Evaluating the Effect of Temporary Casing on Drilled Shaft Rock Socket Friction

GRIP 2016
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Ultimate Side Resistance

- Usually designed as a function of the parent rock properties and characteristics:
  - UCS
  - Unconfined Compression Strength
  - Recovery
  - RQD
  - Split Tensile Strength
Ultimate Side Resistance

  \[ f_{max} = 0.65pa \sqrt{\frac{q_u}{p_a}} \] and \( qu \leq f’c \)

- Kulhawy et al. (2005) – Base of FHWA (2010)
  \[ f_{max} = C \ast p_a \sqrt{\frac{q_u}{p_a}} \] and \( qu \leq f’c \)

  \[ f_{max} = \frac{1}{2} \sqrt{q_u q_t} \] and \( qu \leq f’c \)
Construction Effects (GRIP 2015) not addressed by design

- Excavation Equipment
- Reinforcement Bar Size and Cage Spacing
- Concrete properties
- Cased or Slurry Supported
- Vibrated or Oscillated Casing
- Slurry Type
- Slurry Exposure
- Temporary or Permanent Casing
Problem Statement

- Construction methods affect drilled shaft side shear resistance which is not fully addressed by design.

- The effects from full length or partial length temporary casing can present the same concern.

- The primary objective of this study is to **quantify the effects of temporary casing** installation and extraction on the resulting side shear in the portions of the rock sockets used to embed and seal the casing.
Study Motivation

455-15.7 Casings. Ensure casings are metal . . .

. . . . **If temporary casing is advanced deeper** than the minimum top of rock socket elevation shown in the Plans or actual top of rock elevation is deeper, withdraw the casing from the rock socket and overream the shaft. If the temporary casing cannot be withdrawn from the rock socket before final cleaning, **extend the length of rock socket** below the authorized tip elevation one-half of the distance between the minimum top of rock socket elevation or actual elevation if deeper, and the temporary casing tip elevation.
Scenarios

- Top of rock is not where the borings put it and so the rock socket has to start deeper,
- Operator inadvertently forces the casing deeper than planned although the “rock” is really pretty good
- Top of rock is technically where the borings put it, but the quality is so bad the casing must be advanced deeper to ensure a tight/adequate seal.
Casing Conditions

- **Permanent**
  - Full length
  - Partial length

- **Temporary**
  - Full length
  - Partial length

- **Telescoping / Combination**
Misconceptions

- Use of casing makes more predicable shaft
- No anomalies occur within permanent cased regions
- Temporary cased sections have more reliable cross sections
Slump Loss in Temporary Casing

- **Mobilized Unit Skin Friction (psi)**
  - Constructability Limit
  - FDOT Slump Loss Limit

- **Slump at Casing Extraction (in)**
  - Values range from 2.0 to 12.0
Temporary Casing Removal

(I) Slurry filled cavity formed outside the casing

(II) Pile concreted, casing lifted in cavity under pressure

(III) Casing is lifted higher. Concrete slumps into the void. Contaminated slurry flows into pile.
Quantifying the Effects

- How does temporary casing affect the resulting side shear?
- Does concrete flow out and form intimate bond with surrounding rock?
  
  or

- Do residual fragments of crushed rock remain and get squeezed/trapped between outward flowing concrete?
Construction with temporary casing
Effects of casing extraction
Construction of rock sockets
Effects on the side resistance (O’Neill and Hassan, 1994)
Case Study 1

Casings Extracted from Outside-in

Casings Extracted from Inside-out
Case Study 2

Fill

Some fill and weathered limestone with trace sand
3 < N < 19

Loose sand and weathered limestone with trace sand
3 < N < 11

Very soft to very hard weathered limestone
3 < N < 100
Rec from 0% to 65%
RQD from 0% to 45%

Very hard limestone, N = 100,
Rec = 88%, RQD = 60%
### Case Study 2

<table>
<thead>
<tr>
<th></th>
<th>Uncased</th>
<th>Cased</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Date constructed</strong></td>
<td>7/15 and 7/16/09</td>
<td>7/20/09</td>
</tr>
<tr>
<td><strong>Load test date</strong></td>
<td>7/31/09</td>
<td>8/3/09</td>
</tr>
<tr>
<td><strong>Reported Mobilized Capacity</strong></td>
<td>4,183 kips</td>
<td>4,189 kips</td>
</tr>
<tr>
<td><strong>Maximum displacement</strong></td>
<td>0.43in</td>
<td>0.37in</td>
</tr>
<tr>
<td><strong>Permanent displacement</strong></td>
<td>0.10in</td>
<td>0.15in</td>
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</tbody>
</table>
Top of Shaft Load – Displacement

