

# Behavior of High Pressure grouted Screw Piles in Santa Clara, CA

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*Helical Pier Systems Ltd Sponsored Project*

## Abstract

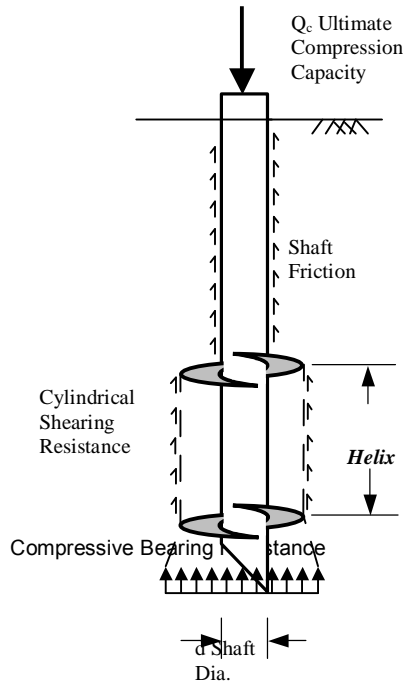
Screw piles have been used widely in engineering applications to provide structural stability against axial compression, uplift, overturning and lateral forces. Screw piles are also known as Helical Piles or Piers, Helical Anchors and Screw Anchors. In that project site in Santa Clara, CA, several column foundations in the building had to be reinforced to sustain the earthquake forces that will be exerted on the foundations in the event of an earthquake. Due to overhead and space limitation the reinforcement was proposed using High pressure grouted mini piles. An alternative solution using screw piles with high-pressure grout in loose sand was proposed. With the cost saving expected, if the alternative solution is implemented, the engineer and owner accepted to carry out preliminary pile load tests on site to verify the design and assure that the behavior of the pile meets the acceptable criteria. Three preliminary and sixteen working pile load tests were done on site and they all passed the acceptable criteria. The high-pressure grout increased the Screw pile capacity by 40% compared to un-grouted Screw pile and accordingly saved the total project cost and time.

## Introduction

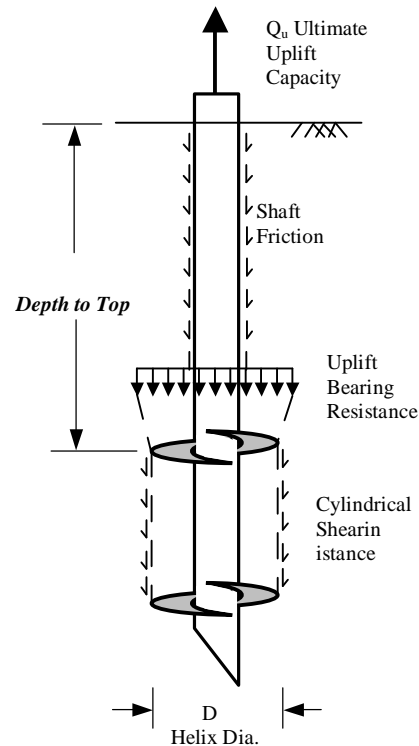
Due to overhead and accessibility concerns at the job site Mini piles were proposed to reinforce the foundation on the building (Marvell Campus, Building 4, Santa Clara, CA). The reinforcement of the original foundations was proposed to sustain major earthquake forces; which might be exerted on the foundation in the event of any earthquake occurs on site (refer to US Geological survey, 1990). Due to existence of Loose sand layer at a depth between 8-11.0 m (refer to CPT Test results in Appendix), high pressure grouted screw piles were proposed to be used instead of mini piles to carry a working load of 375 Kn ( 84 Kips) and to be tested to 150% working load ( 560 Kn, 125 Kips). The Screw Pile proposed is 89 mm shaft diameter (3 1/2"), 17.6m deep (55') with five helices [ .25m \* .30m \* .36m \* .36m \* .36m] i.e.( 10" \* 12" \* 14" \* 14" \* 14"). With the help of high pressure grouting pump after installation of the screw piles grout was pushed into the loose sand layer through grout ports in the pile. Volume of grout ,as well as, the pressure of grout at each pile location was monitored and recorded. Three preliminary Pile Load tests before the commencement of the job were done as well as 16 working pile load tests were carried out during construction. Two un-grouted screw pile tests were performed on site to compare the pile behavior. The conclusion of the tests performed on site confirmed the economical use of high-pressure grouted screw piles. The high pressure grouted piles showed 40 % higher capacity of the piles compared to the un-grouted piles.

