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

GRIP 2014

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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

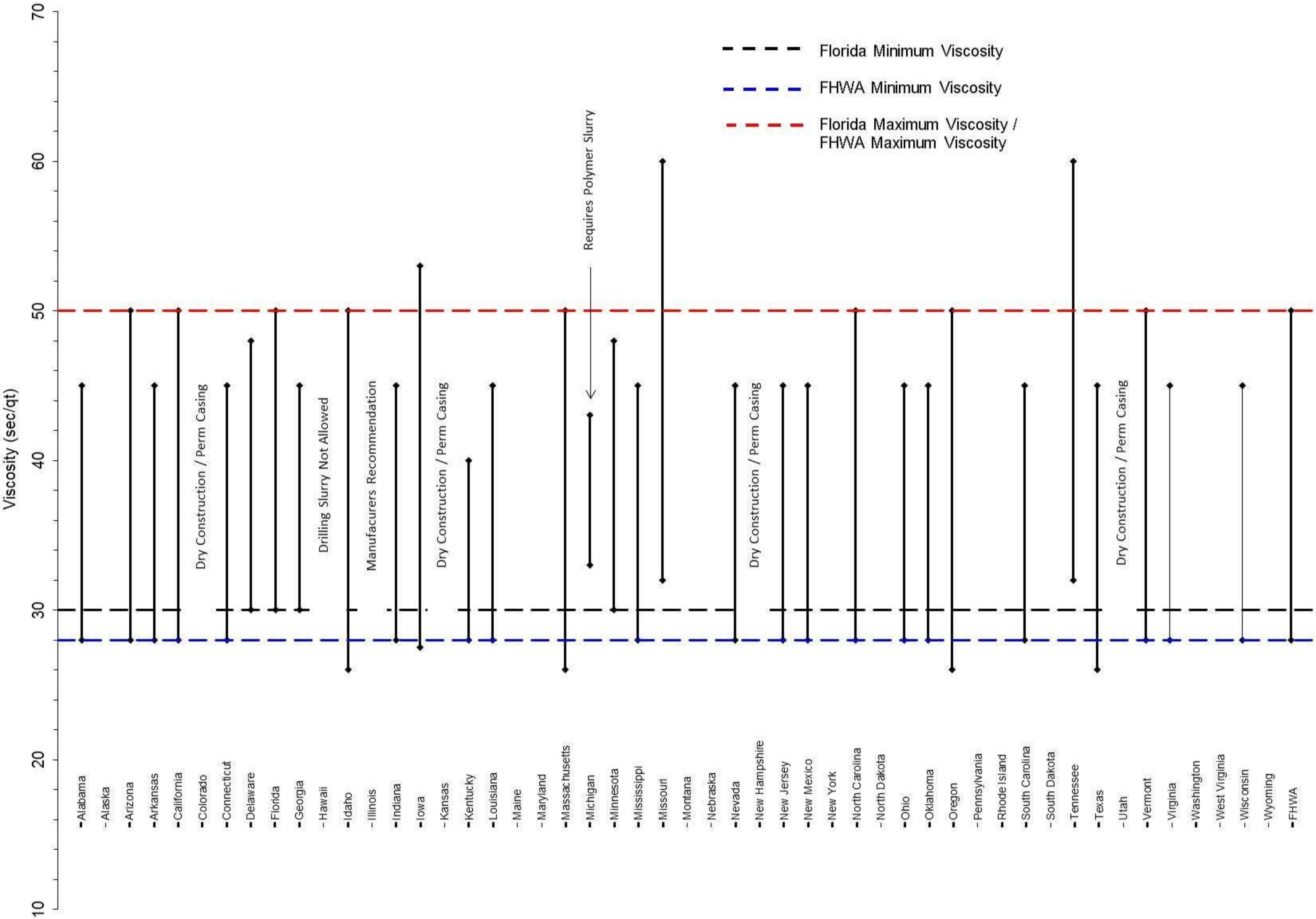
- Task 1 Literature Review
- Task 2 Rebar Pull-out Testing
- Task 3 Laboratory Side Shear Testing
- Task 4 Full Scale Side Shear Testing
- Task 5 Reporting

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


Viscosity (sec/qt)
10
20
30
40
50
60
70
Florida Minimum Viscosity
FHWA Minimum Viscosity
Florida Maximum Viscosity /
FHWA Maximum Viscosity
Requires Polymer Slurry
Dry Construction / Perm Casing
Drilling Slurry Not Allowed
Manufacurers Recommendation
Dry Construction / Perm Casing
Dry Construction / Perm Casing
Dry Construction / Perm Casing
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

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

Rebar Bond Strength

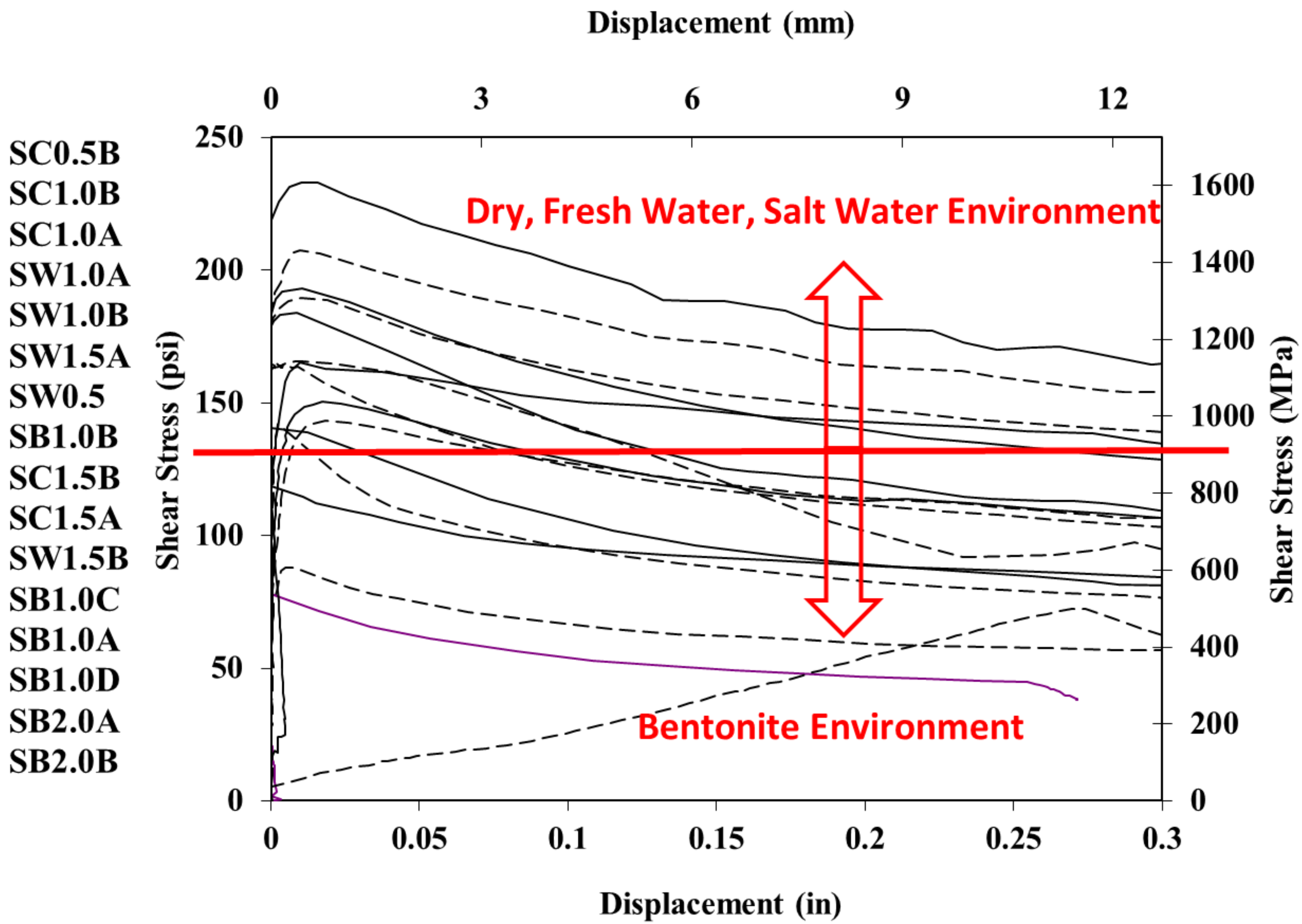
- Butler (1973), Fleming and Sliwinski (1977), Federation of Piling Specialists (1975)

- “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

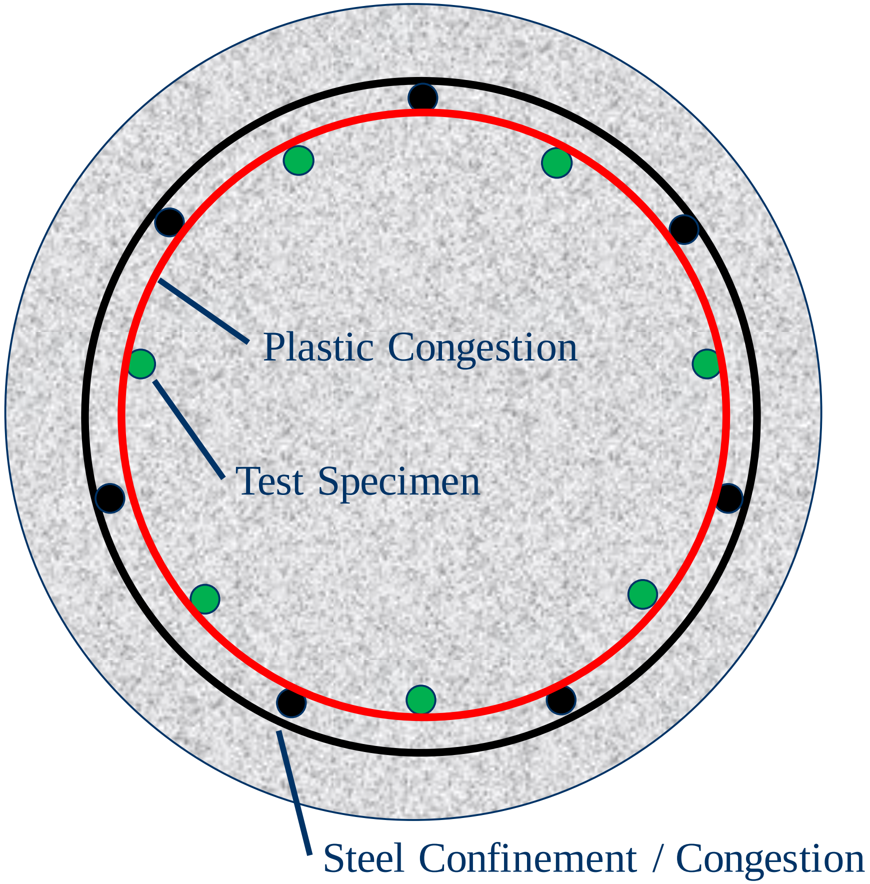
Pile / Seal Slab Bond



Mullins, G., Sosa, R. and Sen, R. (1999). “Seal Slab/Pile Interface Bond”. *Final Report* submitted to Florida Department of Transportation, November, 151 pp.

