Evaluation Of SCC and Class IV Concrete Flow In Drilled Shafts – Part 1

BDV25 TWO977-25

Closeout Meeting
Presented by
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USF UNIVERSITY OF SOUTH FLORIDA

Closeout Meeting Information

- Project Manager: Dale DeFord, Ph.D.
- Principal Investigator: Gray Mullins, Ph.D., P. E.
- Co-Principal Investigator: Abla Zayed, Ph.D.
- Research Institution: University of South Florida
- Contract Title: Evaluation Of SCC and Class IV Concrete Flow In Drilled Shafts – Part 1
- Contract Number: BDV25 TWO977-25

Outline

- Introduction
- Background
- Objectives
- Tasks
- Summary
- Conclusions / Recommendations
- Project Benefits
- Implementation Items
- Future Work

In 1870, 70 bridges collapsed in the U.S.

In the past 16 months 2 major bridges have collapsed from unforeseen corrosion/durability issues

August 14, 2018 Genoa, Italy


VERNAZZA

October 1, 2019 Taiwan

Study Motivation

A construction technique was discovered that leaves the protective concrete cover with a condition suspected to compromise the reinforcing steel protection.

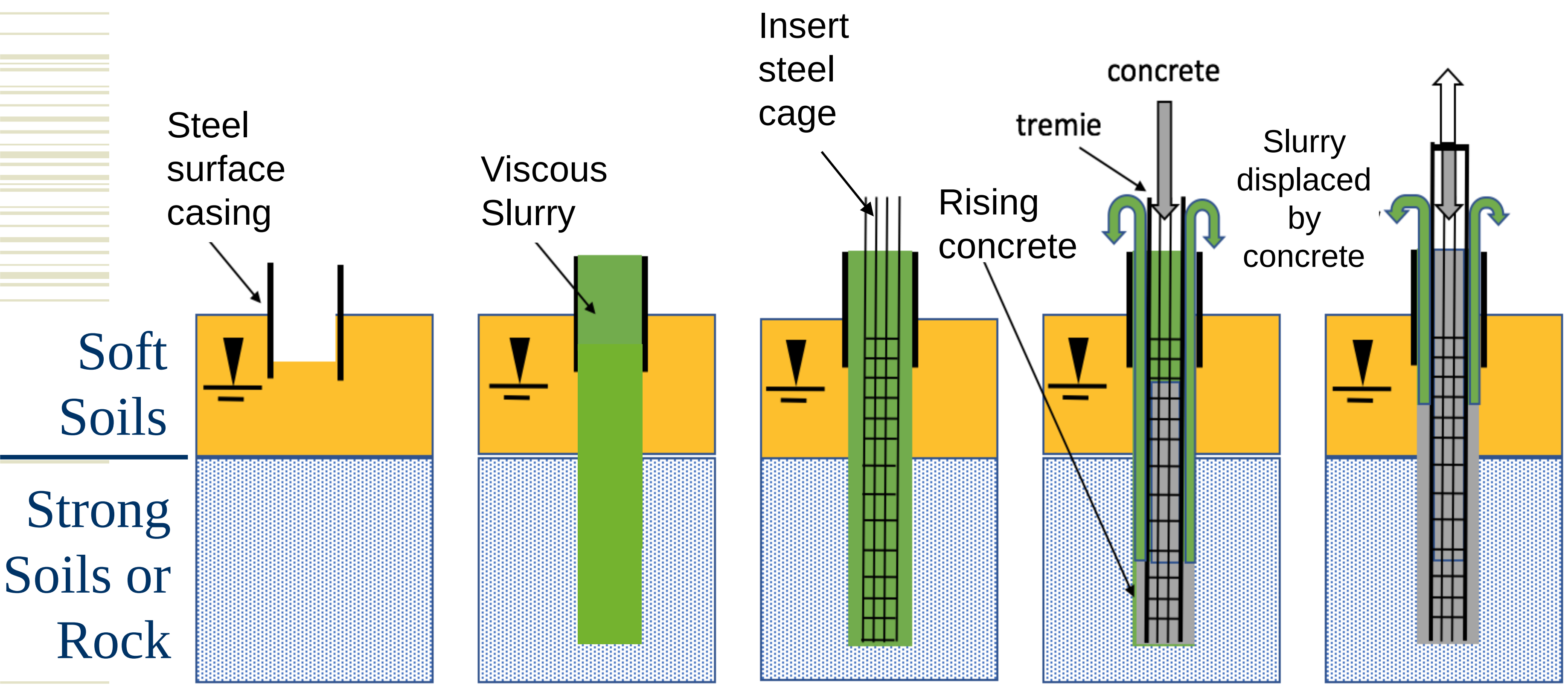
Objective

- Assess the effects of concrete flow on drilled shaft performance
  - Rebar bond
  - Durability / Corrosion Resistance
  - Soil / concrete bond
- Evaluate methods of inspecting/detecting poor concrete conditions

Tasks

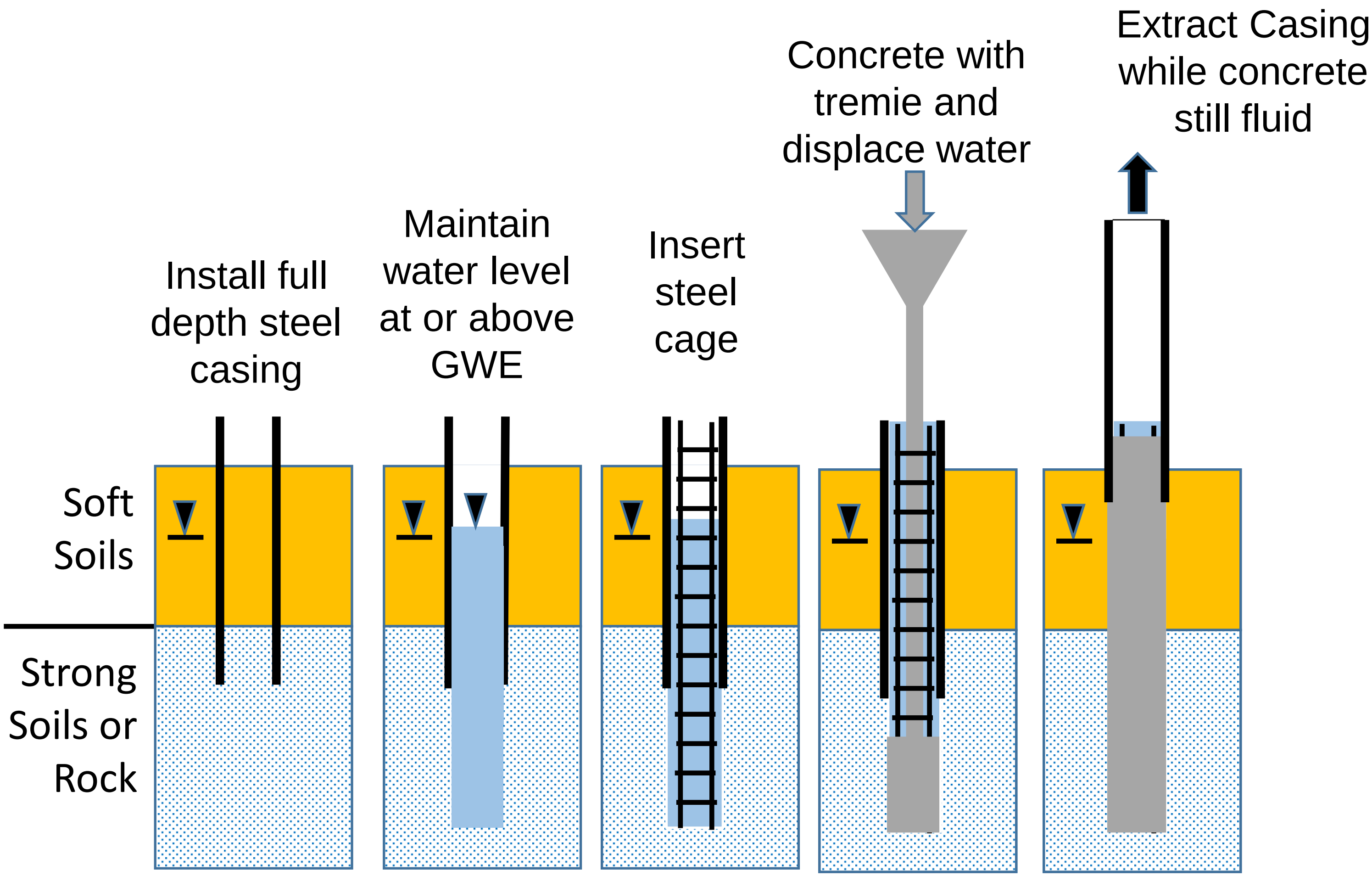
- Literature review
- Rheological modeling
- Rebar pullout tests
- Concrete coring/strength distribution
- Corrosion resistance
- Surface roughness (lab)
- Underwater bridge inspections
- Surface roughness (field)

Background
Drilled Shaft Construction
(slurry stabilization)

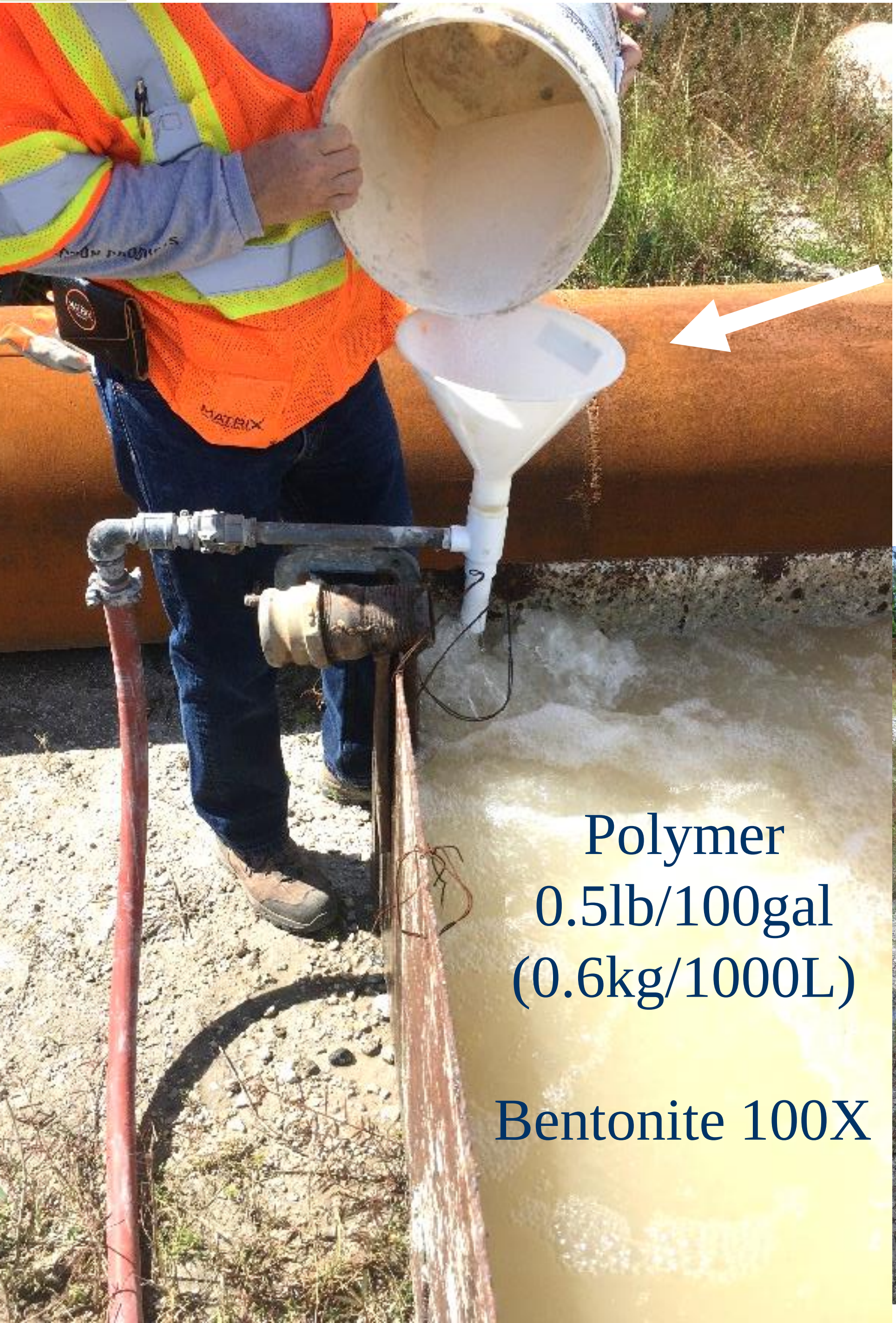


Drilled Shaft Construction

Casing Stabilized / Water Displaced



Slurry Preparation



Mix with venturi eductor

Recirculate

Excavation and Cleanout

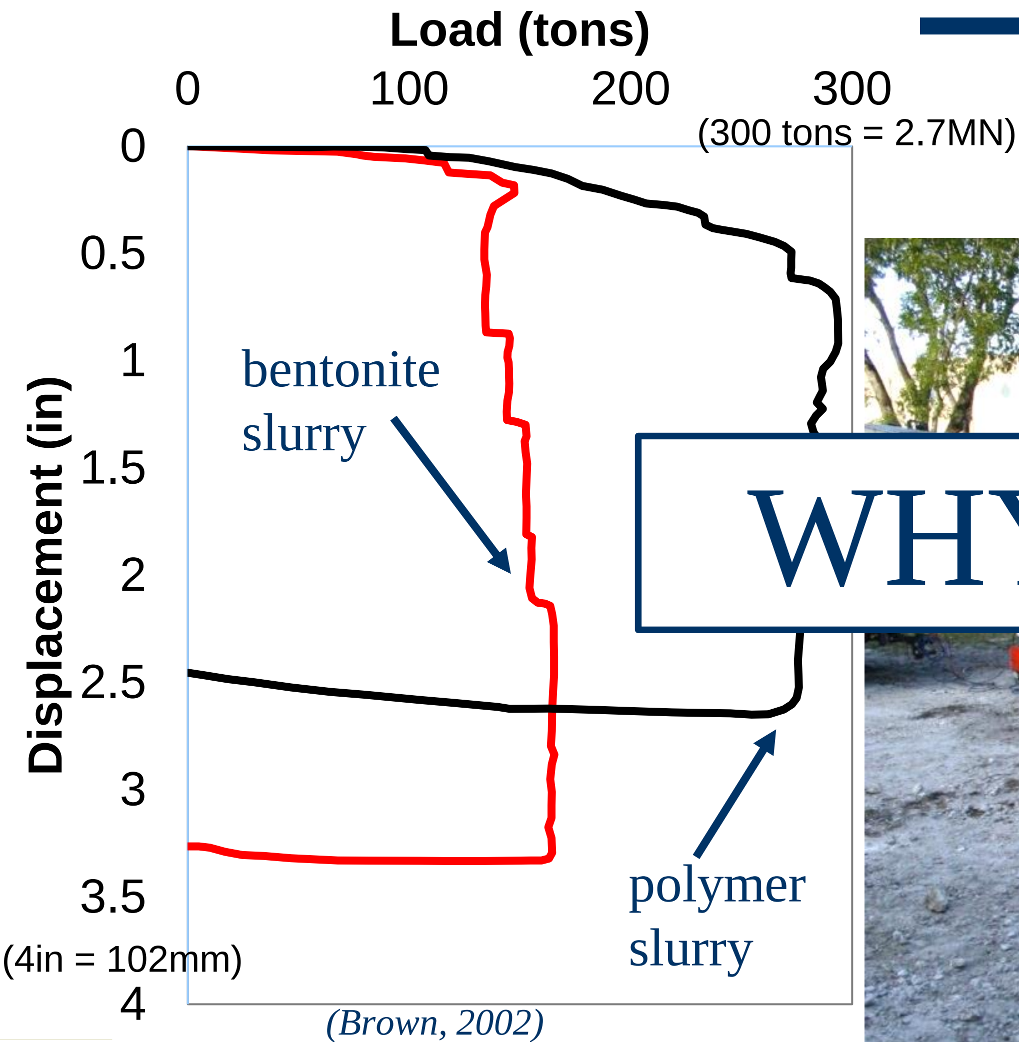
Steel Reinforcing Cage Placement

Lower tremie pipe to bottom of excavation

Place concrete through tremie pipe and displace slurry

Surface Casing Extraction

Effects of Slurry on Side Resistance (concrete to soil shear strength)