## Multi Helix Screw Pile design

Compression Loading Forces Acting on a Multi-helix Screw Pile



Tension Loading Forces Acting on a Multi-helix Screw Pile



### 1. Cohesive Soil

#### 1.1 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))

$$Q_t = S_f (\pi D L_c) C_u + A_H (C_u N_u + \gamma' H) + \pi d H_{eff} \alpha C_u$$

Where:

- $Q_t$  = ultimate screw pile uplift capacity, (kN)
- $\gamma'$  = Effective unit weight of soil above water table or buoyant weight if below water table, (kN/m<sup>3</sup>)
- $N_u$  = 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.

$$N_u = 1.2 (H / D) \leq 9 \quad (\text{Meyerhof 1976})$$

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:

$$Q_t = (\pi D L_c) C_u + A_H (C_u N_u + \gamma H)$$

## 2. Cohesionless Soil

### 2.2 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,  $\phi$ . 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,  $\phi$  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  $H/D < (H/D)_{cr}$

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

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

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

Where:

- $Q_t$  = ultimate screw pile uplift capacity, (kN)
- $\gamma$  = Effective unit weight of soil, (kN/m<sup>3</sup>)
- $\phi$  = 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<sup>2</sup>)
- $D_a$  = 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)

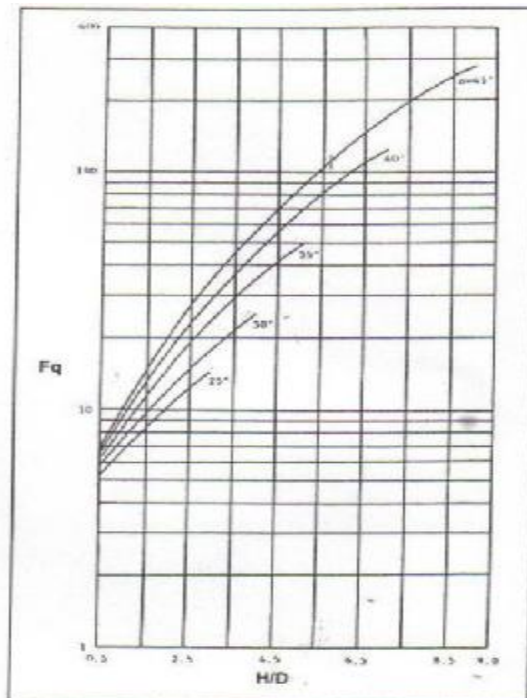
Friction Angle, $\phi$	20°	25°	30°	35°	40°	45°	48°
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Depth (H/D) <sub>cr</sub>	2.5	3	4	5	7	9	11
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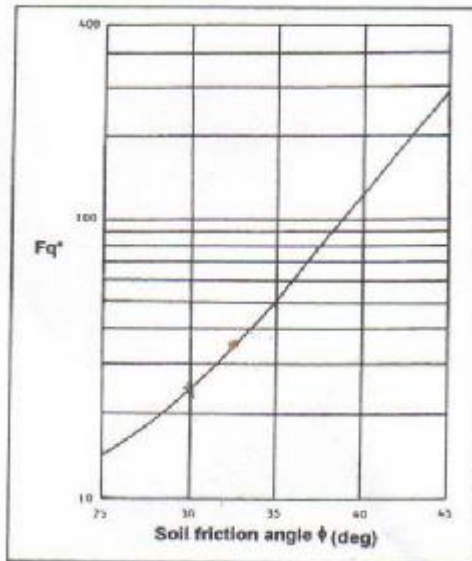
This coefficient,  $K_u$  is used to empirically quantify the lateral stress acting on the failure surface as the screw pile is pulled out from the soil. The lateral stress outside the cylindrical failure surface increases to a passive state due to the screw action during the installation process. The 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, $\phi$	Meyerhof's Coefficient for Foundation Uplift	Recommended Coefficients for Helical Anchors
25°	1.20	0.70
30°	1.50	0.90
35°	2.50	1.50
40°	3.90	2.35
45°	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)