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)

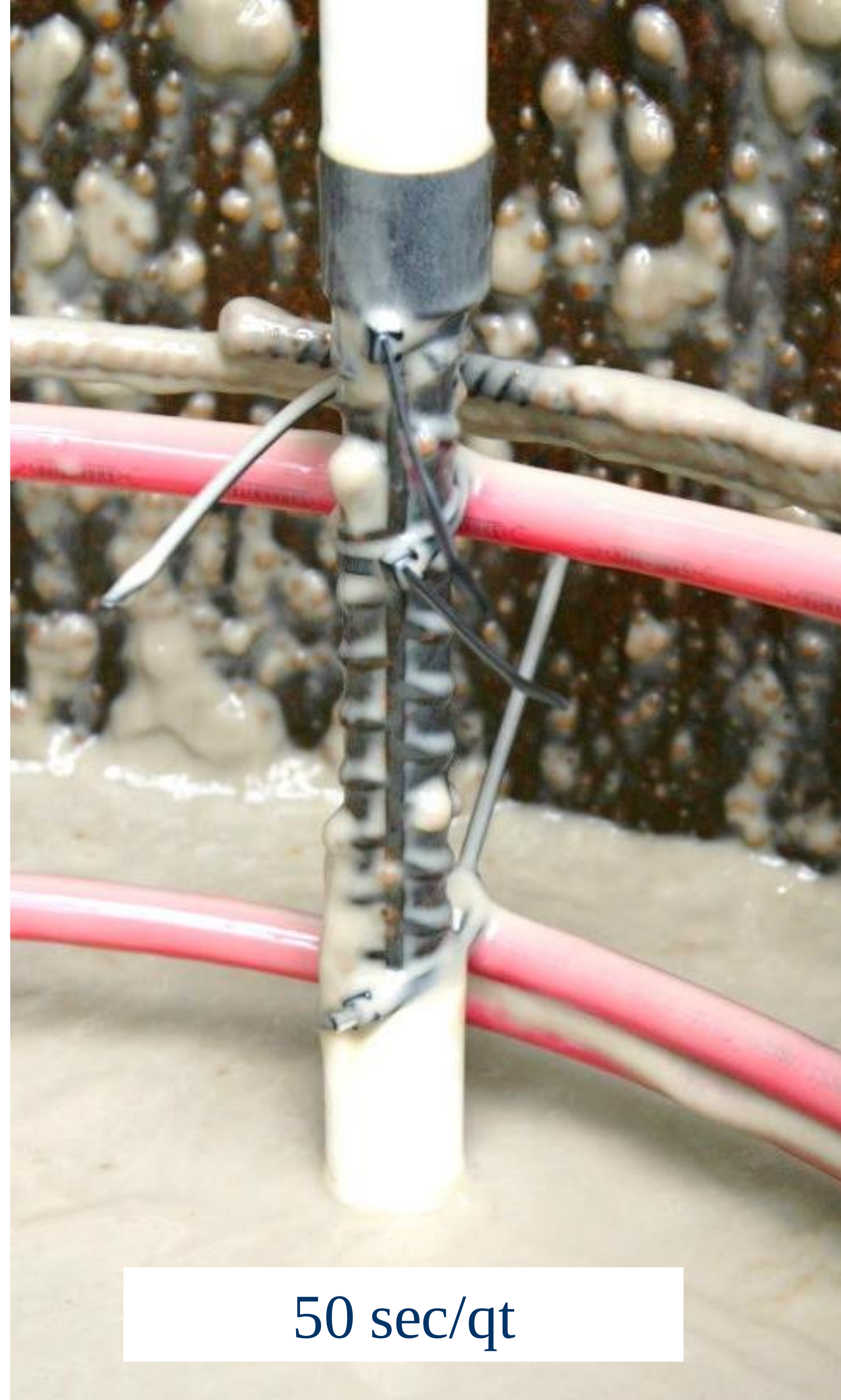
Rebar Pullout Testing Setup

Bentonite
30 sec/qt

30 sec/qt

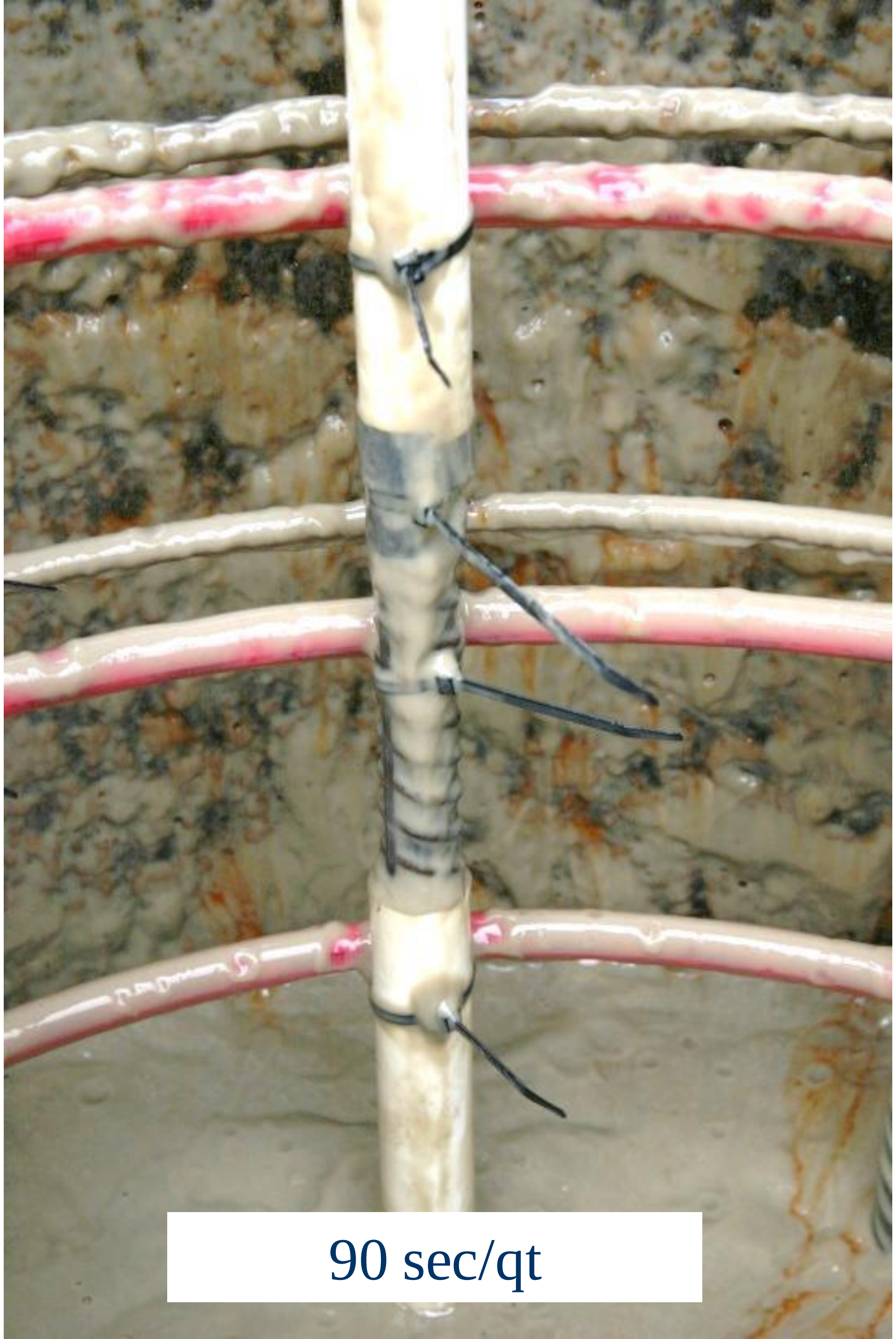
40 sec/qt

30 sec/qt

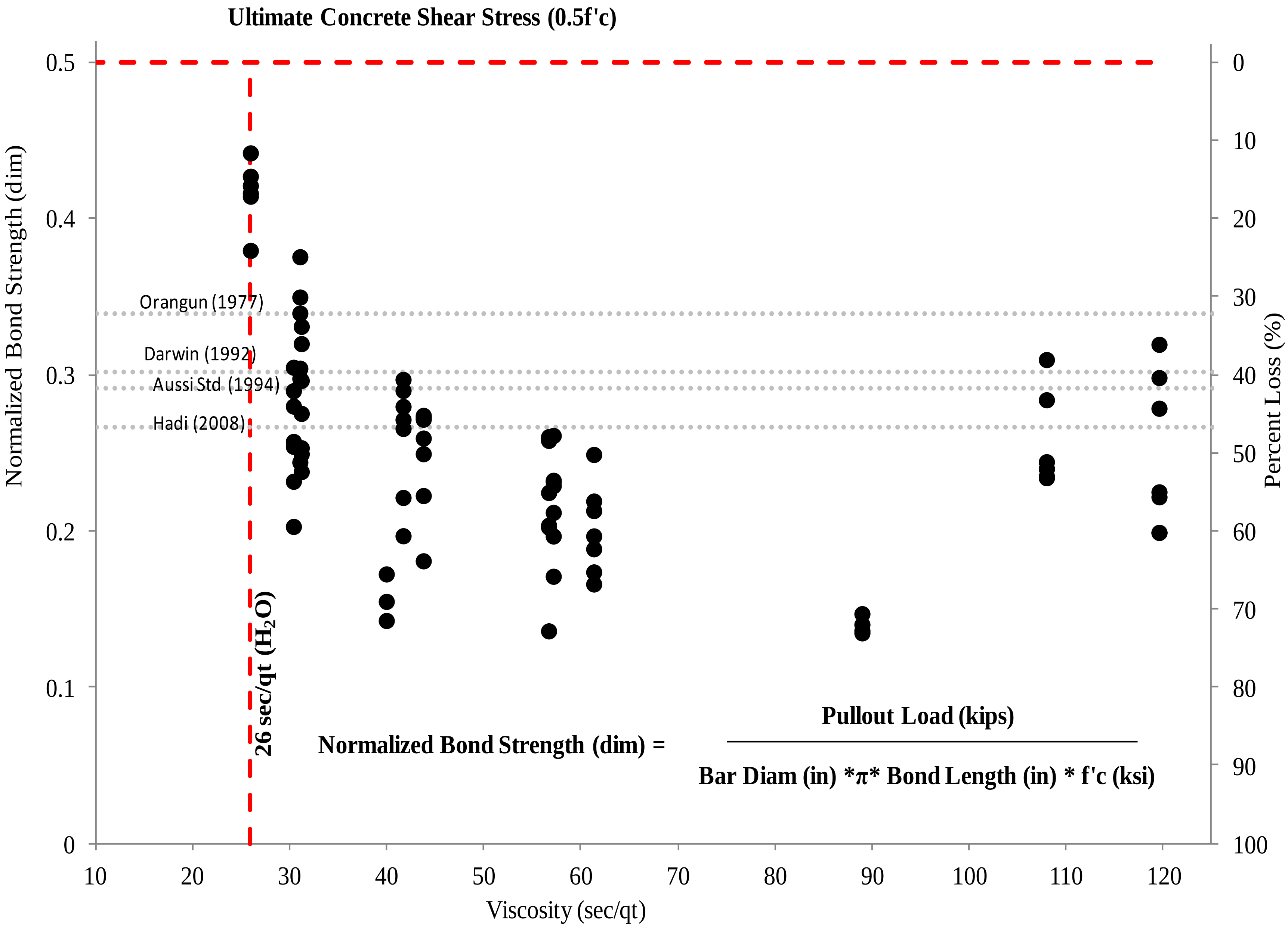


50 sec/qt

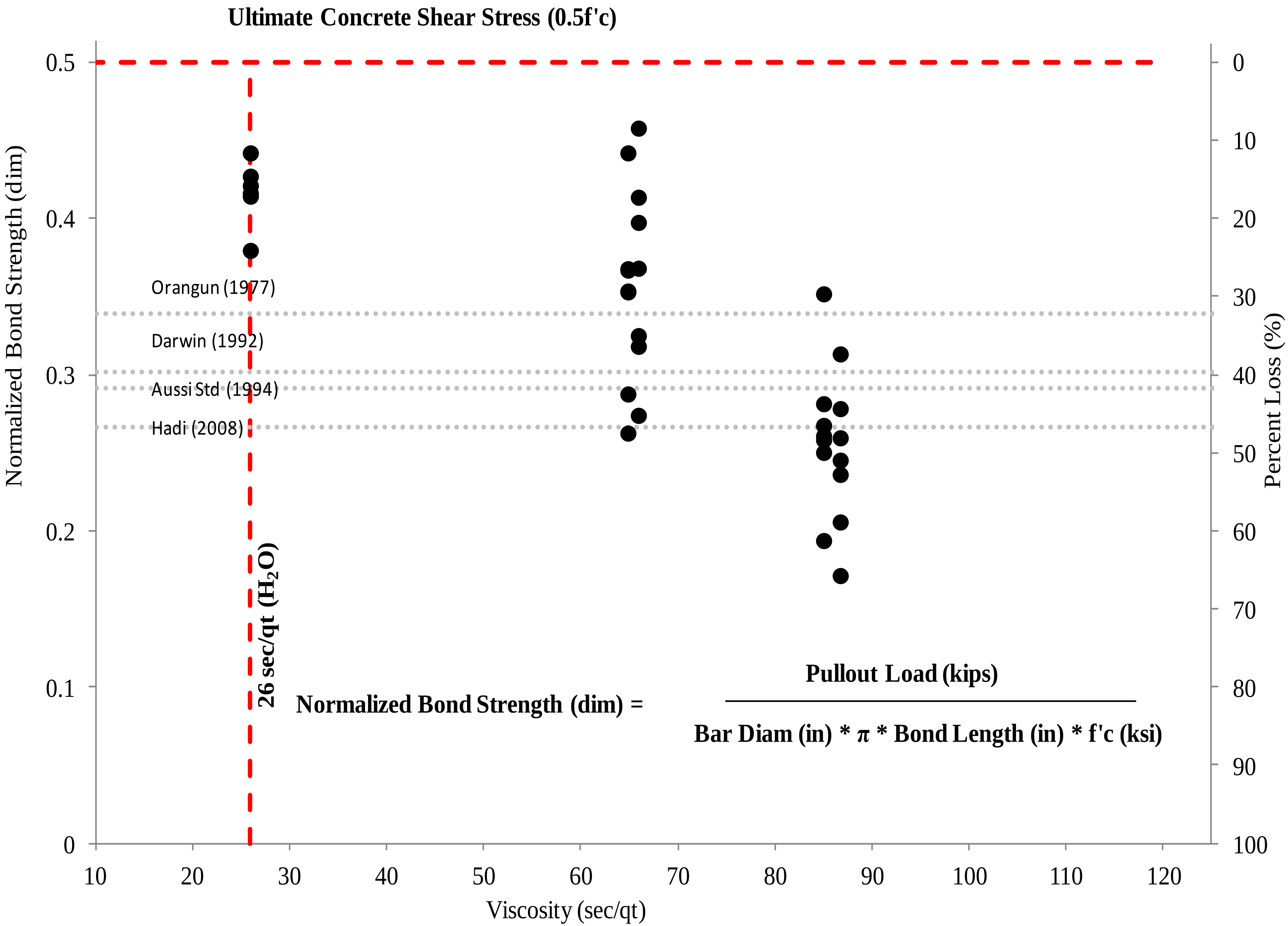
30 sec/qt



90 sec/qt



Ultimate Concrete Shear Stress (0.5f'c)
Orangun (1977)
Darwin (1992)
Aussi Std (1994)
Hadi (2008)
26 sec/qt (H_2O)
