

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



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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



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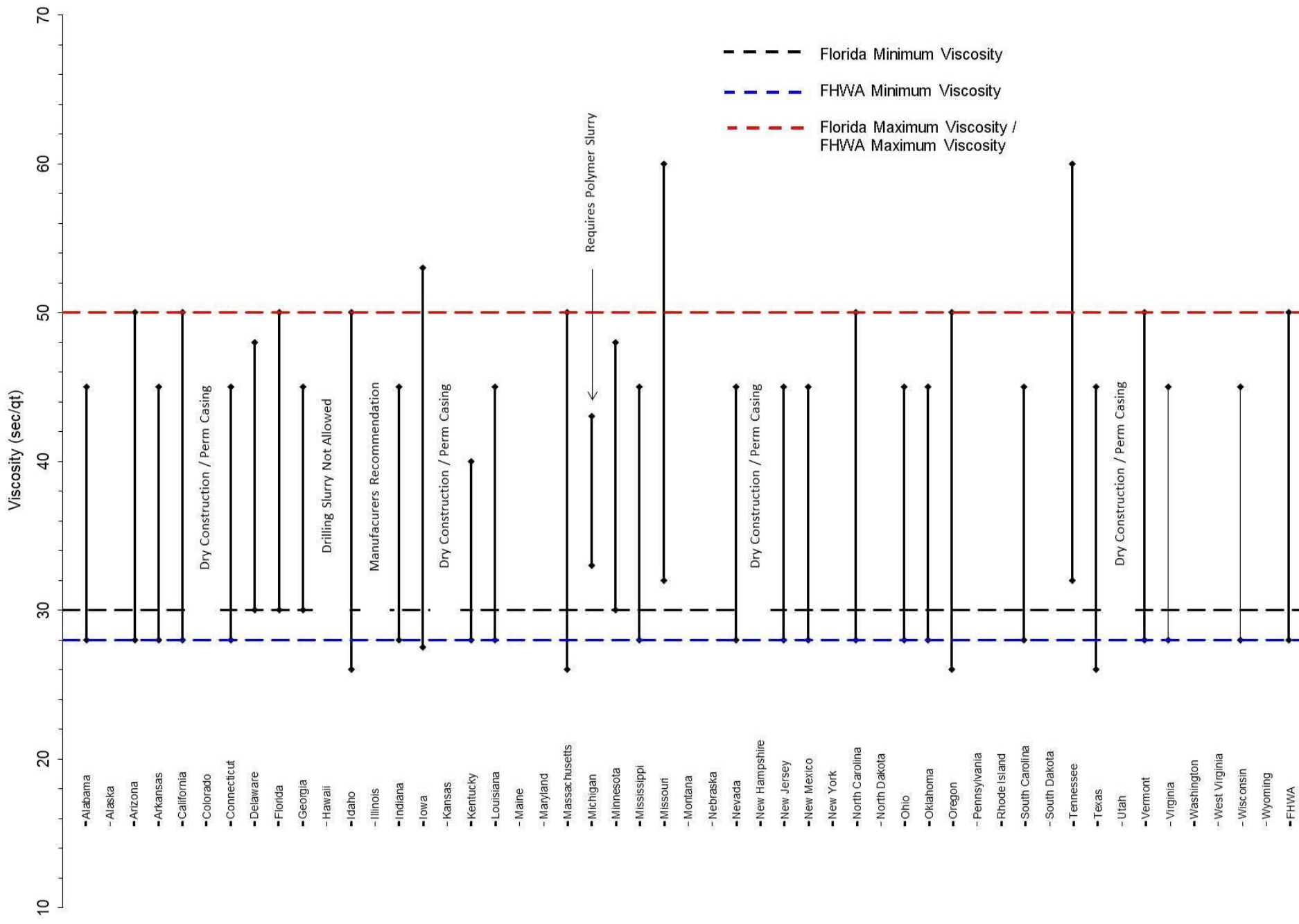
# Task 1: Literature Review

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- ◆ 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



# 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)

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

[www.clean-water-for-laymen.com](http://www.clean-water-for-laymen.com)

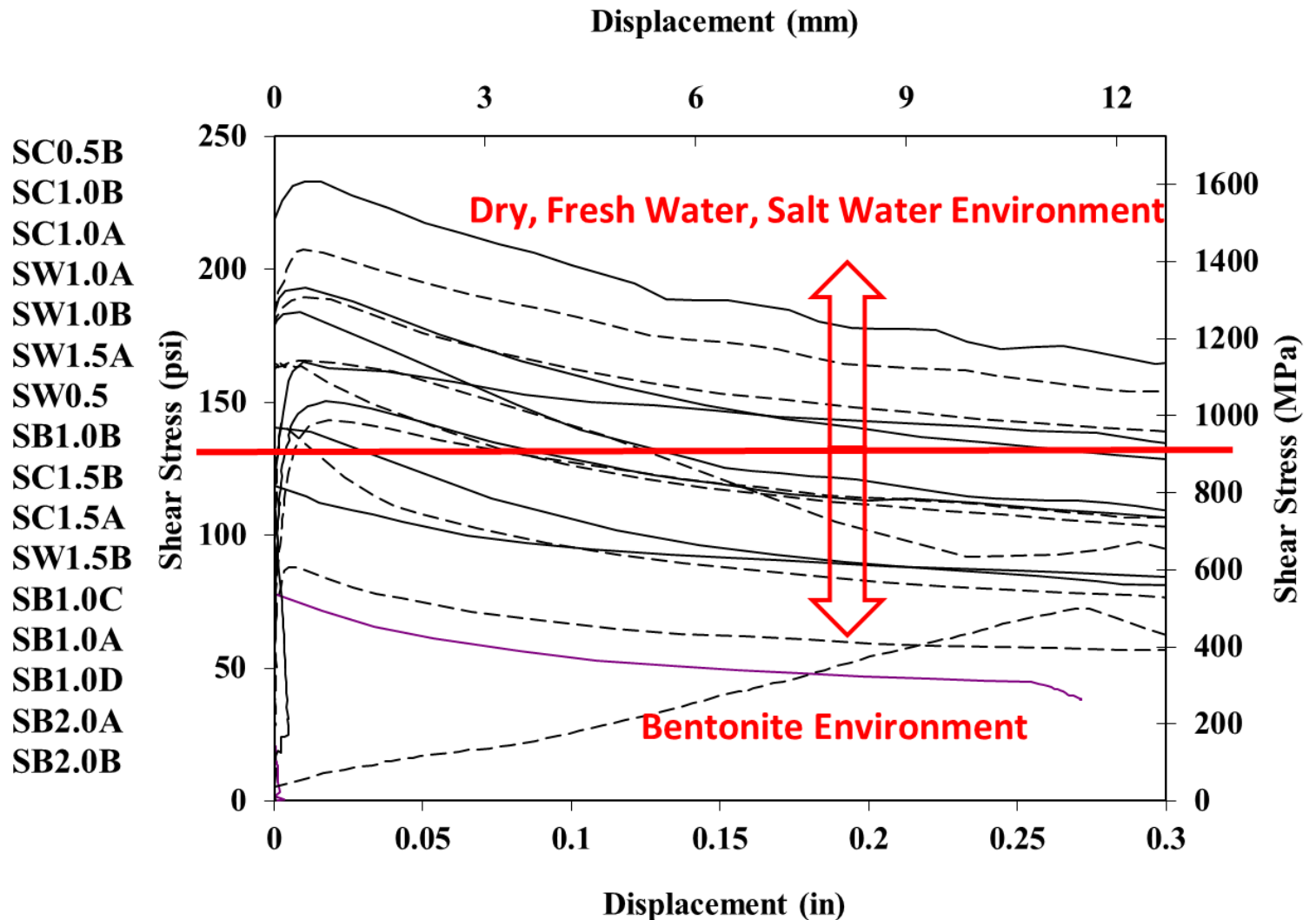
# Rebar Bond Strength

- ◆ 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),

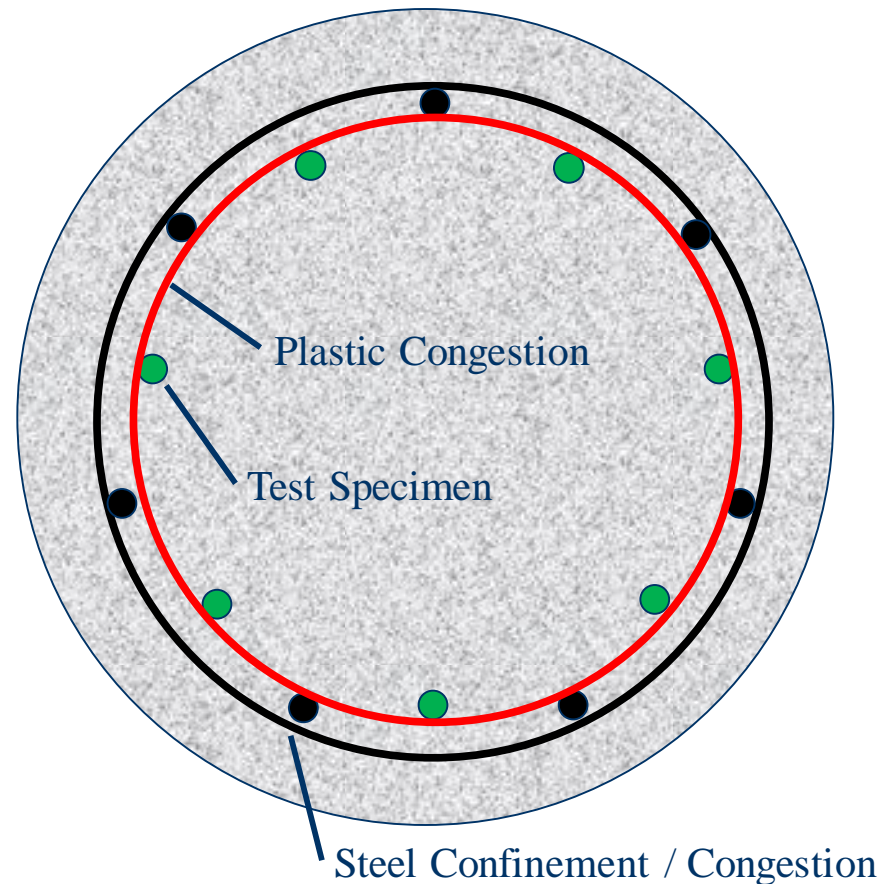
- ◆ Bentonite displaced specimens
  - Rebar tied to stirrups in a line
  - Concrete flow not representative of tremie placement in shafts
- ◆ Plain concrete specimens
  - Rebar stabbed into already poured concrete
  - Not tied to stirrups