Load (kips)

Displacement (in)

Cased
Uncased
Top Segment Unit Side Shear

Midpoint Displacement (in)

Unit Side Shear (ksf)

-0.35
-0.3
-0.25
-0.2
-0.15
-0.1
-0.05
0

Cased - Top Segment
Uncased - Top Segment
Segment 2 Unit Side Shear

Midpoint Displacement (in)

Unit Side Shear (ksf)

Cased - Segment 2
Uncased - Segment 2
Segment 3 Unit Side Shear

Graph showing the relationship between Unit Side Shear (ksf) and Midpoint Displacement (in) with two lines indicating Cased and Uncased conditions for Segment 3.
Bottom Segment Unit Side Shear

![Graph showing midpoint displacement against unit side shear for cased and uncased bottom segments.]

- Cased - Bottom Segment
- Uncased - Bottom Segment
Toe of Shaft Load – Displacement

![Graph showing the relationship between displacement and load for cased and uncased conditions. The graph plots displacement (in inches) on the y-axis and load (in kips) on the x-axis. Two curves are shown: one for cased conditions (red) and one for uncased conditions (black). The cased condition shows a steeper curve, indicating a smaller displacement for the same load compared to the uncased condition.]
Case Study 3 Castelli and Fan (2002)

Test Shaft 1
36" dia

Test Shaft 2
48" dia

SP
N = 40

SC
N = 3 to 13

SP
N = 7 to 22

Limestone
N = 16 to 50/3" to 50/1"

Marl
N = 20 to 65

Bot.
Temp.
Casing
<table>
<thead>
<tr>
<th>Test Shaft No</th>
<th>Shaft Diameter (inches)</th>
<th>Maximum O-cell load (tons)</th>
<th>Strain Gage Elevation (ft)</th>
<th>Limestone Classification and SPT N-Value</th>
<th>Mobilized Side Shear (tsf)</th>
<th>Upward Disp. (inches)</th>
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<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>970</td>
<td>-18 to -21</td>
<td>Decomposed Limestone, N ≈ 7</td>
<td>0.5</td>
<td>0.94</td>
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<td></td>
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<td></td>
<td>-21 to -25</td>
<td>Cemented Limestone, N ≈ 50/1in to 50/5in</td>
<td>8.2</td>
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<td></td>
<td></td>
<td></td>
<td>-25 to -28</td>
<td></td>
<td>19.0</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>-29 to -34.3</td>
<td></td>
<td>5.6*</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>48</td>
<td>1465</td>
<td>-17.7 to -21.7</td>
<td>Decomposed Limestone, N ≈ 16</td>
<td>2.1*</td>
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<tr>
<td></td>
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<td></td>
<td>-21.7 to -25.6</td>
<td>Cemented Limestone, N ≈ 50/3in</td>
<td>6.2*</td>
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<tr>
<td></td>
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<td></td>
<td>-25.6 to -29.5</td>
<td>Cemented Limestone, N ≈ 50/3in</td>
<td>14.1*</td>
<td></td>
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<tr>
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<td></td>
<td>-29.5 to -32.3</td>
<td>Weakly Cemented Limestone, N ≈ 20 to 50/4in</td>
<td>4.1*</td>
<td></td>
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</table>

* Failure was not observed on these segments.
Small Scale Testing
Test Bed Preparation

- Target weaker limestone vulnerable to extended casing embedment
- Simulated limestone made from calcium carbonate / coquina shell combinations
- Casing installed with vibratory or drop hammer
- Use high strength pull out anchor rods
Target Simulated Limestone

Saxena, 1982
Lime Chemical Reactions

\[ CaO + H_2O \rightarrow Ca(OH)_2 + \text{heat (slaked lime)} \]

\[ Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \]

In Pounds:

\[ 1.00[Ca(OH)_2] + 0.6[CO_2] \rightarrow 1.35[CaCO_3] + 0.25[H_2O] + \text{heat} \]
Full Scale Tests

- RW Harris’ Miami Office has limestone near surface
- Pull out frame or Simply supported beam D1143 or D3689
- Rapid Load Test ASTM D7383
100 kip pullout frame
500 ton RLT system
Questions?