Normalized Bond Strength (dim) = Pullout Load (kips) / Bar Diam (in) *π* Bond Length (in) * f'c (ksi)
Normalized Bond Strength (dim)
Percent Loss (%)
Viscosity (sec/qt)
0
0.1
0.2
0.3
0.4
0.5
10
20
30
40
50
60
70
80
90
100
110
120



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Normalized Bond Strength (dim)
Percent Loss (%)
Viscosity (sec/qt)
0
0.1
0.2
0.3
0.4
0.5
10
20
30
40
50
60
70
80
90
100
110
120

Durability Evaluation After Pressure Washing

90 sec

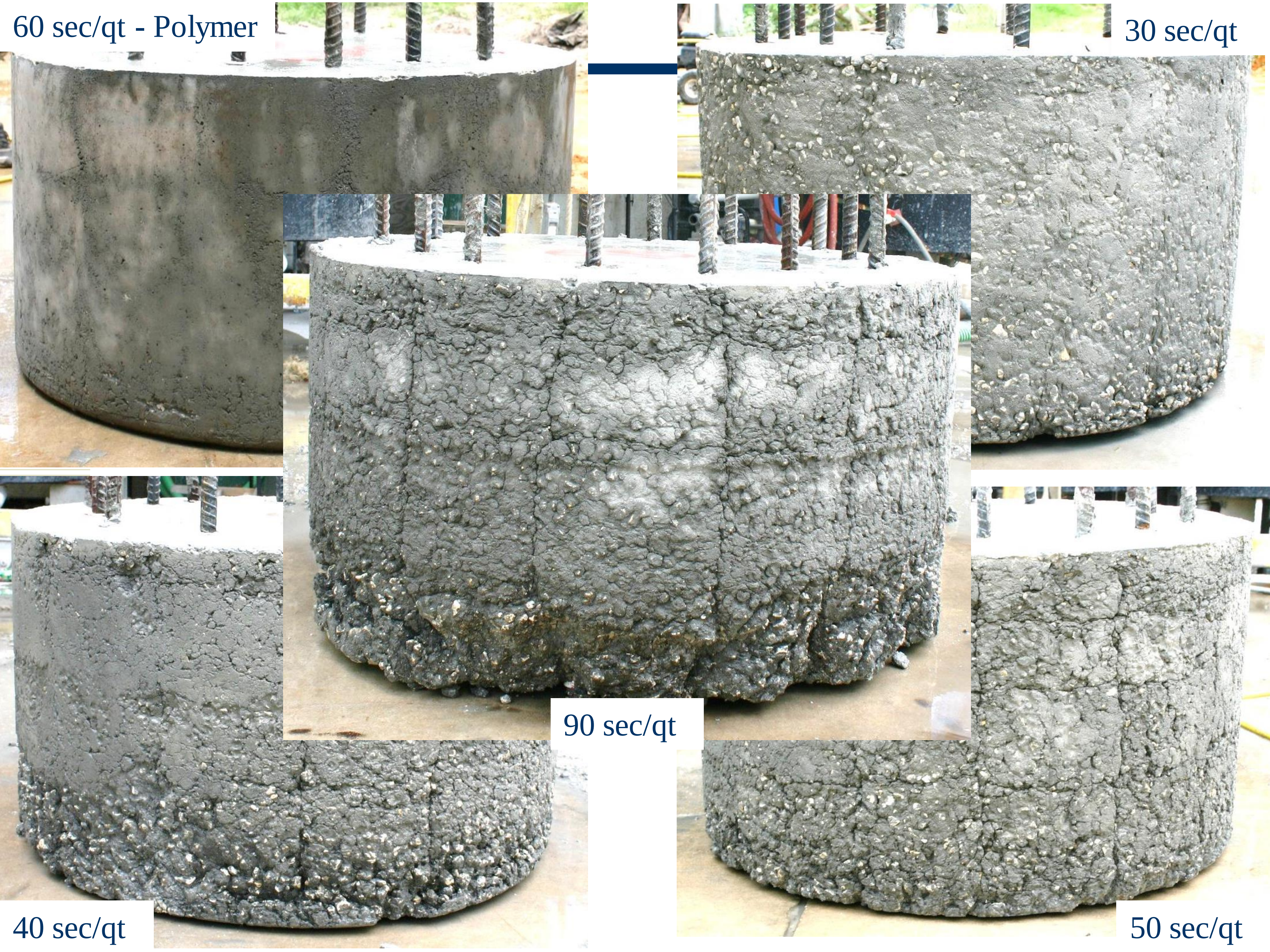
40 sec

26 sec/qt (Water Control)

