Considerations for the Design and Installation of Helical Pile Foundations

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Helical Foundation Systems: Topics We Will Cover

• Helical Terminology, Shaft Comparison & General Discussion
• Typical Applications
• Determination of Capacity
• Verification of Capacity
• Load Testing
• ICC-ES AC358
• Structural Design

Did You Know?

• The use of helical piles in construction dates back nearly 200 years
• 1830’s - helical piles used in England for moorings and foundations for lighthouse structures
• Increased use following WWII with advancements in power equipment
• 2007 – ICC-ES approves AC358, Acceptance Criteria for Helical Foundation Systems and Devices
• 2009 – Helical piles included within Chapter 18 of IBC 2009
Terminology

Helical Foundation System
A factory-manufactured steel foundation designed to resist axial compression, axial tension, and/or lateral loads from residential and commercial structures. The system consists of a central shaft, one or more helix-shaped bearing plates, and a bracket that allows attachment to structures.

New Construction and Retrofit Style Brackets

New Construction Helical Piles

Helical Foundation Systems

Round Shaft Helical Pier
Helical Pier = A helical foundation system primarily designed to support compression loads.
- Hollow round shaft
- Round shaft better suited for compression applications
**Helical Foundation Systems**

**Square Shaft Helical Tieback**

*Helical Anchor/Tieback* = A helical foundation system primarily designed to support tension (uplift) loads.

- Solid square or hollow round shaft
- Square shaft better suited for certain tension applications

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**Advantages of Round Shaft Helical Piers**

*(Versus Square Shaft Helical Piers)*

- Greater Structural Section Modulus
- Higher Lateral Resistance (can also be grouted solid)
- Generally Higher Torque Resistance
- Rigid Coupling versus Socket and Pin Coupling – Reduces Variances from Straightness

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**Comparison of Coupling Details**

**Round Shaft Coupling**

**Square Shaft Coupling**

- Shafts are in direct contact at couplers
  - Removes coupler weld and bolts from axial compression load path
  - Holes are easier to line up
Comparison of Coupling Details

Advantages of Square Shaft Helical Piles
(Versus Round Shaft Helical Piles)

- Greater Soil Penetration for a Given Torque
- Less Surface Area Exposed to Corrosion
- Degree of Shaft Twist Indicates Approximate Applied Torque
- More Forgiving During Installation (Advantage for Less Experienced Installers)

Square Shaft Helical Anchors

- Square shaft originally developed as an anchor to resist tension loads.
- Later marketed to support foundations and compression loads.
- Square shaft helicals are a good product in the right application; i.e.,
  - tension, or
  - light, concentric compression loads where SPT ≥ 10 blows/foot.
- Square shafts do not function as well as round shafts in compression, especially as eccentrically-loaded piers in retrofit applications.
Benefits of Helical Piles and Anchors

- High-capacity deep foundation alternative
- Predictable capacity
- Lead sections and extensions can be configured to achieve design depth and capacity
- All-weather installation
- Can be installed with either handheld or smaller construction equipment
- Can be installed in areas of limited or tight access
- Vibration-free installation (unlike traditional driven piles)
- Installs quickly without generating spoils
- Load tests can be conducted immediately following installation
- Foundation concrete can be poured immediately following installation
- Clean installation – no messy grout (tiebacks)

Helical Foundation Systems:

Typical Applications
New Construction Helical Piles

Helical pile installation with mini-excavator

New Construction Helical Piles

(204) 2.88" and 3.5" OD piles to support warehouse additions; larger equipment required to provide "crowd" for helix penetration

New Construction Helical Piles

(172) 2.88", 3.5" and 4.5" OD piles installed for additions to school; large equipment and drive heads required for installation torque as high as 18,000 ft-lb.

New Construction Helical Piles

(29) 7" OD piles installed at a nuclear power plant; 100 kip design working load; 50,000 ft-lb drive head.
New Construction Helical Piles

YMCA waterpark and lap pool; limited access for equipment

New Construction Helical Piles

(34) 3.5” OD helical piles advanced

New Construction Helical Piles

Helical piles cut to design elevation and new construction brackets set; completed waterpark addition

New Construction Helical Piles

(8) 3.5” OD helical piles installed to support pedestrian / snowmobile bridge
(8) 3.5" OD helical piles installed to support pedestrian / snowmobile bridge

2.38" OD vertical and battered piles support a boardwalk

Boardwalk saddle bracket connected with clevis to battered helical pile.
New Construction Helical Piles

(21) 3.5” OD helical piles support elevated boardwalk on steep slope.

