

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



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Presented by: Danny Winters, P.E.

USF UNIVERSITY OF
SOUTH FLORIDA

Civil & Environmental Engineering

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

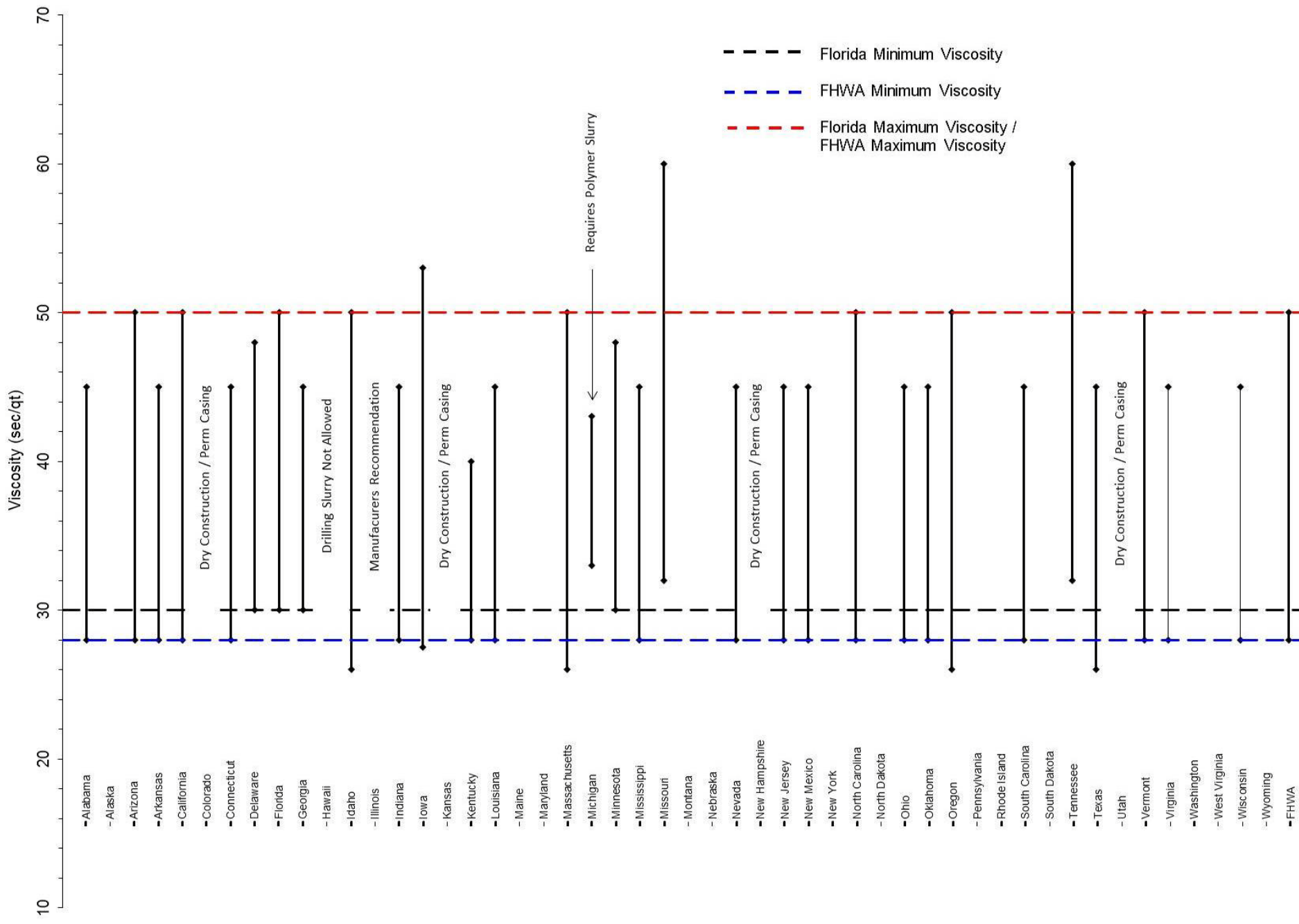
Task 1: Literature Review

- ◆ Updated State Specifications
- ◆ Effects on Bond Strength
- ◆ Rheology of Bentonite



Current Slurry Specifications

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



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)