### Site Soil description

Ten boreholes (including soils samples and Standard penetration tests) as well as six Cone penetration tests were provided for analysis. In building number 2 (where the high pressure screw piles was proposed as an alternative to high pressure grouted Mini piles), borehole number 6 and 7 as well as cone penetration tests CPT# 1, CPT #2) are the most representative at the screw pile location.

- Summary of the soil description on site
  1. 0-1.0 m fill material (Silty sand with Gravel)
  2. 1.0-8.0 m Fat Clay (Stiff)
  3. 8.0 – 11.0 m Silty Sand (Loose to Medium Dense)- Grouting is suggested to densify Sand in this layer
    - § CPT Tests shows Fr (fine ratio)  $\leq 5\%$
  4. 11.0 – 14.0 m Clay (Stiff- Trace of fine sand and Gravel)
  5. 14.0 – 20.0 m Clay (Stiff to Very Stiff)
- Water Table was found at 2.50 m from G.L.

### Method Statement for installation and grouting of Screw Anchors in Santa Clara

#### 1. Pile Description

- Shaft diameter = 3.5"
- Shaft wall thickness = 0.254"
- Pile embedment depth = 55'

## 2. Pile fabrication

The screw pile is made of 8 sections each 7' in length. Due to overhead limitations, 7' sections were selected to maximize sectional length and minimize Pile connections. The first section had 3 helices [0.25m \* 0.3m \* 0.35m], (10" \* 12" \* 14") each spaced at 3 helix diameters apart (Drawing 04-040-D). The lead point on the section is cut to a 45° to help in targeting and installation. The following section had 2 more helices [0.35m \* 0.35m], (14" \* 14") placed to match the pattern of the lead section (Drawing 04-040-C). The coupling connections on all extensions were welded-on, 2 bolt hole couplers. All extension sections were 7' straight runs of pipe. Drawing 04-040-B shows the grout extensions including size and location of grout ports. Drawing 04-040-A presents the standard extensions.

## 3. Pile Installation

The first lead section (7' long) with triple helices 10" \* 12" \* 14" will be Installed. Upon completion of installation of this section the second Section of 7' long with Twin 14" \* 14" helices (with two 0.5" grouting Holes drilled around the top helix) will be added (bolted connection- same Bolt as above) and installed. The third and fourth sections (each of 7' long with grouting holes) will be installed the same way as second section- that is based on the assumption of the existence of the sand layer between 28' - 42' deep from Installation Grade elevation (Refer to CPT02-CPT05 Submitted By M/S. Treadwell Rollo). The remaining extensions will be installed with a bolted connection to the previous section. Pile Minimum penetration depth = 55'. Upon completion of installation of each Pile, a pull out force of Approximately 10 Kips will be applied to take any mechanical slack out of The system. Each day installation records for each pile installed on that day will be submitted to the geotechnical engineer to compare actually installation Torque to expected (also to figure out if the grout holes are placed in sandy Layers or clayey layers- please refer to grout mix design in each case).