Helical Tiebacks

Tiebacks support sheet pile wall at interstate bridge abutment

New Construction Helical Piles

(21) 3.5” OD helical piles support elevated boardwalk on steep slope.

Helical Tiebacks

Tiebacks provide sheet pile stabilization for interstate bridge abutment
Installation utilizing hand-held equipment

Tieback and waler installation complete on box culvert extending below I-80

(73) Tiebacks installed within gabion baskets to support hillside cut above walking trail
Helical Tiebacks

(73) Tiebacks installed within gabion baskets to support hillside cut above walking trail

Helical Tiebacks

(73) Tiebacks installed within gabion baskets to support hillside cut above walking trail

Helical Tiebacks

(69) Tiebacks used to rebuild five-tiered railroad tie retaining wall

Helical Tiebacks

Similar work completed more than one year later on the opposite side of the drive-through
Stabilization of department store basement walls during conversion to movie theater

Use of hand-held equipment to stabilize department store basement walls during conversion to movie theater

Tensioning of tiebacks to stabilize department store basement walls during conversion to movie theater

Stabilization of department store basement walls during conversion to movie theater
Retrofit Helical Piers

(54) 2.88” OD retrofit piers to support new load from renovation

Helical Foundation Systems:

Determination of Capacity

Helical Pile/Tieback Capacity

- Individual Bearing Method
- Cylindrical Shear Method
- Torque Correlation Method

FOS = 2 is typically used in Helical Pile/Tieback design if torque is monitored during installation.
**Individual Bearing Method**

- Ultimate Capacity Equal to the Sum of the Individual Helix Plate Capacities
- Skin Friction Along Shaft Assumed to be Zero
- Helix Spacing $\geq 3D$

\[ Q_{ult} = \Sigma A_h (c N_c + \sigma'_v N_q) \]

- $Q_{ult}$ = Ultimate Capacity
- $A_h$ = Area of Individual Helix Plate
- $c$ = Cohesion
- $\sigma'_v$ = Effective Vertical Overburden Pressure
- $N_c, N_q$ = Bearing Capacity Factors
- $N_c \approx 9$, for cohesive soil when $\Phi = 0$

**Cylindrical Shear Method**

Ultimate Capacity Equal to the Sum of the Shear Strength Along the Cylinder of Soil Between the Helix Plates and the Bearing Capacity of the Bottom Helix Plate.

\[ Q_{ult} = 2 \pi R L (c + K_o \sigma'_v \tan \Phi) + A_b (c N_c + \sigma'_v N_q) \]

- $Q_{ult}$ = Ultimate Capacity
- $R$ = Average Helix Radius
- $L$ = Total Spacing Between All Helix Plates
- $K_o$ = At-Rest Earth Pressure Coefficient
- $\Phi$ = Soil Friction Angle
- $A_b$ = Area of Bottom Helix Plate
Torque Correlation Method

Ultimate Capacity Equal to the Product of the Installation Torque and an Empirical Torque Factor
(Also Referred to as the Capacity : Torque Ratio)

\[ Q_{ult} = KT \]

\[ K = \text{Empirical Torque Factor} \ (\text{ft}^{-1}) \]

\[ T = \text{Installation Torque} \ (\text{ft-lb}) \]

ICC-ES AC 358 for Helical Foundation Systems and Devices lists K:

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Value of K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5-inch and 1.75-inch square</td>
<td>10 ft^{-1}</td>
</tr>
<tr>
<td>2.875-inch O.D. round</td>
<td>9 ft^{-1}</td>
</tr>
<tr>
<td>3.0-inch O.D. round</td>
<td>8 ft^{-1}</td>
</tr>
<tr>
<td>3.5-inch O.D. round</td>
<td>7 ft^{-1}</td>
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</tbody>
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Value of K is not Constant and Depends on:

- **Soil Conditions** – K is Higher in Sands, Gravels, and Overconsolidated Clays, and Lower in Normally Consolidated Clays and Sensitive Clays.

- **Pier Shaft Diameter** – K is Inversely Proportional to Shaft Diameter.