# Pile / Seal Slab Bond



# 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)

# Rebar Pullout Testing Setup



# Bentonite 30 sec/qt





30 sec/qt



40 sec/qt



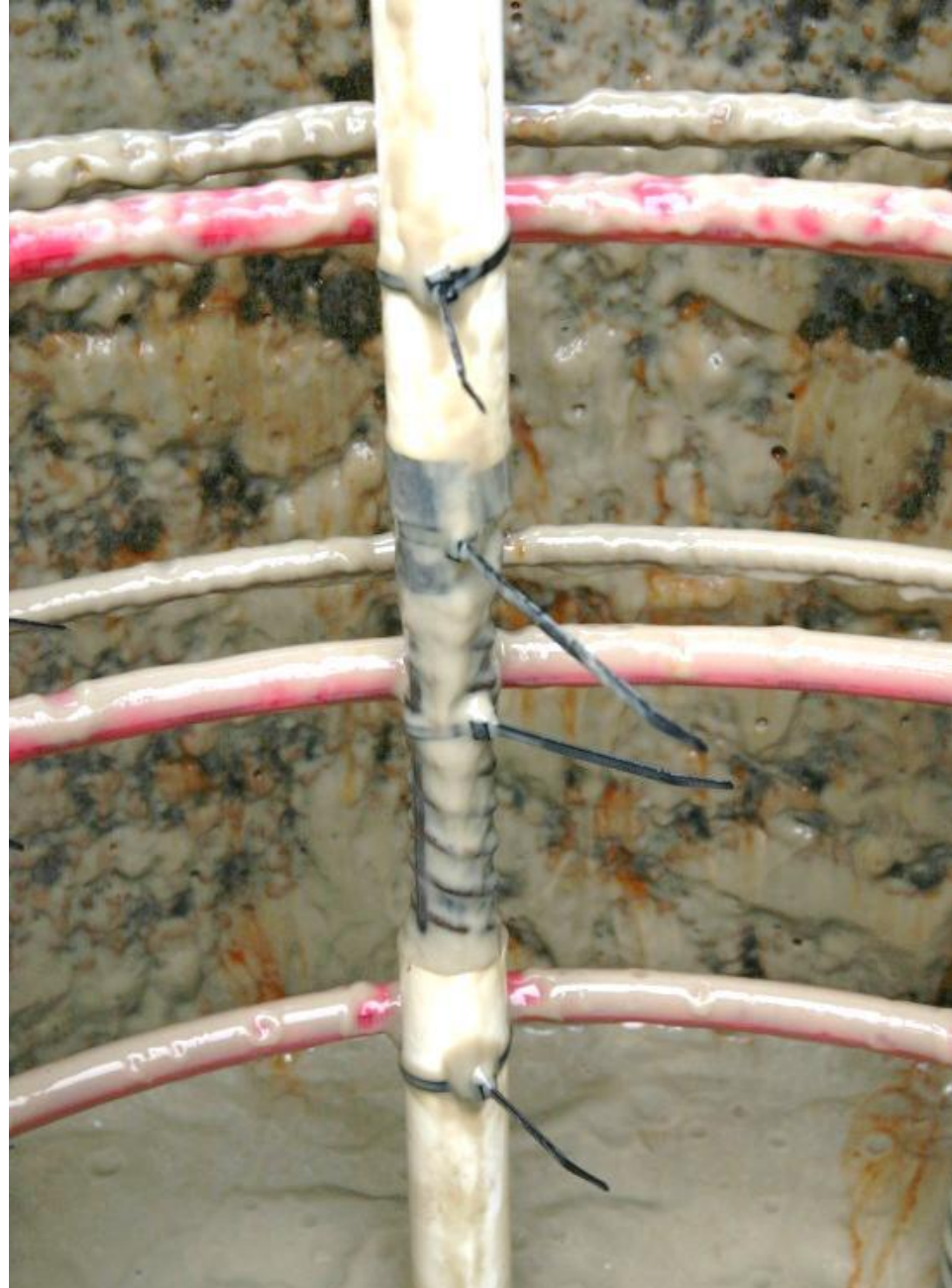
30 sec/qt



50 sec/qt



30 sec/qt



90 sec/qt

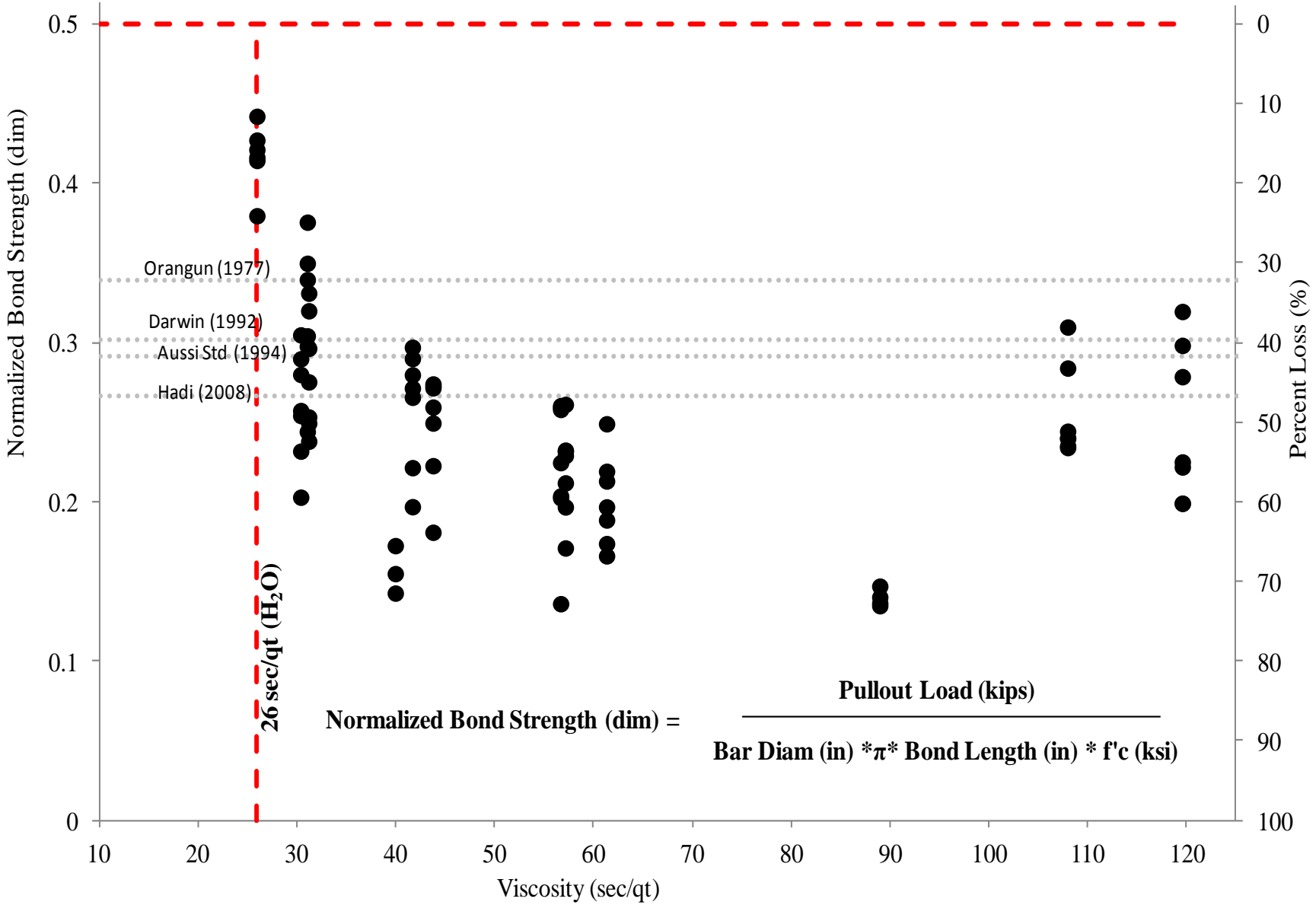




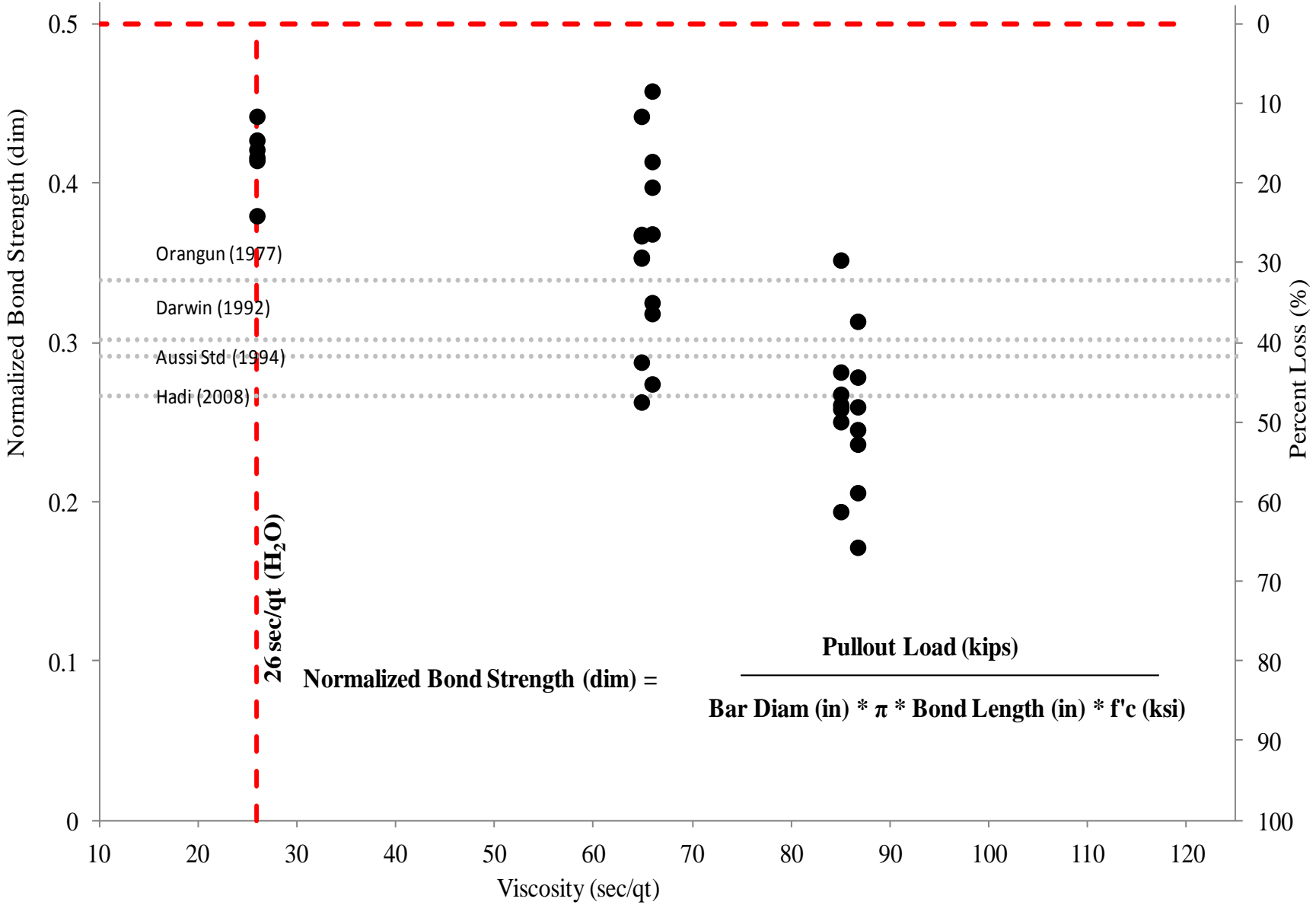




### Ultimate Concrete Shear Stress (0.5f'c)



### Ultimate Concrete Shear Stress (0.5f'c)



# Durability Evaluation After Pressure Washing



90 sec

40 sec



26 sec/qt (Water Control)