## 4. Grouting procedures

Upon completion of installation, water will be pumped into the pile with Pressure pump (delivery pressure of 60 psi or more) to open the grouting Holes. The pressure will start high and when the holes are opened the Operator will realize the immediate drop of pressure. Grouting with grout mix (described below) will be pumped to the pile till we reach a pumping pressure of 30 psi. Grout has to set for a week before testing.

## 5. Grout Mix

- Sandy Layers
  - i. Water / Cement Ratio = 1 / 1 by weight (normal Portland cement)
  - ii. Plasticizer / Retarder will be added according to the manufacturer's recommendations.
  
- Clayey Layers
  - Option (1)
    - i. Water/ Cement Ratio = 1/ 1 by weight (very fine grained Cement)

- ii. Plasticizer / Retarder will be added according to the manufacturer's recommendations.
- Option (2)
- i. Chemical Grout (see recommendation from Construction Materials Manufacturer for grout in Clay)

#### **6. Pile Test Load**

- Ultimate pile test load = 560 KN (125 Kips)
- Pile Working Load = 375 KN (84 Kips)

#### **Pile Load Tests and analysis**

Three preliminary pile load tests were done according to ASTM 3689.

#### **Passing Criteria**

1. Test piles shall be identified as 'passing' if the deflection under the test load (560 KN-125 Kips) sustained for 10 minutes is less than or equal 1mm (0.04").
2. If deflection under test load above is greater than 1.0mm (0.04"), then the test load will be maintained for an additional 50 minutes. Deflection then will be measured and used to determine capacity of pile

#### **Conclusions after the preliminary pile load tests**

Treadwell and Rollo (geotechnical engineer for that job) quoted in their report the following: "on the basis of the pier load test results and discussion with Paradigm (Structural Engineers for that site) and ALMITA (Manufacturer and designers of screw piles), we conclude that the ultimate uplift load of 125 Kips is acceptable of the helical piers. With a factor of safety = 1.5, the pier working load may be taken = 375 KN -84 Kips" unquote.

#### **Proof pile load tests**

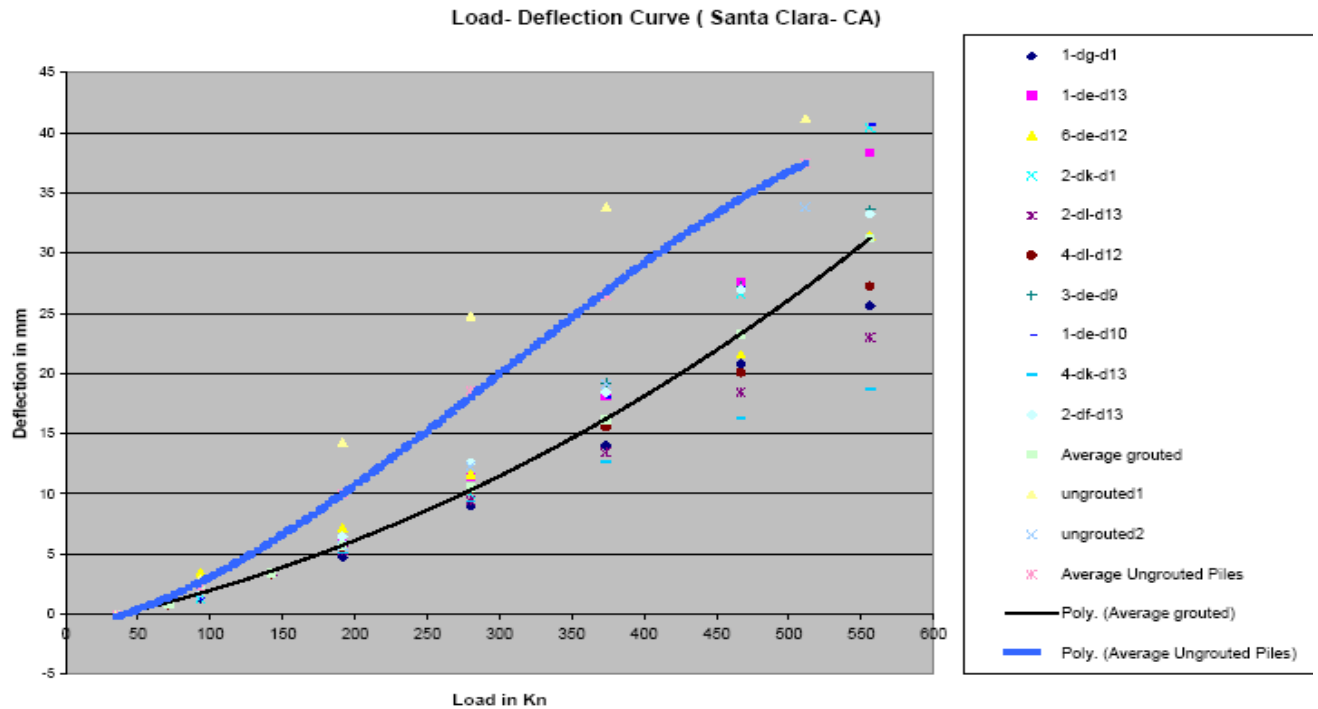
Sixteen working pile load tests (proof tests) were performed on site (one pile for each cluster was chosen to be tested). The passing criteria were kept the same as above.

