameters for the design of the above tested piles using all the above methods were taken as results of extensive fully instrumented full-scale pile load tests done by ALMITA Manufacturing Ltd. under the supervision of university of Alberta, Canada.

The field test results presented in this paper were predicted reasonably well using the suggested methods. High-pressure cement grout was also applied through grouting pipes attached to Screw Piles in loose sand and 2 full-scale pile load tests were performed to compare grouted and un grouted behavior of screw piles in uplift, 2 full-scale in compression and 2 tests were performed to compare the Lateral capacity of grouted pile to the un grouted one. High-pressure grout in this kind of soils seems to improve the pile performance as well as it is also proved to be very cost effective.

INTRODUCTION

Helical piles are ground anchors constructed of helical-shaped circular plates welded to steel circular or square shaft at a specific spacing. Figure. 1,2 shows a typical configuration for a multi helix screw pile in uplift and compression. The piles are screwed in the ground using either truck mounted or excavator with special rotary head. ALMITA Manufacturing Ltd has fabricated and installed piles to Carry 3200 KN uplift force in dense sand at Fort McMurray, Alberta, Canada.

MULTI HELIX SCREW PILE DESIGN

Cohesive Soil

Compressive Loading

In the case of compressive loading, the total failure resistance can be summarized as follows:

Figure 1. Compression Loading Forces Acting on a Multi-helix Screw Pile

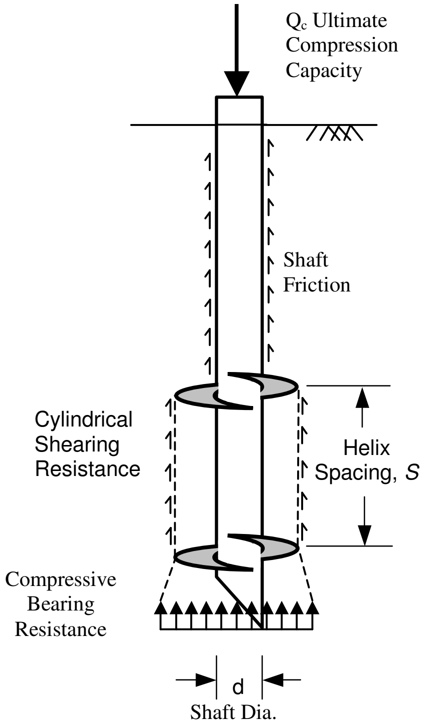
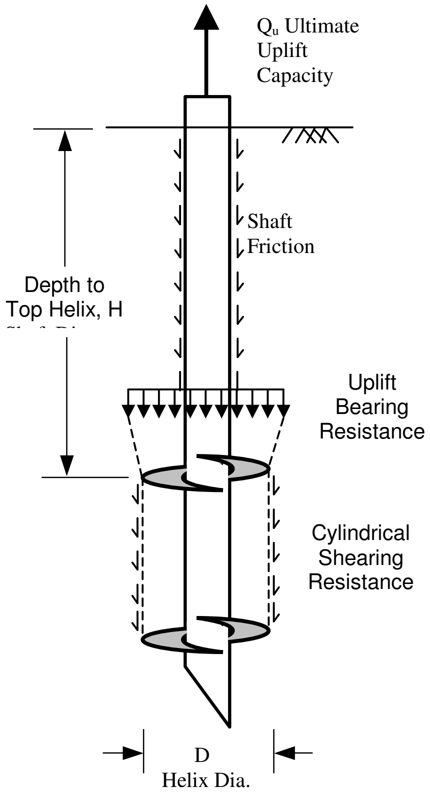


Figure 2. Tension Loading Forces Acting on a Multi-helix Screw Pile



$$Q_c=Q_{helix}+Q_{bearing}+Q_{shaft} \tag{1.1}$$

Where:

Q_c = ultimate pile compression capacity
Q_{helix} = shearing resistance mobilized along the cylindrical failure surface
$Q_{bearing}$ = bearing capacity of pile in compression
Q_{shaft} = resistance developed along steel shaft