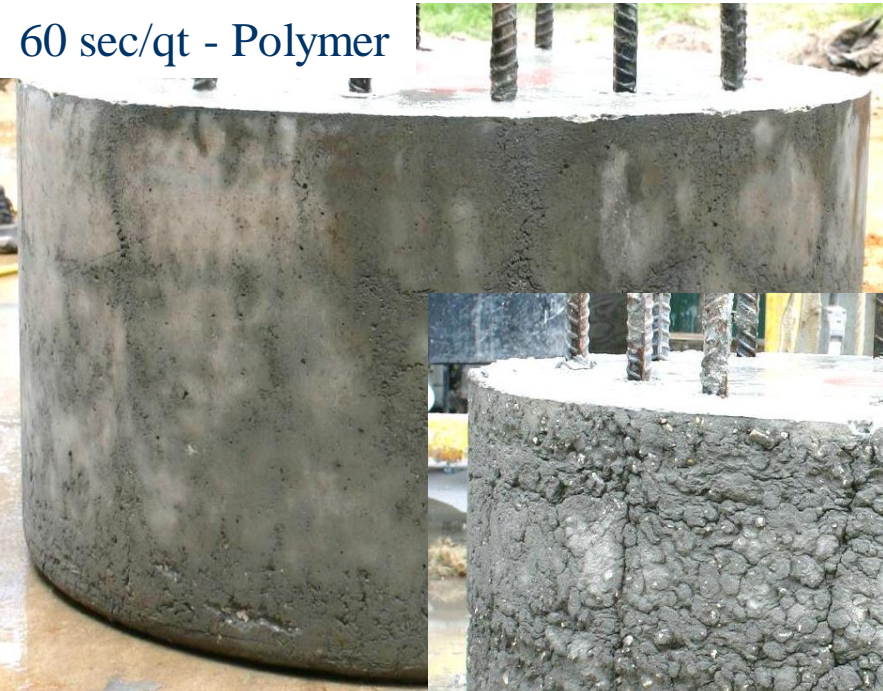
40 sec/qt



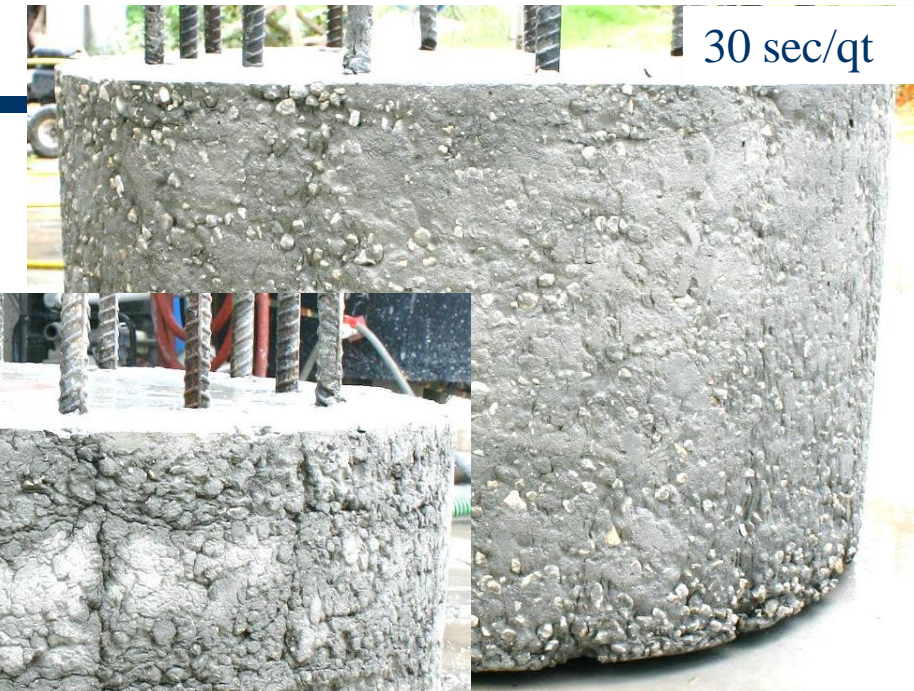
50 sec/qt



90 sec/qt



60 sec/qt - Polymer



30 sec/qt



90 sec/qt



40 sec/qt



50 sec/qt

# Concrete Cores



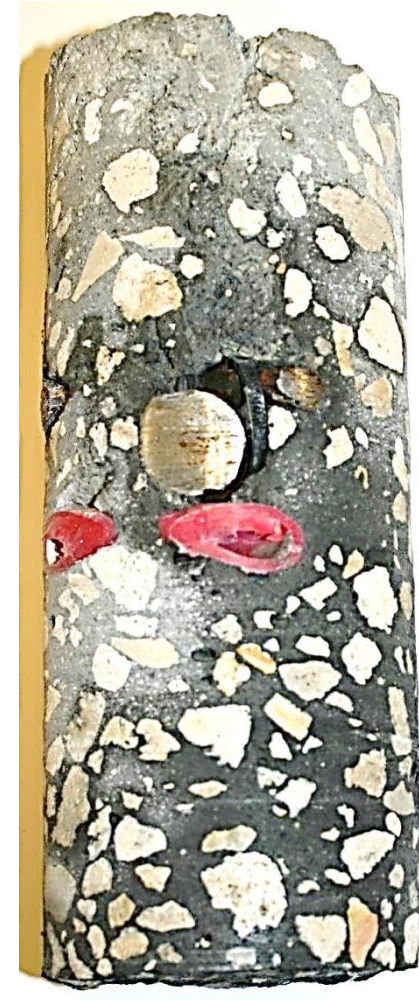
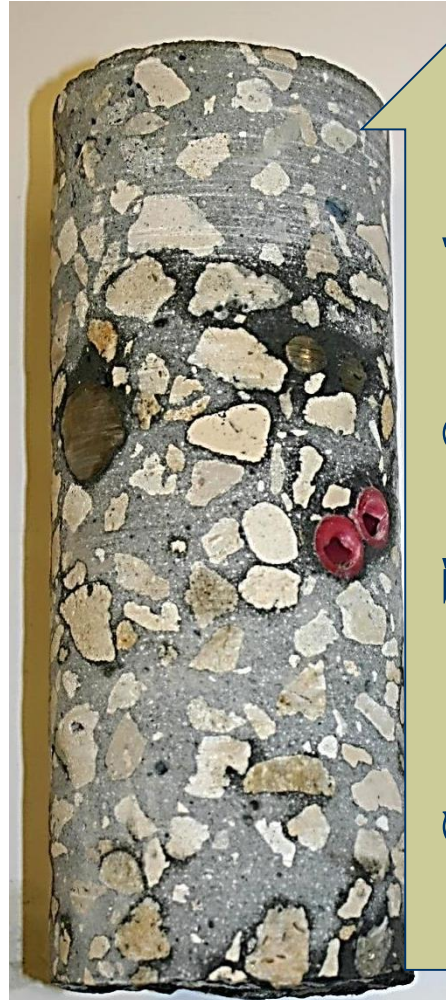
# Concrete Cores