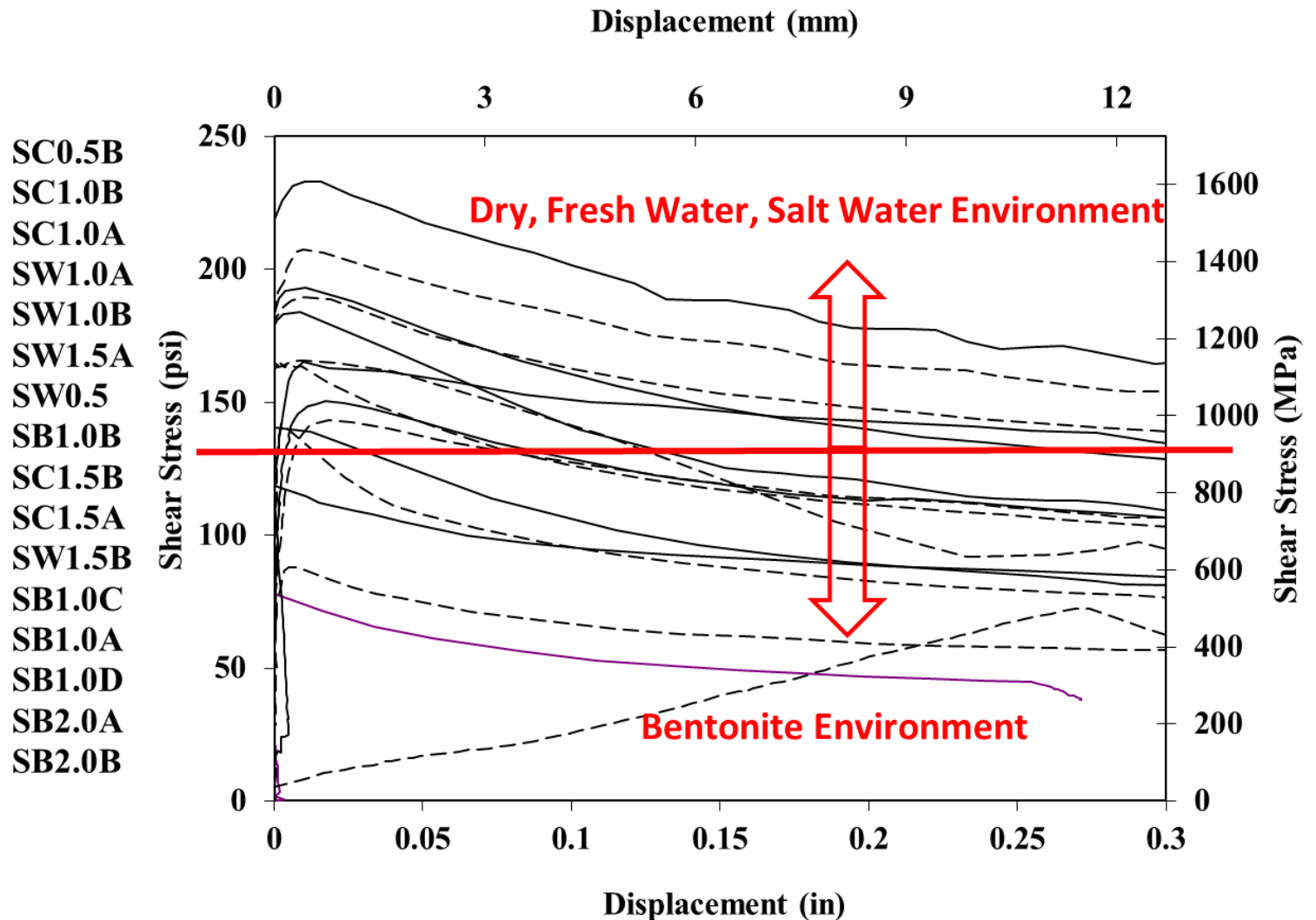
Table 1 Drilling Mud Thickness Guidelines

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

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)

Pile / Seal Slab Bond



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)

$$u = 0.083045 \sqrt{f'_c} \left[\left(1.06 + 2.12 \frac{c}{d_b} \right) \left(0.92 + 0.08 \frac{C_{\max}^*}{C_{\min}} \right) + 75 \frac{d_b}{L_d} \right]$$

- ◆ Australian Standard (1994)

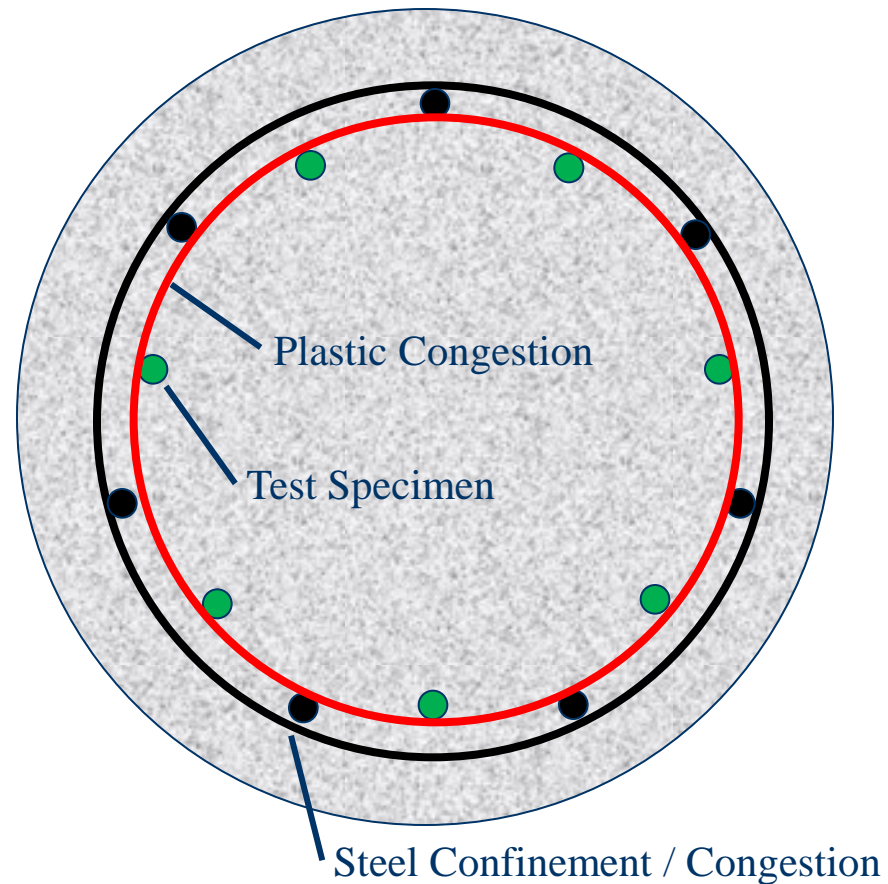
$$u = 0.265 \sqrt{f'_c} \left(\frac{c}{d_b} + 0.5 \right)$$