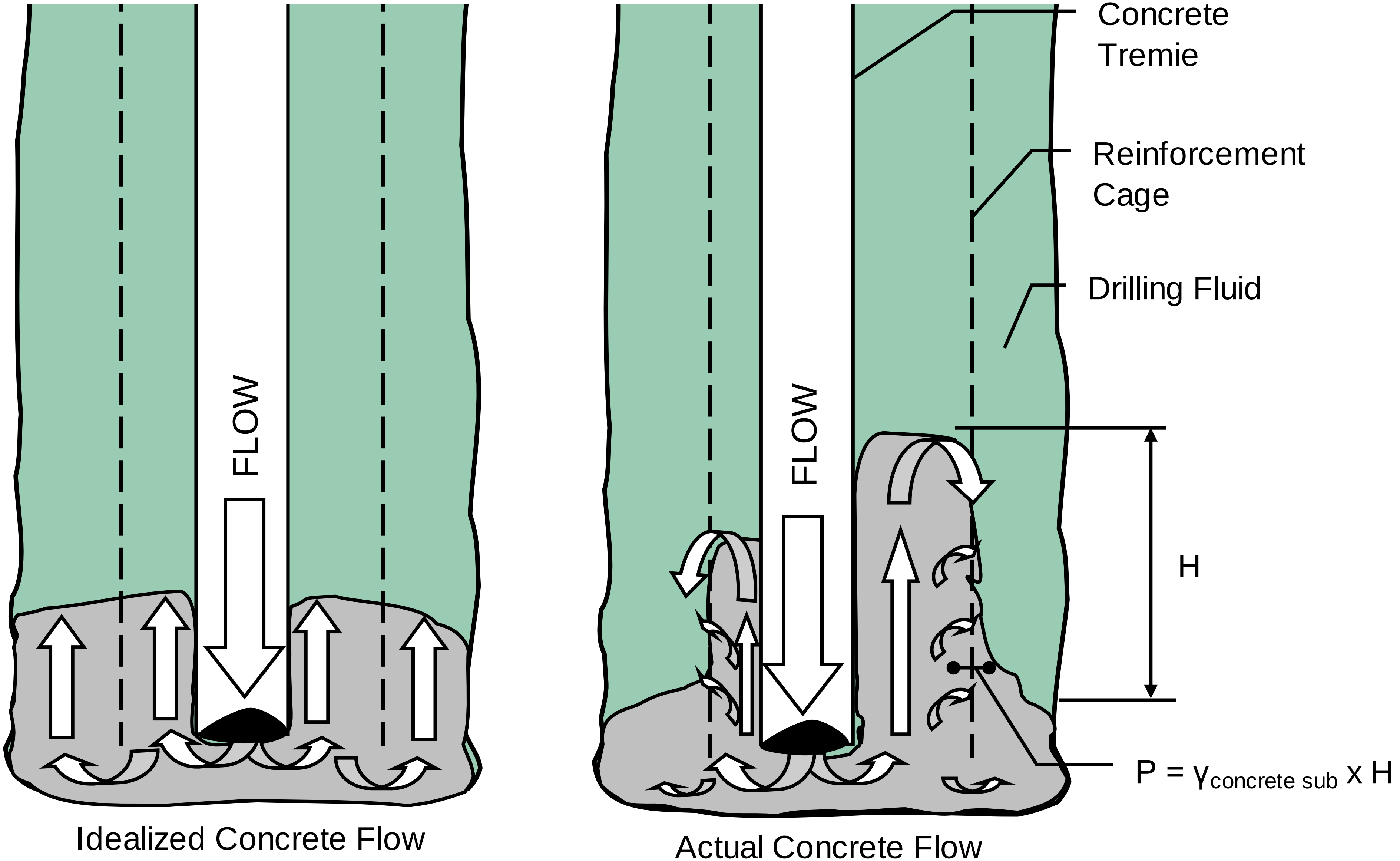


(Brown, 2002)

Load Testing

WHY?

Concrete Flow in Drilled Shafts



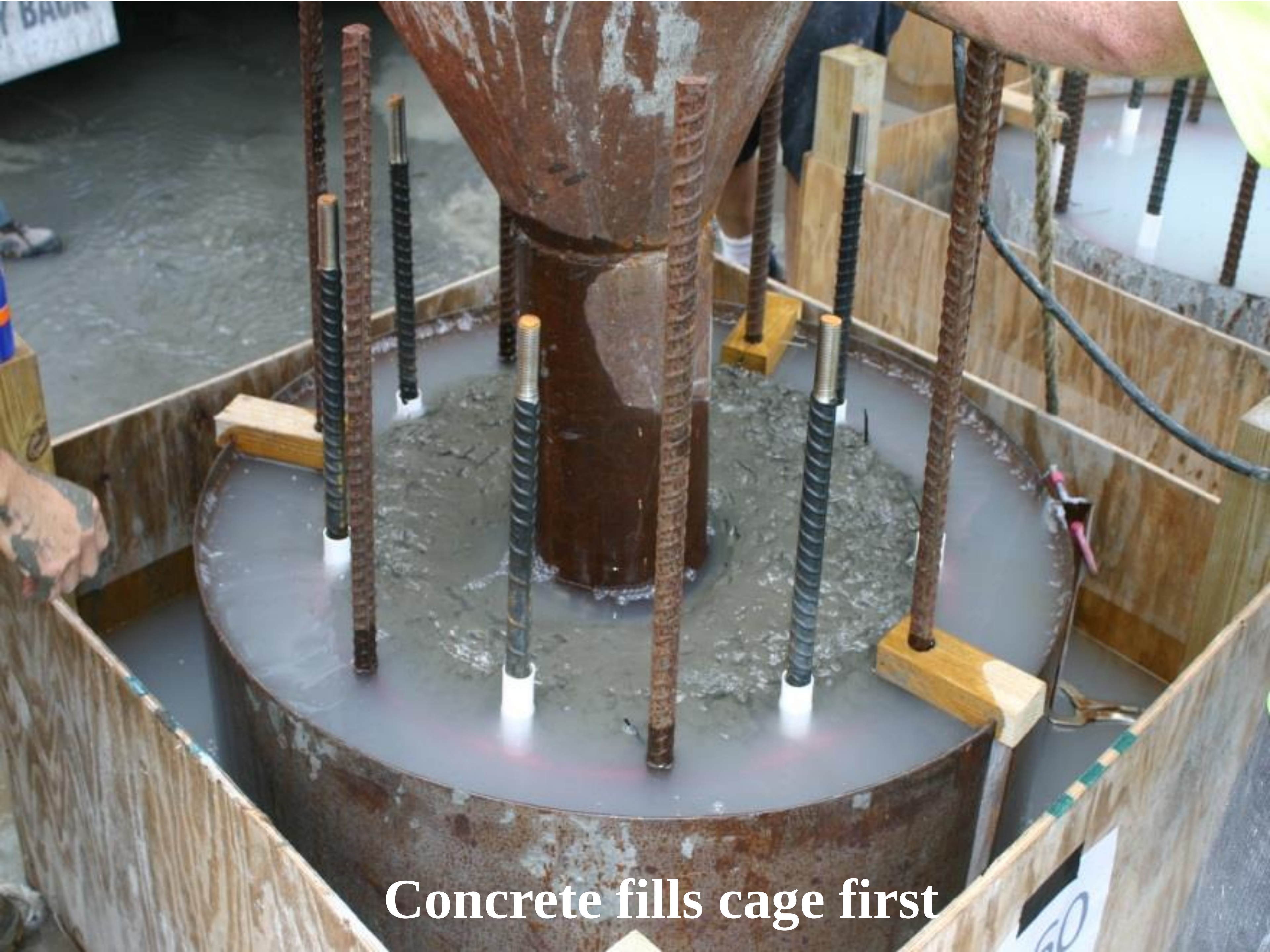
Deese, G. and Mullins, G. (2005). "Factors Affecting Concrete Flow in Drilled Shaft Construction," ADSC GEO3, GEO Construction Quality Assurance / Quality Control Conference Proceedings, Bruce, D.A. and Cadden, A. W. (eds) pp. 144-155, November.

Drilling Fluid: Water

Drilling Fluid: Bentonite

Drilling Fluid: Attapulgite

Drilling Fluid: Polymer



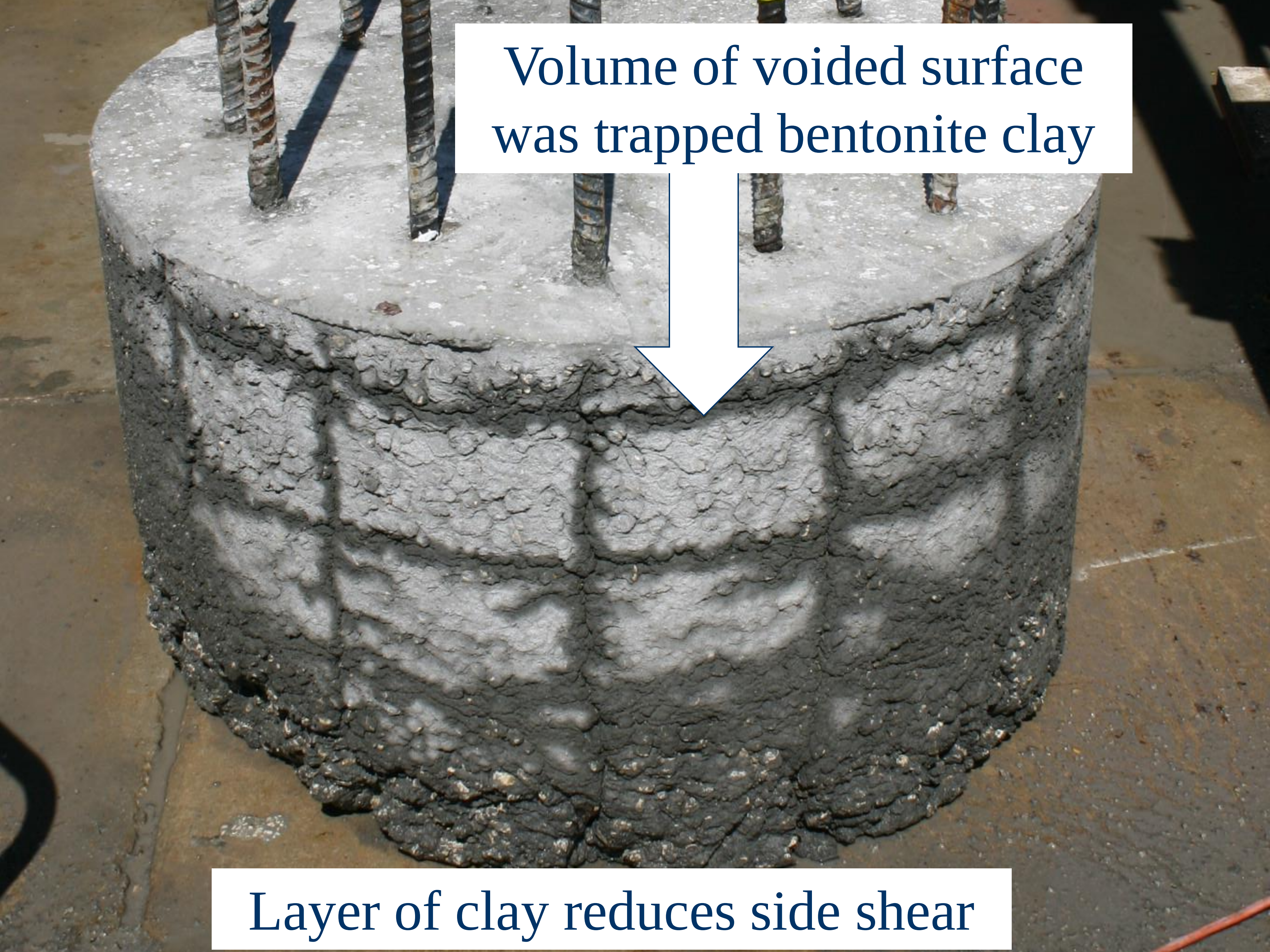
Concrete fills cage first

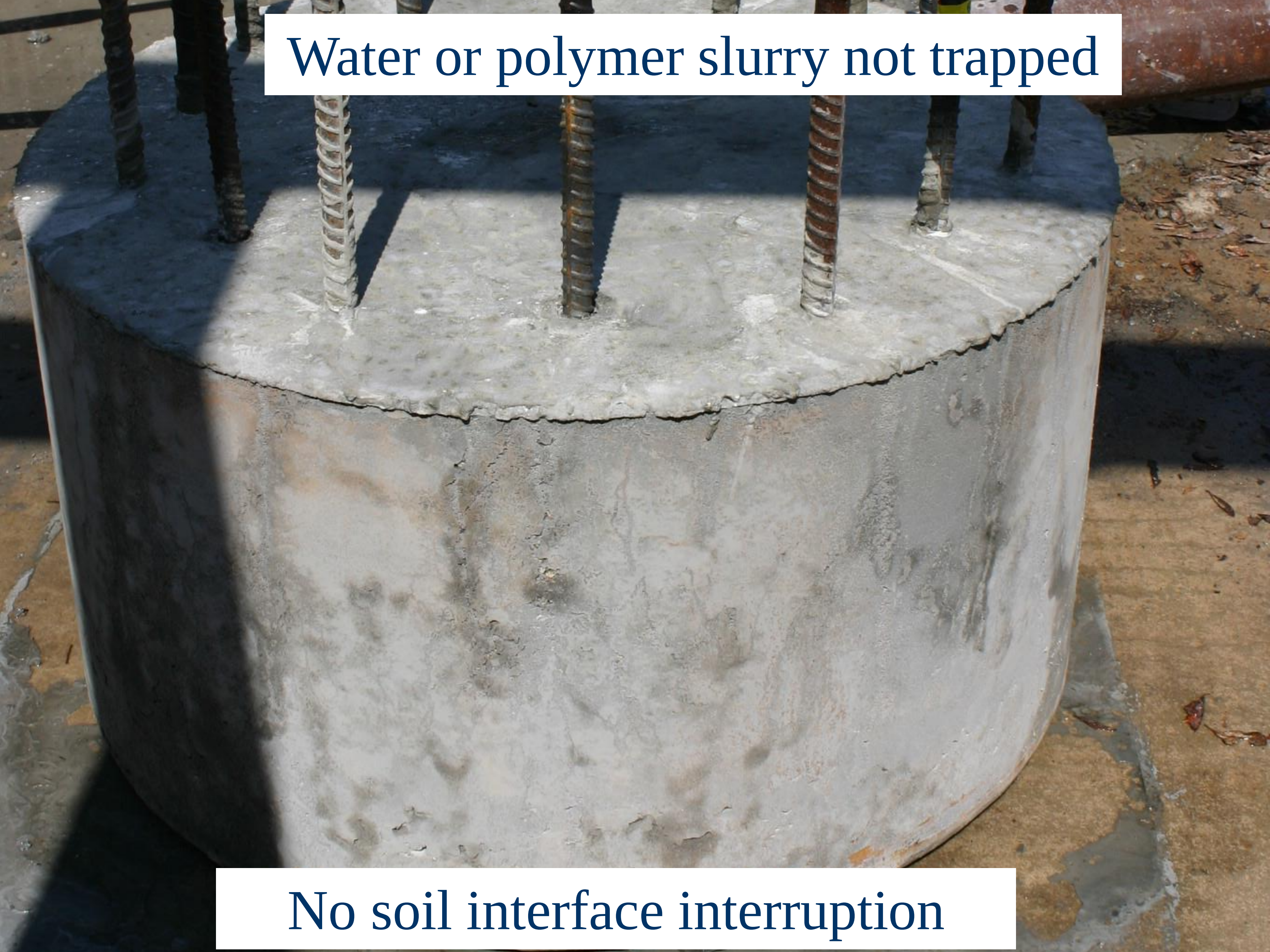

Then presses through cage


Creases form that
may not fully close


CAUTION
IF YOU CAN'T SEE MY
MIRRORS, I CAN'T SEE YOU.
PLEASE
STAY BACK


Bentonite shafts show severe creases


Volume of voided surface
was trapped bentonite clay
Layer of clay reduces side shear


Water or polymer slurry not trapped
No soil interface interruption

Bowen (2013)

Bowen (2013)

Water

Bowen (2013)

60 sec/qt
Polymer

Bowen (2013)