For a cohesive soil the ultimate compression capacity of the helical screw pile using a cylindrical shearing method as proposed by Mooney (1985) and Narasimha (1991) is:

$$Q_c = Sf\,(\pi D L_c)\,C_u + A_H C_u N_c + \pi d H_{eff} \alpha C_u \qquad (1.2)$$

Where:

D = diameter of helix, (m)
L_c = is the distance between top and bottom helical plates, (m)
C_u = undrained shear strength of soil, (kPa)
A_H = area of the helix, (m^2)
N_c = dimensionless bearing capacity factors (*Tables 1.1and 1.2*)
d = diameter of the shaft, (m)
H_{eff} = effective length of pile, $H_{eff} = H - D$, (m)
α = Adhesion factor (see Figure. 3)
Sf = Spacing Ratio Factor

Table 1.I. Bearing Capacity Factor N_c Related to the Pile Diameter (after CFEM, 1992)

Pile Toe Diameter (m)	N_c
Smaller than 0.5	9
0.5 to 1.0	7
Larger than 1.0	6

Table1.2 Bearing Capacity Factors, N_c for Cohesive Soils, and Modified for Helix Selection (after ALMITA)

Helix Diameter		N_c
< 0.50 m	(< 20 in)	9.0
0.51 m	(20 in)	8.33
0.56 m	(22 in)	7.67
0.61 m	(24 in)	7.33
0.76 m	(30 in)	7.0
0.91 m	(36 in)	6.67
0.97 m	(38 in)	6.33
> 1.0 m	(40 in)	6.0

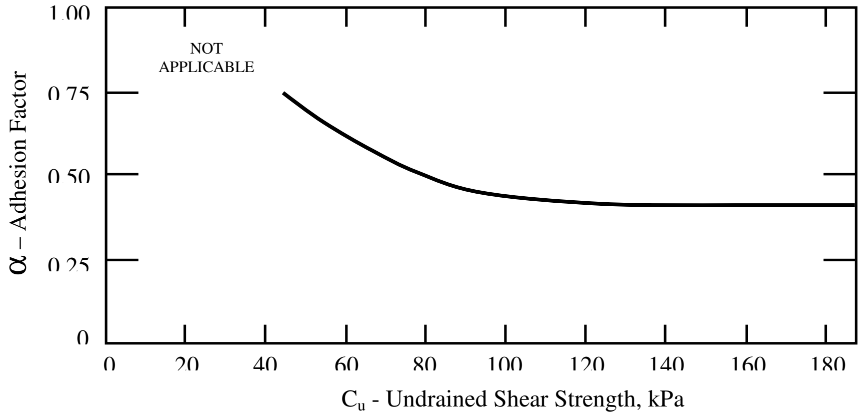


Figure 3: Reduction of Undrained Shear Strength for Anchorage Design (after CFEM, 1992)

Explanation of some of the terms:

The prediction of the bearing resistance developed from the bottom helix is independent of the embedment depth. The bearing capacity factor N_c, proposed by Meyerhof (1976), provides reasonable predictions for screw piles loaded in compression. Values of N_c are summarized in *Table1.1 and Table1.2*.

For estimation of the shaft adhesion, an effective shaft length H_{eff} is used in the calculation, which the effective shaft length is defined as the depth of the top helix (H) minus the top helix diameter (D). The adhesion developed along the steel shaft is considered in cases where sufficient installation depth (deep pile) is provided. For shallow condition (i.e. embedment ratio H/D < 3), the shaft adhesion is considered as insignificant, and thus, Q_{shaft} is not included in the equation. *Figure 3.0* describes the determination of the, α, adhesion factor.