Landmark Paper by Hoyt and Clemence (1989), *Uplift Capacity of Helical Anchors in Soil*

- Evaluated 91 Load Tests at 24 Different Test Sites
- Variety of Soil Conditions: Sand, Silt, and Clay Soils
- Calculated Capacity Ratio \( \frac{Q_{actual}}{Q_{calculated}} \) Using:
  - Individual Bearing Method
  - Cylindrical Shear Method
  - Torque Correlation Method

Found Torque Correlation Method to Yield More Consistent Results than the Other Two Methods

(Torque is a Direct Measure of Soil Shear Strength)
Tools to Determine Torque and Capacity

- Pressure gauges
- Differential Pressure Indicator
- Shear Pin Indicator
- Mechanical Dial Torque Indicator
- PT-Tracker (Marian Technologies)
- Wireless Torque Transducer

Understanding Correlation to Torque

Pressure "In" gauge minus Pressure "Out" gauge (Differential Pressure, psi)

Use manufacturer torque chart to correlate differential pressure to torque (Torque, ft-lb)

Multiply torque by the torque factor (Assume 2.88" OD shaft and K = 9 ft⁻¹)

Ultimate Capacity, lb

Wireless Torque Transducer

Helical Foundation Systems: Load Testing
AC358 Provides:

- Design criteria for helical components
  - Bracket capacity (P1)
  - Shaft capacity (P2)
  - Helix capacity (P3)
  - Soil capacity (P4)
- Testing criteria for helical components
- System capacity is the least value of all of the design and testing results
  - Considers corrosion loss rates for a 50-year design period
P1 – Bracket Capacity
(Retrofit or Side Load Brackets)

P1 – Bracket Capacity
(Model 288, Std. Bracket, 30" Sleeve)

P1 – Bracket Capacity
(Model 288, Std. Bracket, 30" Sleeve)

P2 – Shaft Capacity – Torsion Testing
(Model 288)
P3 - Design Considerations: True Helix Shape

Helix Plate Geometry
- Diameter
- Helix Angle
- Leading Edge
- Pitch
- Thickness
- Trailing Edge

P3 – Helix Capacity – Torsion Testing
(Model 288 with 14” Helix)

P3 – Helix Capacity – Thrust
(Model 288 with 14” Helix)
P3 – Helix Capacity – Thrust  
(Model 288 with 14” Helix)

P4 – Soil Capacity  
(ASTM D1143 Quick Load Test – Compression)

P4 – Soil Capacity  
(ASTM D3689 – Tension)

ICC-ES Evaluation Report ESR-xxxx
Helical Foundation Systems:
Structural Design with Helical Piles

Design Considerations
• Helical piers are slender
  – Depend on passive resistance of surrounding soil to maintain stability in compression
  – IBC 1810.2.1
    • Braced
      – Any soil other than fluid soil...
      – KL = 0
    • Unbraced
      – 5 ft into stiff soil
      – 10 ft into soft soil
• Perform best when arranged to function as axially loaded elements

Design Considerations
• Friction under pile cap/grade beam?
  – NO!! IBC 1810.3.11
• Passive Resistance?
  – NO!! Geotechnical Report

Design Considerations
• Remember?
  – IBC 1810.2.1
    • Braced
      – Any soil other than fluid soil...
      – KL = 0
    • Unbraced
      – 5 ft into stiff soil
      – 10 ft into soft soil
Design Considerations

0.90” < r < 1.25”
90 < KL/r < 150
40% to 70% loss
Column Strength

Design Considerations

- Solution #1
  - Hairpin bar into slab

Design Considerations

- Solution #2
  - Deepen Pile Cap/Grade Beam

Design Considerations

Shallow Distribution
Deep Distribution
Design Considerations

- Solution #3
  - Battered Piles

Lateral Load

Vertical Load

When Would You Choose Helicals?

- Products are specified
- Alternative to deep excavations or removal and replacement of foundation soils
- Alternative to other deep foundations such as auger cast piles, driven piles, drilled shafts, etc.
  - Especially in limited quantities
  - Very low mobilization costs
- Conditions of limited or tight access
- Minimal vibrations from installation required
- Remote sites where concrete is difficult to deliver
- Contaminated soil
- Environmentally sensitive sites
- Schedule sensitive projects
  - Installs quickly
  - No time required for concrete to cure
- After project has started and additional support is determined

Questions Regarding Helical Foundation Systems