Defining the Upper Viscosity Limit for Mineral Slurries used in Drilled Shaft Construction

GRIP 2013
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Two Primary Concerns

- At what point does increased viscosity become too thick to easily displace during concreting?

- At what point does increased viscosity affect side shear capacity?
Research Approach

- Task 1 Literature Review
- Task 2 Rebar Pull-out Testing
- Task 3 Laboratory Side Shear Testing
- Task 4 Full Scale Side Shear Testing
- Task 5 Reporting
Task 1: Literature Review

- Updated State Specifications
- Effects on Bond Strength
- Rheology of Bentonite
## Current Slurry Specifications

<table>
<thead>
<tr>
<th>Slurry Property</th>
<th>Mineral Slurry Required Ranges</th>
<th>Polymer Slurry Required Ranges</th>
<th>Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>64 – 73 pcf (fresh water)</td>
<td>62 – 64 pcf (fresh water)</td>
<td>Mud density balance: FM 8-RP13B-1</td>
</tr>
<tr>
<td></td>
<td>66 – 75 pcf (salt water)</td>
<td>64 – 66 pcf (salt water)</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>30-50 sec</td>
<td>Viscosity Range Published By The Manufacturer for Materials Excavated</td>
<td>Marsh Cone Method: FM 8-RP13B-2</td>
</tr>
<tr>
<td>pH</td>
<td>8-11</td>
<td>pH Range Published By The Manufacturer for Materials Excavated</td>
<td>Electric pH meter or pH indicator paper strips: FM 8-RP13B-4</td>
</tr>
<tr>
<td>Sand Content</td>
<td>4% or less</td>
<td>0.5% or less</td>
<td>FM 8-RP13B-3</td>
</tr>
</tbody>
</table>
Recommended Viscosity

- **Clay**
  - 40-45 sec/qt (Wyo-Ben)

- **General / Normal Conditions**
  - 45-55 sec/qt (Wyo-Ben)
  - 30-35 sec/qt (CETCO)

- **Sand and Gravel**
  - 55-65 sec/qt (Wyo-Ben)
  - 30-40 sec/qt (CETCO)

- **Fluid Loss Control**
  - 40-45 sec/qt (CETCO)

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### Table 1: Drilling Mud Thickness Guidelines

<table>
<thead>
<tr>
<th>Material Being Drilled</th>
<th>Sediment Grain Size</th>
<th>Marsh Funnel Viscosity (seconds/quart)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural swelling clays*</td>
<td>&lt;0.08mm</td>
<td>32 to 37</td>
</tr>
<tr>
<td>Non-swelling clays and fine sand</td>
<td>0.08-0.43mm</td>
<td>40 to 45</td>
</tr>
<tr>
<td>Medium sand</td>
<td>0.43-2.0mm</td>
<td>45 to 55</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>2.0-4.8mm</td>
<td>55 to 65</td>
</tr>
<tr>
<td>Gravel</td>
<td>4.8-19.0mm</td>
<td>65 to 75</td>
</tr>
<tr>
<td>Coarse gravel</td>
<td>&gt;19.0mm</td>
<td>75 to 85</td>
</tr>
</tbody>
</table>

www.clean-water-for-laymen.com
Rebar Bond Strength

- Butler (1973), Fleming and Sliwinski (1977), Federation of Piling Specialists (1975)

- “The current state of knowledge on this topic suggests that the use of mineral and polymer slurries for drilled shaft construction does not reduce the bond resistance between concrete and reinforcing bars. There is currently no reason to account for the use of drilling fluids when considering development length of rebar in drilled shafts.” (FHWA 2010)
Rebar Bond Strength

- **Orangun et al. (1977)**
  \[ u = 0.083045 \sqrt{f_c'} \left[ 1.2 + 3 \frac{c}{d_b} + 50 \frac{d_b}{L_d} \right] \]

- **Darwin et al. (1992)**
  \[ u = 0.083045 \sqrt{f_c'} \left[ \left( 1.06 + 2.12 \frac{c}{d_b} \right) \left( 0.92 + 0.08 \frac{C_{\text{max}}}{C_{\text{min}}} \right) + 75 \frac{d_b}{L_d} \right] \]

- **Australian Standard (1994)**
  \[ u = 0.265 \sqrt{f_c'} \left( \frac{c}{d_b} + 0.5 \right) \]