30 sec/qt
Bentonite

Bowen (2013)

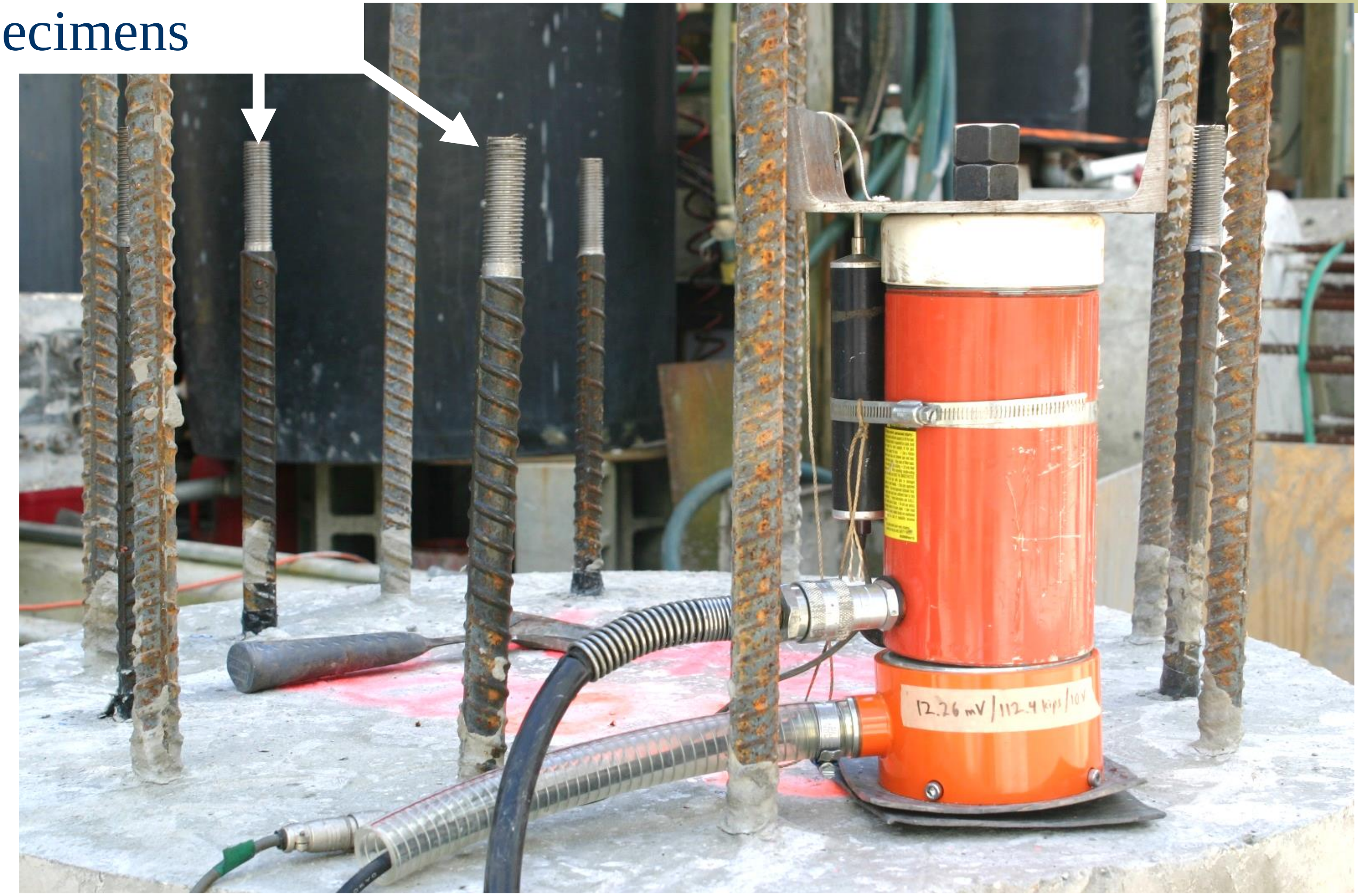
40 sec/qt
Bentonite

Bowen (2013)

Bowen (2013)

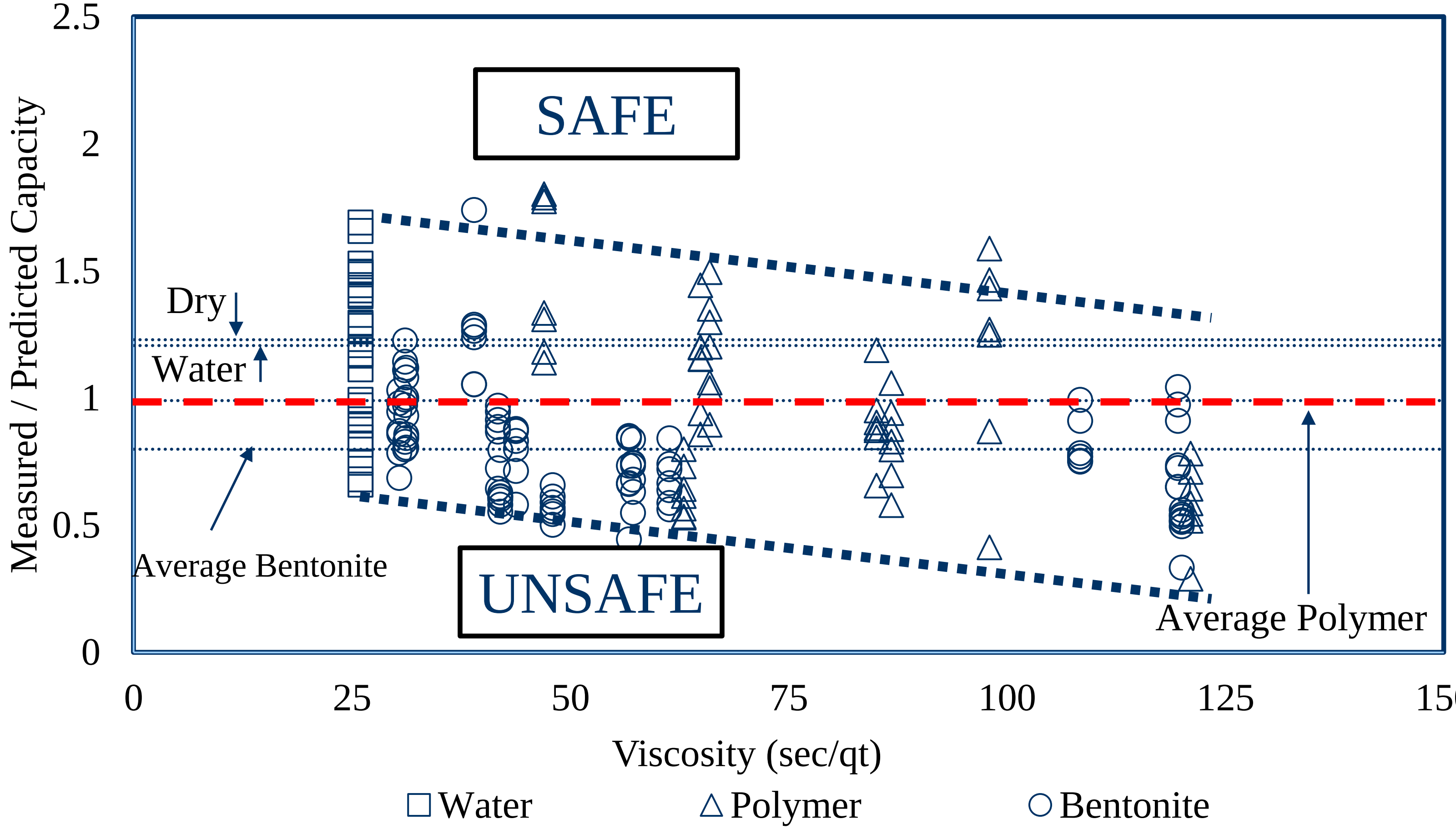
Effects of Slurry on Rebar Pullout Resistance
(reinforcing steel to concrete bond)

Threaded pullout specimens

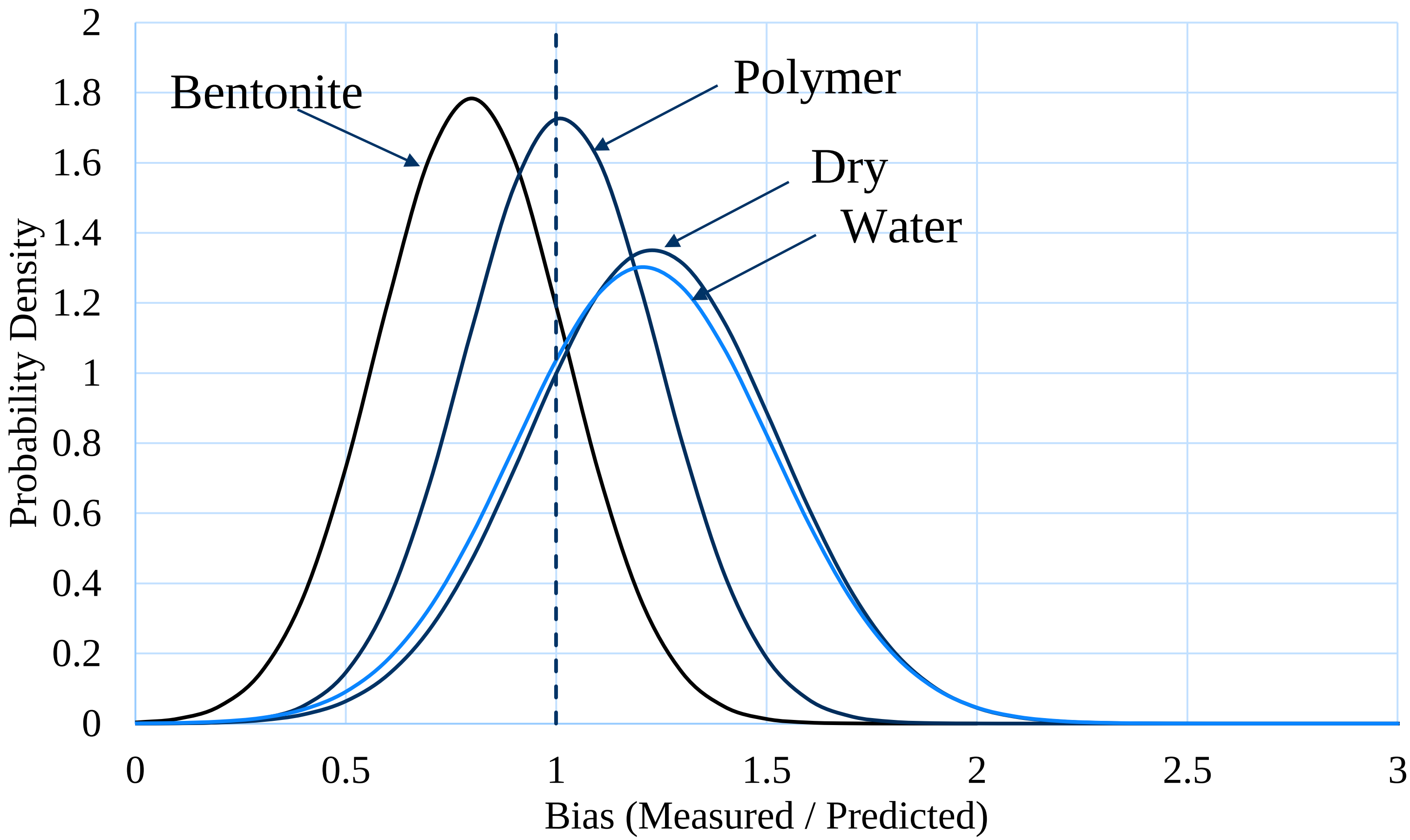


Effects of Slurry on Rebar Bond

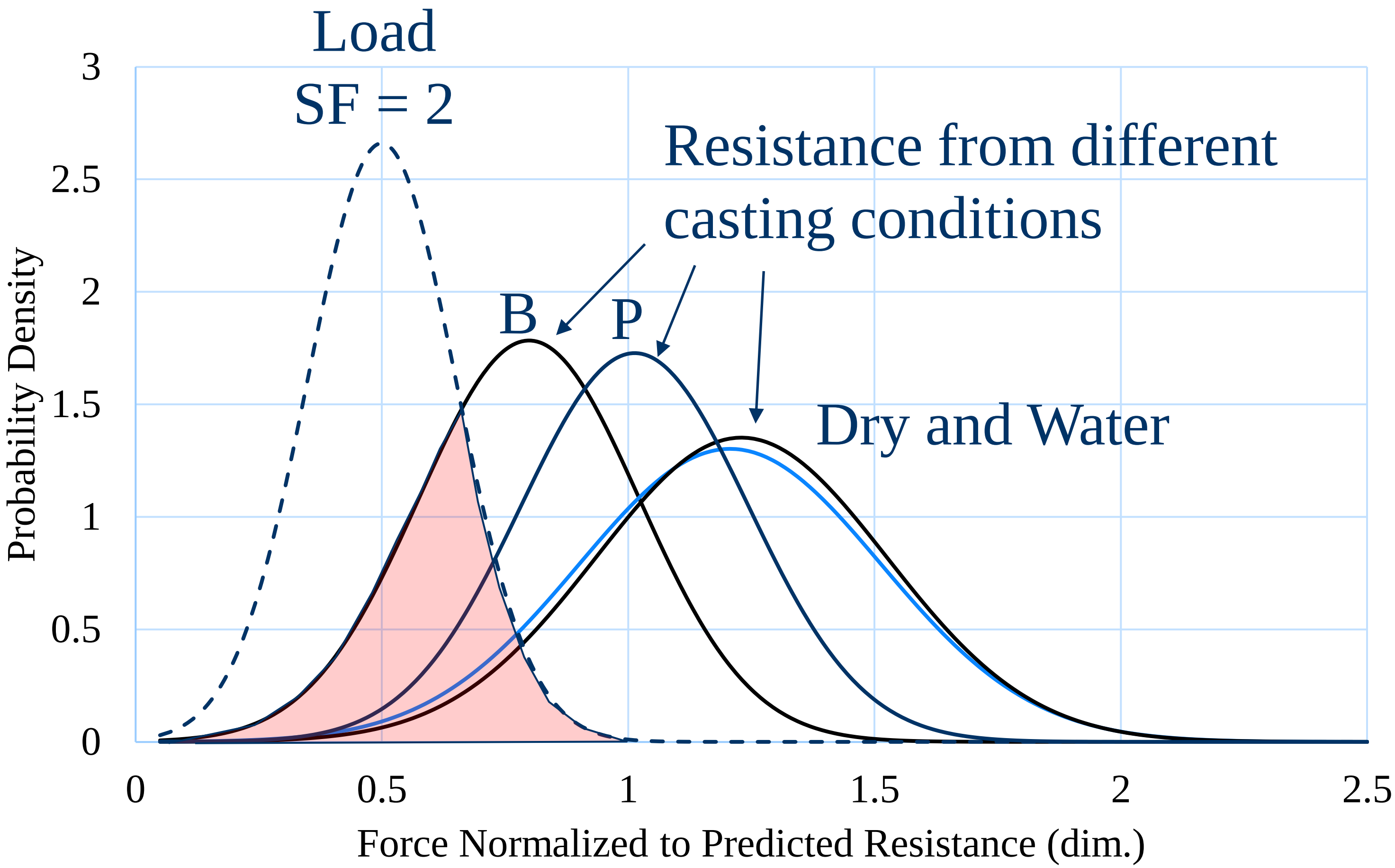
(227 rebar pullout tests; 58 shafts)



Effects of Slurry on Rebar Bond
(measured / prediction ratio)