40 sec/qt

50 sec/qt

90 sec/qt

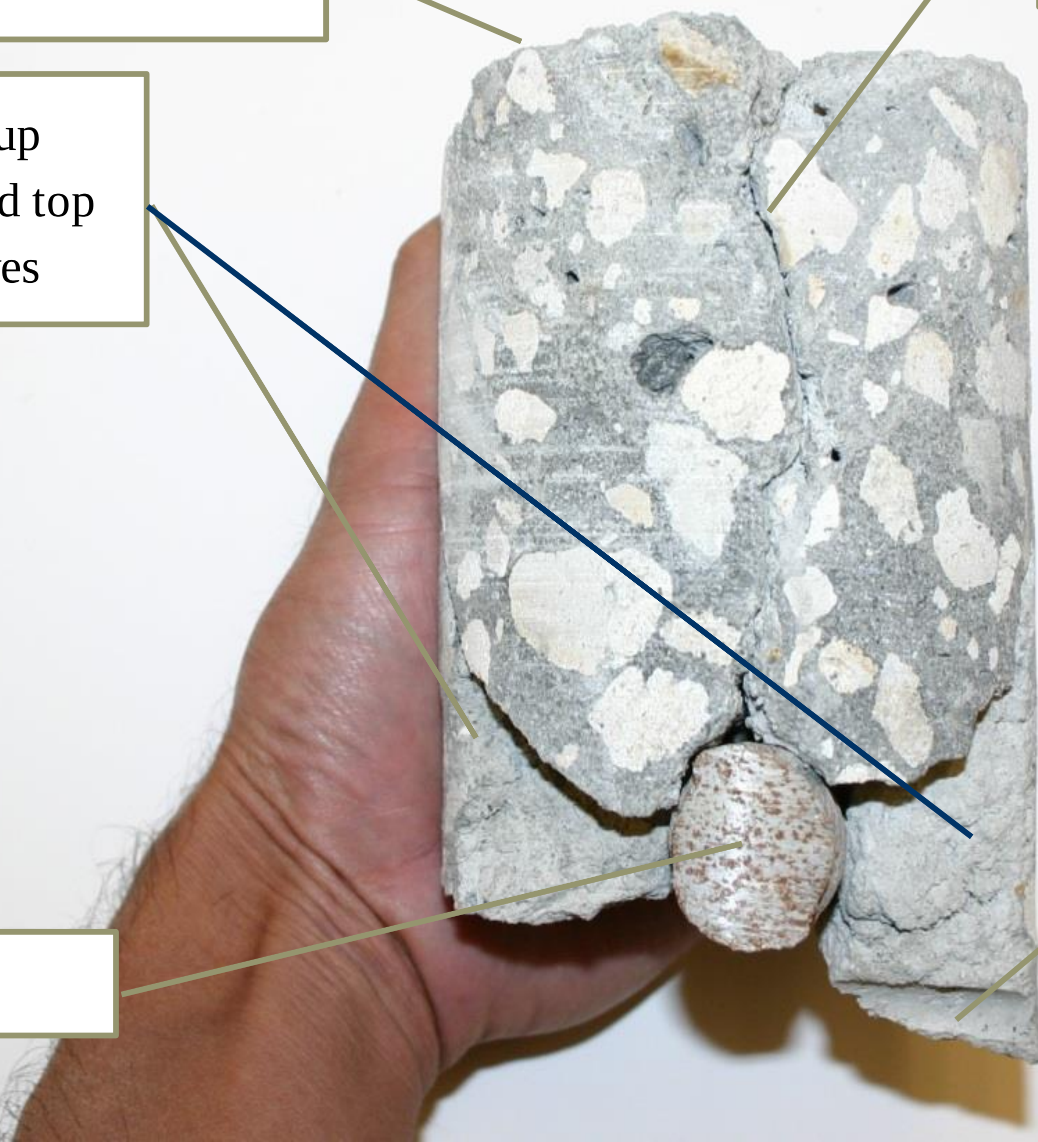

60 sec/qt - Polymer
30 sec/qt
90 sec/qt
40 sec/qt
50 sec/qt

Concrete Cores

Concrete Cores

H_2O | 60s Polymer | 30s | 40s

Concrete Core – 50 sec/qt



Concrete Core – 50 sec/qt

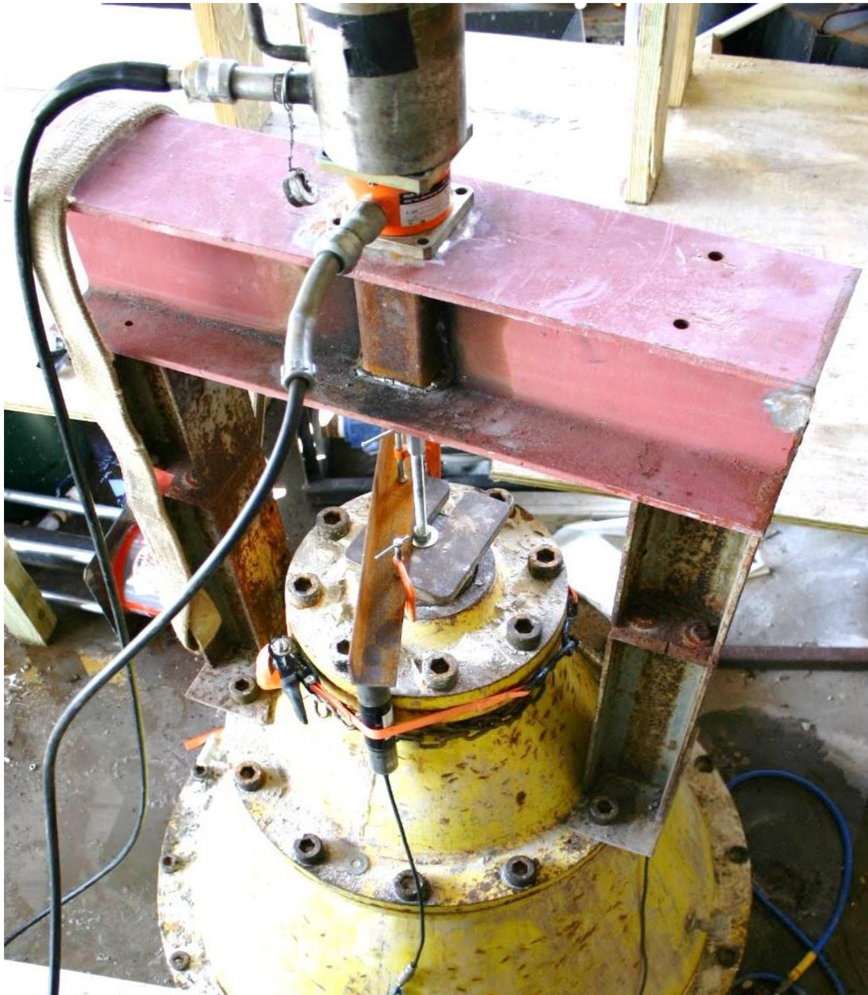
Concrete Core – 50 sec/qt

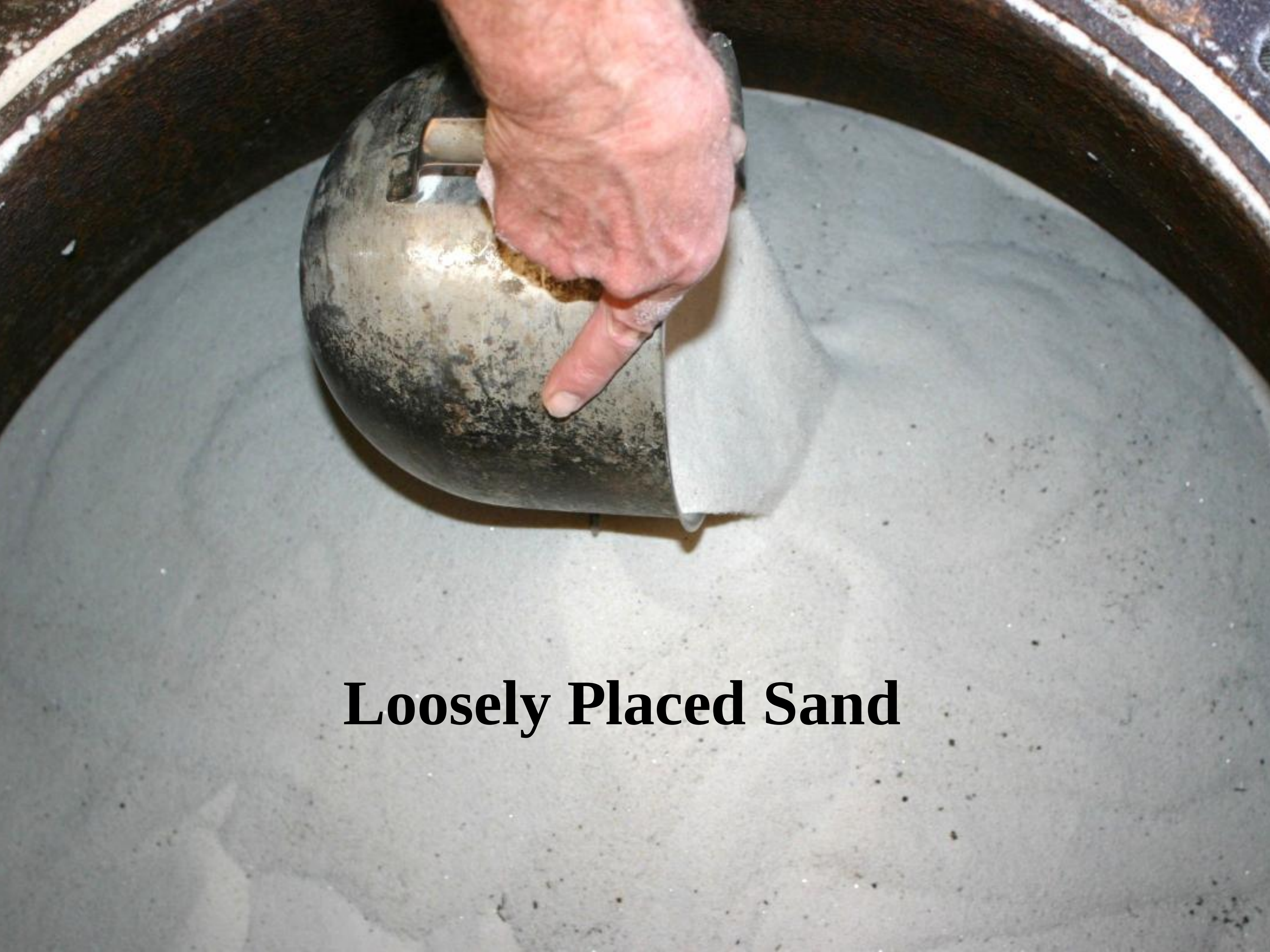
Concrete Core – 90 sec/qt

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

Sand / Mortar Mix

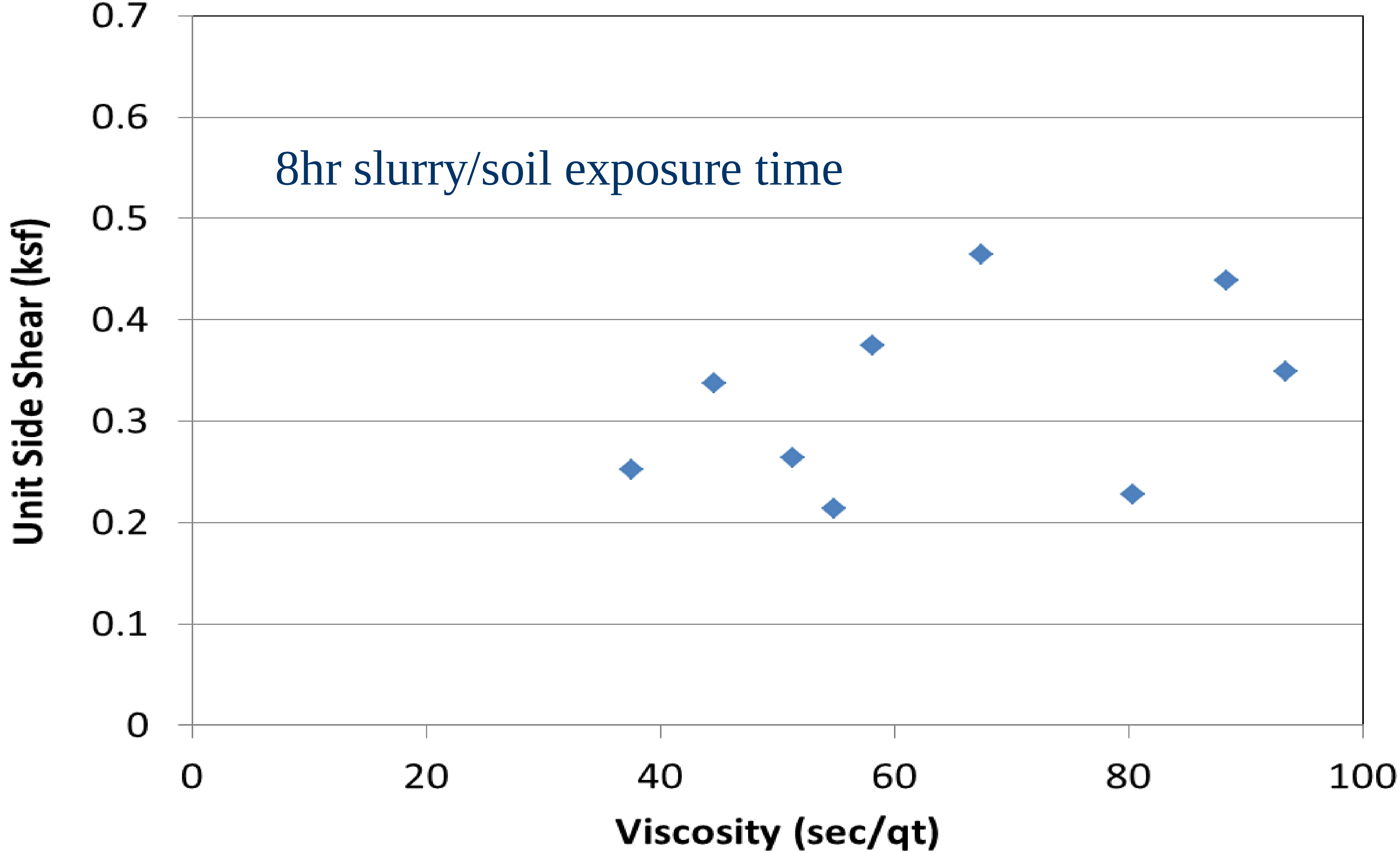