#### **Un-grouted pile load tests**

Two piles were Un-grouted on site (refused to accept grout) and because the actual load on both was less than the 84 Kips, those two piles were treated as un-grouted piles and were both tested to compare the behavior of grouted vs. un-grouted piles.

#### **Test results**

Analyzing all the tests done on site, the graph drawn below shows the load (KN) deflection (mm) (total uplift deflection).



### Pile Load Test analysis and Conclusion

Based on the assumption that the grouted sand will behave as dense - very dense sand, the top clayey soil is soft (Undrained shear strength = 50 Kpa) and the layer below the sand is firm to stiff Clay (Undrained shear strength = 75 Kpa) and using the Cylindrical shear method for load transfer analysis, the pile ultimate load = 570 KN. Using the same analysis with loose sand (not grouted), the pile ultimate load = 450 Kn. From the analysis above, the high-pressure grout increases the pile ultimate capacity by 40%. The actual test results proved that for a specific pile deflection the grouted piles achieved almost 40% higher load higher than the un-grouted to get the same uplift deflection. i.e. for 15 mm total deflection, 250 KN required for the Un-grouted piles compared to 350 KN for the grouted ones. The test results also show for a specific load, the total deflection of the pile is much less for the grouted piles in comparison to the Un-grouted piles. i.e. at 400 KN the Un-grouted pile deflected 27.0mm compared to 17.0mm for the grouted pile.