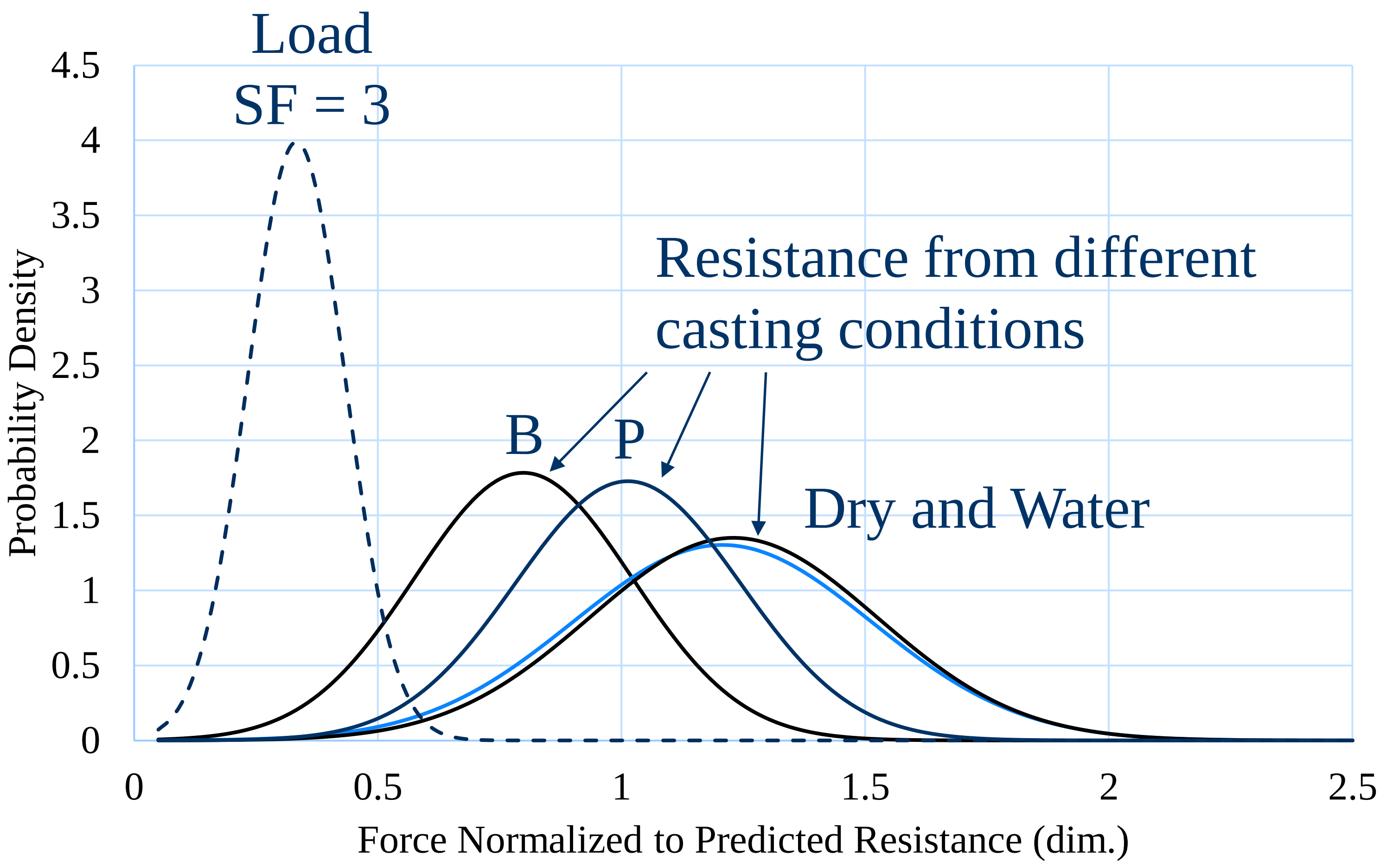


Effects of Slurry on Rebar Bond
(load vs resistance; Safety Factor = 2)



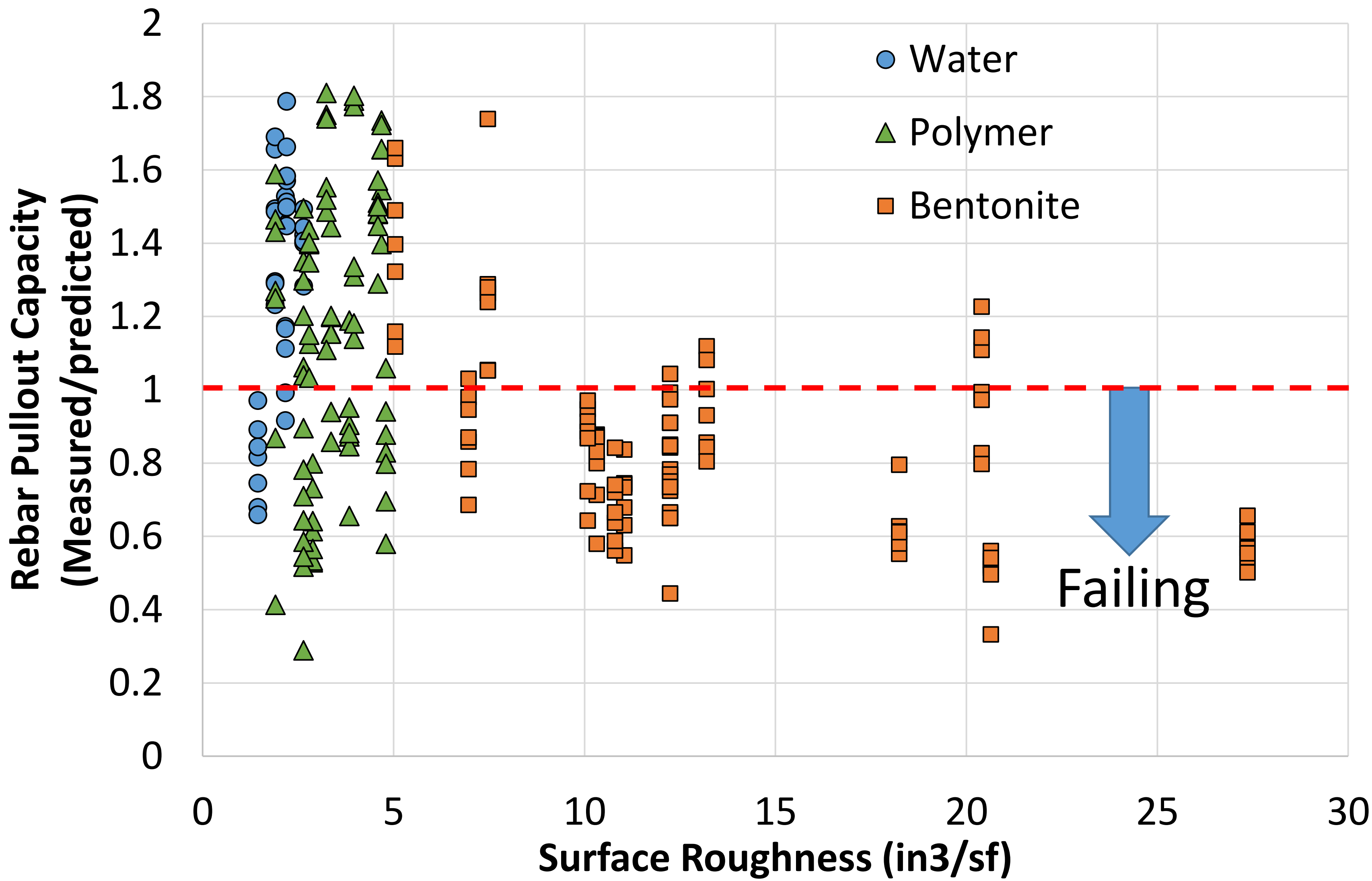
Effects of Slurry on Rebar Bond

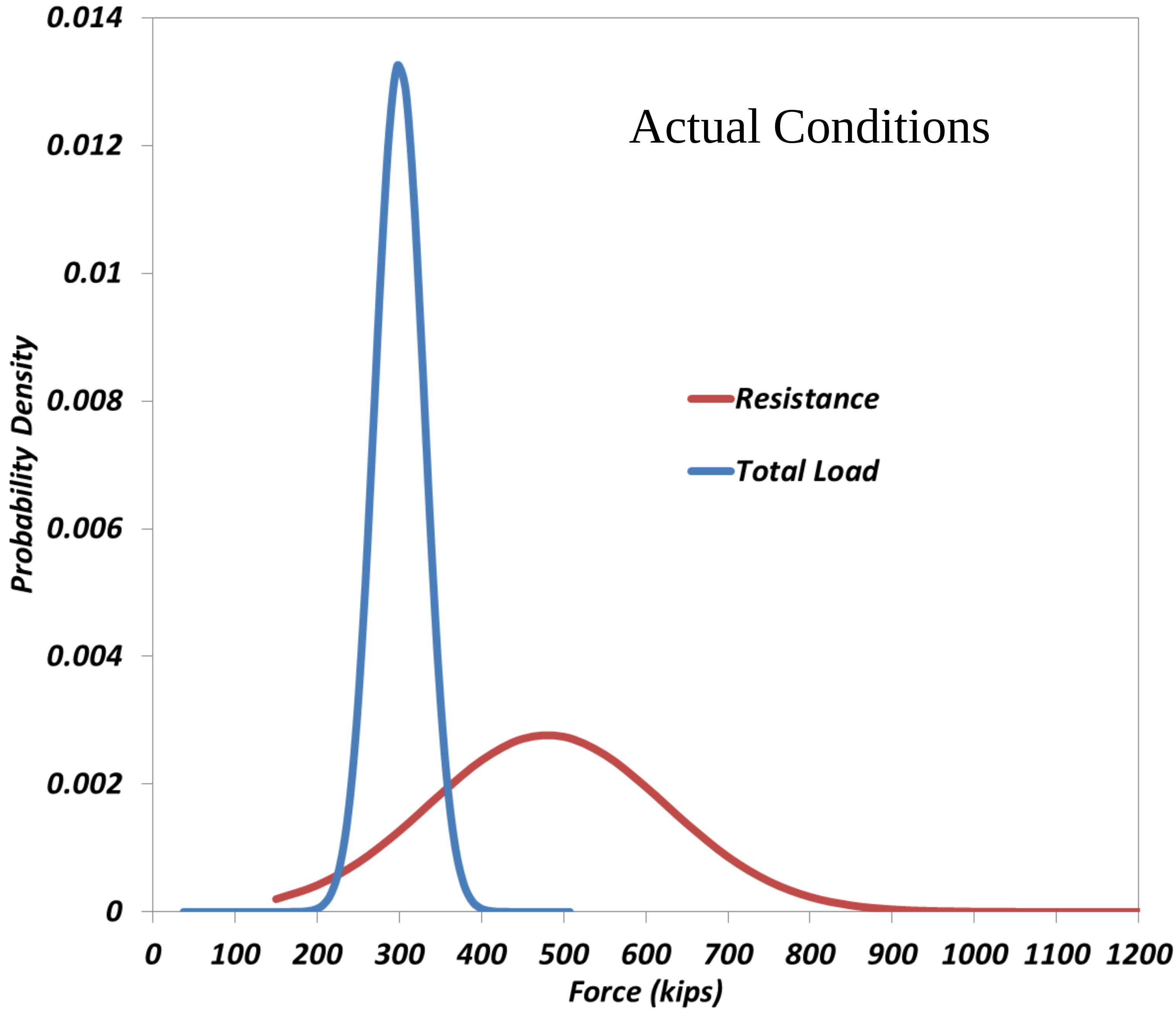
(load vs resistance; Safety Factor = 3)



Surface Roughness vs Rebar Pullout

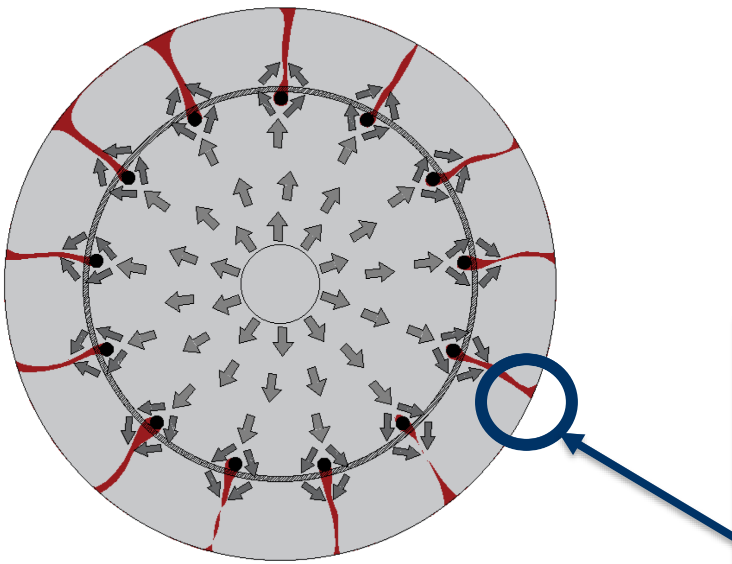
(Costello, 2018)



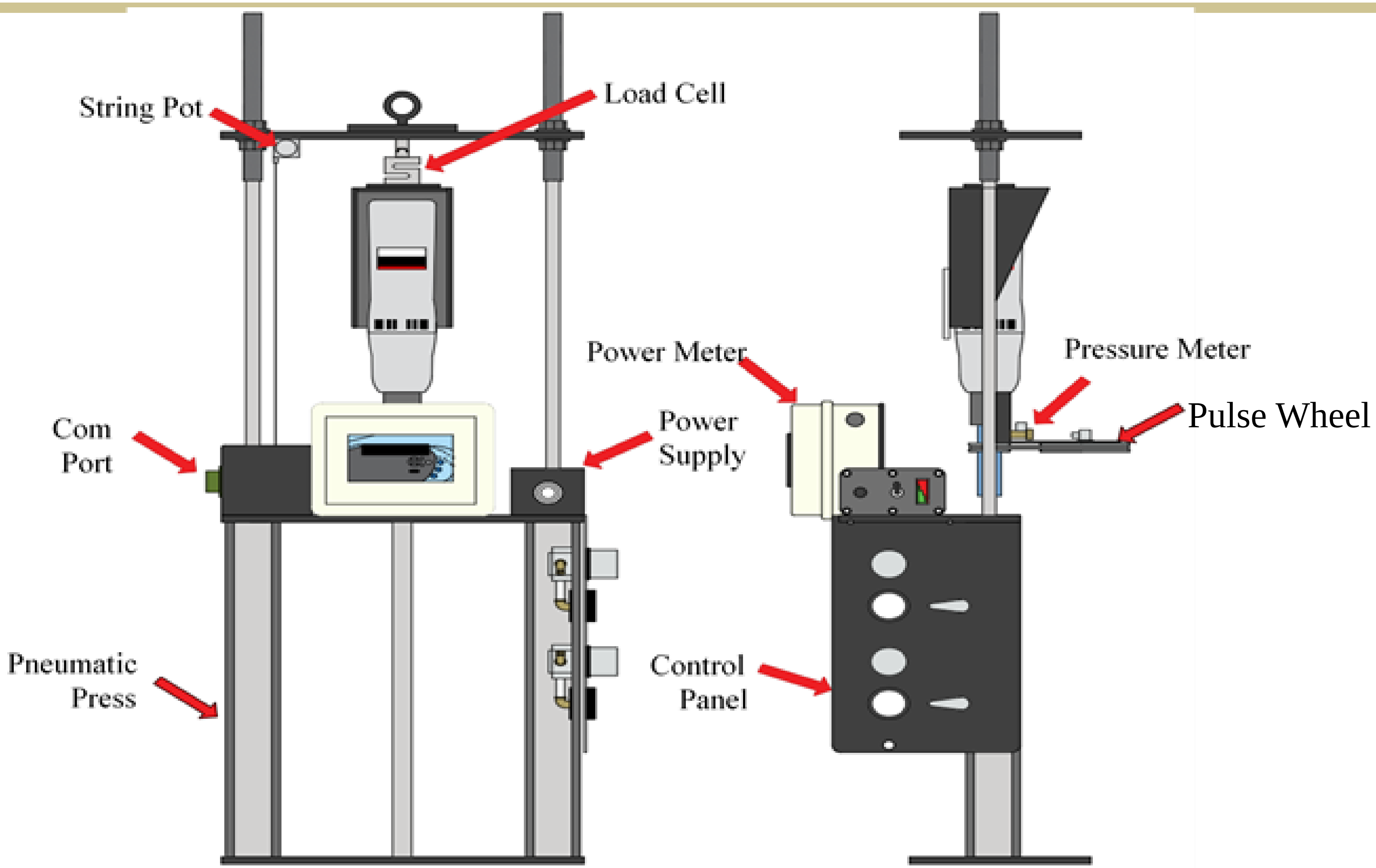


Actual Conditions
Resistance
Total Load
Probability Density
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
Force (kips)

Effects of Slurry on Concrete Strength
(quality of the cover)