H<sub>2</sub>O

60s Polymer

30s

40s



Concrete Flow Outwards

# Concrete Core – 50 sec/qt

Outer face of shaft

Vertical crease  
extended to depth  
of bar

Crease from stirrup  
completely separated top  
from bottom halves

Concrete flow from  
center to outer edge of  
shaft

Vertical bar

Stirrup location



# Concrete Core – 50 sec/qt



# Concrete Core – 50 sec/qt



# Concrete Core – 90 sec/qt

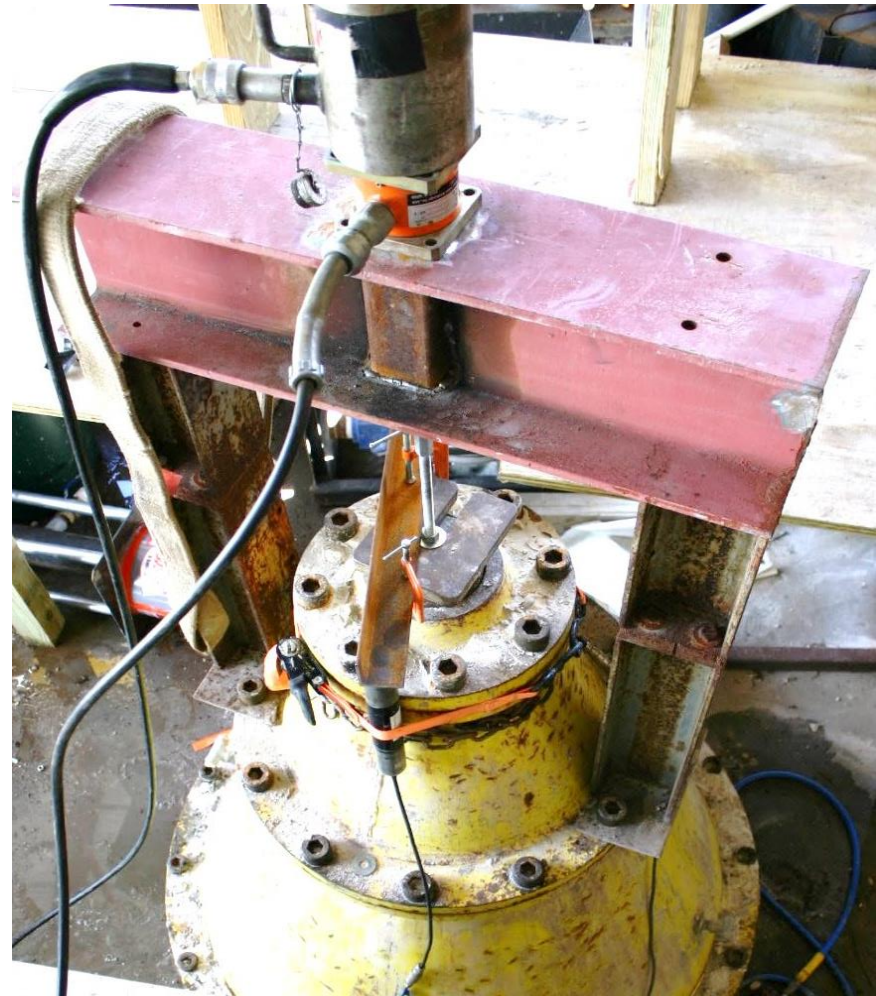


# Concrete Core – 90 sec/qt



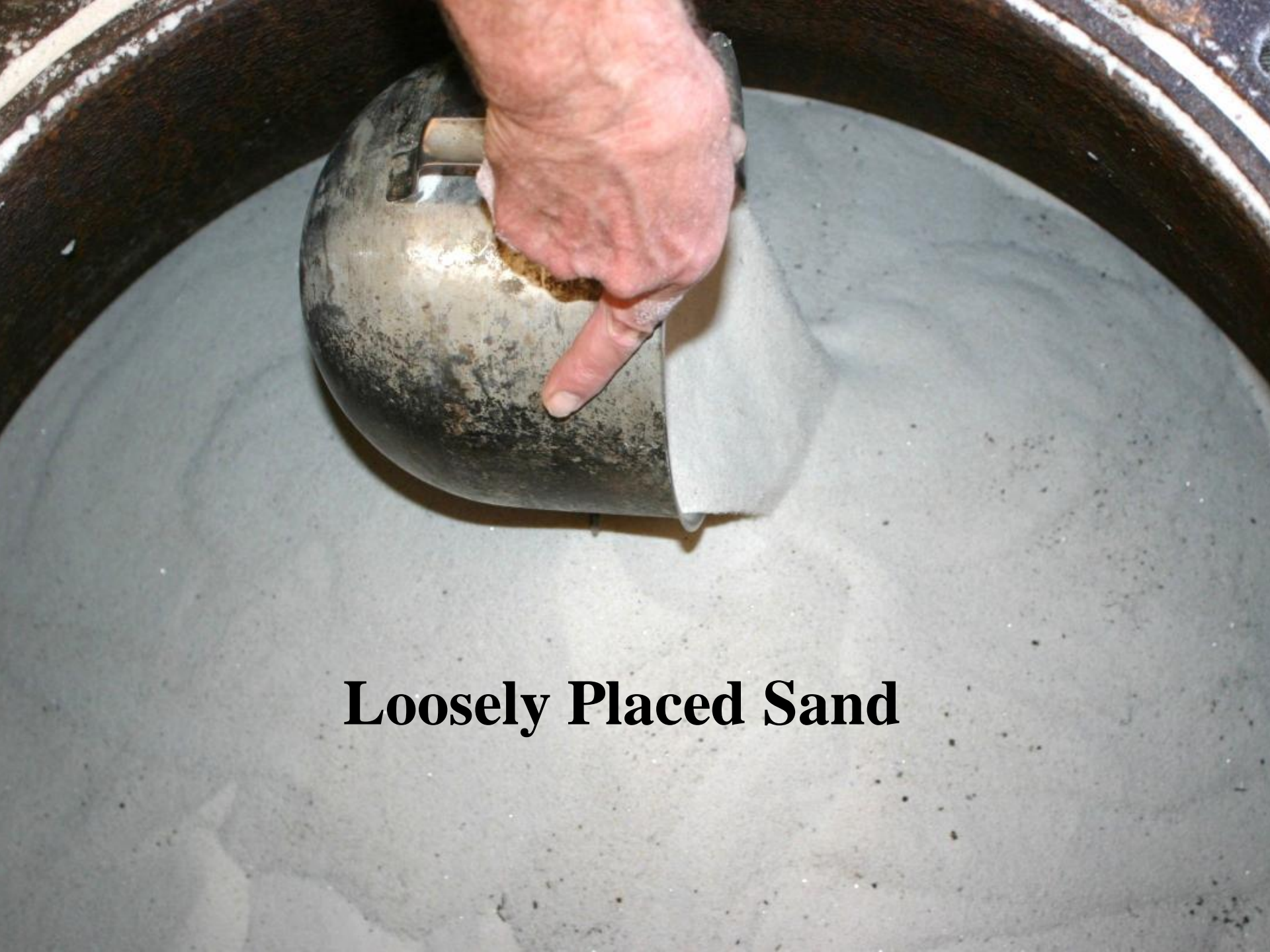
# Task 3: Laboratory Side Shear Evaluation

- ◆ Pull out tests in FCV
- ◆ 36 inch Long
- ◆ 4 inch Diameter
- ◆ Varying Viscosities & Slurry Type