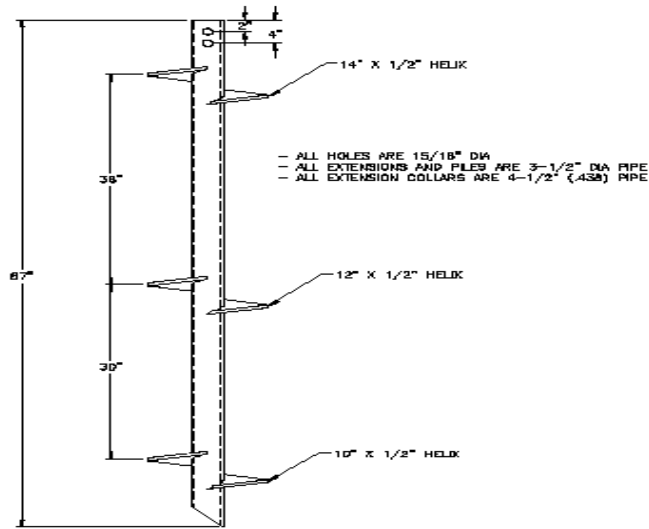
## Conclusion and summary

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 that 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 uplift capacity of the screw piles in Santa Clara (Marvell Campus, Building 4, Santa Clara, CA) by 40 % compared to the Un-grouted Piles (for the same deflection).
8. High pressure grouting improves the pile performance for the specific acceptance criteria at Santa Clara job site. To have the same pile deflection higher load was required for the grouted Piles compared to the Un-grouted piles.
9. The use of High-pressure grout with Screw Anchors in loose sand is a very cost-effective way to improve pile performance.
10. The project using the high-pressure grouted screw piles was completed on time and within budget (High pressure grouted screw piles was a cheaper alternative solution than mini piles).

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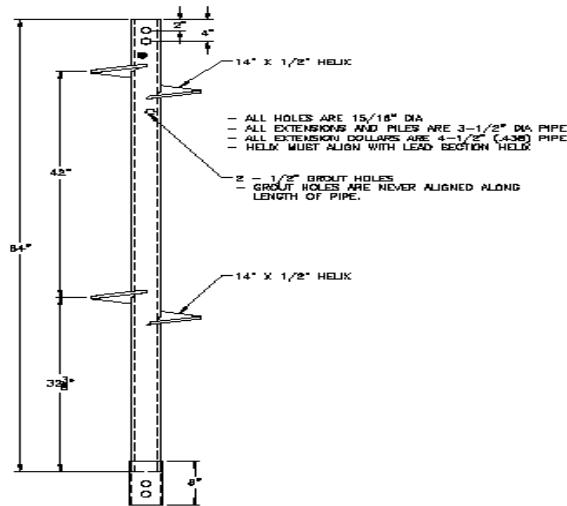
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## Appendix



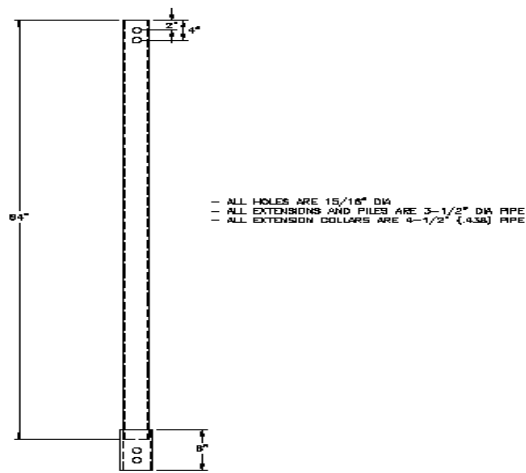
SCREW PILE

<p>8809 - 42 AVE. RICHMOND, ALBERTA CANADA T4N 1A8 PH: (403) 782-2800 1-800-303-1808 FAX: (403) 740-2809</p>	<b>Project:</b> HELICAL PIER SYSTEMS GROUTED SCREW PILE DETAILS SANTA CLARA, CA		<b>Drawing Title:</b> FILE CONFIGURATION.DWG	
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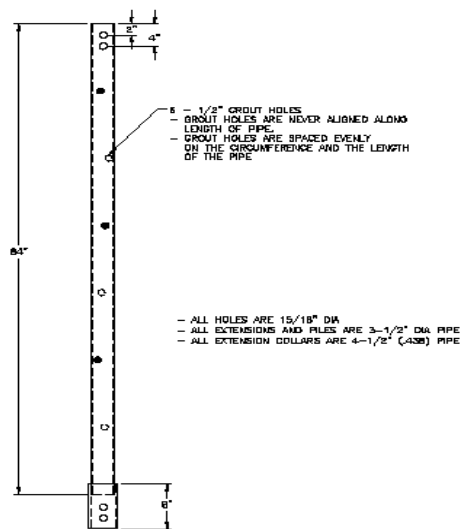
HELIX EXTENSION