- ◆ 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

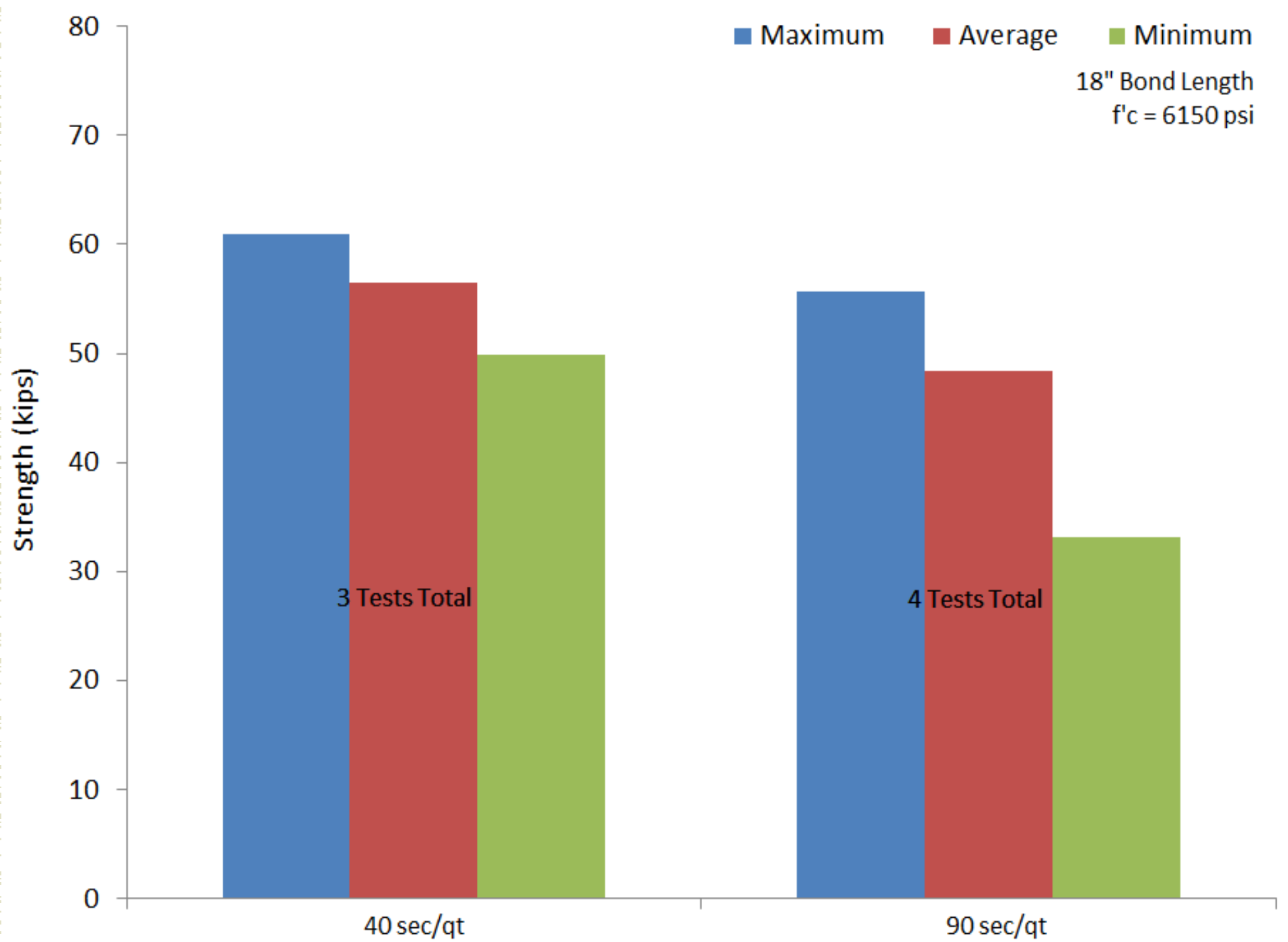


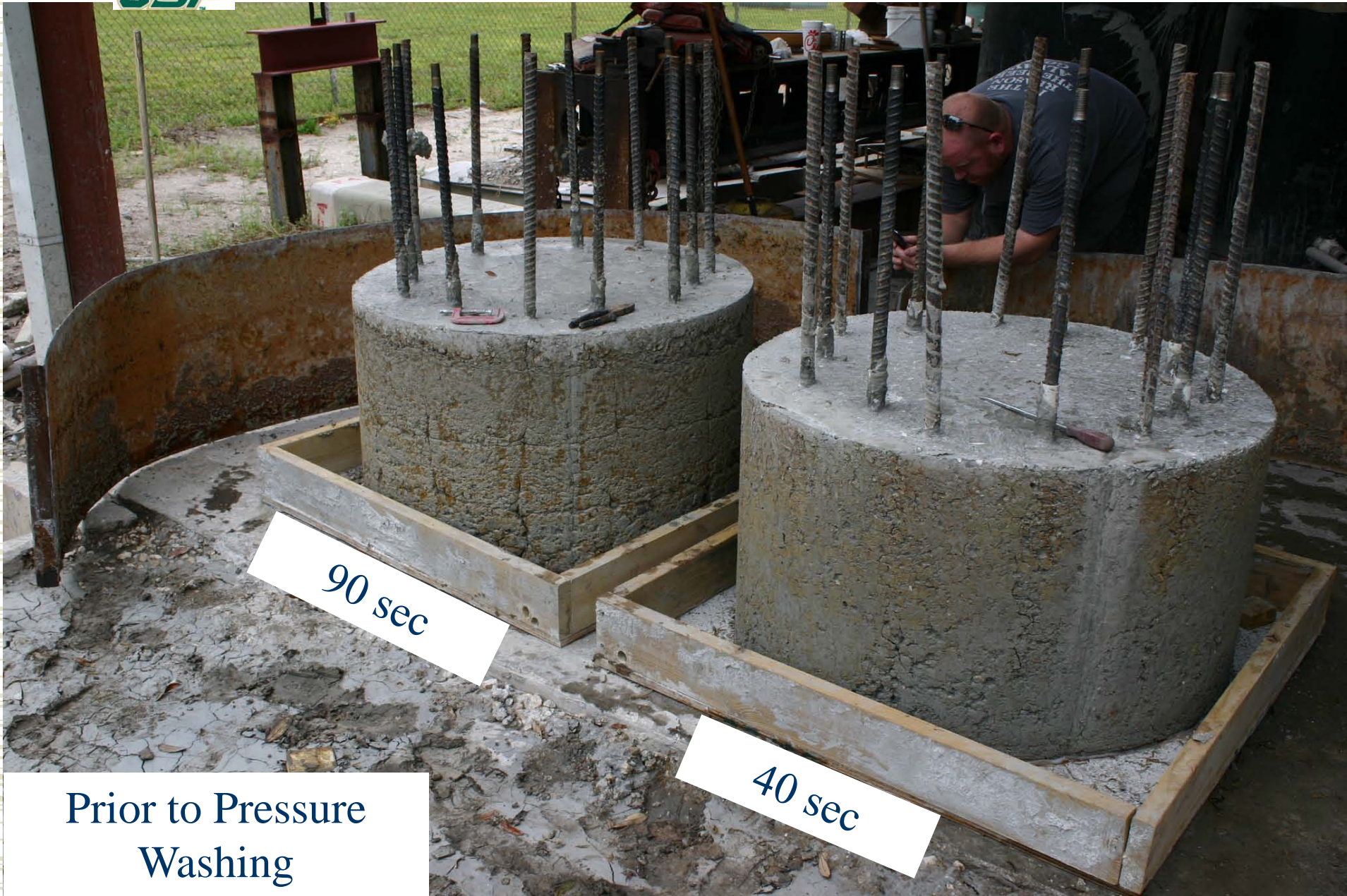




Placement #1

- ◆ 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





Prior to Pressure
Washing