**Loosely Placed Sand**



Stress Sand in Cell and Excavate



Sand / Mortar Mix



# Place Tremie and Attach Hopper





**Install Full-length Threaded Rod**



Pull out Testing



Disassemble and Remove Shaft

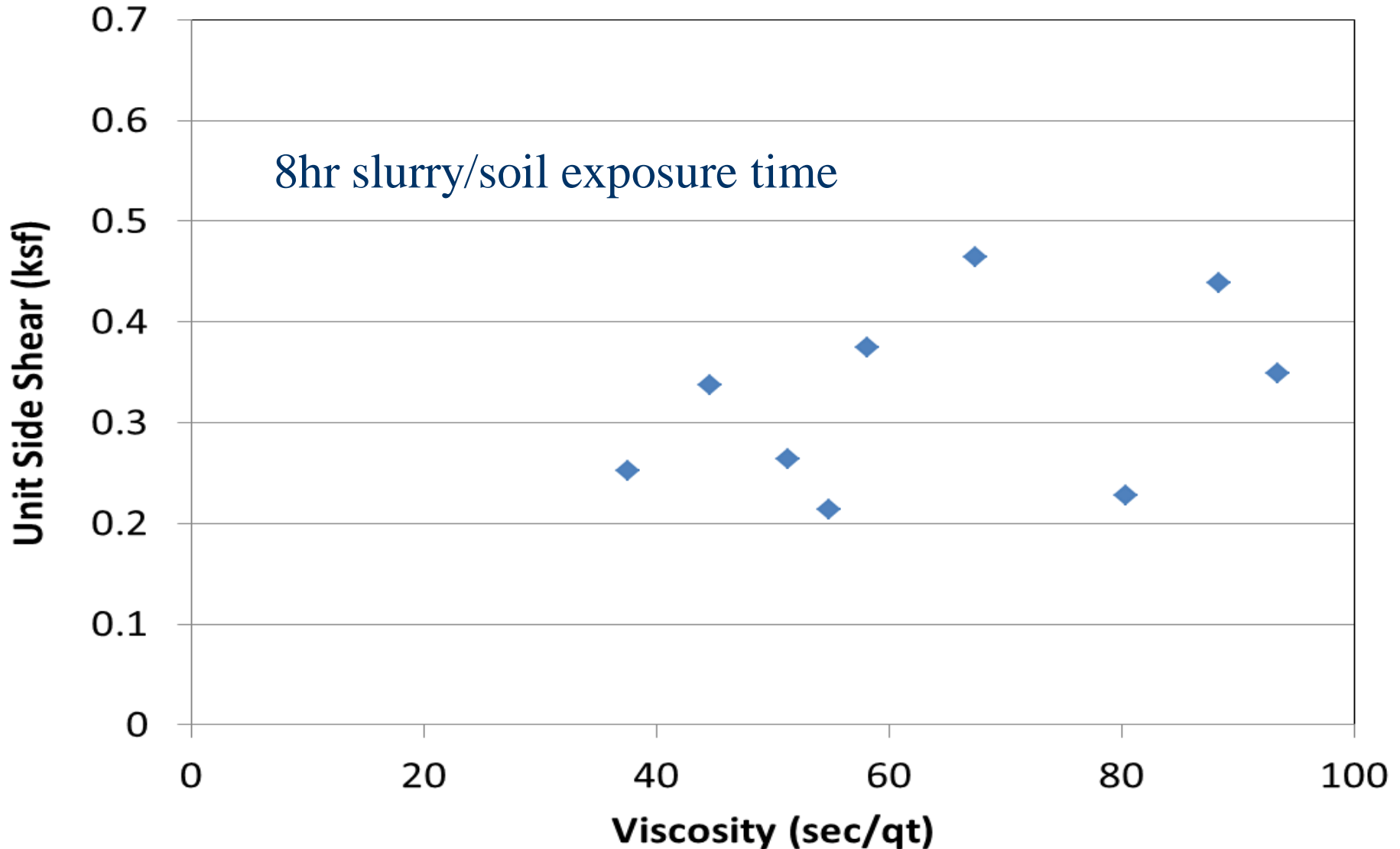






# Results of Lab Tests (bentonite)

8hr slurry/soil exposure time



# 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

123<sup>rd</sup> Avenue North

44<sup>th</sup> Street

1230



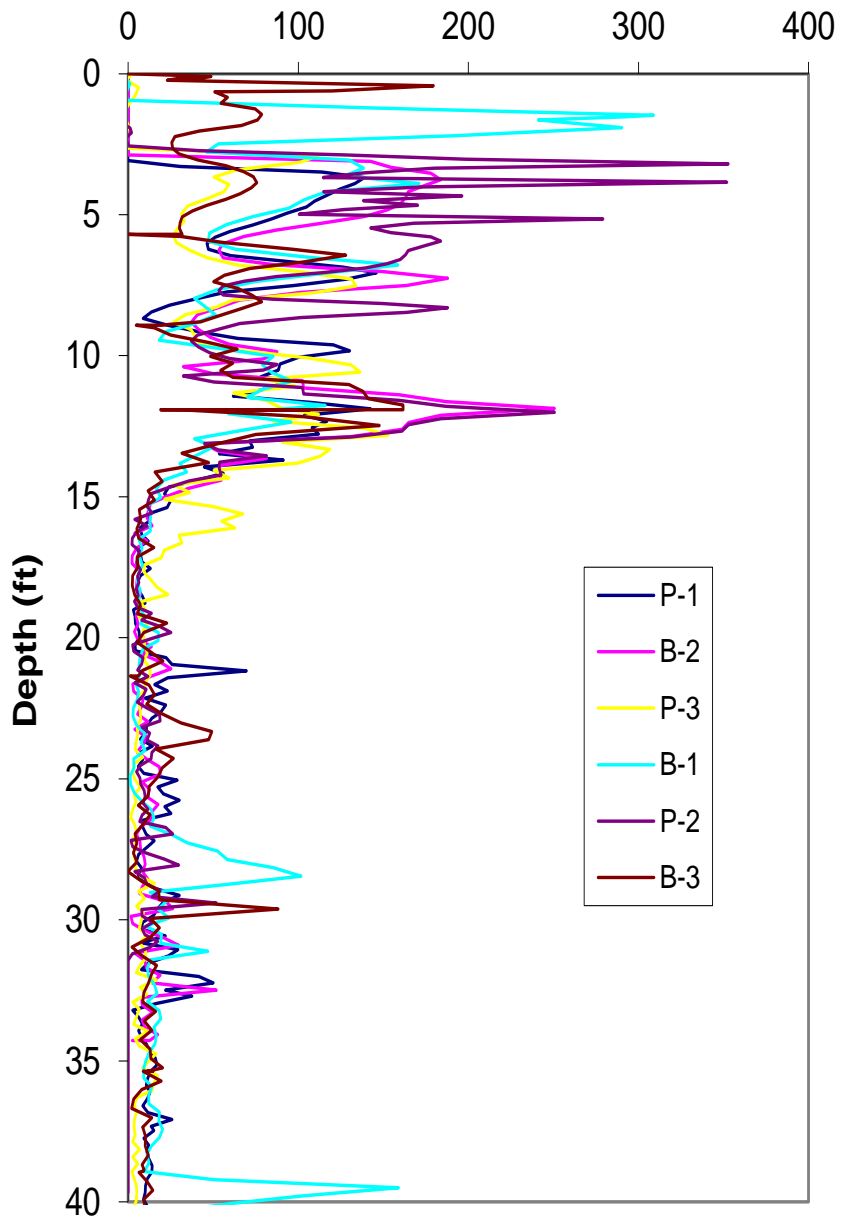
Test Site

Google earth

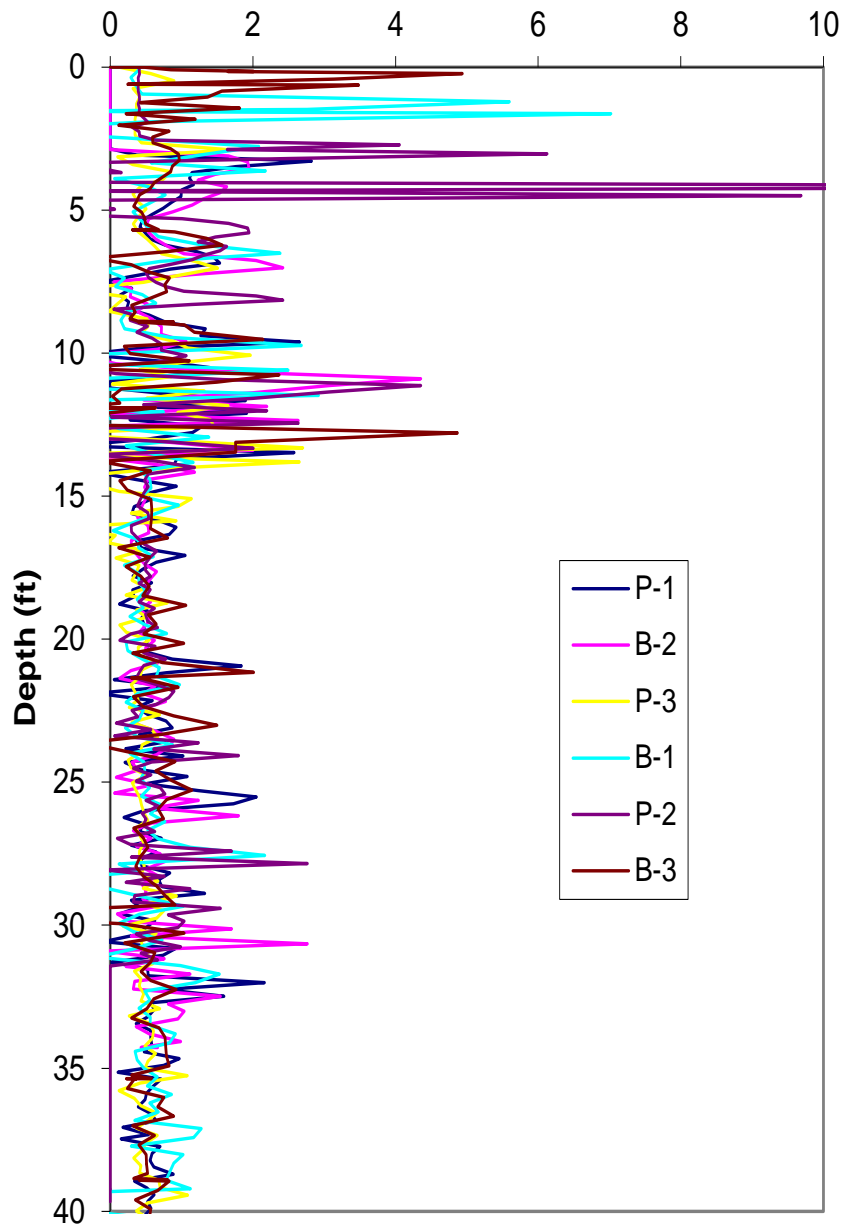
# CPT Soundings

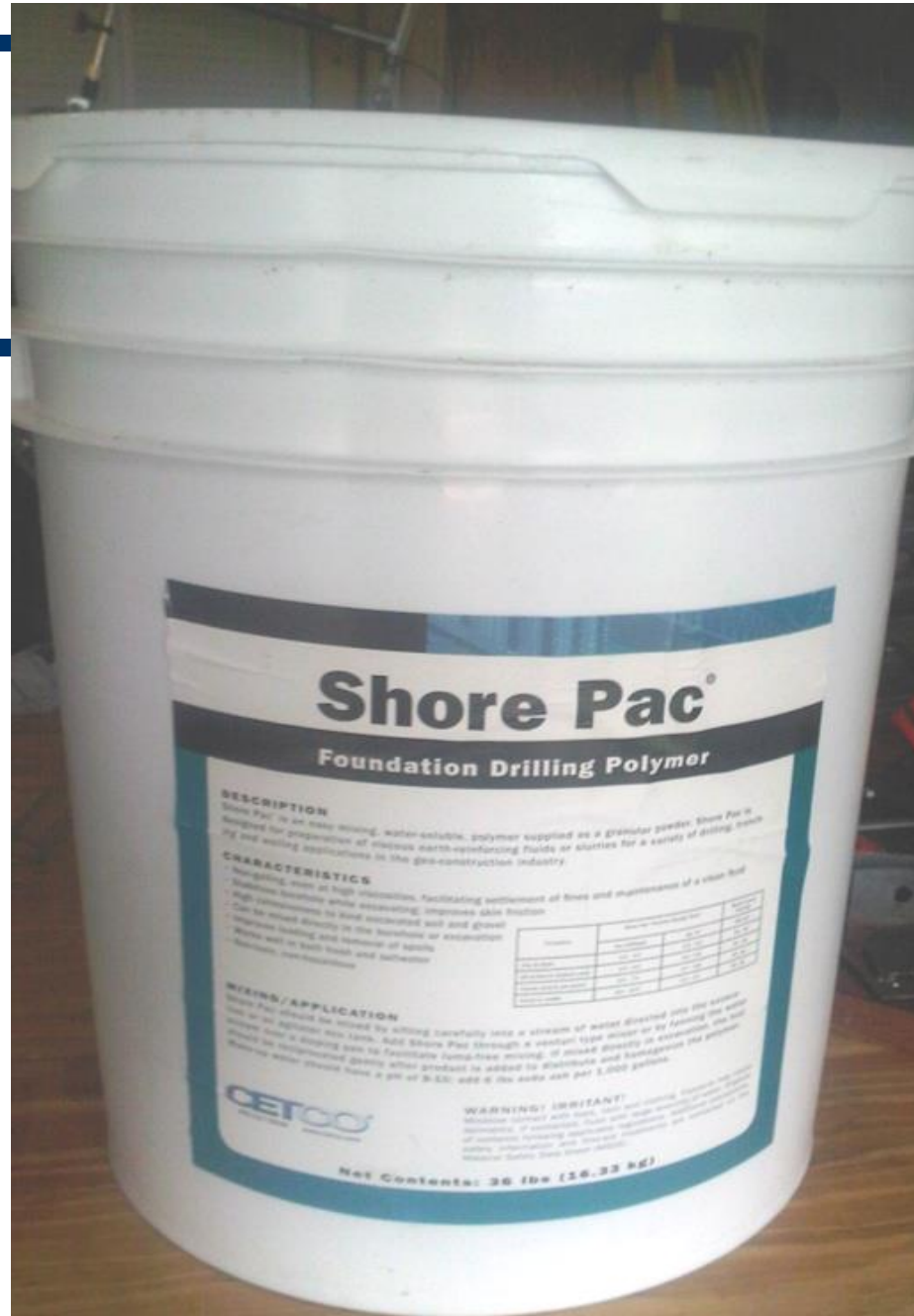
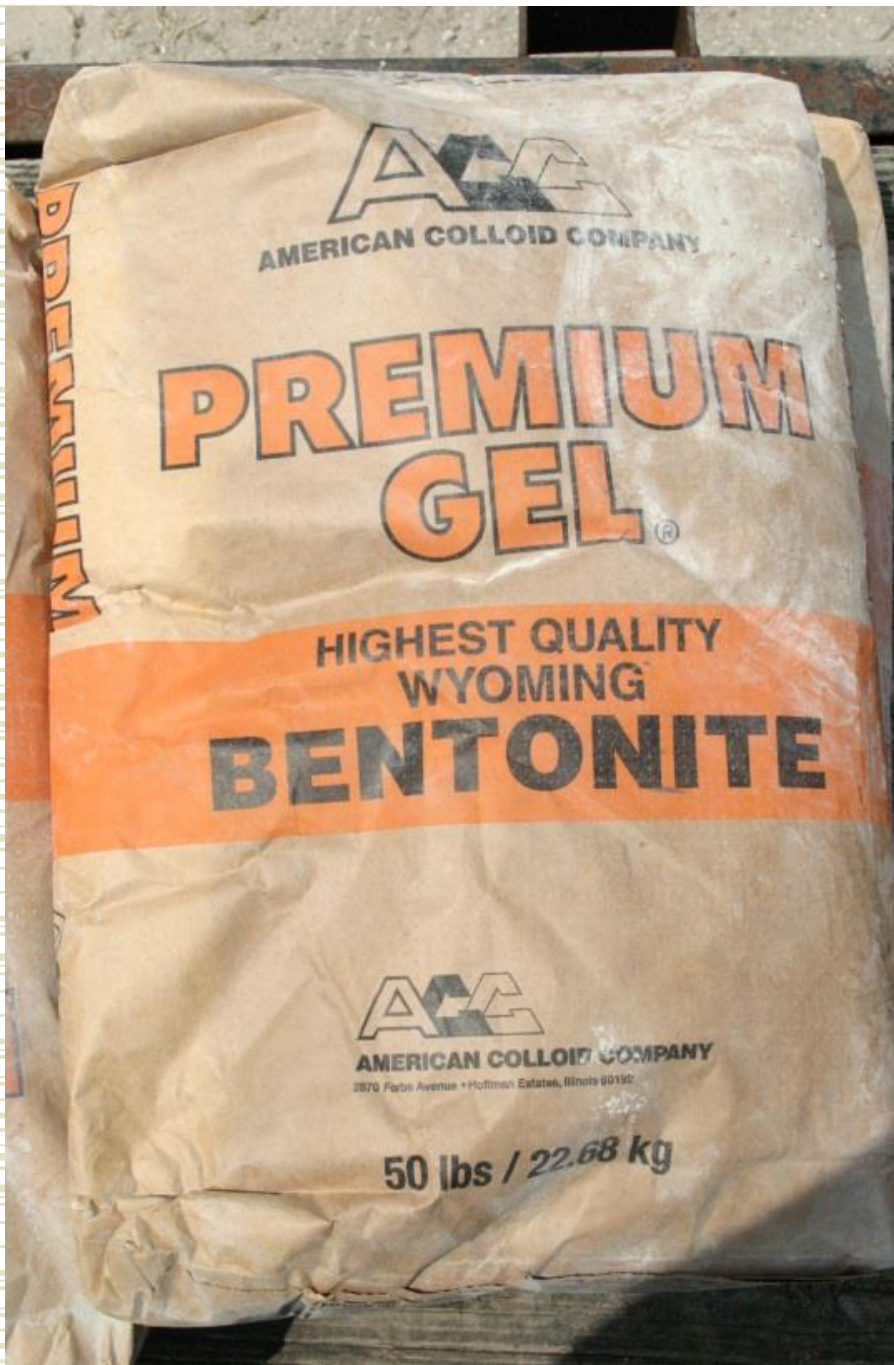


### Tip Stress (TSF)



### Sleeve Friction (TSF)





# Shore Pac<sup>®</sup>

## Foundation Drilling Polymer

### DESCRIPTION

Shore Pac<sup>®</sup> is an easy mixing, water-soluble, polymer supplied as a granular powder. Shore Pac is designed for preparation of viscous earth-reinforcing fluids or slurries for a variety of drilling, casing and sealing applications in the geo-construction industry.

