Drilled Shaft Resistance Based on Diameter, Torque and Crowd
(Drilling Resistance vs. Rock Strength)
BDV 31 977 20

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Undergraduate Students: Stephen Crawford, Matt Andrews,
Shelby Brothers, Tim Copeland, Aaron Hendricks, Michael Ferguson

FDOT Geotechnical Research in Progress Report
Presented by: Michael Rodgers, M.E.

University of Florida
Department of Civil & Coastal Engineering
Presented August 1, 2014
Scope

• From 5 Drillings Parameters
  – Torque, T
  – Crowd, F
  – Penetration rate, u
  – Rotational speed, N
  – Bit diameter, d

  Obtain Drillability Strength, Ds
  Karasawa (2002)

• Compare Ds vs. Laboratory strengths, \(q_u\) and \(q_t\)
  – In Laboratory on Homogenous Blocks at 4 different design strengths with 2 different bit diameters (4.5” and 6”)
  – In the Field Ds. Vs Cores (Laboratory \(q_u\), and \(q_t\))

• Field Drilling
  – Obtained drill rig monitoring equipment from Jean Lutz, N.A.
  – Sites: Little River (Quincy); Overland (Jacksonville); Kanapaha (Gainesville) – All Sites have load tests
Jean Lutz Monitoring Equipment

DIALOG (DAQ)

C16400 - Pressure Transducer (Torque)

C16400 - Pressure Transducer (Crowd)

F82 - Rotary Encoder (Penetration rate)

VR28 - Proximity Sensor (Rotational speed)

Junction Boxes
Laboratory Coupler to Monitor Crowd and Torque

• Main shaft constructed using Aluminum pipe
  – 2” O.D. and 1” I.D.
• 2 sets of torque rosettes and 2 sets of axial strain gages
  – Full bridge
  – Located approximately 180° apart
  – Compensates for bending and temperature effects
• Lord Microstrain V-Link LXRS for wireless data transmission
Drilling Process

- Create large synthetic limestone (Gatorock) blocks
  - (40” x 22.5” x 22.5”)
- Select proper drill parameter settings
  - Rotational speed
  - Penetration rate
- Monitor applied torque and crowd (axial) forces
- Using these drilling parameters, “Drillability Strength”, $D_s$, is found
\( D_s \) vs. \( q_u \)

- \( D_s = \frac{a_F}{a_T^2} = \frac{64NT^2}{Fud^3} \)
- Karasawa compared:
  - Drillability Strength of rock, \( D_s \)
  - Unconfined Compressive Strength, \( S_c \) or \( q_u \)
- \( D_s \) vs. \( q_t \) (split tension) plot will also be developed

\*\( S_c \) (\( q_u \) – unconfined compression)

Karasawa, 2002
Axial Force Calibration

• During preliminary axial calibration, peak loads only reached 55 lbs
• It was noticed during drilling peak loads for some rock strengths far exceeded 55 lbs
  – Up to 500+ lbs.
• It was decided to recalibrate the system using higher axial loads
• How does the applied torque forces affect the axial loading?
Axial Force Calibration

- Used the Instron on UF’s campus to provide the loading
- The drill rod was vertically leveled
- Constant loads were applied in 2 minute intervals
  - 100, 250 and 500 lbs
- Baseline readings were taken for 2 minutes before and after each loading phase
  - Does it return back to zero?
- Provides 960 readings for each loading and resting period
  - 800 readings from each period are used for the averages
Axial Force Calibration

• Results displayed an approximate percent difference of 38% for each load.

<table>
<thead>
<tr>
<th>Loading Phase</th>
<th>Channel 2 (Uncalibrated)</th>
<th>Channel 4 (Uncalibrated)</th>
<th>Channel 2 (Calibrated)</th>
<th>Channel 4 (Calibrated)</th>
<th>Measured Load (lbs)</th>
<th>% Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>-9.668798065</td>
<td>-4.093927414</td>
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• Applied load vs. measured load plot was created
  – Should provide a linear curve
  – Allows loads to be adjusted equally providing a calibration factor
Axial Force Calibration

- Linear trend was confirmed by $R^2 = 0.9999$ with the intercept set to zero

- A calibration factor was developed between the predicted and measured loads
Axial Force Calibration

- Using the equation from the curve, \( y = 0.6168x \)
- \( 1 / 0.6168 = 1.621271077 \)
  - Calibration factor = 1.621271077
- Multiply the measured load by the Calibration factor to obtain the adjusted measured load
- Adjusted measured loads now matched the applied loads
  - Instron ± 3 lbs sensitivity

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<th>Channel 4 (Calibrated)</th>
<th>Measured Load (lbs)</th>
<th>% Difference</th>
<th>Adjusted Load (lbs)</th>
<th>% Difference</th>
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<td>-174.83</td>
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<td>-38.08%</td>
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<td>-231.78</td>
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<td>307.89</td>
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<td>499.17</td>
<td>0.22%</td>
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</tbody>
</table>
Axial Force Calibration