- **Hadi (2008)**
  \[ u = 0.083045 \sqrt{f_c'} \left[ 22.8 - 0.208 \frac{c}{d_b} - 38.212 \frac{d_b}{L_d} \right] \]
Task 2: Rebar Pullout Testing

- 42 inch Diameter
- 24 inch Depth
- 14 - #8 Main Bars
  - 7 Threaded for Pullout
  - Varying Bond Length
  - 6 inch Clear Spacing
- Varying Viscosities & Slurry Type
Rebar Pullout Testing Setup
Placement #1

- 18 inch Bond Length
  - ACI equations full development length ~ 47 inches
  - Anticipated Strength ~ 27 kips
- Viscosities 40 & 90 sec/qt
- FDOT approved Drilled Shaft Mix Design
- Slump 8.25 inches
- 12 hour Slurry Contact Time
18" Bond Length

$ f'c = 6150 \text{ psi} $

<table>
<thead>
<tr>
<th>Test Duration</th>
<th>Maximum</th>
<th>Average</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 sec/qt</td>
<td>60</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>90 sec/qt</td>
<td>60</td>
<td>50</td>
<td>40</td>
</tr>
</tbody>
</table>

3 Tests Total
4 Tests Total
Prior to Pressure Washing

90 sec

40 sec
Placement #1
After Pressure Washing

90 sec
40 sec
Placement #2

- 10 inch Bond Length
  - Anticipated Strength ~ 43 kips
- Viscosities 26 (Water Control), 40, 50, & 90 sec/qt
- FDOT approved Drilled Shaft Mix Design
- Slump 9.0 inches
- 12 hour Slurry Contact Time
Water Control

Thread Failure

All tests failed in the threads.

10” Bond Length
f’c = 4360 psi

Strength (kips)
26 sec/qt (Water Control)

40 sec/qt

50 sec/qt

90 sec/qt
Placement #3a

- 6 inch Bond Length
- Viscosities 30, 40, 50, 90 (mineral)
- FDOT approved Drilled Shaft Mix Design
- Slump 4 inches
  - Could not achieve minimum slump
- 12 hour Slurry Contact Time Exceeded
  - Did not place concrete
- Removed Slurry from Forms
Placement #3a
30 sec/qt
30 sec/qt

50 sec/qt
Placement #3b

- 6 inch Bond Length
  - Anticipated Strength ~ 27 kips
- Viscosities 30, 40, 50, 90 (mineral) & 2-60 (polymer) sec/qt
- FDOT approved Drilled Shaft Mix Design
- Slump 8.0 inches
- 12 hour Slurry Contact Time
6" Bond Length
f'c = 4530 psi

Strength (kips)

30 sec/qt, 40 sec/qt, 50 sec/qt, 90 sec/qt, 60 sec/qt Polymer, 60 sec/qt Polymer
Placement #3b – Concrete Flow

- 60 sec/qt - Polymer
- 30 sec/qt
- 40 sec/qt
- 50 sec/qt
- 90 sec/qt
Concrete Cores
Concrete Cores

H₂O | 60s Polymer | 30s | 40s
Concrete Cores

H₂O
60s Polymer
30s
40s
Concrete Cores

- H$_2$O
- 60s Polymer
- 30s
- 40s
Concrete Cores

H₂O

60s Polymer

30s

40s

Concrete Flow Outwards
Concrete Cores

H₂O  60s Polymer  30s  40s
Concrete Core – 50 sec/qt
Concrete Core – 50 sec/qt
Concrete Core – 90 sec/qt
Concrete Core – 90 sec/qt
A Closer Look at the Pullout Results
Ultimate Concrete Shear Stress (0.5f'c)

Normalized Bond Strength (dim) = \[
\frac{\text{Pullout Load (kips)}}{\text{Bar Diam (in) } \times \pi \times \text{Bond Length (in) } \times f'c (ksi)}
\]

Viscosity (sec/qt)

- Orangun (1977)
- Darwin (1992)
- Aussi Std (1994)
- Hadi (2008)

26 sec/qt (H₂O)
Future Work

- Rebar Pullout Testing
  - 6 inch Bond Length
  - 26 (Water Control), 30, 50 sec/qt Mineral, 60 & 2 – 150 sec/qt Polymer
- Concrete – Soil Interaction Testing
- Full Scale Testing (Phase II)
Questions?