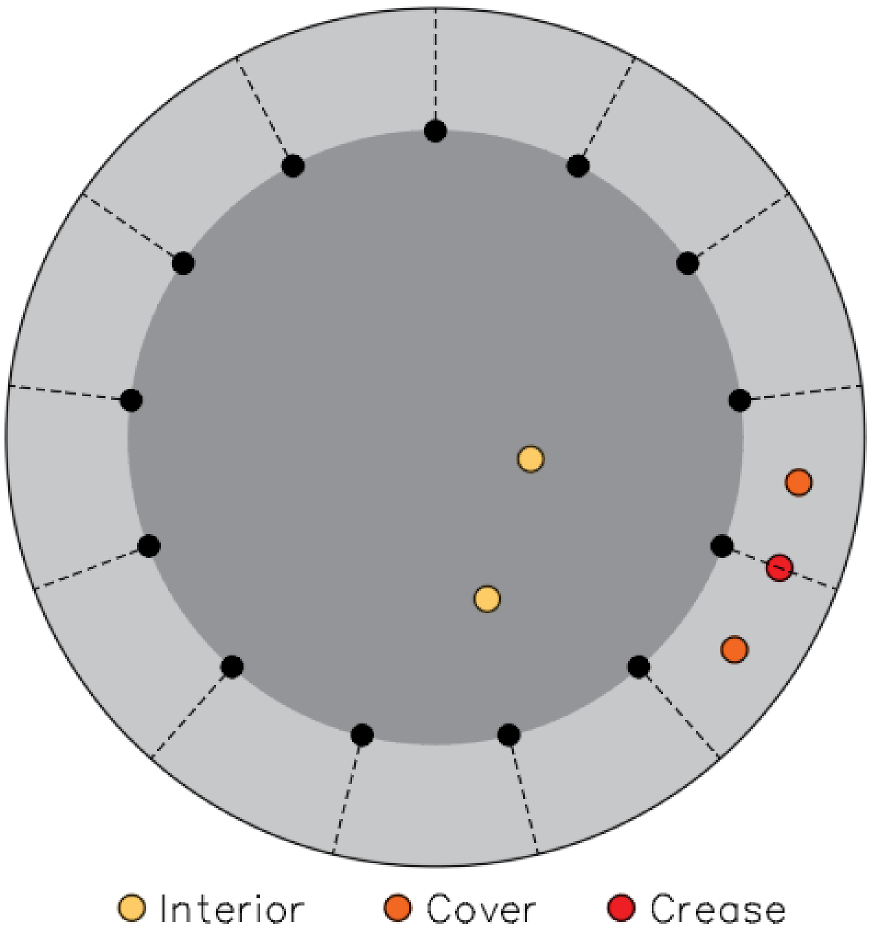


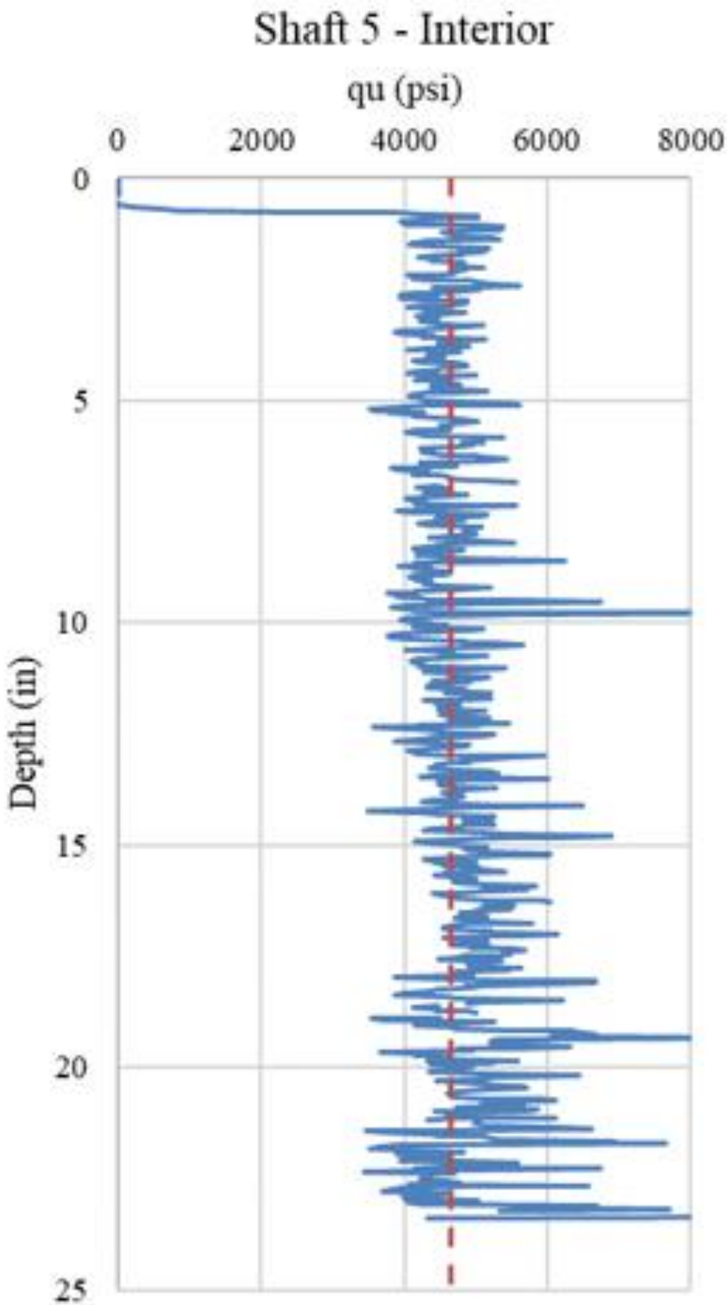
Concrete penetrometer



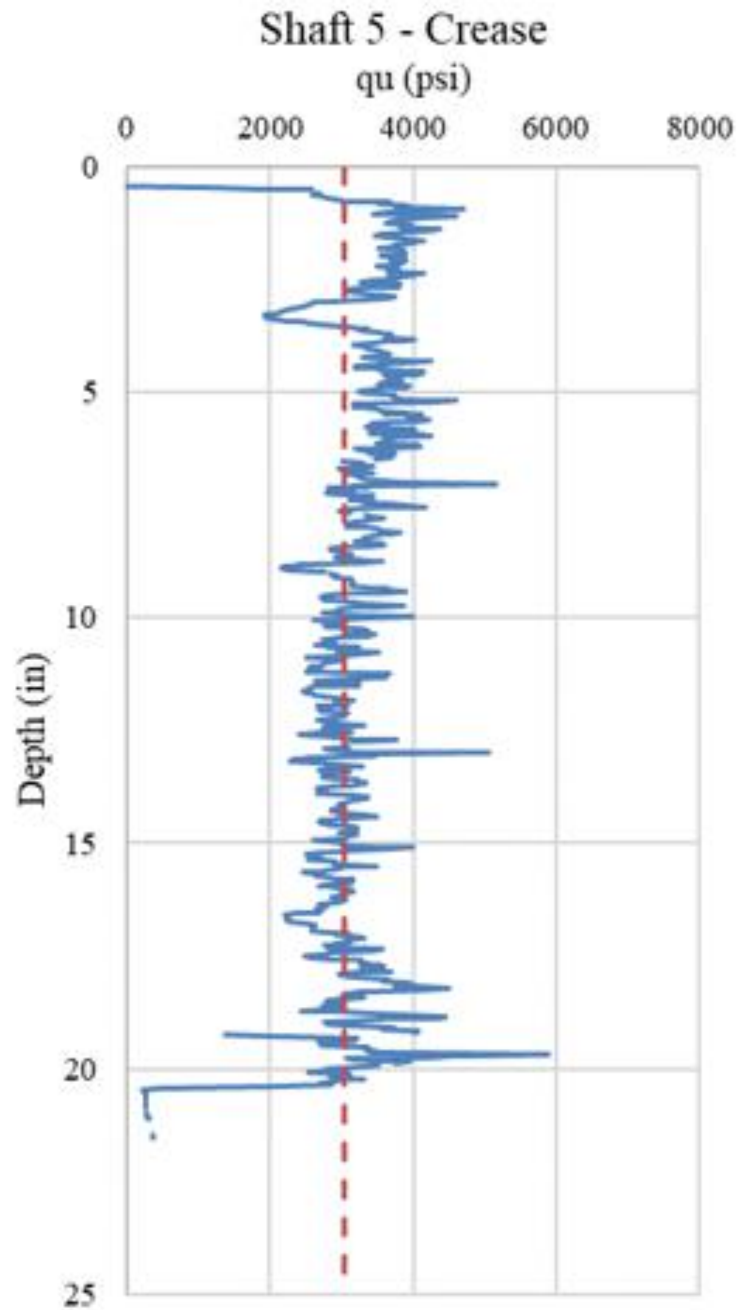

PQM II
PROPERTY OF TAMPA ELECTRIC
BIG BEND ELECTRIC SHOP

Coring Locations





Shaft 5 - Interior
qu (psi)
0
2000
4000
6000
8000
0
5
10
15
20
25
Depth (in)



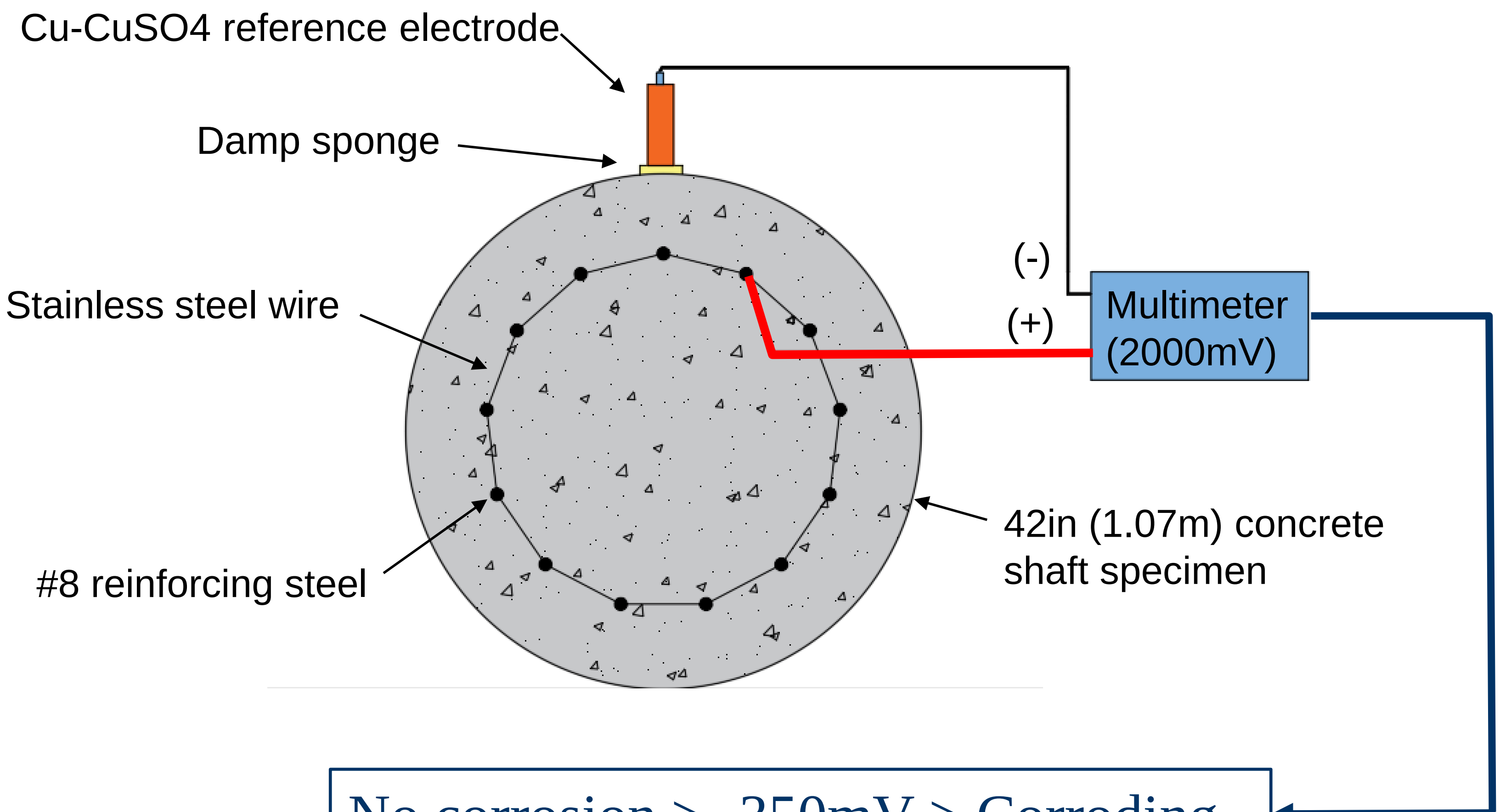
Shaft 5 - Crease
qu (psi)
0
2000
4000
6000
8000
0
5
10
15
20
25
Depth (in)

Bentonite					
Shaft #	Viscosity	Baseline	Crease	Cover 1	Cover 2
	(sec)	(psi)			
1	44	4688	0.82	0.81	0.74
3	40	4296	0.86	1.03	0.94
4	55	4268	1.06	1.08	0.91
5	90	5023	0.61	0.94	0.82
7	30	4304	0.67	0.68	0.88
8	40	4532	0.88	0.91	0.91
9	57	5627	0.74	0.67	0.88
10	90	5142	0.77	0.76	0.80
13	30	3796	0.93	0.94	0.94
14	30	4512	0.68	0.93	0.90
15	56	4742	1.05	0.92	0.95
21	42	5092	0.73	0.81	0.95
45	37	4847	0.83	0.84	0.89
		Average	**0.82**	**0.87**	**0.89**

Polymer					
Shaft #	Viscosity	Baseline Strength	Ratio To Crease	Ratio To Cover 1	Ratio To Cover 2
	(sec)	(psi)			
11	65	4220	1.04	1.22	1.06
12	66	5976	0.77	0.96	0.96
16	85	4045	0.87	0.89	0.94
17	85	4345	0.91	0.91	0.93
19	63	5739	0.84	0.86	0.97
20	121	4720	0.76	1.01	0.96
		Average	**0.86**	**0.98**	**0.97**

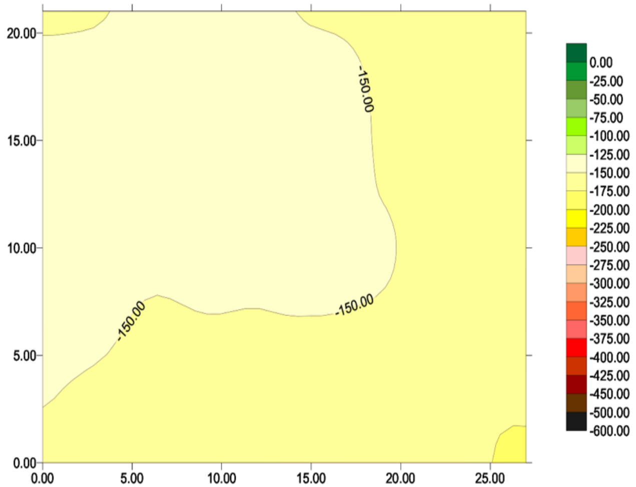
Water					
Shaft #	Viscosity	Baseline Strength	Ratio To Crease	Ratio To Cover 1	Ratio To Cover 2
	(sec)	(psi)			
6	26	4752	0.85	0.87	0.96
18	26	3957.3	0.84	1.12	1.12
22	26	4597.6	0.88	1.02	1.03
32	26	4956.7	1.15	0.91	0.92
46	26	5341.3	0.86	0.95	1.01
		Average	**0.92**	**0.97**	**1.01**

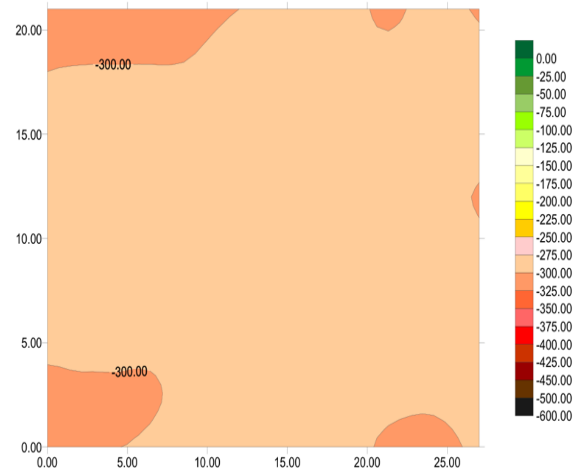
Effects of Slurry on Corrosion Resistance
(is concrete cover protecting steel?)