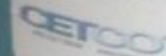
### CHARACTERISTICS

- Non-flammable, non-toxic, high viscosity, facilitating settlement of fines and maintenance of a clean fluid
- Stable, because of its excellent, improves skin friction
- High compressive to sand encased soil and gravel
- Can be mixed directly in the borehole or excavation
- Improves bearing and retention of spoils
- Works well in both fresh and saltwater
- Excellent performance

Property	Value
Specific Gravity	1.05
Particle Size (d <sub>50</sub> )	150 microns
Particle Size (d <sub>10</sub> )	75 microns
Particle Size (d <sub>20</sub> )	100 microns
Particle Size (d <sub>40</sub> )	125 microns
Particle Size (d <sub>60</sub> )	150 microns
Particle Size (d <sub>80</sub> )	175 microns
Particle Size (d <sub>100</sub> )	200 microns
Particle Size (d <sub>200</sub> )	250 microns
Particle Size (d <sub>400</sub> )	300 microns
Particle Size (d <sub>600</sub> )	350 microns
Particle Size (d <sub>800</sub> )	400 microns
Particle Size (d <sub>1000</sub> )	450 microns
Particle Size (d <sub>1200</sub> )	500 microns
Particle Size (d <sub>1400</sub> )	550 microns
Particle Size (d <sub>1600</sub> )	600 microns
Particle Size (d <sub>1800</sub> )	650 microns
Particle Size (d <sub>2000</sub> )	700 microns
Particle Size (d <sub>2200</sub> )	750 microns
Particle Size (d <sub>2400</sub> )	800 microns
Particle Size (d <sub>2600</sub> )	850 microns
Particle Size (d <sub>2800</sub> )	900 microns
Particle Size (d <sub>3000</sub> )	950 microns
Particle Size (d <sub>3200</sub> )	1000 microns
Particle Size (d <sub>3400</sub> )	1050 microns
Particle Size (d <sub>3600</sub> )	1100 microns
Particle Size (d <sub>3800</sub> )	1150 microns
Particle Size (d <sub>4000</sub> )	1200 microns
Particle Size (d <sub>4200</sub> )	1250 microns
Particle Size (d <sub>4400</sub> )	1300 microns
Particle Size (d <sub>4600</sub> )	1350 microns
Particle Size (d <sub>4800</sub> )	1400 microns
Particle Size (d <sub>5000</sub> )	1450 microns
Particle Size (d <sub>5200</sub> )	1500 microns
Particle Size (d <sub>5400</sub> )	1550 microns
Particle Size (d <sub>5600</sub> )	1600 microns
Particle Size (d <sub>5800</sub> )	1650 microns
Particle Size (d <sub>6000</sub> )	1700 microns
Particle Size (d <sub>6200</sub> )	1750 microns
Particle Size (d <sub>6400</sub> )	1800 microns
Particle Size (d <sub>6600</sub> )	1850 microns
Particle Size (d <sub>6800</sub> )	1900 microns
Particle Size (d <sub>7000</sub> )	1950 microns
Particle Size (d <sub>7200</sub> )	2000 microns
Particle Size (d <sub>7400</sub> )	2050 microns
Particle Size (d <sub>7600</sub> )	2100 microns
Particle Size (d <sub>7800</sub> )	2150 microns
Particle Size (d <sub>8000</sub> )	2200 microns
Particle Size (d <sub>8200</sub> )	2250 microns
Particle Size (d <sub>8400</sub> )	2300 microns
Particle Size (d <sub>8600</sub> )	2350 microns
Particle Size (d <sub>8800</sub> )	2400 microns
Particle Size (d <sub>9000</sub> )	2450 microns
Particle Size (d <sub>9200</sub> )	2500 microns
Particle Size (d <sub>9400</sub> )	2550 microns
Particle Size (d <sub>9600</sub> )	2600 microns
Particle Size (d <sub>9800</sub> )	2650 microns
Particle Size (d <sub>10000</sub> )	2700 microns

### MIXING / APPLICATION

Shore Pac should be mixed by adding carefully into a stream of water directed into the desired hole or an agitator mix tank. Add Shore Pac through a venturi type mixer or by forcing the water through a standard gun to facilitate lump-free mixing. If mixed directly in excavation, the water should be recirculated through either product is added to slurry and homogenized the product. Slurry water should have a pH of 9-10; add 6 lbs extra ash per 1,000 gallons.



**WARNING! IRRITANT!**  
Avoid contact with skin, eyes and clothing. Cleanse thoroughly if contacted. Flush with water. Avoid breathing dust. Do not ingest. Do not get into eyes, nose or mouth. Do not get on face. Do not get on hands. Do not get on feet. Do not get on shoes. Do not get on clothes. Do not get on hair. Do not get on jewelry. Do not get on glasses. Do not get on contact lenses. Do not get on hearing aids. Do not get on dentures. Do not get on prosthetics. Do not get on implants. Do not get on medical devices. Do not get on electronic equipment. Do not get on electrical equipment. Do not get on power lines. Do not get on telephones. Do not get on radios. Do not get on televisions. Do not get on computers. Do not get on printers. Do not get on scanners. Do not get on copiers. Do not get on fax machines. Do not get on modems. Do not get on routers. Do not get on switches. Do not get on outlets. Do not get on plugs. Do not get on sockets. Do not get on fuses. Do not get on breakers. Do not get on relays. Do not get on transformers. Do not get on capacitors. Do not get on inductors. Do not get on resistors. Do not get on diodes. Do not get on transistors. Do not get on integrated circuits. Do not get on microprocessors. Do not get on microcontrollers. Do not get on microconverters. Do not get on microrelays. Do not get on microswitches. Do not get on microactuators. Do not get on microvalves. Do not get on micropumps. Do not get on microturbines. Do not get on microengines. Do not get on microgenerators. Do not get on microprocessors. Do not get on microcontrollers. Do not get on microconverters. Do not get on microrelays. Do not get on microswitches. Do not get on microactuators. Do not get on microvalves. Do not get on micropumps. Do not get on microturbines. Do not get on microengines. Do not get on microgenerators.

Net Contents: 36 lbs (16.33 kg)



**Bentonite 40 to 90 sec/qt**



**Polymer 60 to 130 sec/qt**







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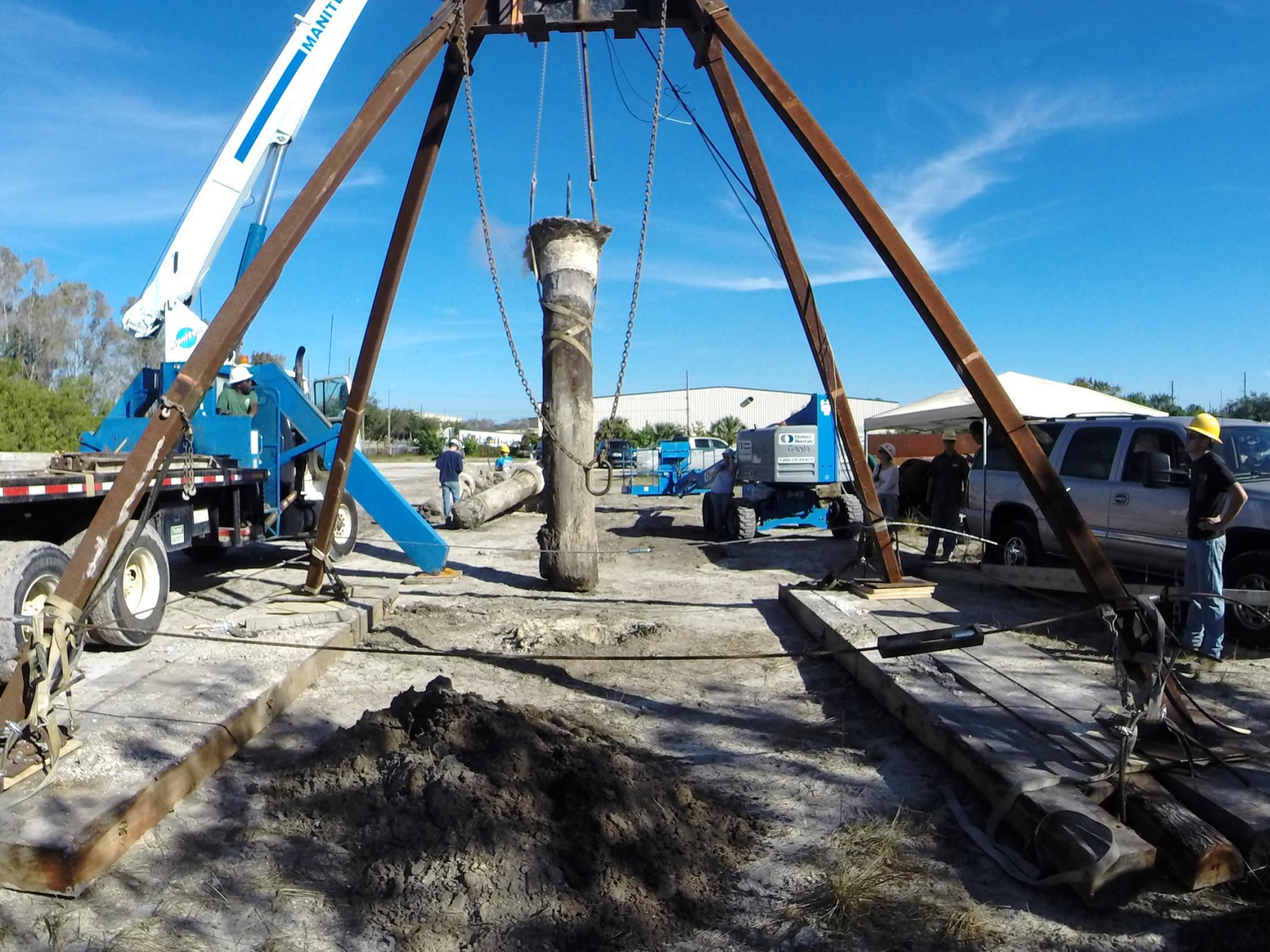