- Calibrate coupler system using Node Commander software
- The Calibration factor was used to adjust the software’s slope
  - Software slope developed through shunt calibration
  - Slope converts bits to lbf
- This will be used for the remainder of the drillings
Torque Loading Effects on Axial Force

- Channel 2 is in compression
- Channel 4 is in tension
- Values are opposite in sign and approximately offset each other
- The system is functioning properly
  - Forces negate one another

<table>
<thead>
<tr>
<th>M (in-lbs)</th>
<th>W (lbs)</th>
<th>Ch-1</th>
<th>Ch-2</th>
<th>Ch-3</th>
<th>Ch-4</th>
<th>%Diff 1-3</th>
<th>%Diff 2-4</th>
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</thead>
<tbody>
<tr>
<td>140.8</td>
<td>8.8</td>
<td>-141.34</td>
<td>-55.20</td>
<td>-143.87</td>
<td>54.59</td>
<td>1.79%</td>
<td>1.10%</td>
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<tr>
<td>281.6</td>
<td>17.6</td>
<td>-283.02</td>
<td>-101.77</td>
<td>-283.22</td>
<td>99.32</td>
<td>0.07%</td>
<td>2.41%</td>
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<tr>
<td>422.4</td>
<td>26.4</td>
<td>-423.09</td>
<td>-145.16</td>
<td>-422.82</td>
<td>139.65</td>
<td>-0.06%</td>
<td>3.80%</td>
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<tr>
<td>563.2</td>
<td>35.2</td>
<td>-561.30</td>
<td>-186.70</td>
<td>-560.20</td>
<td>183.56</td>
<td>-0.20%</td>
<td>1.68%</td>
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</tbody>
</table>
## Investigating the Drilling Procedure

<table>
<thead>
<tr>
<th>Old Drilling Procedure</th>
<th>New Drilling Procedure</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Dry drill 8 inches</td>
<td>• Dry drill 8 inches</td>
</tr>
<tr>
<td>• Clean bit and hole</td>
<td>• Clean bit and hole</td>
</tr>
<tr>
<td>• Wet drill 9 inches</td>
<td>• Wet drill 4 inches</td>
</tr>
<tr>
<td>– Adding water with a cup</td>
<td>– Adding water using continuous flow via controlled nozzle</td>
</tr>
<tr>
<td>– Removing water with suspended solids using a wet vac</td>
<td>– Removing water with suspended solids using a wet vac</td>
</tr>
<tr>
<td>• Clean bit and hole</td>
<td>• Clean bit and hole</td>
</tr>
<tr>
<td>• Wet drill final 3 inches</td>
<td>• Repeat wet drilling in 4 inch increments until 20 inch depth is reached</td>
</tr>
</tbody>
</table>
| – 20 inches total      | }
Comparing Drilling Procedures

**Old Drilling Procedure**
- CV values typically ranged from 0.2 - 0.6
- More problematic with longer drill runs
- Large amounts of debris caked on bit (bit bite)

**New Drilling Procedure**
- CV values consistently range from 0.1 – 0.3
- Can set the drill press to automatically stop at 4 inches, less problematic
- Less debris caked on bit
Reanalyzing Old Data

• Review old drillings
  – Length of drill runs
  – Review drill log comments for any problems during drilling
• Use only the first four inches of each good drill run
  – No problems during drilling
• Use Calibration factor to adjust the recorded axial forces
  – Used in both sets of data to the right

<table>
<thead>
<tr>
<th>Description</th>
<th>T (in-lbs)</th>
<th>F (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>521.5</td>
<td>124.8</td>
</tr>
<tr>
<td>Maximum</td>
<td>849.2</td>
<td>245.9</td>
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<tr>
<td>Minimum</td>
<td>211.6</td>
<td>36.4</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>131.3</td>
<td>52.4</td>
</tr>
<tr>
<td>CV</td>
<td>0.252</td>
<td>0.420</td>
</tr>
</tbody>
</table>

Final Results - 673psi - Wet

<table>
<thead>
<tr>
<th>Description</th>
<th>T (in-lbs)</th>
<th>F (lbf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>421.0</td>
<td>109.4</td>
</tr>
<tr>
<td>Maximum</td>
<td>587.2</td>
<td>230.1</td>
</tr>
<tr>
<td>Minimum</td>
<td>209.0</td>
<td>45.7</td>
</tr>
<tr>
<td>Std. Deviation</td>
<td>73.5</td>
<td>38.4</td>
</tr>
<tr>
<td>CV</td>
<td>0.175</td>
<td>0.351</td>
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</table>
Developing the $D_s$ vs. $q_u$ Curve