Placement #1

After Pressure Washing

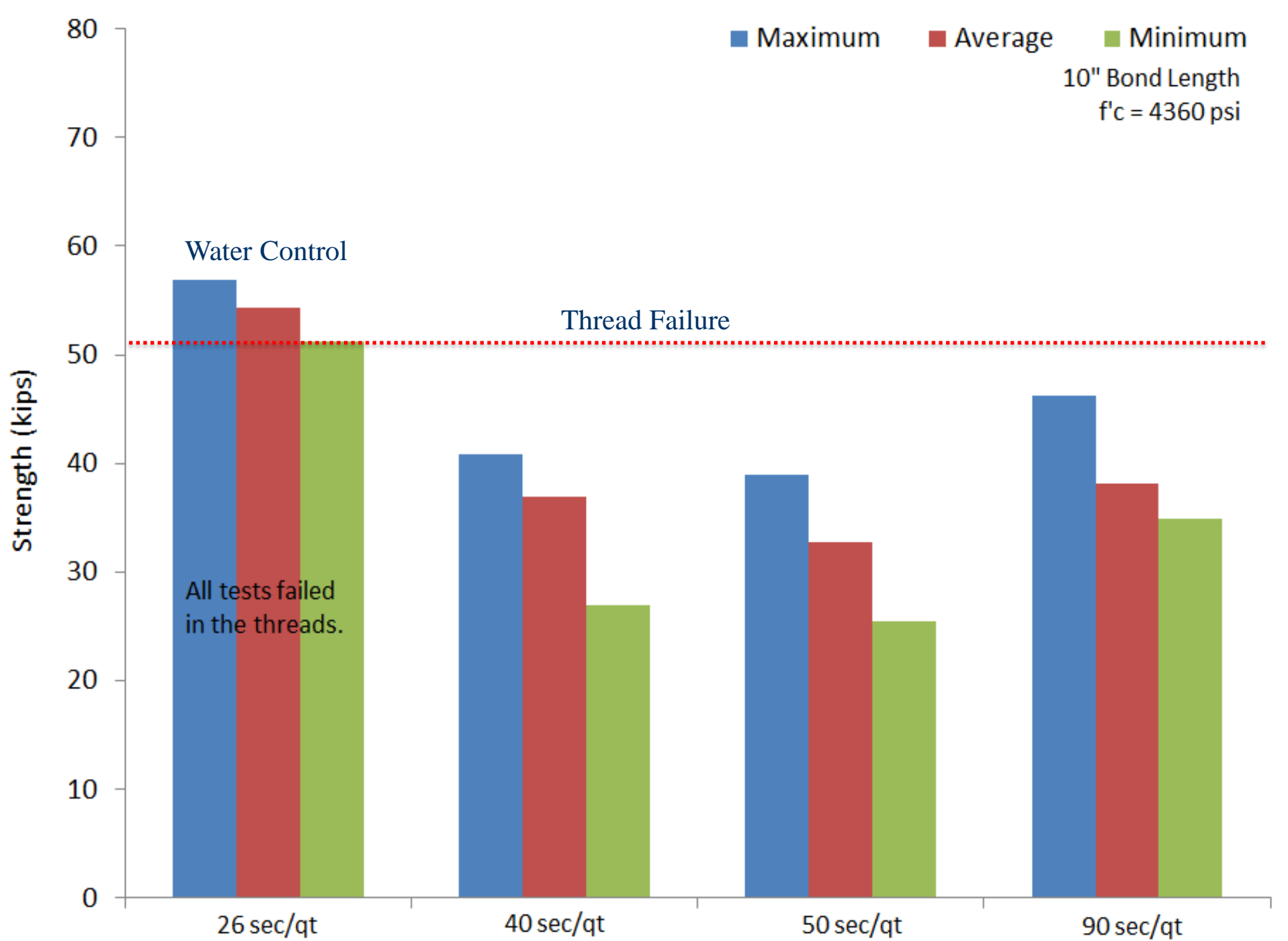


90 sec

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



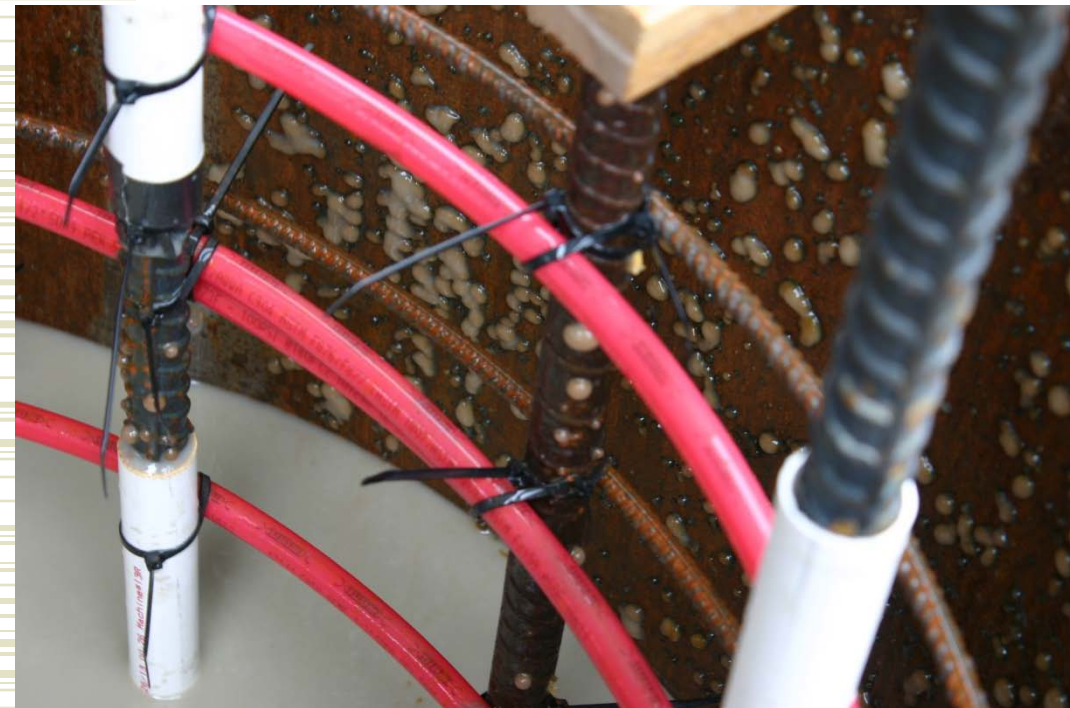


Placement #3a

- ◆ 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