Place Tremie and Attach Hopper


Install Full-length Threaded Rod

Pull out Testing

Disassemble and Remove Shaft


Results of Lab Tests (bentonite)



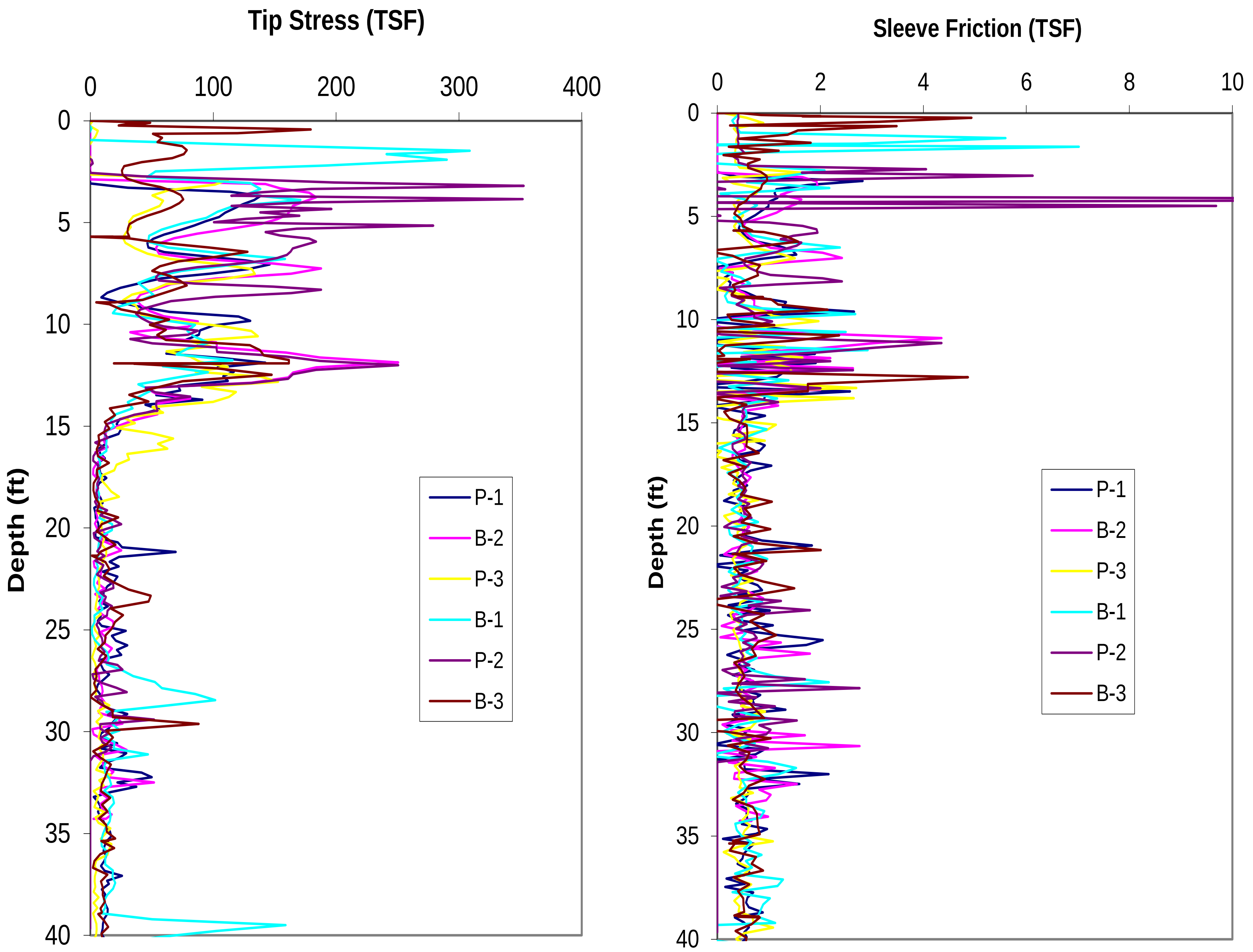
Polymer Slurry (60 sec/qt)

Task 4: Full Scale Side Shear Evaluation

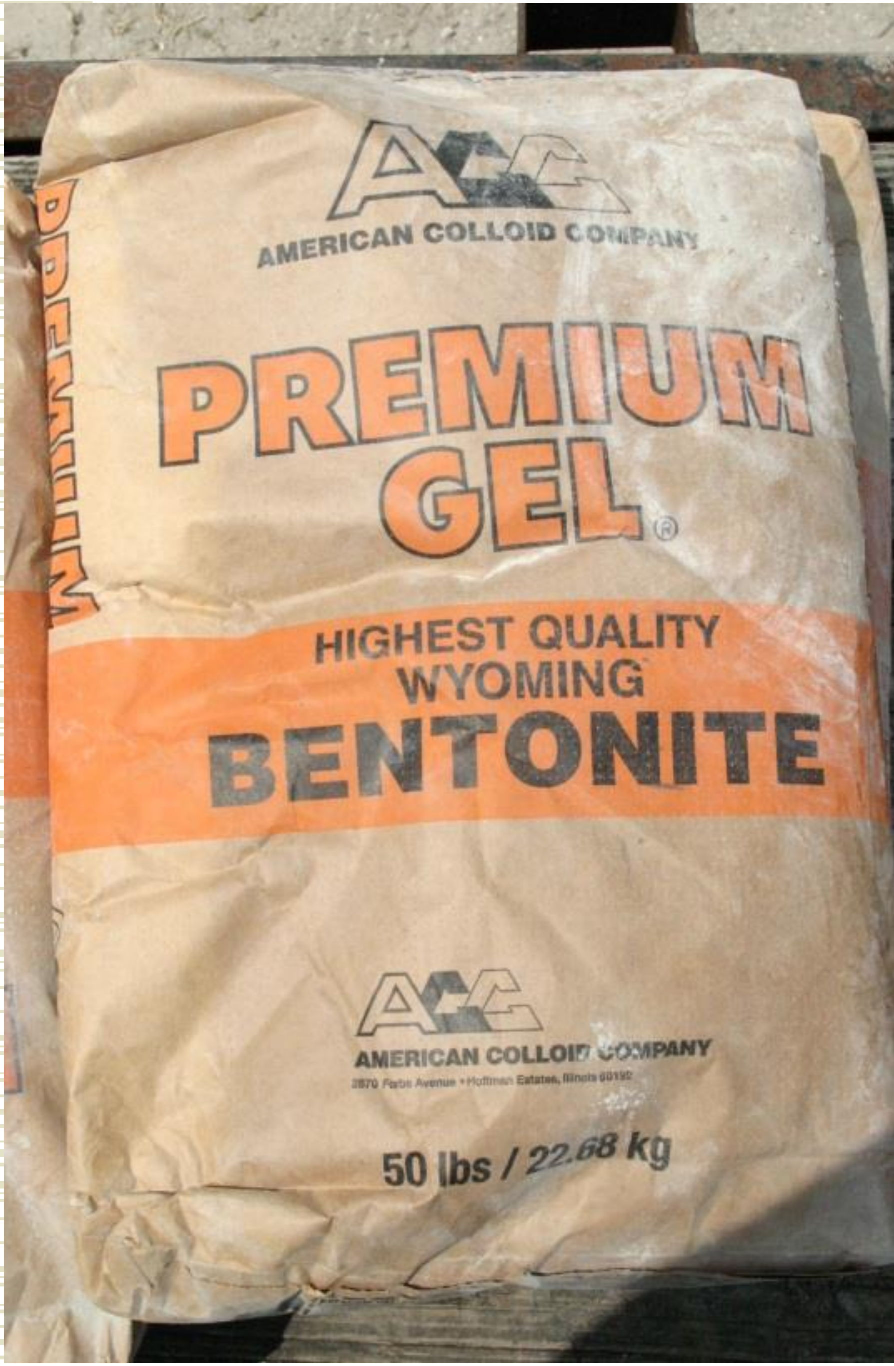
- 12 shafts tested in tension
- 18ft Long
- 20-24 inch Diameter
- Varying Viscosities & Slurry Type
  - Bentonite 40 to 90 sec/qt
  - Polymer 60 to 132 sec/qt
- CPT soundings at each location