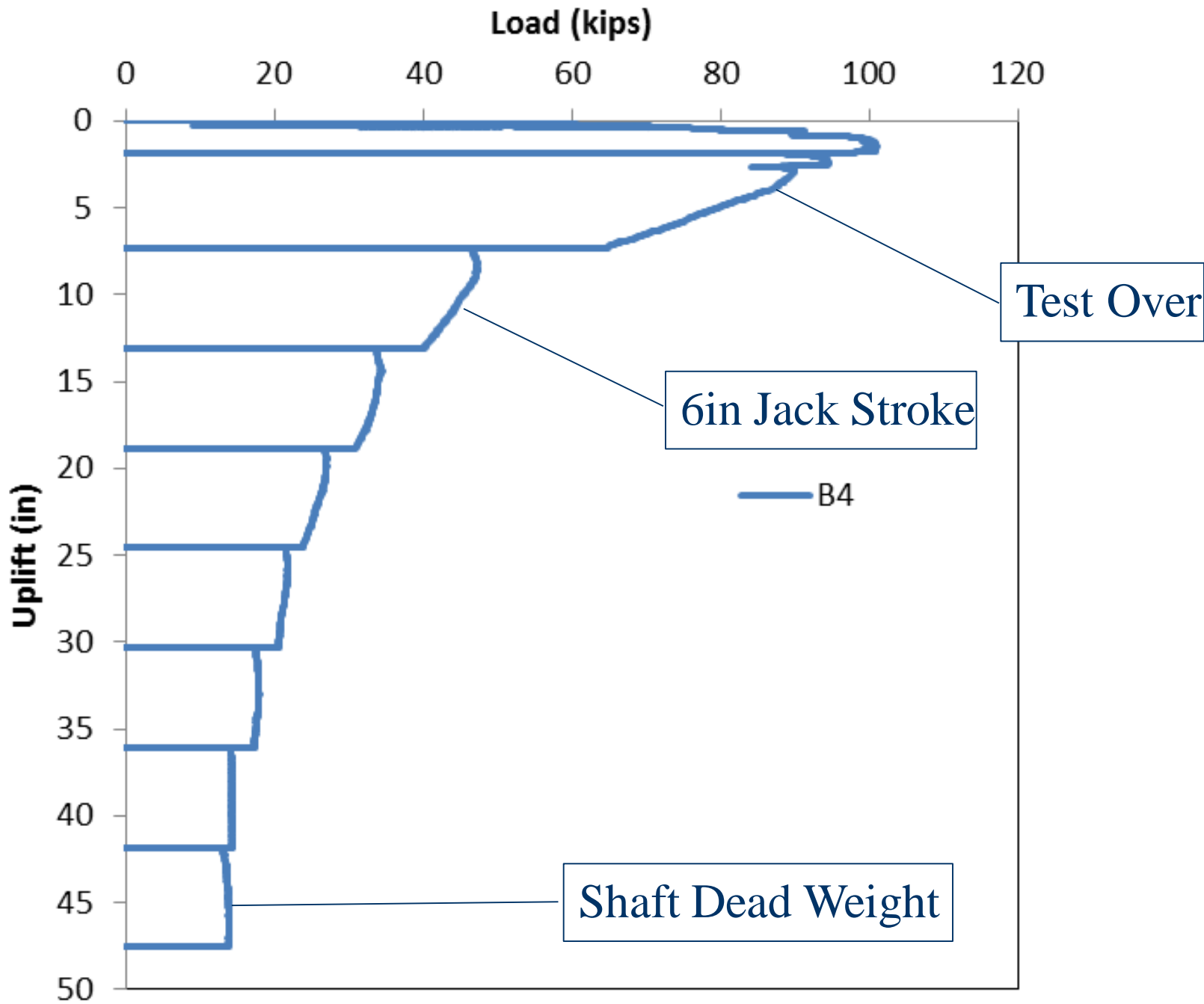




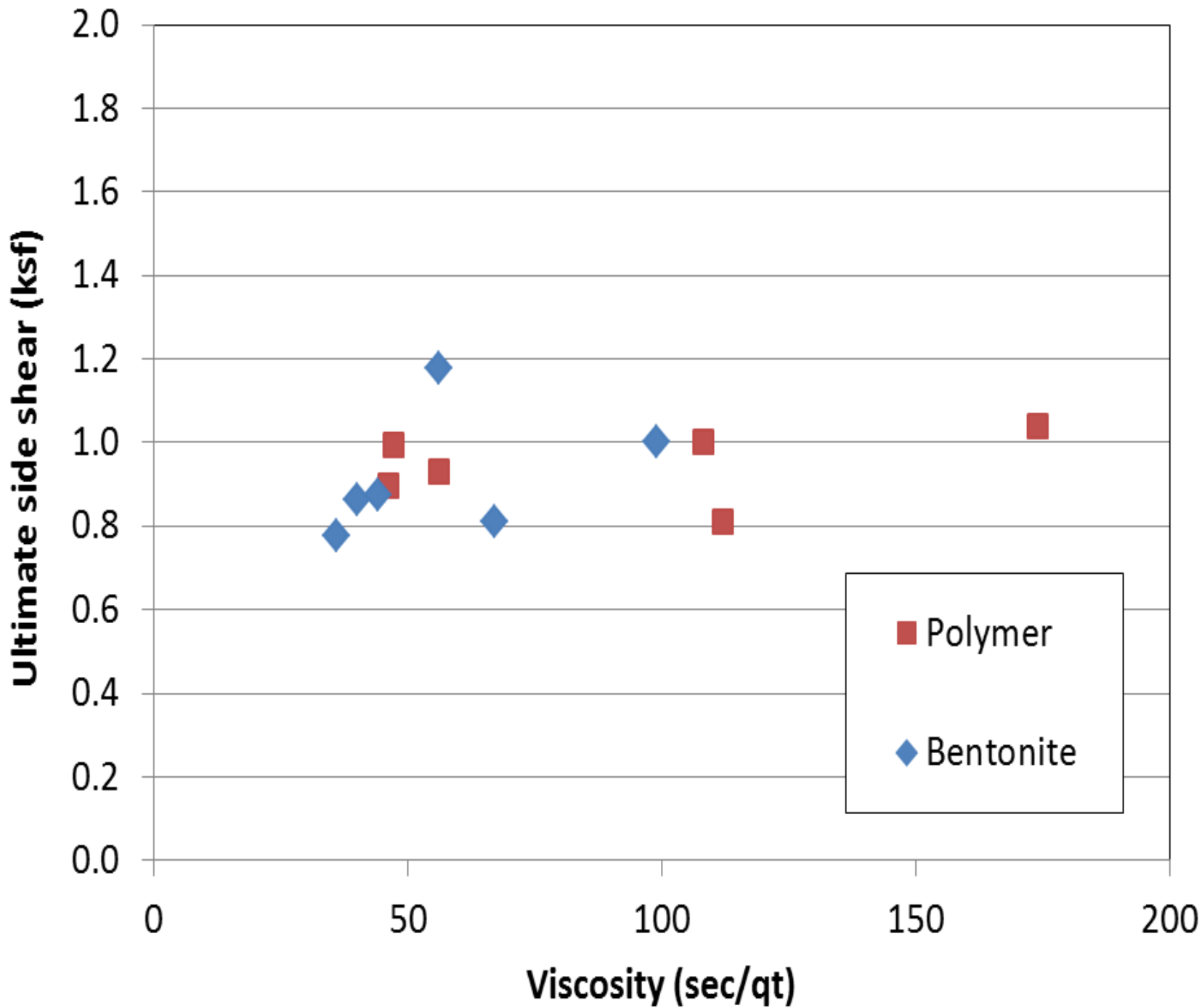


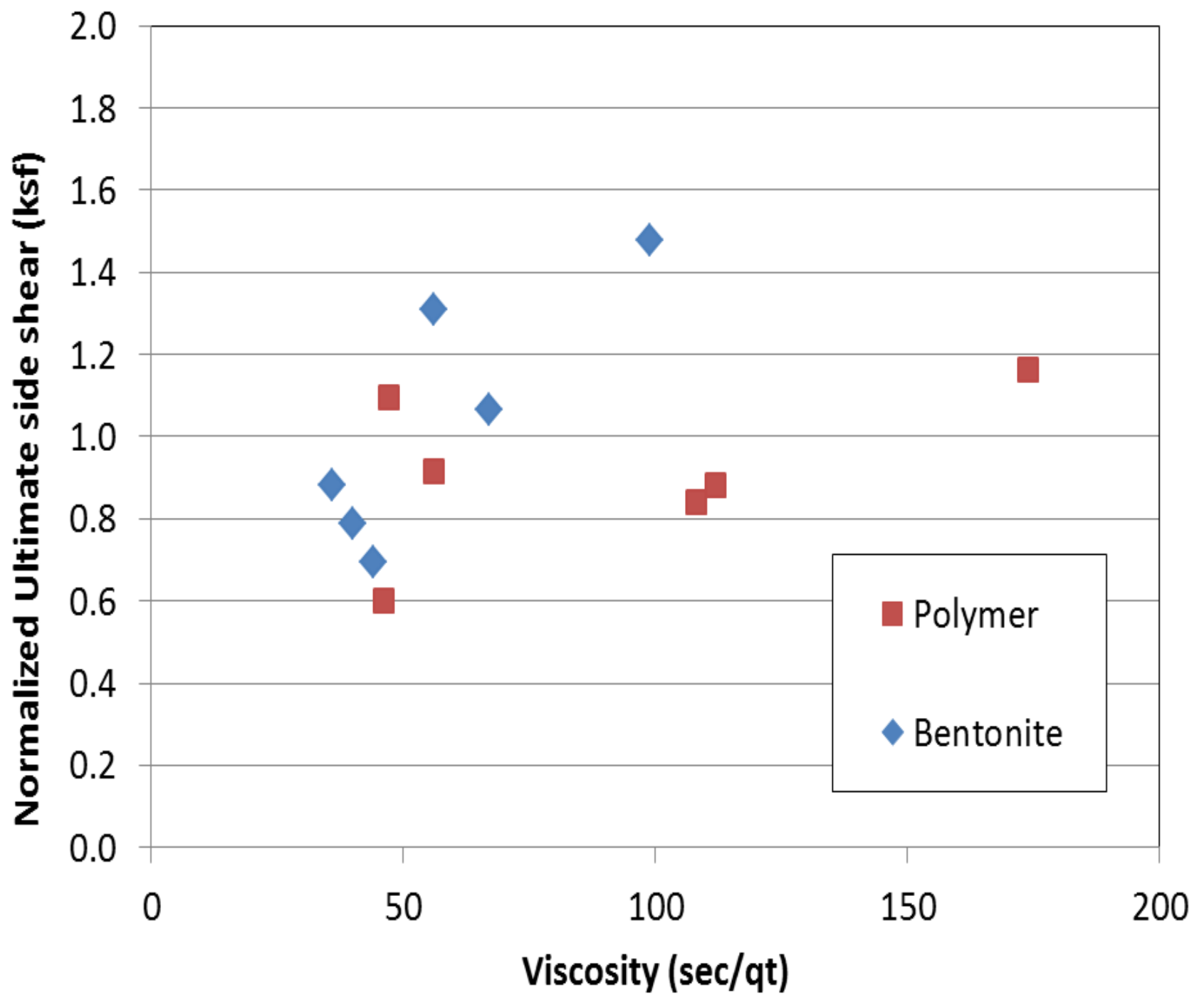












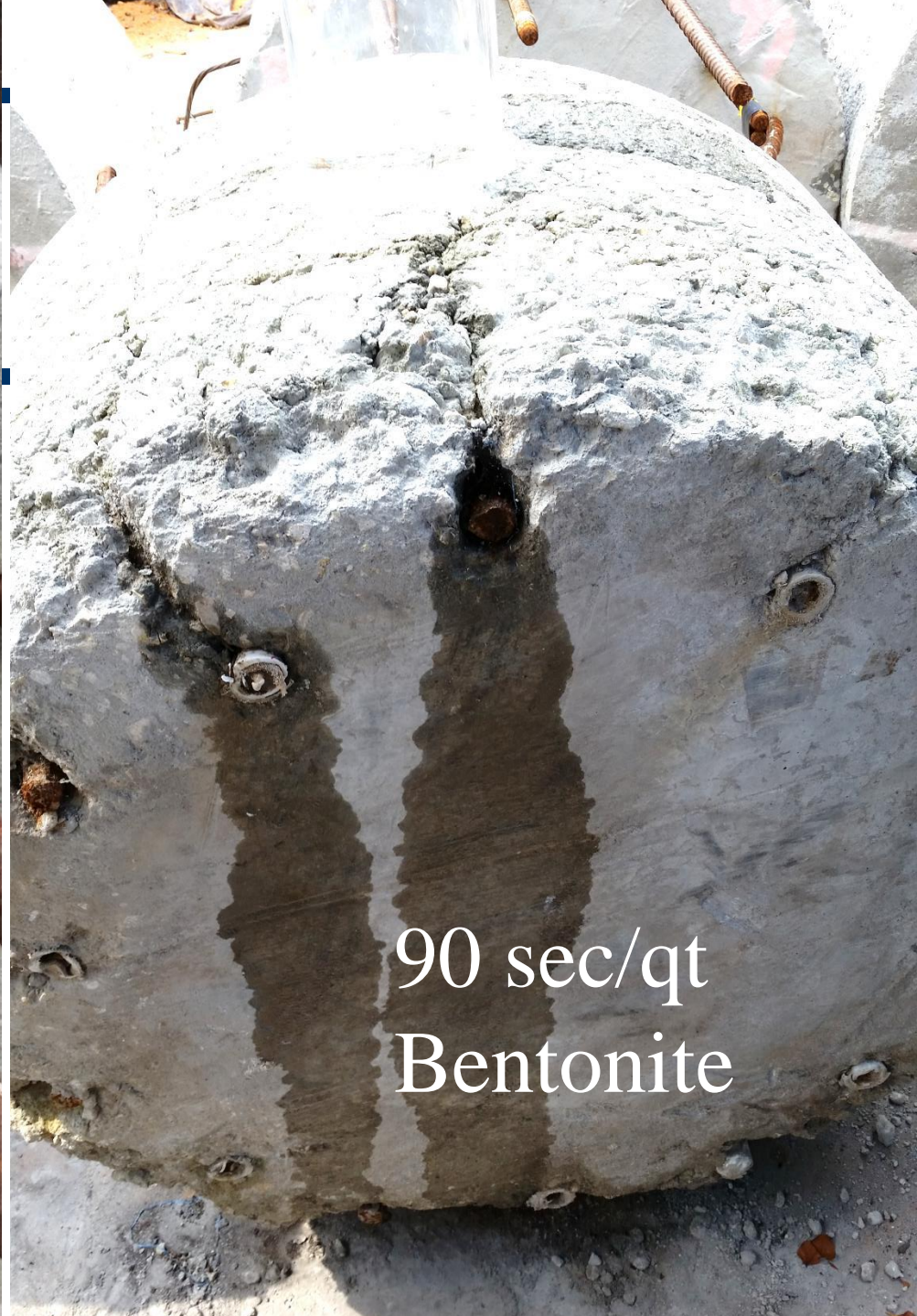
# Cover Effectiveness



# Cover Effectiveness

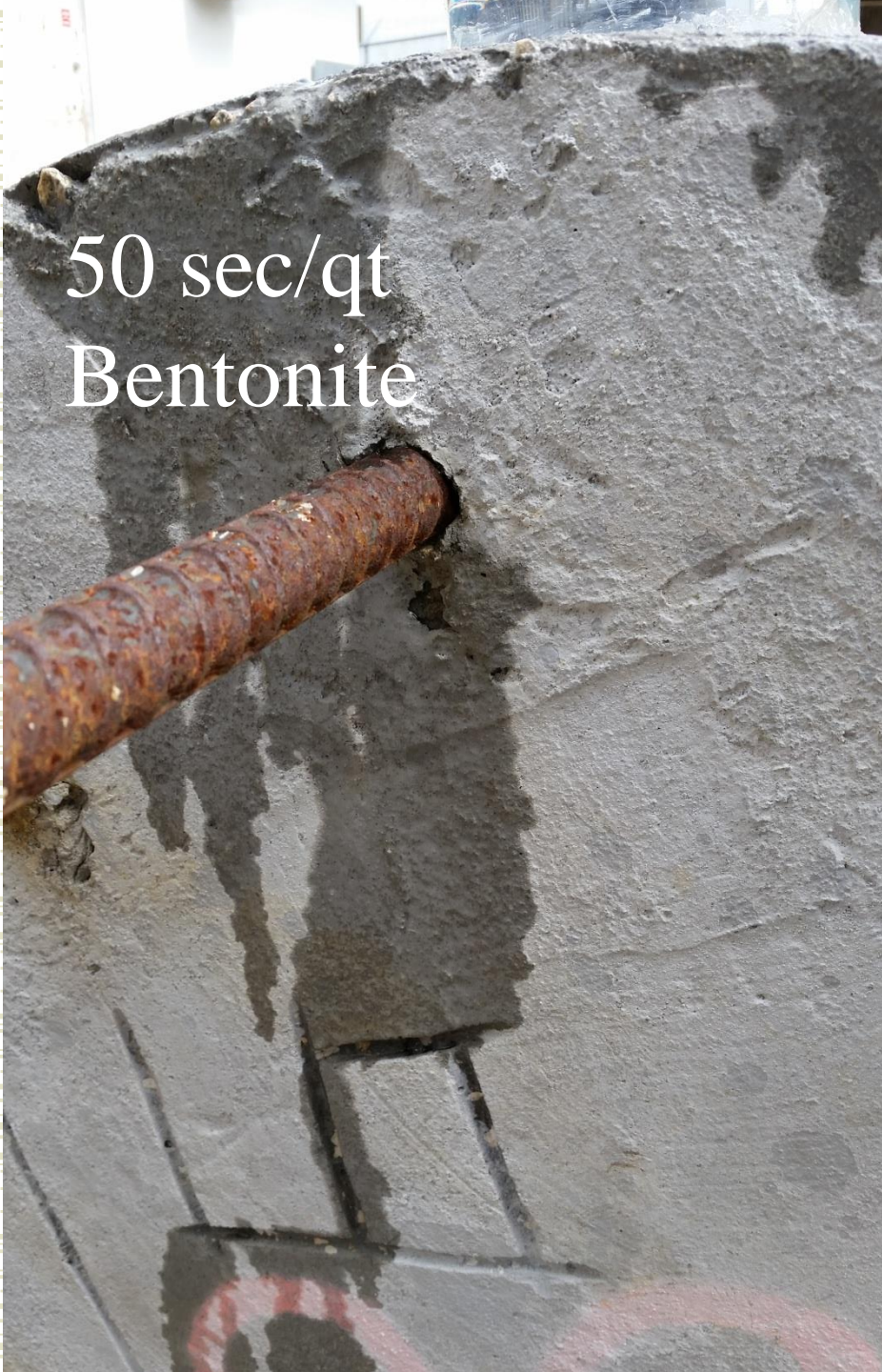