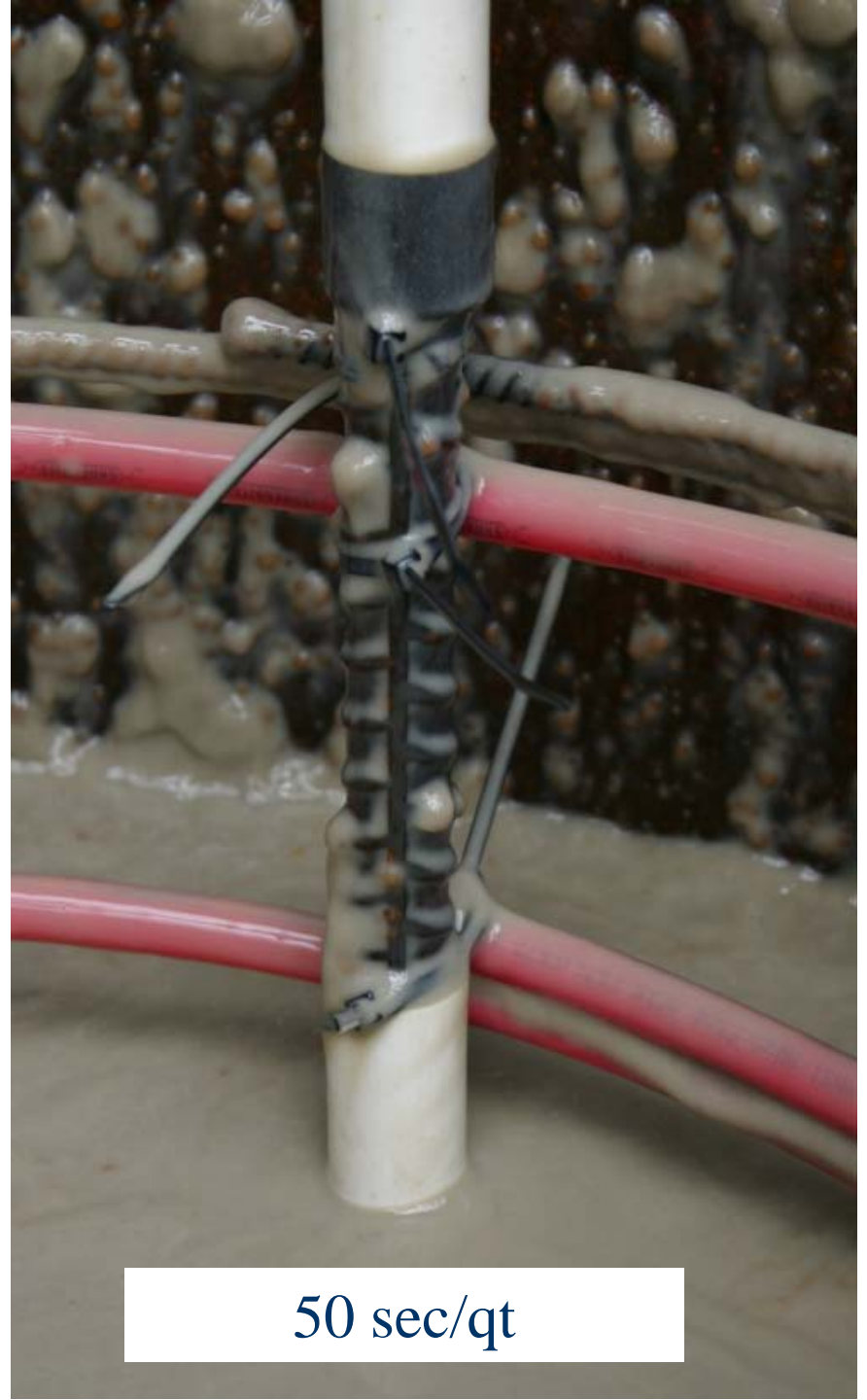
30 sec/qt



40 sec/qt



30 sec/qt



50 sec/qt



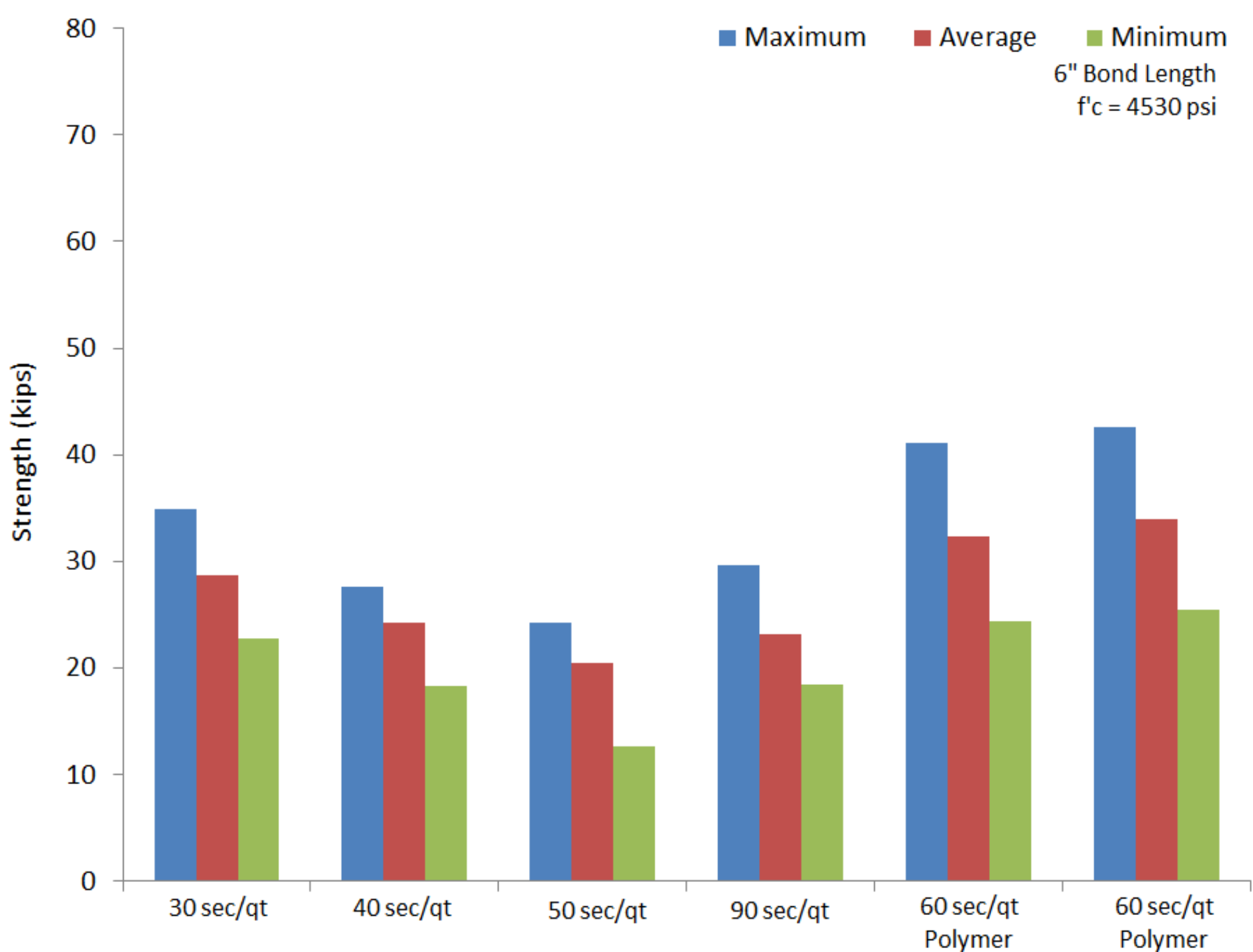
30 sec/qt



90 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



60 sec/qt - Polymer



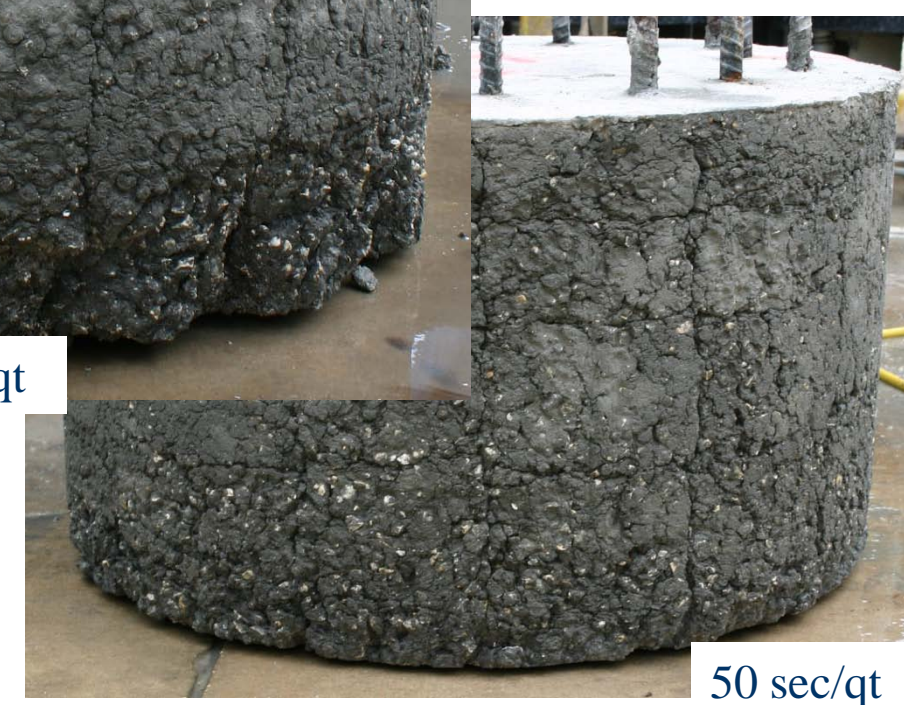