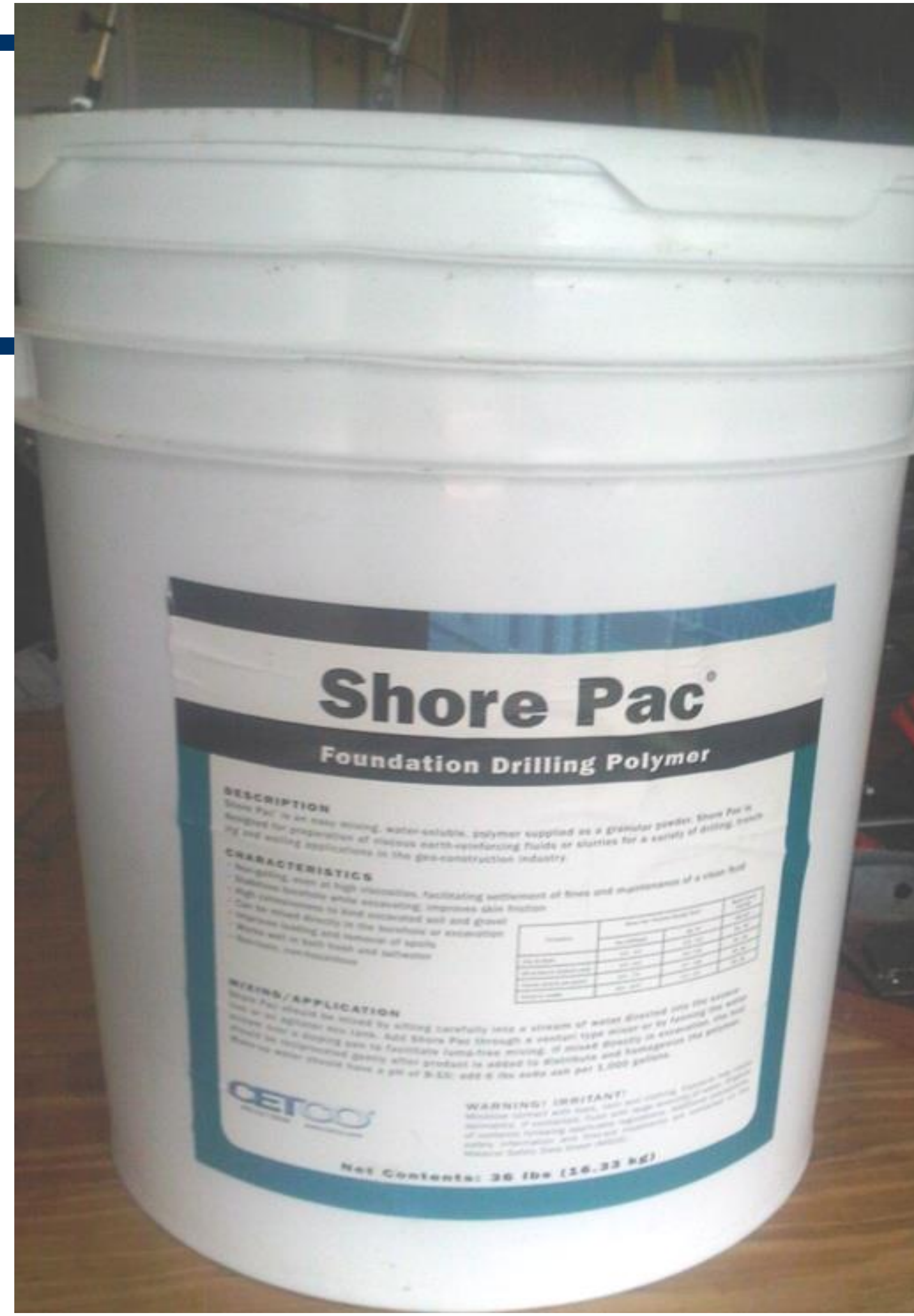

123rd Avenue North
44th Street
Test Site
Imagery Date: 4/4/2010
Google earth

CPT Soundings



Tip Stress (TSF)
0
100
200
300
400
Depth (ft)
0
5
10
15
20
25
30
35
40
P-1
B-2
P-3
B-1
P-2
B-3
Sleeve Friction (TSF)
0
2
4
6
8
10
Depth (ft)
0
5
10
15
20
25
30
35
40
P-1
B-2
P-3
B-1
P-2
B-3


AMERICAN COLLOID COMPANY
PREMIUM GEL®
HIGHEST QUALITY WYOMING BENTONITE
AMERICAN COLLOID COMPANY
50 lbs / 22.68 kg


Shore Pac®
Foundation Drilling Polymer
DESCRIPTION
CHARACTERISTICS
MIXING/APPLICATION
CETCO


Bentonite 40 to 90 sec/qt

Polymer 60 to 130 sec/qt


WATSON

got mud?