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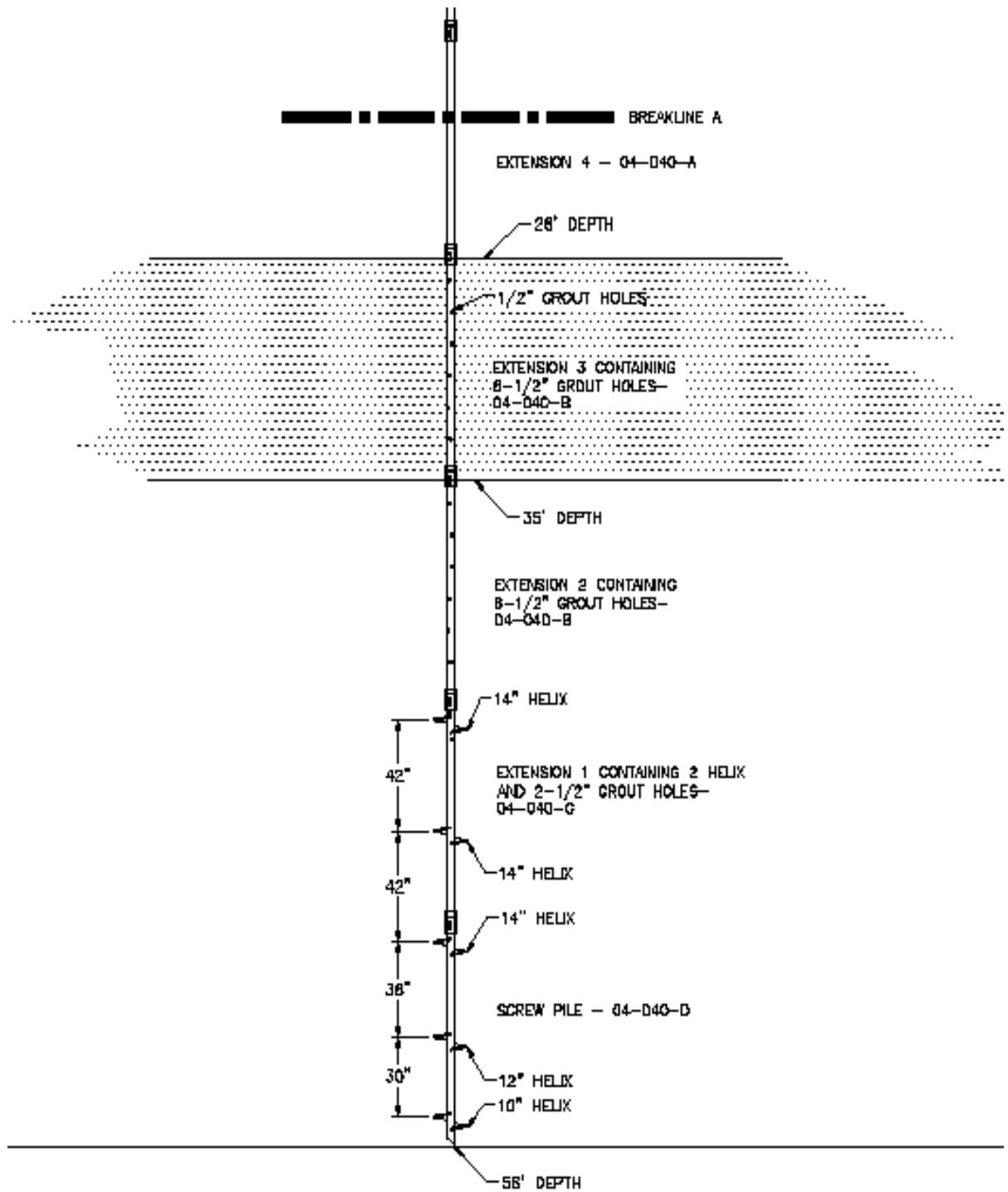
STANDARD EXTENSION

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<b>Revised</b> (None)					



GROUT EXTENSION

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