In the case where shaft resistance is considered negligible the compression capacity equation simplifies to:

$$Q_c = Sf\,(\pi\, D\, L_c)\, C_u \;+\; A_H\, C_u\, N_c \qquad (1.3)$$

Uplift Loading

For predicting the total uplift capacity, a cylindrical shear model is also adopted and the ultimate tension capacity can be determined using the following equation (Mooney (1985), and Narasimha (1991))

$$Q_t = Sf\,(\pi\, D\, L_c)\, C_u \;+\; A_H\,(C_u\, N_u \;+\; \gamma'\, H\,) \;+ \pi\, d\, H_{eff}\, \alpha\, C_u \qquad (1.4)$$

Where:
Q_t = ultimate screw pile uplift capacity, (kN)

γ' = Effective unit weight of soil above water table or buoyant weight if below water table, (kN/m^3)
N_u = dimensionless uplift bearing capacity factor for cohesive soils

For multi-helix screw piles loaded in tension, the ultimate capacity is dependent upon the embedment depth. Generally there are two contributing factors to an increase in the total uplift capacity with increasing depth. First, the shaft resistance increases with embedment depth and secondly, the bearing resistance developed above the top helix is dependent on the depth that the screw pile was installed to. The uplift bearing capacity factor, N_u increases with the embedment ratio (H/D) to a limiting value of approximately equal to 9.

$$N_u = 1.2\,(H / D) \leq 9 \qquad \text{(Meyerhof 1976)} \tag{1.5}$$

Similar to the compression test, for short piles installed at a shallower depth, the term for predicting the shaft adhesion can be neglected since the result is insignificant to the total uplift capacity. The equation can be summarized to:

$$Q_t=(\pi D L_c)C_u+A_H(C_u N_u+\gamma' H) \tag{1.6}$$

Cohesionless Soil

Compressive Loading

For a cohesionless soil the ultimate compression capacity of the helical screw pile using a cylindrical shearing method (Where H/D >=5) as proposed by Mitsch and Clemence (1985) is:

$$Q_c=Q_{helix} + Q_{bearing} + Q_{shaft}$$

$$Q_{helix}=1/2\pi D_a\gamma'(H_3^2-H_1^2)K_s\tan\phi \tag{2.1}$$

$$Q_{bearing}=\gamma' H A_H N_q \tag{2.2}$$

$$Q_{shaft}=1/2P_sH_{eff}^2\gamma' K_s\tan\phi \tag{2.3}$$

$$Q_c =\gamma' H A_H N_q + 1/2\,\pi\, D_a\, \gamma' (H_3^2 - H_1^2)\, K_s \tan\phi + 1/2\, P_s\, H_{eff}^2\, \gamma'\, K_s \tan\phi \tag{2.4}$$

Where:
Q_c = ultimate compression capacity, (kN)
γ' = Effective unit weight of soil, (kN/m^3)
K_s = coefficient of lateral earth pressure in compression loading
ϕ = Soil angle of internal friction, degree
A_H = area of the bottom helix, (m^2)
N_q = dimensionless bearing capacity factor, *Table 2.1*.
D_a = average helix diameter, (m)

H = the embedment depth of pile, (m)
D_1 = diameter of top helix, (m)
H_{eff} = effective shaft length, (m)
H_1 = depth to top helix, (m)
H_3 = depth to bottom helix, (m)
P_s = the perimeter of the screw pile shaft, (m)

Explanation of some of the terms:

Meyerhof (1968) suggested that the bearing capacity factor N_q, can be calculated using:

$$N_q=e^{\pi\tan\phi}\tan^2(45^\circ+\phi/2) \tag{2.5}$$

Values of Nq are summarized in Table 2.1.

Table 2.1 Bearing Capacity Factor, N_q, for Cohesionless soils

Internal Friction Angle, ϕ	0°	5°	10°	15°	20°	22°	24°	26°	28°	30°	32°	34°	36°	38°	40°	42°	44°
N_q	1	2	3	4	6	8	10	12	15	18	23	29	38	49	64	85	115

K_s, coefficient of lateral earth pressure in compression loading, which can be estimated by using the following two tables (*Table 2.2 and 2.3*).

