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

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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>
Viscosity (sec/qt)

- Alabama
- Alaska
- Arizona
- Arkansas
- California
- Colorado
- Connecticut
- Delaware
- Florida
- Georgia
- Hawaii
- Idaho
- Illinois
- Indiana
- Iowa
- Kansas
- Kentucky
- Louisiana
- Maine
- Maryland
- Massachusetts
- Michigan
- Minnesota
- Mississippi
- Missouri
- Montana
- Nebraska
- Nevada
- New Hampshire
- New Jersey
- New Mexico
- New York
- North Carolina
- North Dakota
- Ohio
- Oklahoma
- Oregon
- Pennsylvania
- Rhode Island
- South Carolina
- South Dakota
- Tennessee
- Texas
- Utah
- Vermont
- Virginia
- Washington
- West Virginia
- Wisconsin
- Wyoming
- FHWA
- Florida Minimum Viscosity
- FHWA Maximum Viscosity
- Requires Polymer Slurry
- Dry Construction / Perm Casing
- Drilling Slurry Not Allowed
- Manufacturers Recommendation
Manufacturer’s Recommendations

- **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](http://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)
Fleming and Sliwinski (1977),

- Bentonite displaced specimens
  - Rebar tied to stirrups in a line
  - Concrete flow not representative of tremie placement in shafts

- Plain concrete specimens
  - Rebar stabbed into already poured concrete
  - Not tied to stirrups
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
Placement/Casting Conditions

- Tremie Placed Concrete
- 126 Rebar Pull-out Tests
- Slump 8.25 – 9 inches
  - Water (28 sec/qt)
  - Bentonite (30, 40, 50 and 90 sec/qt)
  - Polymer (60 and 90 sec/qt)
Bentonite
30 sec/qt
Ultimate Concrete Shear Stress (0.5f'c)

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

- Orangun (1977)
- Darwin (1992)
- Aussie Std (1994)
- Hadi (2008)
Ultimate Concrete Shear Stress (0.5$f^c$)

Normalized Bond Strength (dim) = 
\[ \text{Bar Diam (in)} \times \pi \times \text{Bond Length (in)} \times f^c \text{ (ksi)} \]

Pullout Load (kips)

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

Viscosity (sec/qt)
Durability Evaluation
After Pressure Washing

90 sec  40 sec
Concrete Flow

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

Polymer
Concrete Cores
Concrete Cores

H₂O 60s Polymer 30s 40s

Concrete Flow Outwards
Concrete Core – 50 sec/qt

- Vertical crease extended to depth of bar
- Outer face of shaft
- Concrete flow from center to outer edge of shaft
- Crease from stirrup completely separated top from bottom halves
- Vertical bar
- Stirrup location

Notes:
- Concrete flow from center to outer edge of shaft
- Crease from stirrup completely separated top from bottom halves
- Vertical bar
- Vertical crease extended to depth of bar

Legend:
- Concrete Core – 50 sec/qt
- Outer face of shaft
- Vertical bar
- Stirrup location
- Vertical crease extended to depth of bar

Details:
- Concrete used in the core is specified as 50 sec/qt.
Concrete Core – 50 sec/qt
Concrete Core – 50 sec/qt
Concrete Core – 90 sec/qt
Concrete Core – 90 sec/qt
Task 3: Laboratory Side Shear Evaluation

- Pull out tests in FCV
- 36 inch Long
- 4 inch Diameter
- Varying Viscosities & Slurry Type
Loosely Placed Sand
Stress Sand in Cell and Excavate
Place Tremie and Attach Hopper
Install Full-length Threaded Rod
Pull out Testing
Disassemble and Remove Shaft
Results of Lab Tests (bentonite)

8hr slurry/soil exposure time

- Unit Side Shear (ksf)
- Viscosity (sec/qt)
Polymer Slurry (60 sec/qt)
Task 4: Full Scale Side Shear Evaluation

- 12 shafts tested in tension
- 18ft Long
- 20-24 inch Diameter
- Varying Viscosities & Slurry Type
  - Bentonite 40 to 90 sec/qt
  - Polymer 60 to 132 sec/qt
- CPT soundings at each location
CPT Soundings
Bentonite 40 to 90 sec/qt
Polymer 60 to 130 sec/qt
Test Over

6in Jack Stroke

Shaft Dead Weight
Cover Effectiveness
Cover Effectiveness

90 sec/qt Bentonite
90 sec/qt Bentonite
50 sec/qt Bentonite

40 sec/qt Bentonite
30 sec/qt Bentonite
60 sec/qt
Polymer
Corrosion Monitoring

Probable Corrosion

High Probability of Corrosion

Add Cl- Solution

Shaft 7 (B-30s)

Shaft 11 (P-60s)
We think this is the exception.
But is it the norm?
Conclusions

- The presence of bentonite does affect rebar bond very much like that shown for piles in seal slabs.
- However, current estimates of required development lengths underestimate true capacity.
- Higher viscosity bentonite slurry does not affect side shear capacity (relative to 40 sec/qt viscosity).
- Concrete flow through reinforcing cage can cause undesirable effects on durability.
Questions?