90 sec/qt  
Bentonite



90 sec/qt  
Bentonite

50 sec/qt  
Bentonite



40 sec/qt  
Bentonite



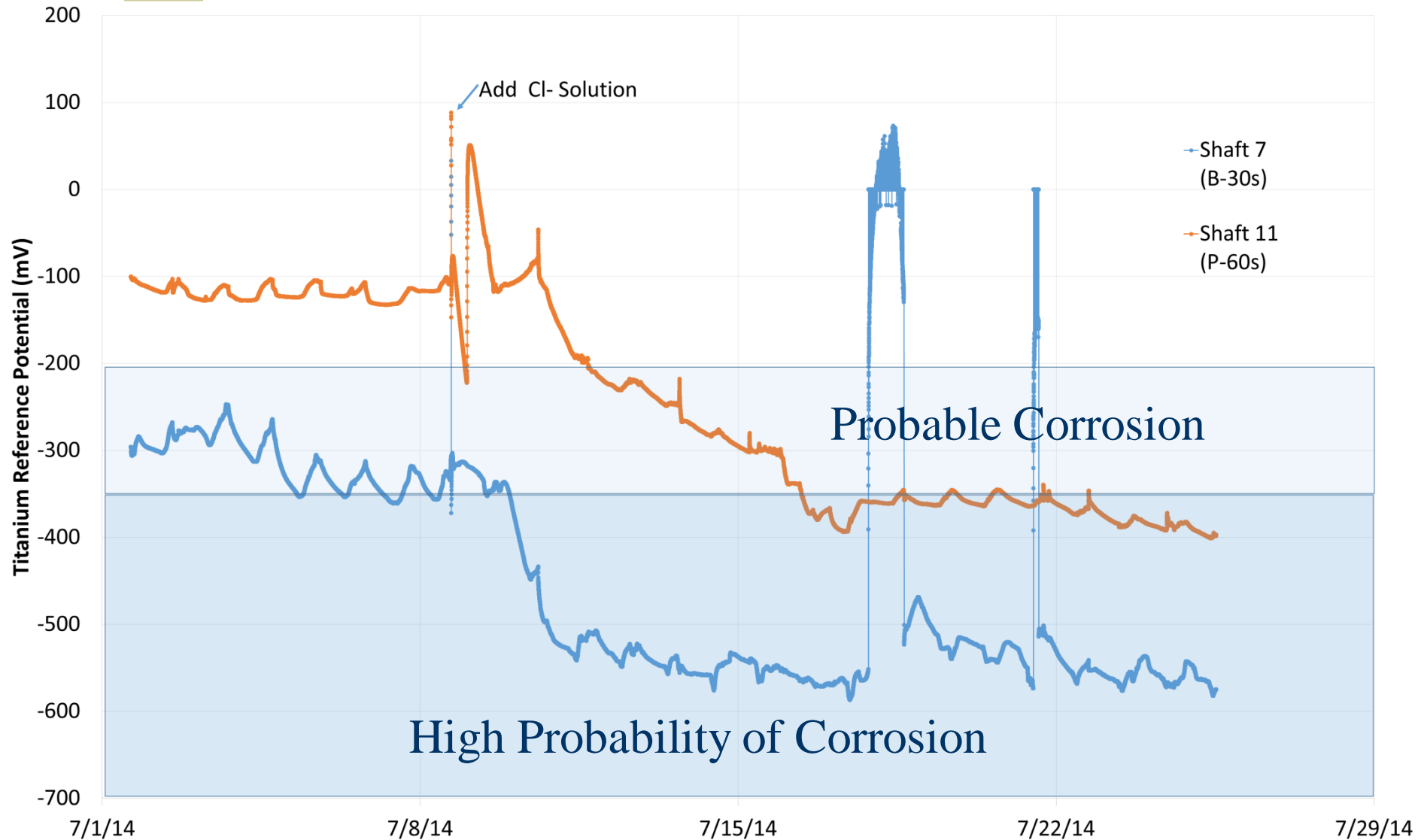
30 sec/qt  
Bentonite



60 sec/qt  
Polymer



# Corrosion Monitoring



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?