Table 2.2. Values of the Coefficient of Horizontal Soil Stress, K_s (after Kulhawy, 1984)

Installation Method	K_s/K_o
Piles, Large Displacement (≥ Ø8-5/8" shaft)	1 to 2
Piles, Small Displacement (< Ø8-5/8" shaft)	0.75 to 1.25

Table 2.3. Typical Values of K_o for Normally Consolidated Sand (after Kulhawy, 1984)

Relative Density	K_o
Loose	0.5
Medium-Dense	0.45
Dense	0.35

CFEM (1992) suggested that K_s is usually assumed to be equal to the coefficient of original earth pressure, K_o, for bored piles, and twice the value of K_o for driven piles.
For the shallow condition (i.e H/D < 5), the ultimate compression capacity of a multi-helix screw pile in sand can be predicted by summing the bearing capacity of the bottom helix and the frictional resistance along the cylinder of soil between the helices without the shaft resistance. Therefore, Equation 2.10 can be expressed as follows:

$$Q_c=\gamma' H A_H N_q+1/2\pi D_a \gamma'(H_3^2-H_1^2)K_s \tan\phi \qquad (2.6)$$

Uplift Loading

For predicting the total uplift capacity, a cylindrical shear model proposed by Mitsch and Clemence (1985) is suggested and the ultimate tension capacity can be determined. Zhang (1999) suggests that there are two distinct failure mechanisms for screw piles loaded in tension in the cohesionless soil, namely the shallow or the deep condition. The shallow condition describes the mechanism where a truncated pyramidal shaped failure surface propagates for the top helix to the ground surface. The central angle of the truncated cone is approximately equal to the soil friction angle, ϕ. A cylindrical failure surface is formed below the top helix. For helical piles installed in a much deeper depth, a failure zone develops directly above the top helix. The overburden pressure confines this failure surface, and therefore the failure zone does not propagate to the ground surface. Meyerhof and Adam (1968)'s theory stated that there is a maximum embedment ratio $(H/D)_{cr}$, where the failure mode changes from shallow to deep and this maximum value increases with an increase in the relative density (D_r), and the internal soil friction angle, ϕ of the sand. Das (1990) expressed the ultimate bearing capacity proposed in Mitsch and Clemence's theory in terms of breakout factor F_q for shallow anchor conditions and F_q^* as follows:

For Multi-helix Screw Pile installed in Shallow Condition $H/D < (H/D)_{cr}$

$$Q_t=\gamma' H A_H F_q+1/2\pi D_a \gamma'(H_3^2-H_1^2)K_u \tan\phi \qquad (2.7)$$

For Multi-helix Screw Pile installed in Deep Condition $H/D > (H/D)_{cr}$

$$Q_t = \gamma' H A_H F_q^* + 1/2 \pi D_a \gamma' (H_3^2 - H_1^2) K_u \tan\phi + 1/2 P_s H_{eff}^2 \gamma' K_u \tan\phi \qquad (2.8)$$

Where:

Q_t = ultimate screw pile uplift capacity, (kN)
γ' = Effective unit weight of soil, (kN/m^3)
ϕ = The soil angle of internal friction, degree
K_u = dimensionless coefficient of lateral earth pressure in uplift for sands
H = embedment depth, (m)
A_H = area of the bottom helix, (m^2)
D_a = average helix diameter, (m)
D_1 = diameter of top helix, (m)

H_{eff} = effective shaft length, $H_{eff} = H_1 - D_1$, (m)
H_1 = depth to top helix, (m)
H_3 = depth to bottom helix, (m)
P_s = the perimeter of the screw pile shaft, (m)
F_{q*} = breakout factor for shallow condition, *see Figure 4*
F_q = breakout factor for deep condition, *see Figure 5*

Explanation of some of the terms:
Embedment ratio (H/D) is defined as the depth to the top helix; H divided by the top helix diameter, D.