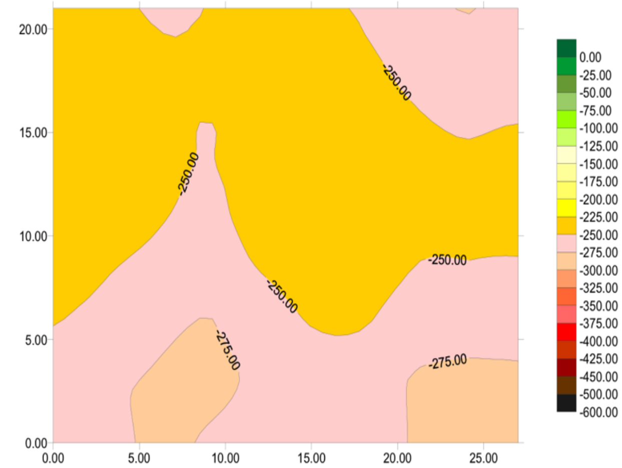


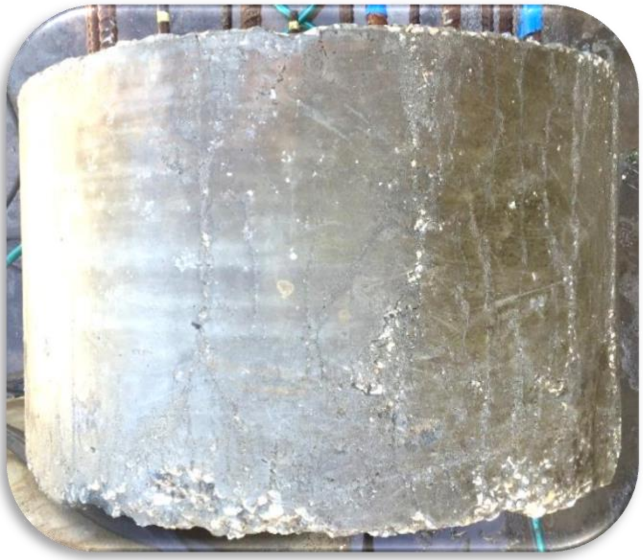
No corrosion > -350mV > Corroding

Effects of Slurry on Corrosion Resistance
(surface potential mapping)



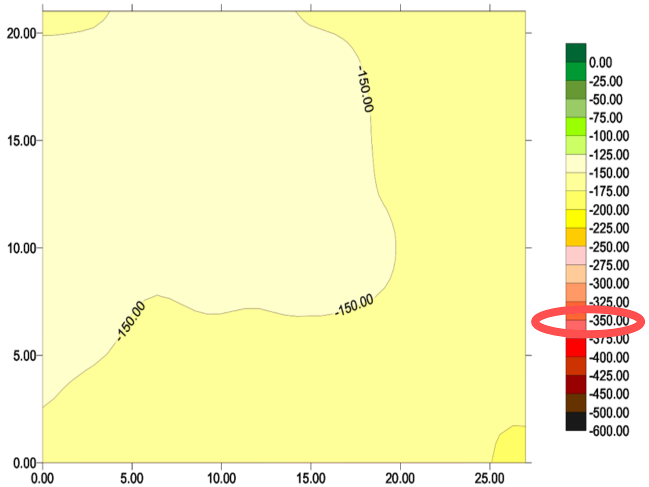




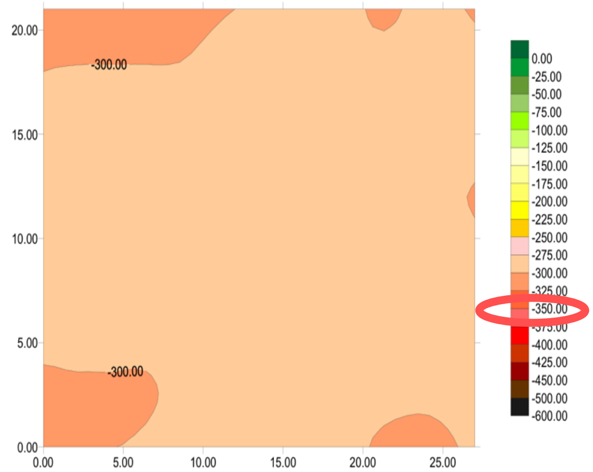


Shaft 6 *Shaft 18* *Shaft 22*

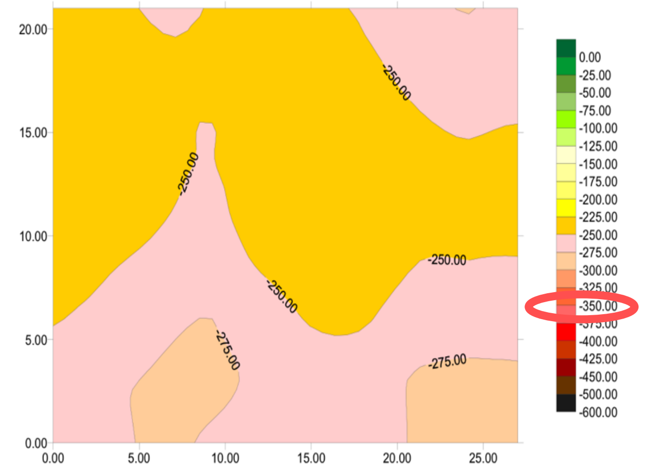
Water



Shaft 6

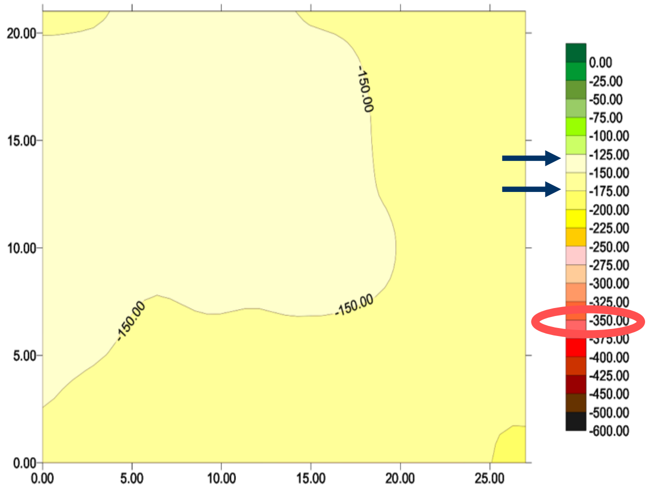


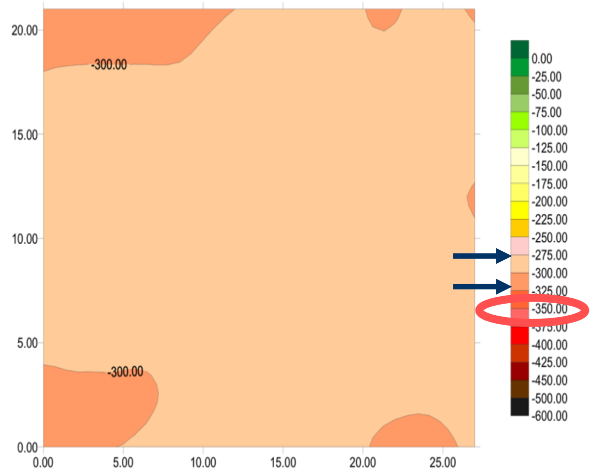
Shaft 18

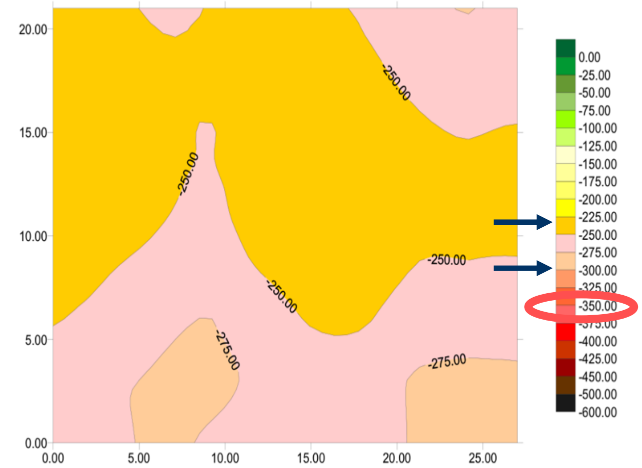


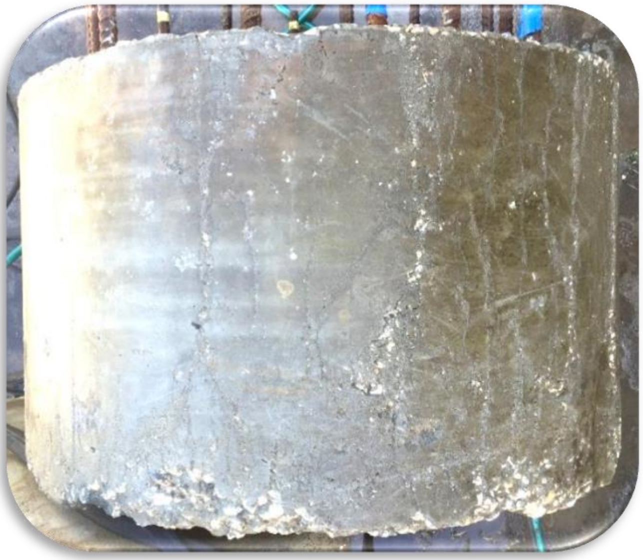
Shaft 22

Water







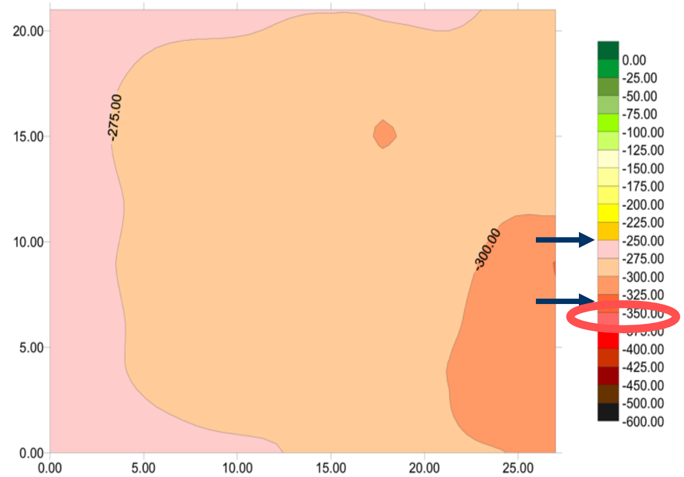


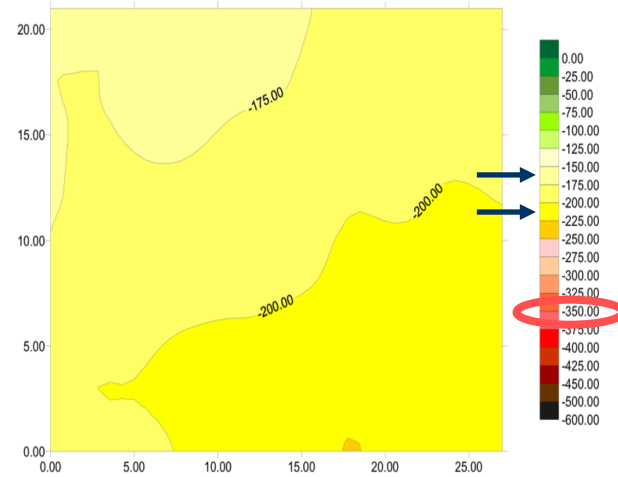
Shaft 6

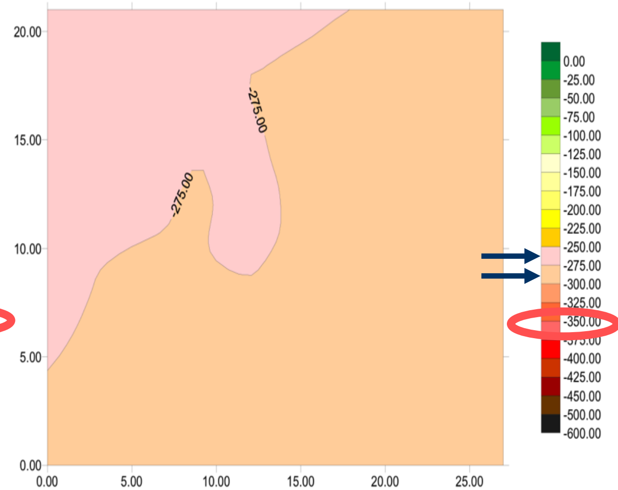
Shaft 18

Shaft 22

Water





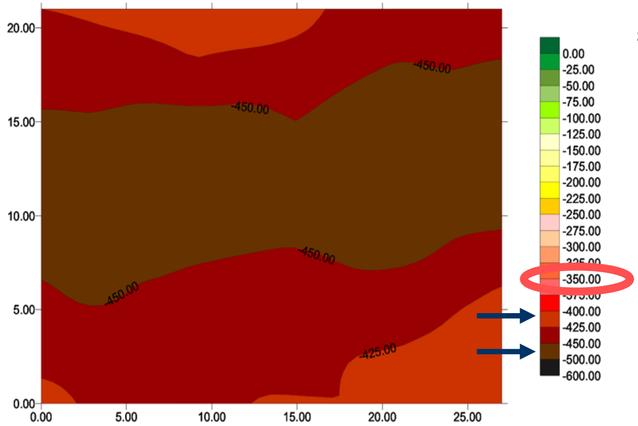


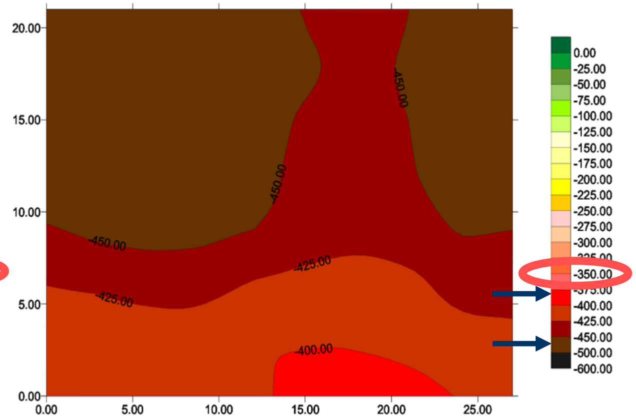
Shaft 11 (60 sec)

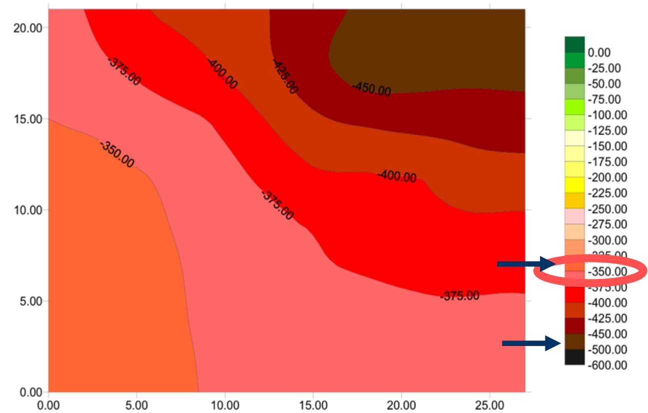
Shaft 12 (60 sec)

Shaft 16 (90 sec)