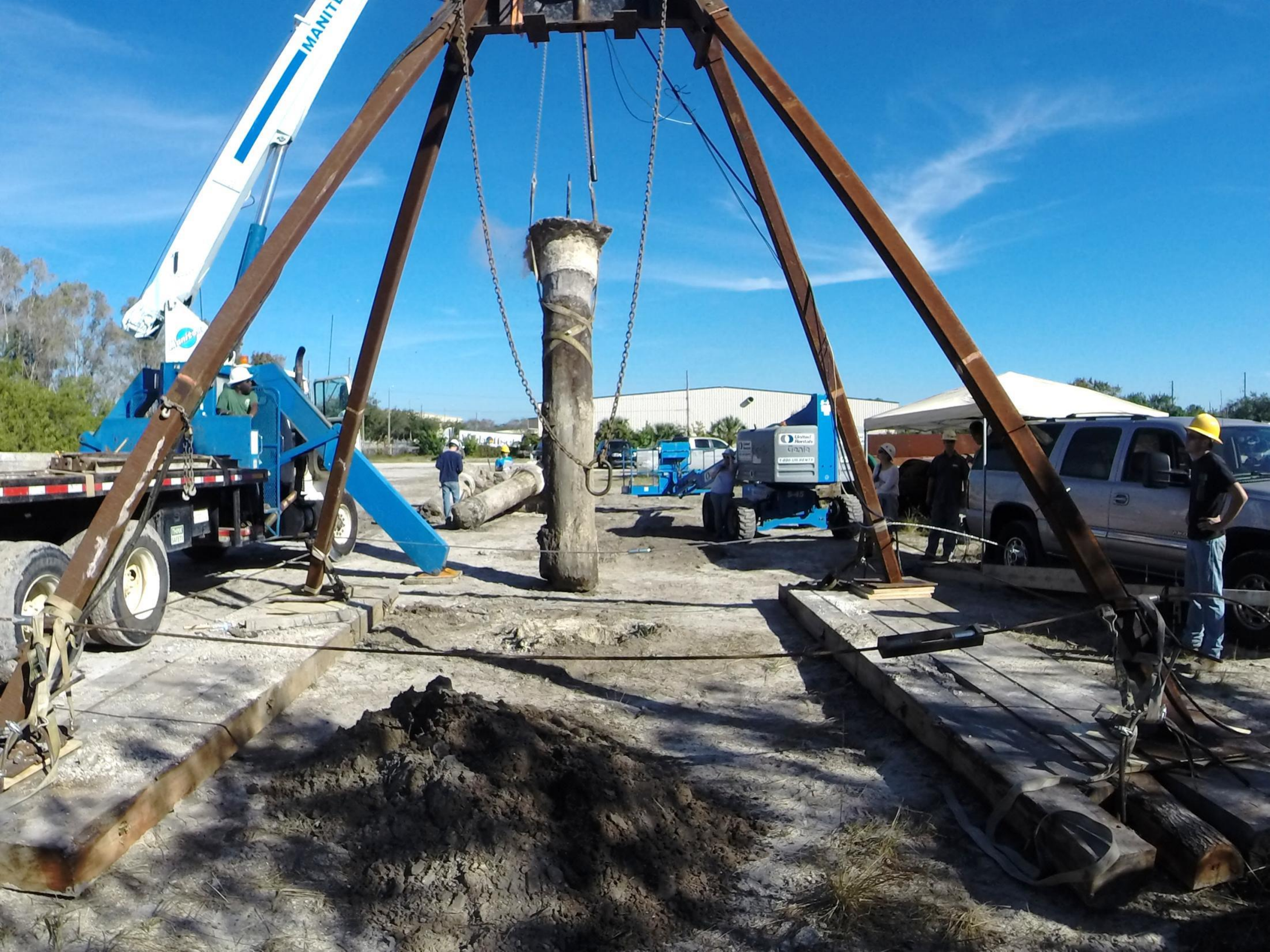
16½


S-45

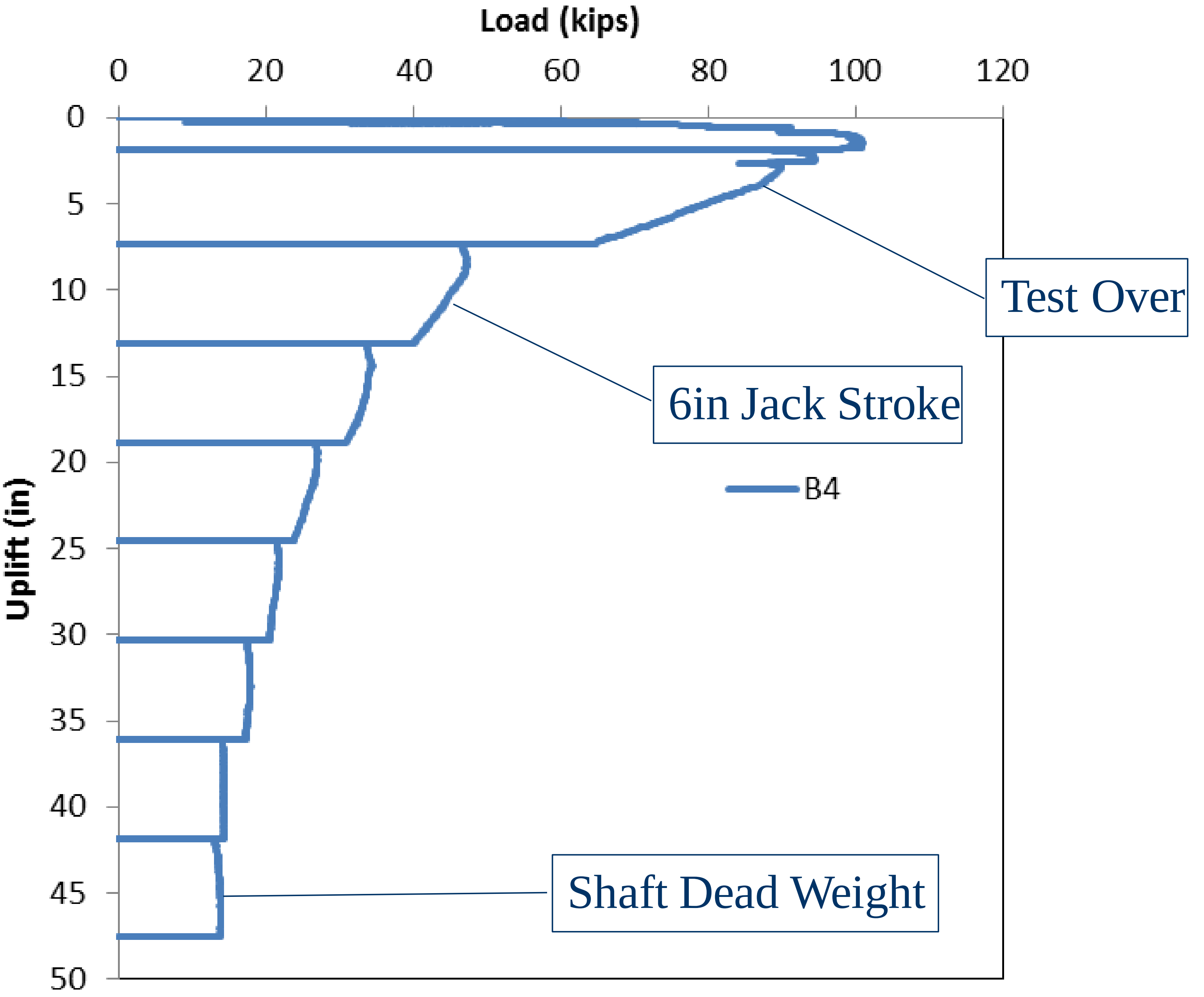

S-45


S-45

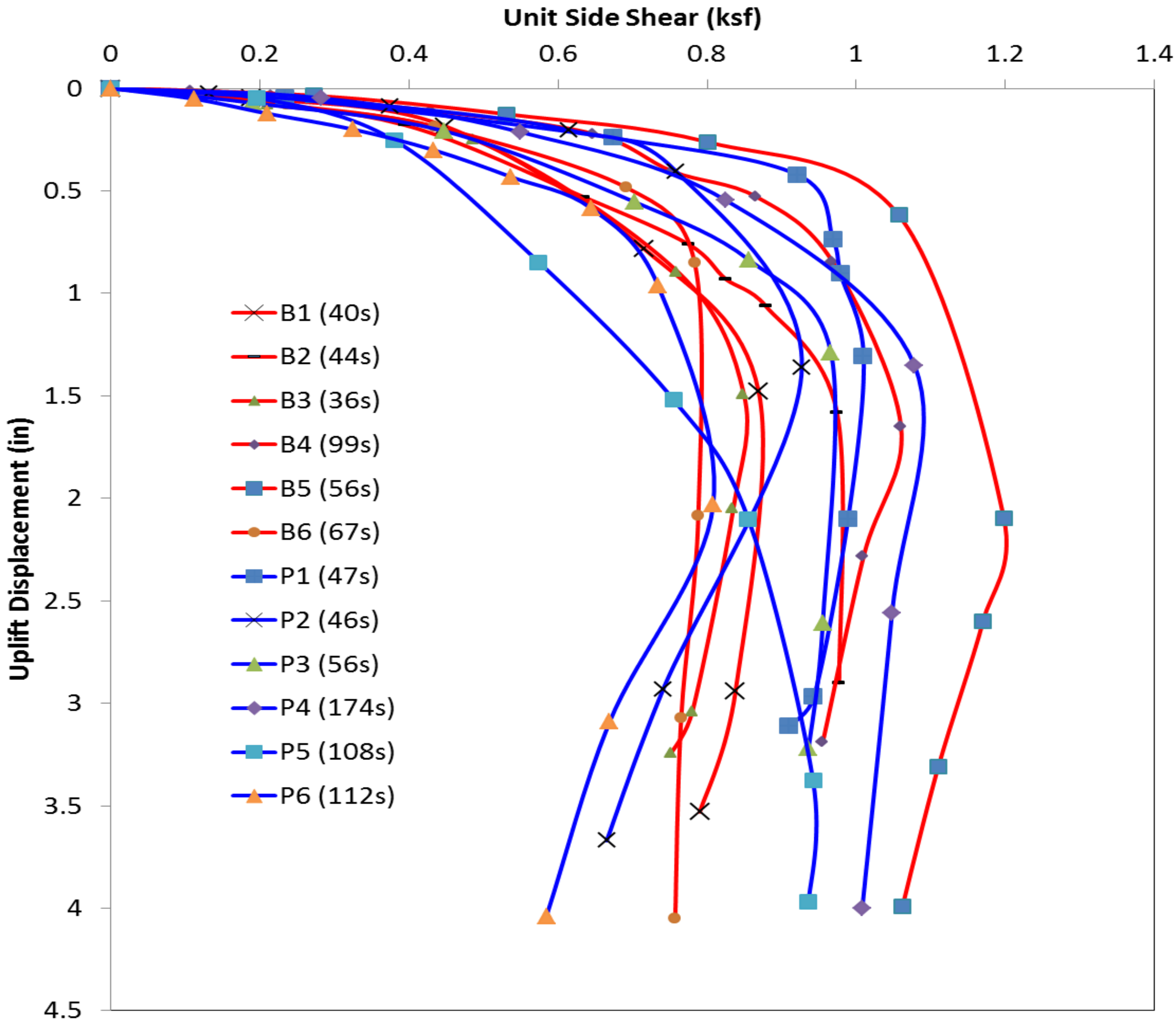

S-45



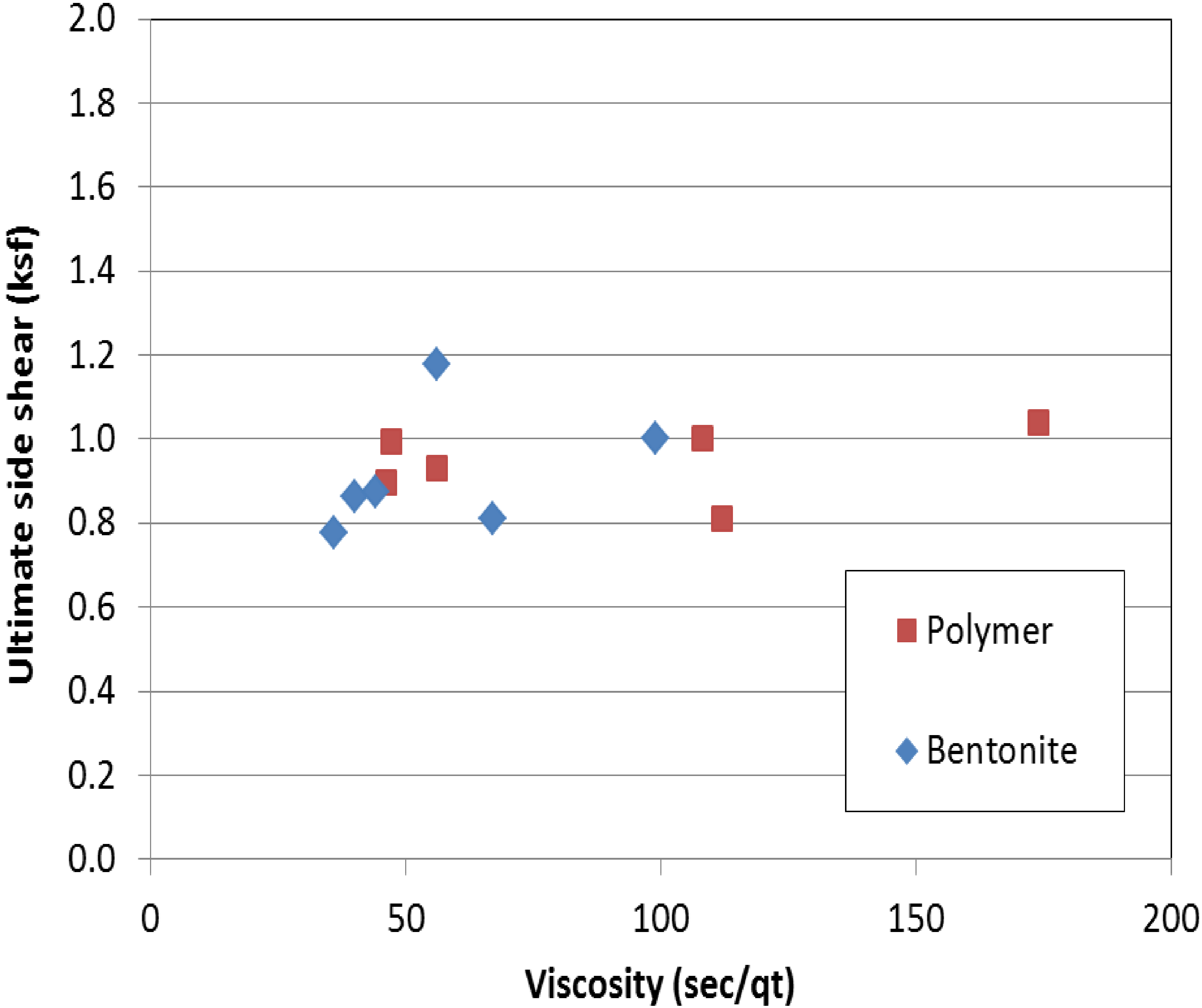
United Rentals
1-800-UR-RENTS

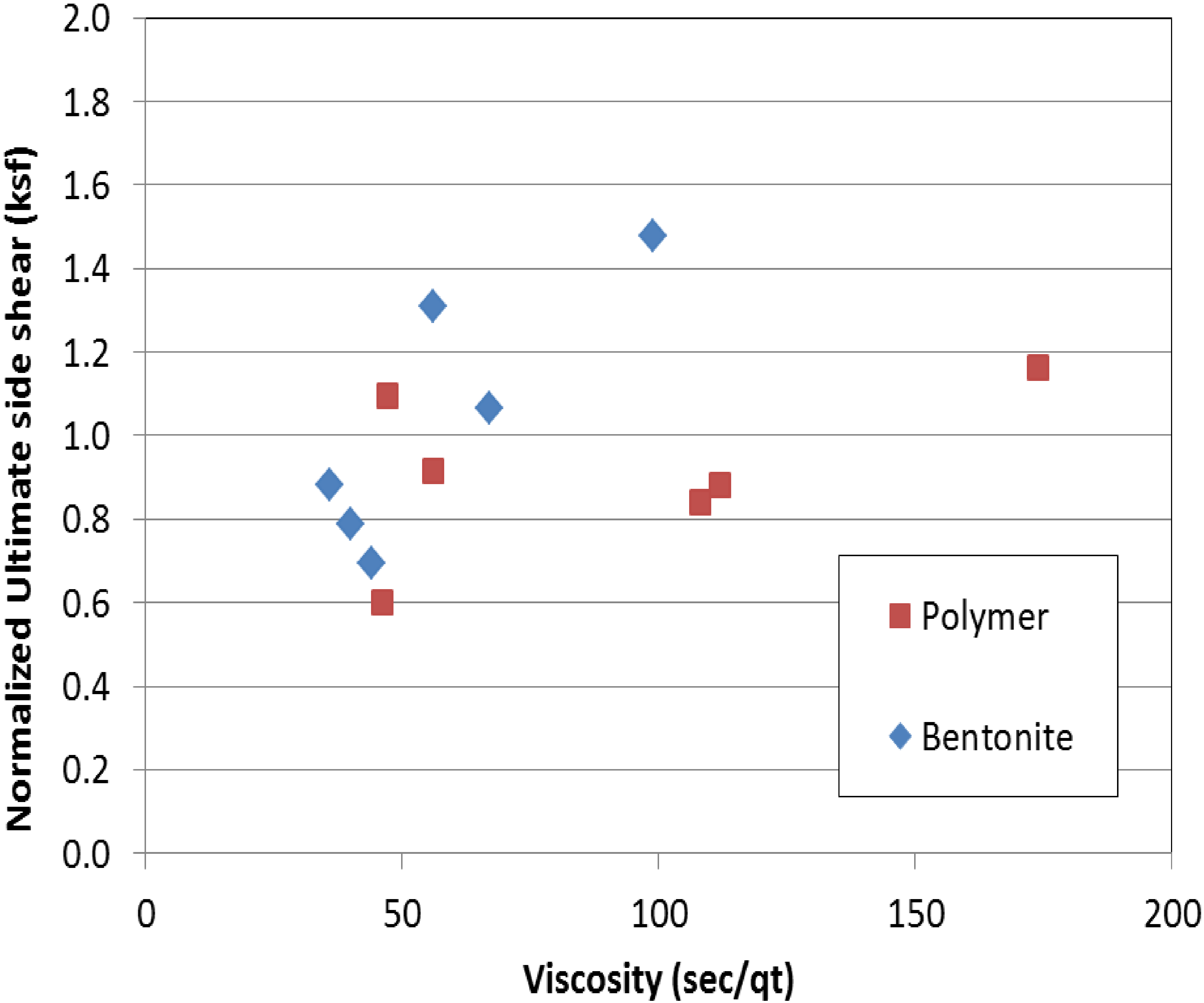


Load (kips)
0
20
40
60
80
100
120
Uplift (in)
0
5
10
15
20
25
30
35
40
45
50
Test Over
6in Jack Stroke
B4
Shaft Dead Weight



Unit Side Shear (ksf)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Uplift Displacement (in)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
B1 (40s)
B2 (44s)
B3 (36s)