30 sec/qt



40 sec/qt



90 sec/qt



50 sec/qt

Concrete Cores



Concrete Cores

H₂O

60s Polymer

30s

40s



Concrete Cores

H₂O

60s Polymer

30s

40s



Concrete Cores

H₂O

60s Polymer

30s

40s



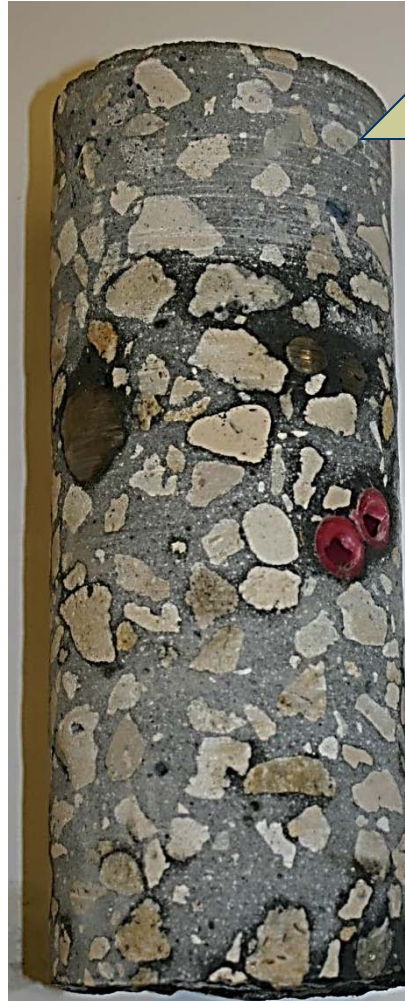