Polymer Slurry







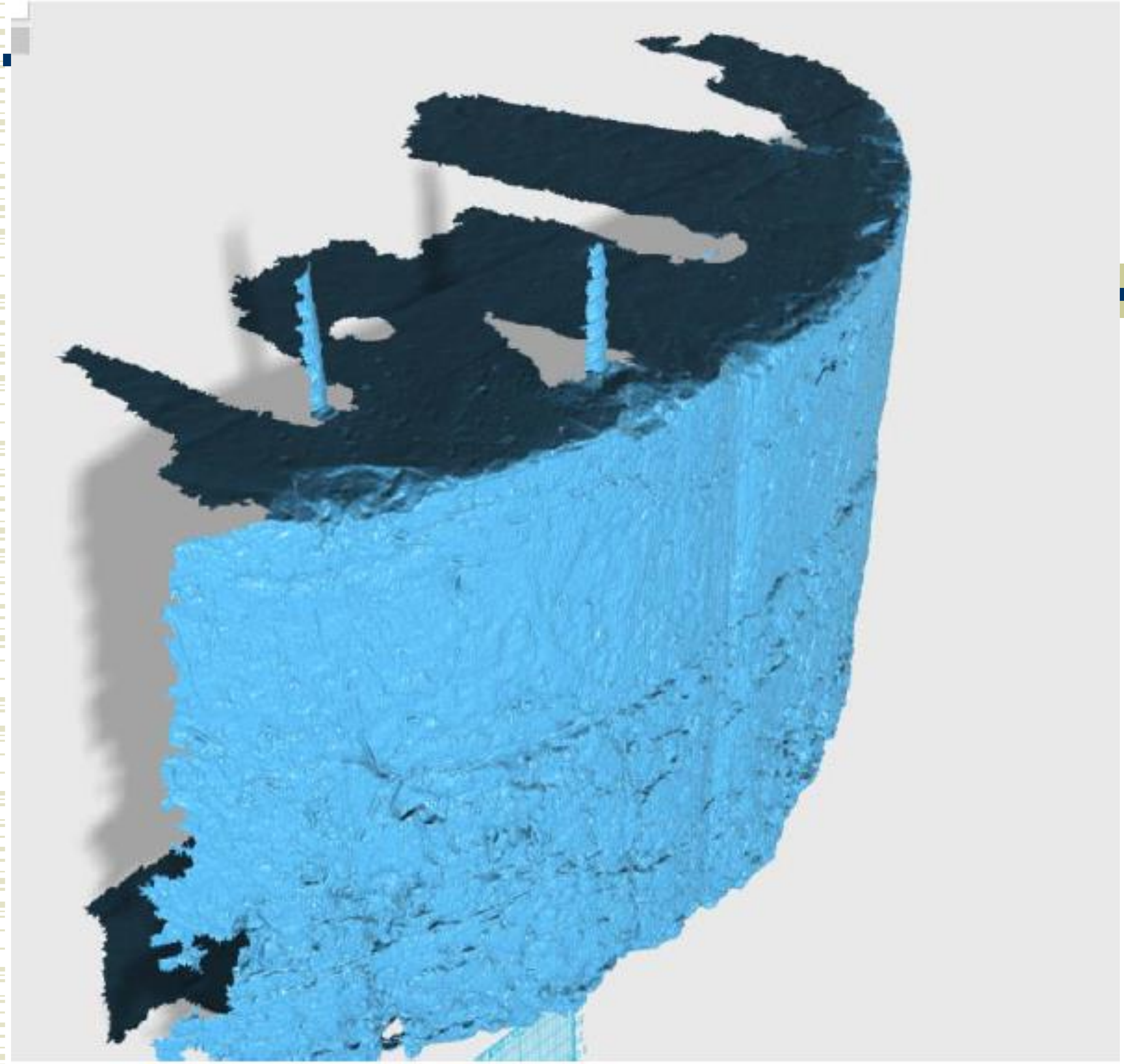
Shaft 4 (50 sec)

Shaft 5 (90 sec)

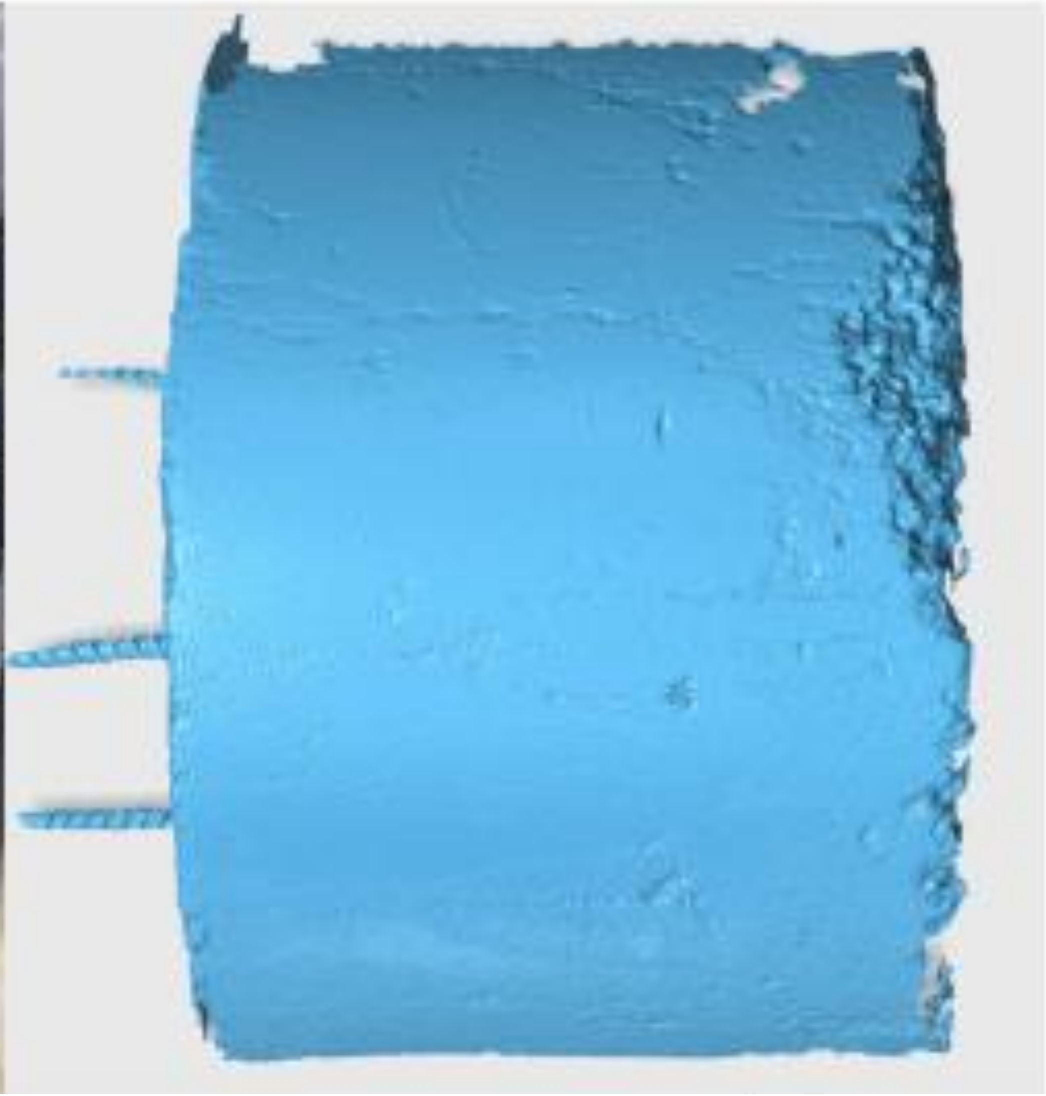
Shaft 7 (30 sec)

Bentonite Slurry

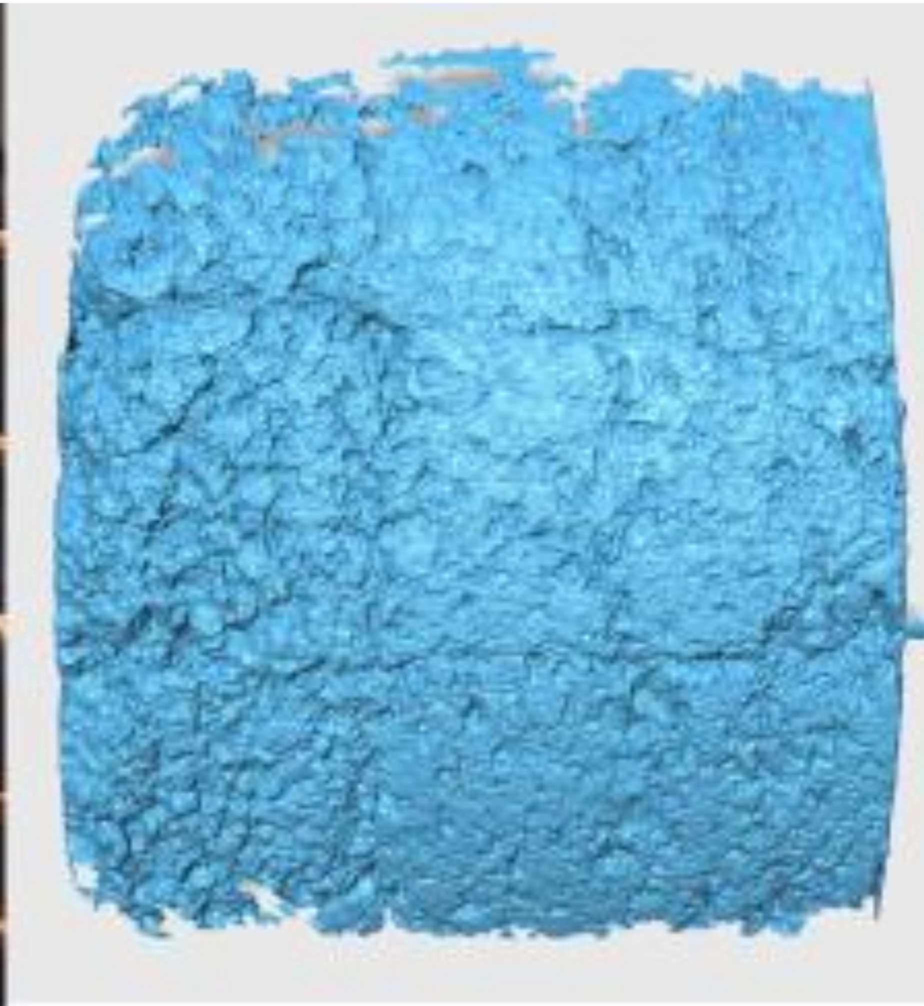
Digitizing Surface Roughness



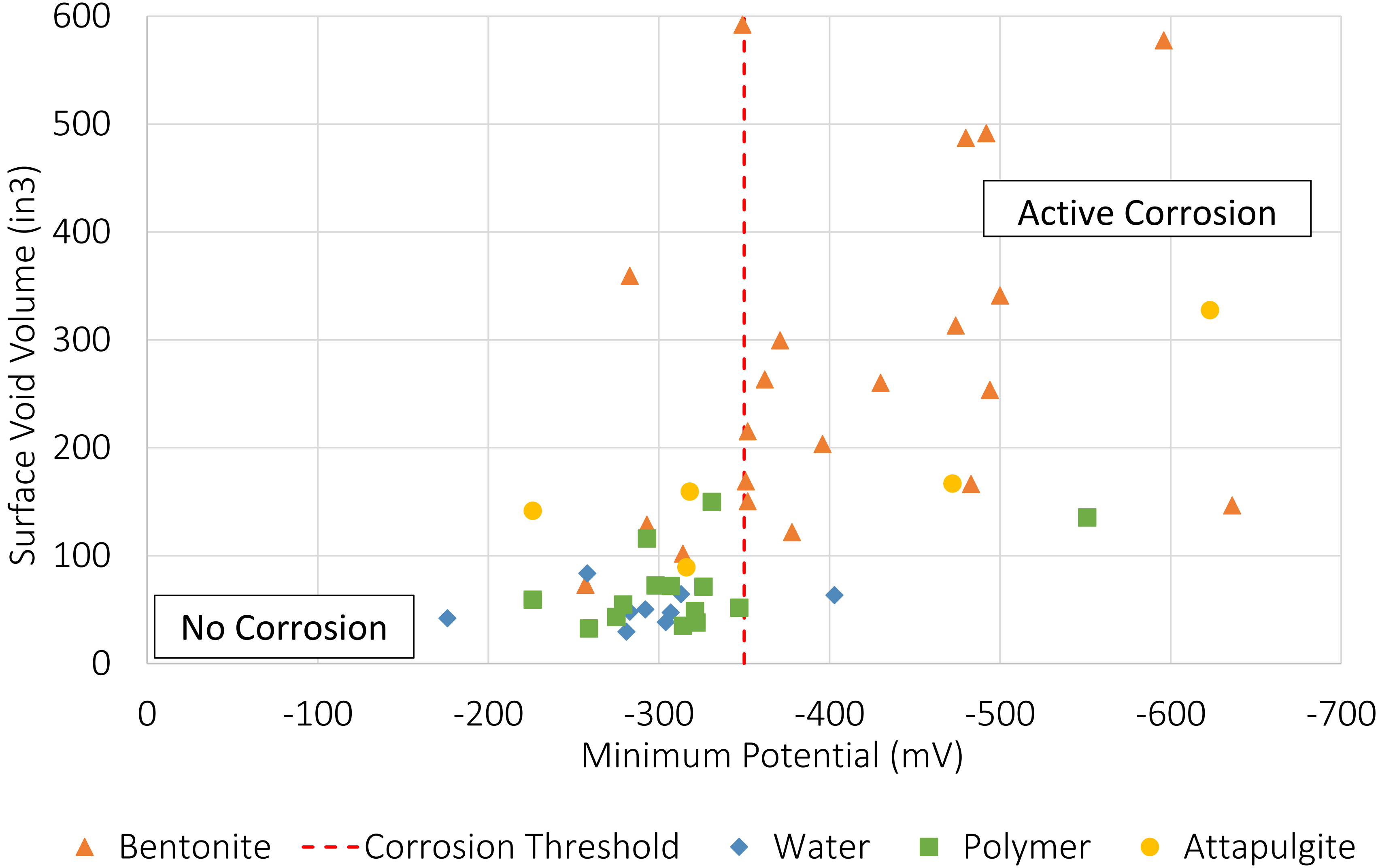
Water and Polymer Shafts



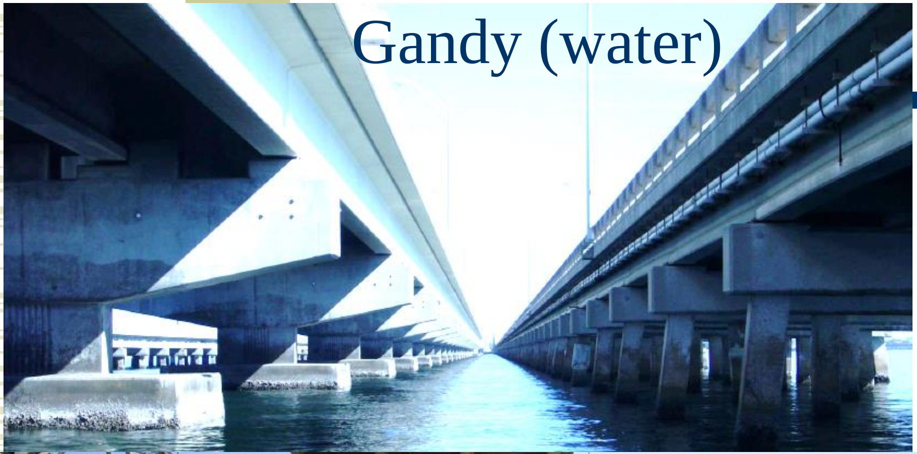
Bentonite Shafts



Surface Roughness

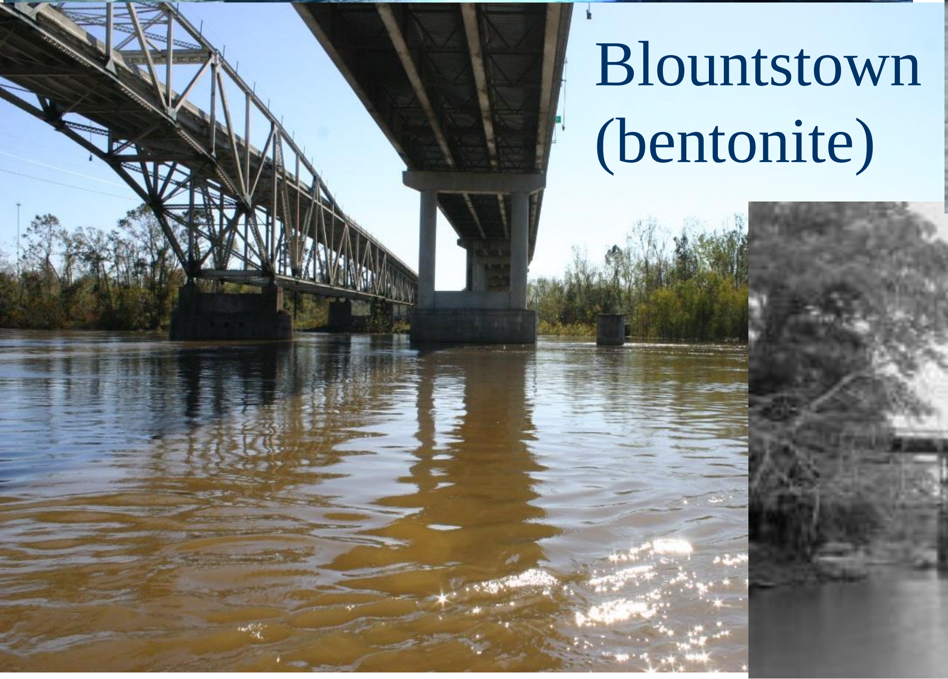


Underwater Shaft Inspections



Gandy (water)