Table 2.4. Critical Embedment Ratio, $(H/D)_{cr}$ for Circular Anchor (after Meyerhof and Adam,1968)

Friction Angle, ϕ	20º	25º	30º	35º	40º	45º	48º
Depth $(H/D)_{cr}$	2.5	3	4	5	7	9	11

This coefficient, Ku is used to empirically quantify the lateral stress acting on the failure surface as the screw pile is pulled out from the soil. The lateral stress outside the cylindrical failure surface increases to a passive state due to the screw action during the installation process. The magnitude of the increase is dependent upon the amount of disturbance and the changes in stress level during the installation.

Table 2.5. Recommended Uplift Coefficients, K_u for Helical Anchors (after Mitsch and Clemence, 1985)

Soil Friction Angle, ϕ	Meyerhof's Coefficient for Foundation Uplift	Recommended Coefficients for Helical Anchors
25º	1.20	0.70
30º	1.50	0.90
35º	2.50	1.50
40º	3.90	2.35
45º	5.30	3.20

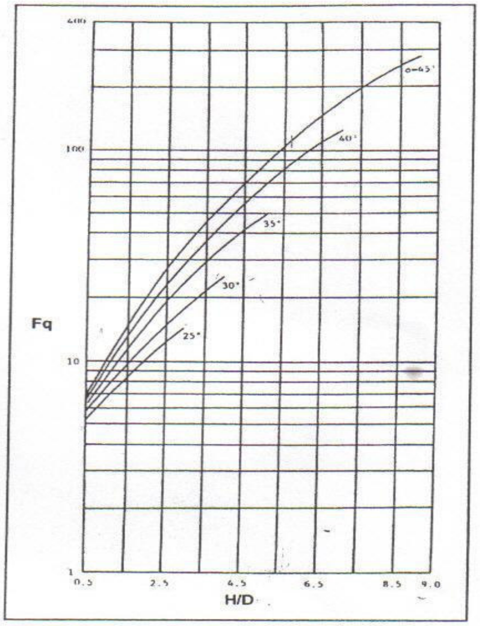


Figure 4. Variation of Breakout Factor with Embedment Depth for Shallow Anchor Condition based on Mitsch and Clemence's Theory (after Das, 1990)

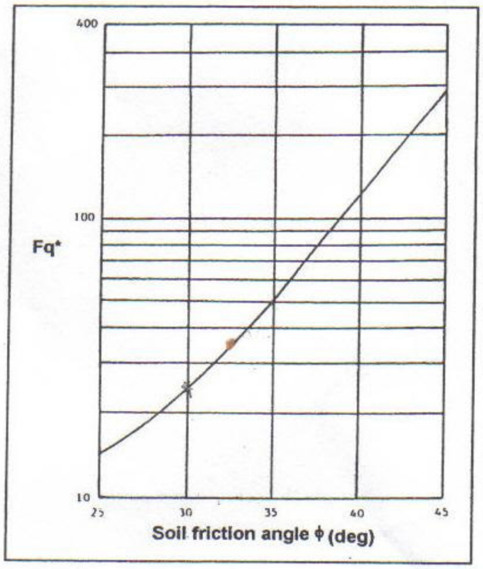


Figure 5 Variation of Breakout Factor with Embedment Depth for Deep Anchor Condition based on Mitsch and Clemence's Theory (after Das, 1990)

Field Screw Anchor tests:

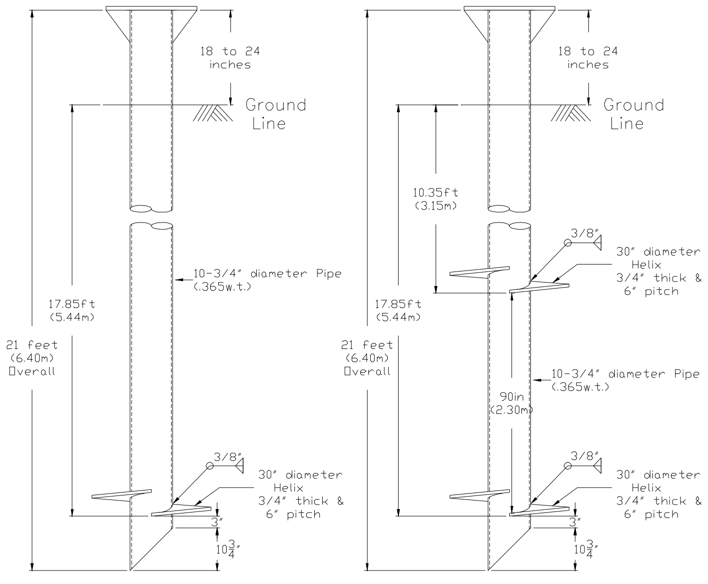
Ruth Lake Project - Fort McMurray, AB

<u>SOIL DESCRIPTION</u>

1. 0 - 2' (Top Soil)
2. 2 - 8' (Clay)
3. 8 - 20' (Clay Till)

<u>PILE DESCRIPTION</u>

Two piles (Figure 3) were used for testing to failure (Compression, Tension and Lateral tests were done for each pile type).



Screw Pile Type C1 & T1 Figure 6 Screw Pile Type C1 & T1

TEST RESULTS SUMMARY

Please refer to Tables 3.1 & 3.2 for ultimate design loads and actual test load for all tested piles

Table 3.1: Comparison of predicted and measured axial pile capacities

Test No	Pile Type and Loading Condition	Measured load at 1 % helix diameter	Measured load at 2% helix diameter	Interpreted Ultimate Capacity (KN) FROM Load Test	Predicted Ultimate Capacity (KN)
C1	Single Helix Compression	369	522	1010	980
C2	Double Helix Compression	462	671	1369	1305
T1	Single Helix Uplift	334	471	809	800
T2	Double Helix Uplift	547	717	1307	1300

Table 3.2: Comparison of Predicted and measured Lateral Loads

Pile No	Pile Type and Loading Condition	Measured load at 6.00 mm displacement	Measured load at 12.00 mm displacement	Predicted sustained load at 6.00 mm
L1	Single Helix	24	39	25
L2	Double Helix	25	37	25

Dover substation Project - Fort McMurray, AB

SOIL DESCRIPTION

- 0 - 4’ (Sand- Medium dense)
- 4 - 8’ (Clay Till)
- 8 - 20’ (Sand- Dense)

PILE DESCRIPTION

One pile (Figure 7) was used for testing to failure (Tension).

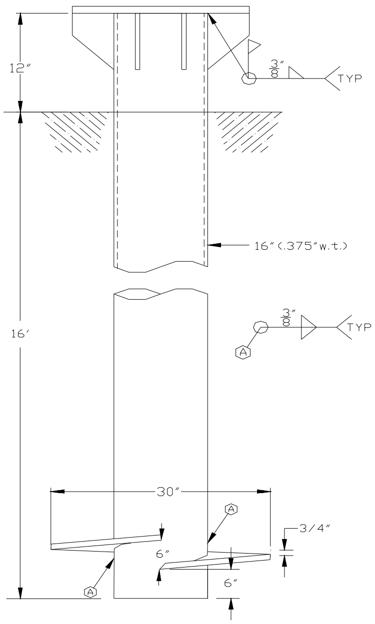


Figure 7

TEST RESULTS SUMMARY

The first load cycle showed 0.787in total upward movement (0.630in when unloaded to Zero Load).

The second load cycle showed 1.339in total upward movement (1.102in when unloaded to Zero Load).