Concrete Cores

H₂O

60s Polymer

30s

40s



Concrete Flow Outwards



Concrete Cores

H₂O

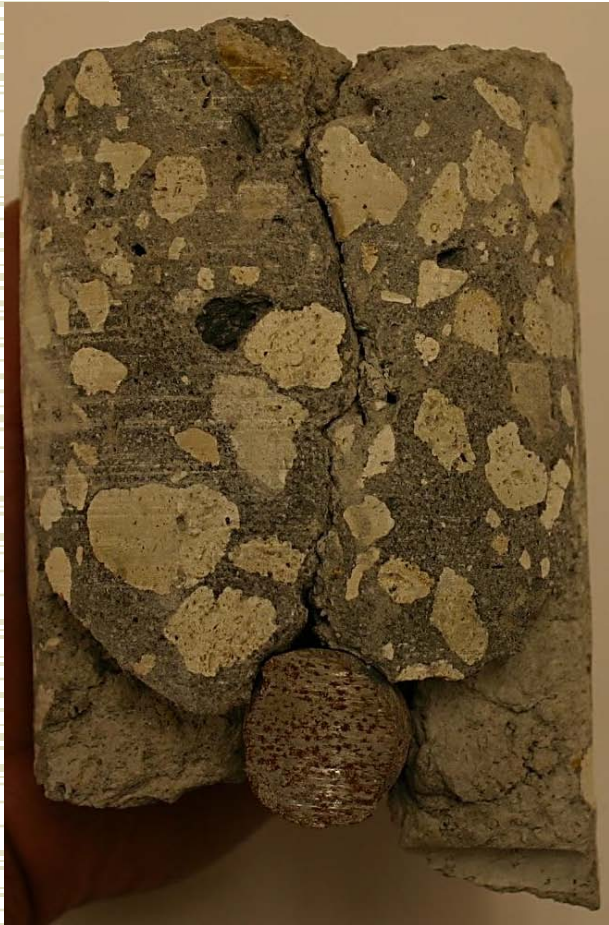
60s Polymer

30s

40s



Concrete Core – 50 sec/qt



Concrete Core – 50 sec/qt



Concrete Core – 90 sec/qt