- Final curve will consist of nearly 70 data points from laboratory drillings
- Different drilling parameters will be used
  - 3 penetration rates (0.008, 0.014, 0.02 in/rev)
  - 2 rotational speeds (20 and 40 rpms)
  - 2 bit diameters (4.5” and 6”)
- Gatorock strengths will range from approximately 140 psi to 1667 psi
- Using 17 drillings a preliminary curve was developed
  - 3 old drillings (updated)
  - 14 new drillings
Preliminary $D_s$ vs. $q_u$ Curve

$y = 0.1715x^2 - 16.165x$
$R^2 = 0.8968$

Ds vs. qu

New Data (4.5" Bit)
Old Data (4.5" Bit)
New Data (6" Bit)
Field Monitoring

• First field monitoring trial took place November 2013 at the Little River Bridge Site (Quincy Florida)
• Case Atlantic allowed monitoring of their IMT AF 250 Drill Rig in cooperation with RS&H
• Successfully monitored a test shaft and a production shaft – Monitored Full Length of Shaft
• Test shaft was instrumented with an Osterberg load cell
  – Instrumented with Strain Gages, i.e. measured skin friction
  – Estimated Skin Friction from $D_s \rightarrow q_u, q_t \rightarrow f_s$
Monitoring Equipment Installation

• IMT AF 250 was a brand new drill rig
• Many of the sensors we planned to install were built in
• Jean Lutz field technician installed and calibrated the equipment
• Installed pressure transducer on the mast for crowd monitoring
• DIALOG (DAQ) was installed in the cab
• Junction box was installed in the electrical compartment
• Tapped into 3 existing sensors to monitor torque, rotational speed and penetration rate
IMT AF 250
Junction Box

Cable running to the cab

Junction Box
DIALOG (DAQ)
Depth Sensor – Penetration Rate

Tapping into the depth sensor
Rotational Speed and Torque Sensors
Installing the Crowd Sensor
Cabling Secured to Hydraulic Lines

- Cabling is secured to the hydraulic lines using zip ties and kept out of the way
  - Does not disturb operations
Monitoring Drilling in Real Time

On the Rig

Off the Rig
Analyzing Field Data

• Using the preliminary $D_s$ vs $q_u$ curve equation:
  • $0.1715x^2 - 16.165x - y = 0$
    – $x = q_u$ (psi)
    – $y = D_s$ (psi)

• The following equation is developed using the quadratic solution:

$$q_u = \frac{16.165 + \sqrt{(-16.165)^2 - 4 \times (0.1715) \times (-D_s)}}{2 \times (0.1715)}$$

• This provides a means to assess rock strength, $q_u$, from recorded field drilling parameters
Rock Strength vs. Depth (Preliminary)

- Core data from Boring B-4 was compared to the data
  - Recovered and tested by FDOT
  - Boring B-4 is the 1 of 6 available for comparison
- Core data and monitored drilling results show similar trends and strengths at respective depths
  - Stratification is observed from both sets of data
Summary of Statistics

- 12.1% difference for the average strength
- 6.9% difference for the maximum strength
- 32.5% difference for the minimum strength
  - Less difference in actual strength than maximum
- Frequency distribution displays a log-normal distribution as expected
- Majority of strengths fell within planned Gatorock strengths for lab drilling
  - 140 – 1667 psi
- Need more Core Strengths to Define Variability

<table>
<thead>
<tr>
<th>Description</th>
<th>Monitored Data qu (psi)</th>
<th>Core Data qu (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average</td>
<td>727.77</td>
<td>827.89</td>
</tr>
<tr>
<td>Max</td>
<td>3406.08</td>
<td>3658.65</td>
</tr>
<tr>
<td>Min</td>
<td>103.59</td>
<td>78.21</td>
</tr>
<tr>
<td>Std Dev</td>
<td>490.92</td>
<td>998.21</td>
</tr>
<tr>
<td>CV</td>
<td>0.67</td>
<td>1.21</td>
</tr>
</tbody>
</table>
Future Plans

• Finish Laboratory Drilling
  – Develop final $D_s$ vs. $q_u$ and $D_s$ vs. $q_t$ curves
• Monitor Overland bridge site in Jacksonville
  – Beginning late August 2014
  – 4 shafts with statnamic load testing planned will be monitored
  – Compare $D_s$ vs Laboratory Strength and Measured Shaft Side Friction
• Continue analyzing Little River Data
  – Obtain more core data
  – Use existing and new core data to develop correlation
  – Compare $D_s$ vs Laboratory Strength and Measured Shaft Side Friction
• Continue Site Investigation at Kanapaha
  – Designated site for the projects static load test
  – Preliminary CPT’s have been taken
  – SPT’s, coring and more CPT’s will take place
• Finalize projects static load test setup and perform testing
  – Estimate shaft capacities from Kanapaha site investigation
  – 2 drill rigs available for shaft installation
• Draft Final Report
Citations


Questions?