Pile Shaft ultimate resistance = 224.8 Kips (Van Weele, 1957)

Pile expected Ultimate resistance = 719.4 Kips (Mayerhof, 1968)

Grouted Piles:

SOIL DESCRIPTION

- 0 - 30' (Sand- Loose, Fine Grained)

PILE DESCRIPTION

Six piles (3 with grouted after installation and 3 without grout) (Figure 8) were used for testing to failure (Compression, Tension and Lateral tests were done). Table 3.3 summarizes the tests results and comparison of the behavior of the grouted to un grouted piles

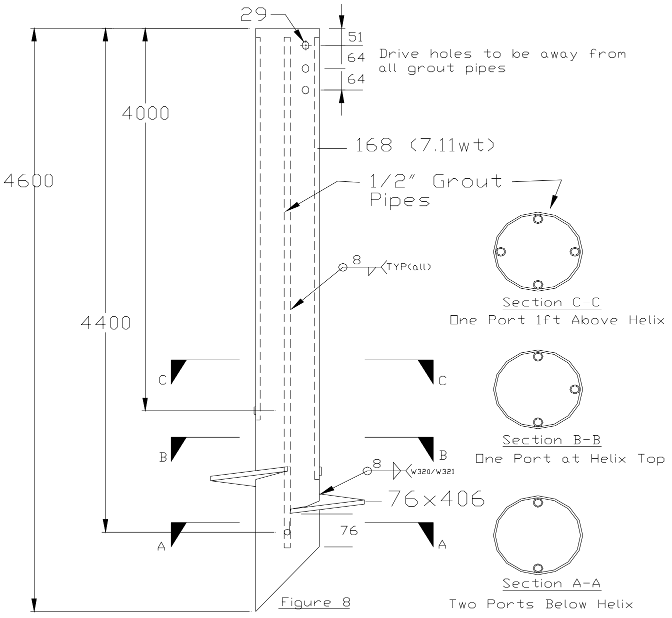


Figure 8

Table 3.3: Comparison of Grouted and Un Grouted pile behavior

Criteria \ Pile Type	Grouted Pile	Un Grouted Pile
For 8.0 mm movement in Compression	230.00	140.00
Ultimate Load in Compression	330.00	230.00
For 8.0 mm movement in Uplift	205.00	78.00
Ultimate Load in Uplift	330.00	156.00
For 6.0 mm Lateral Movement	13.00	6.00
For 6.0 mm Lateral Movement	22.00	13.00

SUMMARY AND CONCLUSIONS:

1. An analogy between anchor uplift and bearing capacity can be made. Deep anchors in uplift act similarly to foundation in bearing. Values for uplift capacity factors vary with soil strength parameters and H/D Ratio, the upper limit being the values for bearing capacity factors (Mooney 1985).
2. The cylindrical failure surface below the top helix develops as a result of stress relieve, suction and upward pressure forces exerted by the helices on the soil within the anchor cylinder (Mooney 1985).

3. The long-term uplift capacity of anchors in clay is dependent on the soil's stress history. Normally consolidated clay exhibits an increase in capacity of 20 to 30 % due to consolidation occurring above helices. Drained strength parameters should be used to predict long-term anchor capacity in normally consolidated clays (Mooney 1985).
4. Anchors in silt tend to exhibit the same behavior as anchors in clay, Drained strength parameters should be used in case of long-term loading (Mooney 1985).
5. The ultimate uplift capacity of multi-helix anchors can be predicted by an equation considers the shear resistance along the cylindrical failure surface, the uplift resistance above the top helix, and the shear resistance along the anchor shaft.
6. The installation of helical anchors in sand causes an increase in the lateral stresses. The magnitude of stress increase is proportional to the initial relative density of the sand (Clemence 1985)
7. High pressure grouting increased the compression, uplift and lateral ultimate capacity of the piles
8. High pressure grouting improves the pile performance at specific acceptance criteria (8 mm movement in uplift or compression or 6 mm for lateral movement).
9. The use of High-pressure grout with Screw Anchors in loose sand is very cost-effective way to improve pile performance.
10. The values of compression, uplift and lateral resistance calculated by the proposed equations compare favorably with measured values from field.

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