Concrete Core – 90 sec/qt

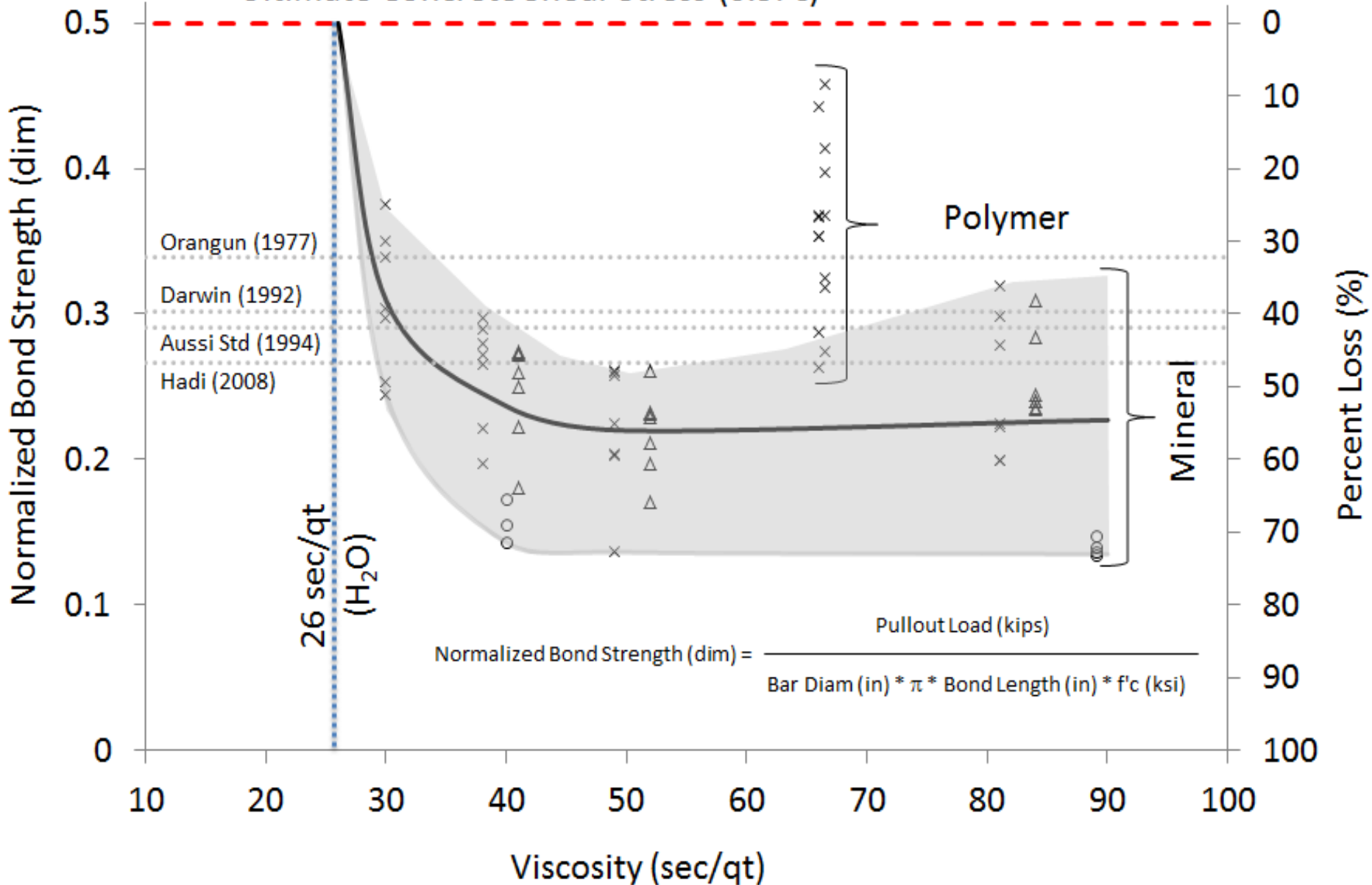


A Closer Look at the Pullout Results



O - Placement #1
 Δ - Placement #2
 X - Placement #3b

Ultimate Concrete Shear Stress (0.5f'c)



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?