B4 (99s)
B5 (56s)
B6 (67s)
P1 (47s)
P2 (46s)
P3 (56s)
P4 (174s)
P5 (108s)
P6 (112s)


2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Ultimate side shear (ksf)
0
50
100
150
200
Viscosity (sec/qt)
Polymer
Bentonite

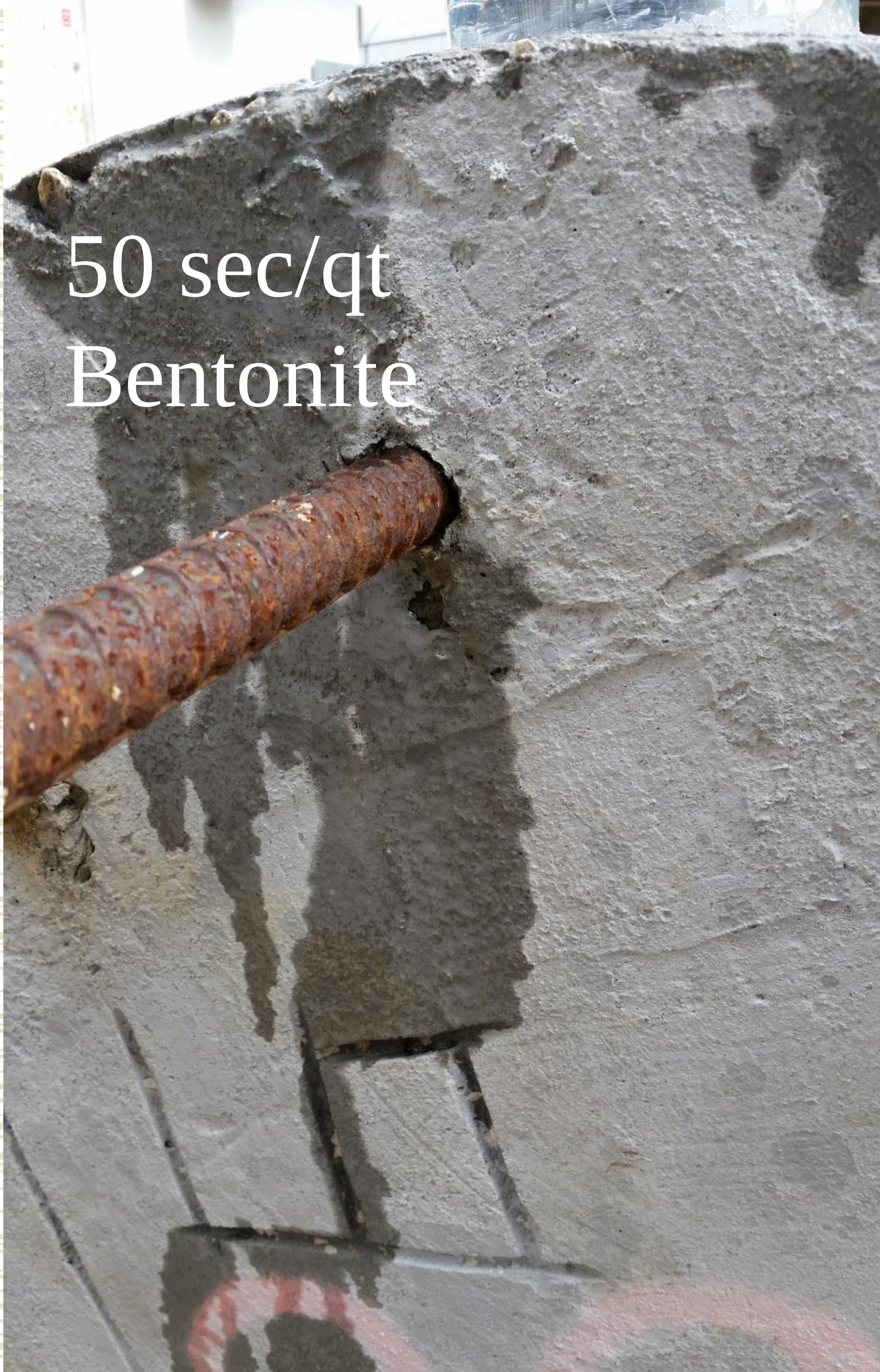


Normalized Ultimate side shear (ksf)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
Viscosity (sec/qt)
Polymer
Bentonite

Cover Effectiveness

Cover Effectiveness


90 sec/qt
Bentonite

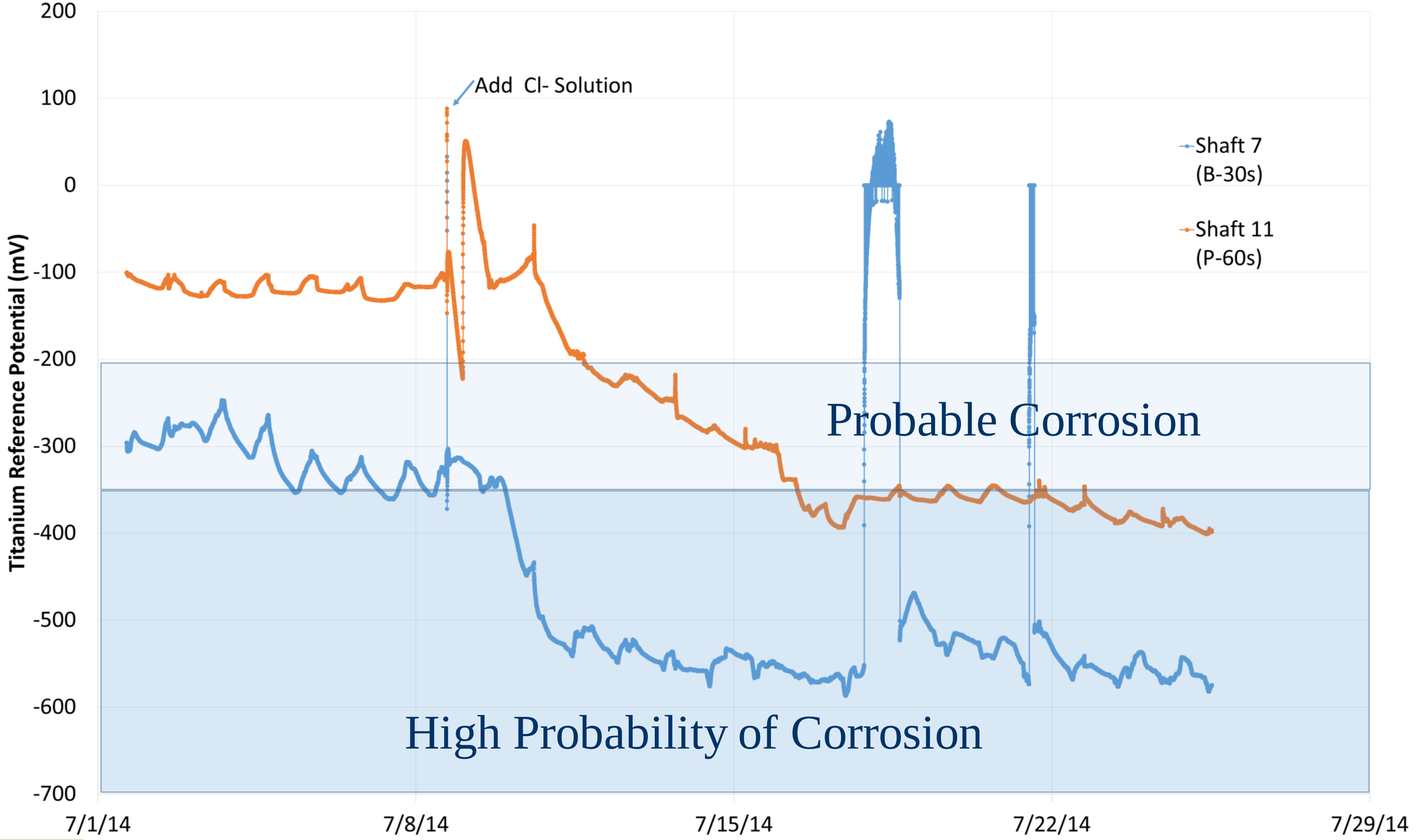

50 sec/qt
Bentonite


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?