Bridge of Lions (attapulgite)



Blountstown (bentonite)

US90 / Choctawhatchee (bentonite)

Casing Removal

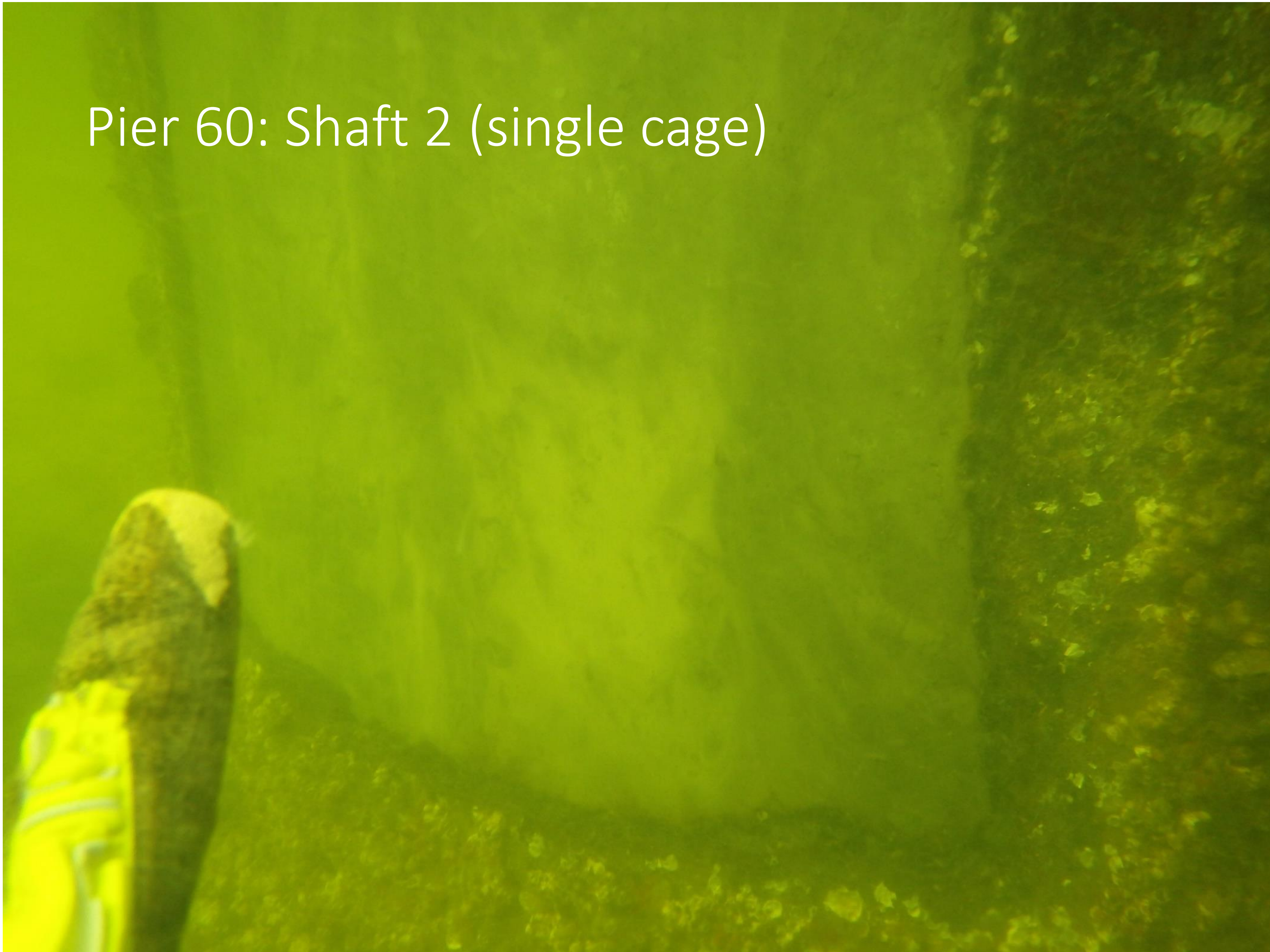
Water-cast Shafts

Gandy Bridge

US92 over Tampa Bay

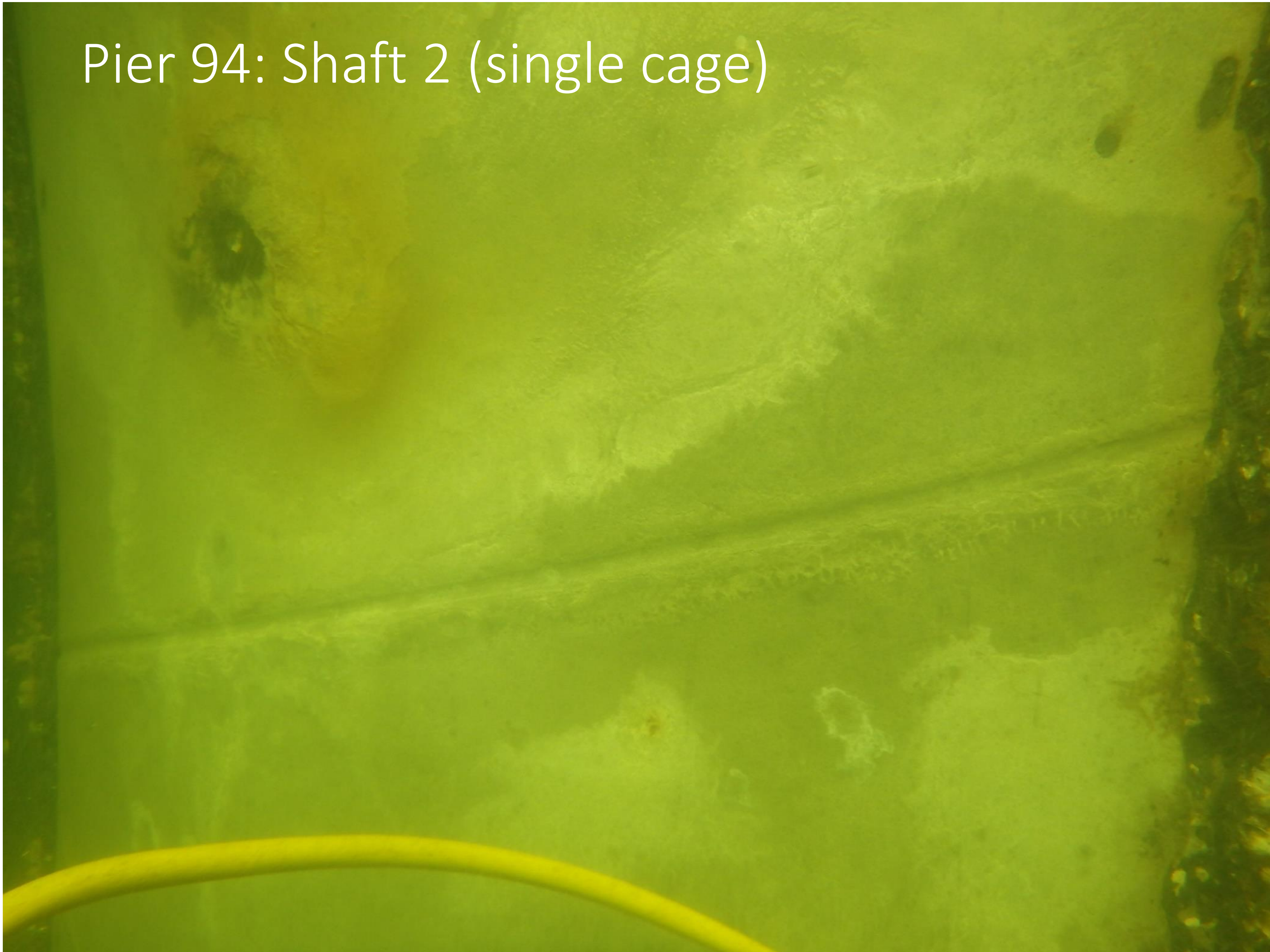
(salt water)

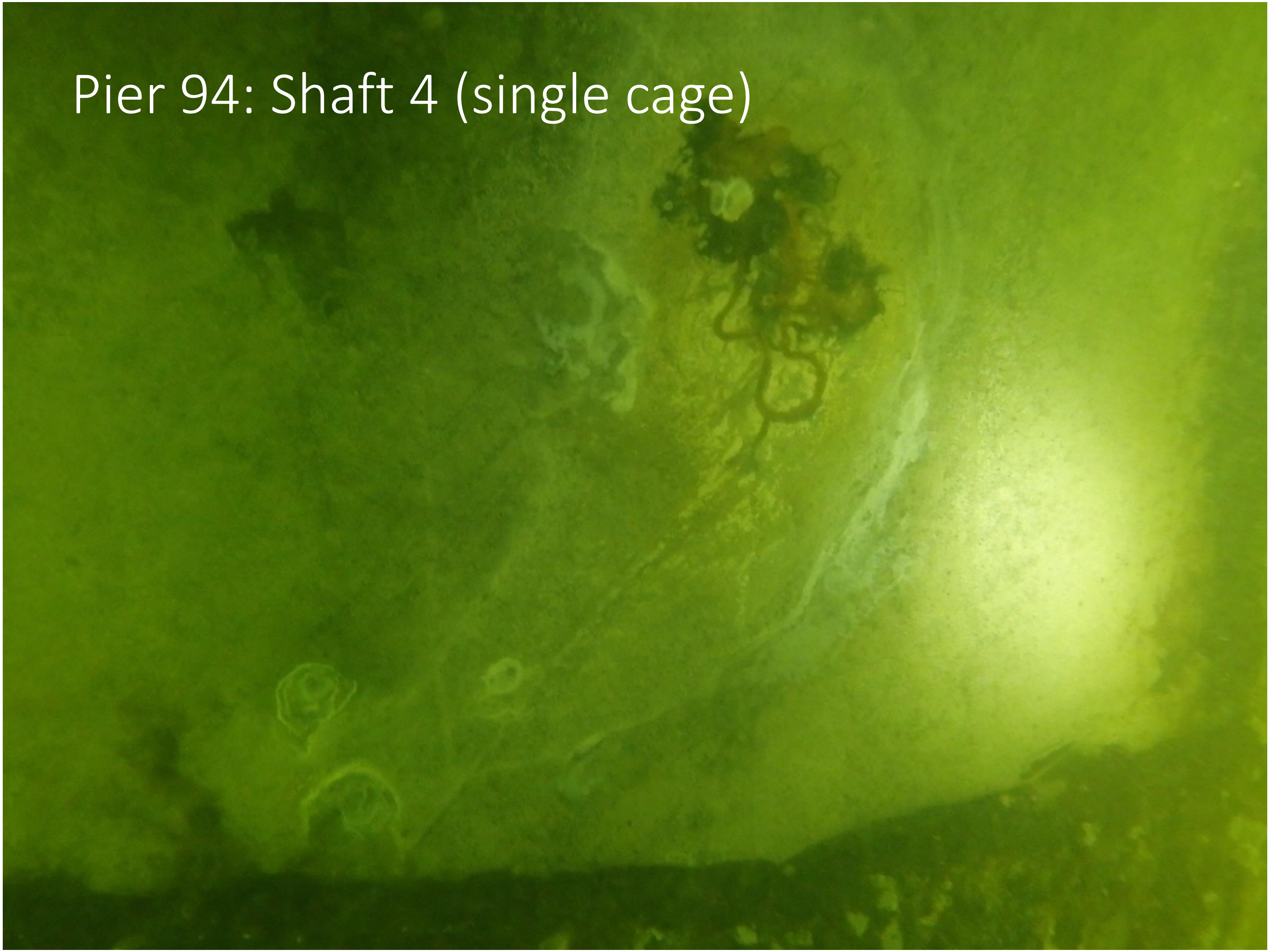
Pier 60: Shaft 2 (single cage)


Pier 60: Shaft 2 (single cage)

Pier 60: Shaft 4 (single cage)

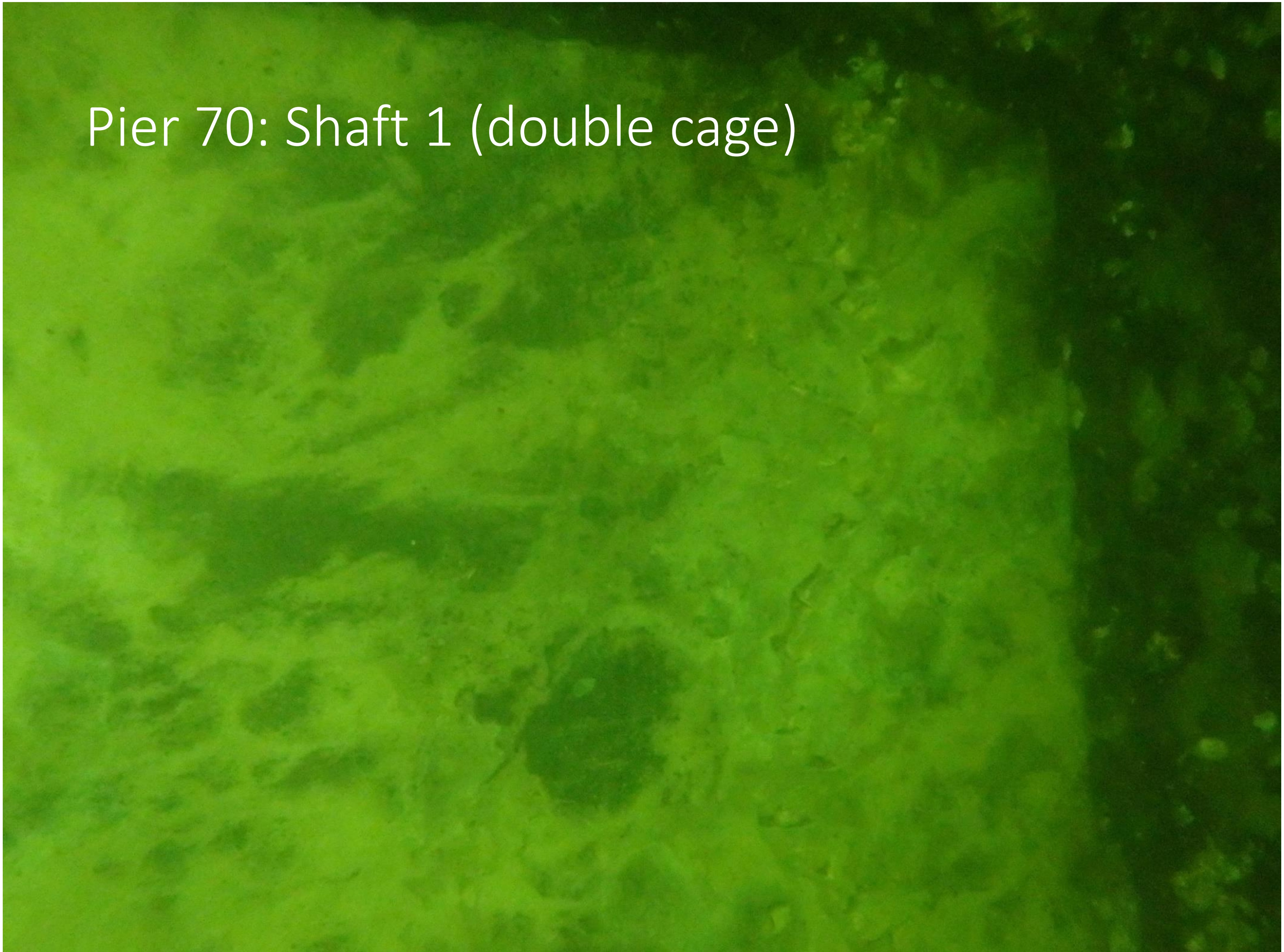
Pier 94: Shaft 2 (single cage)



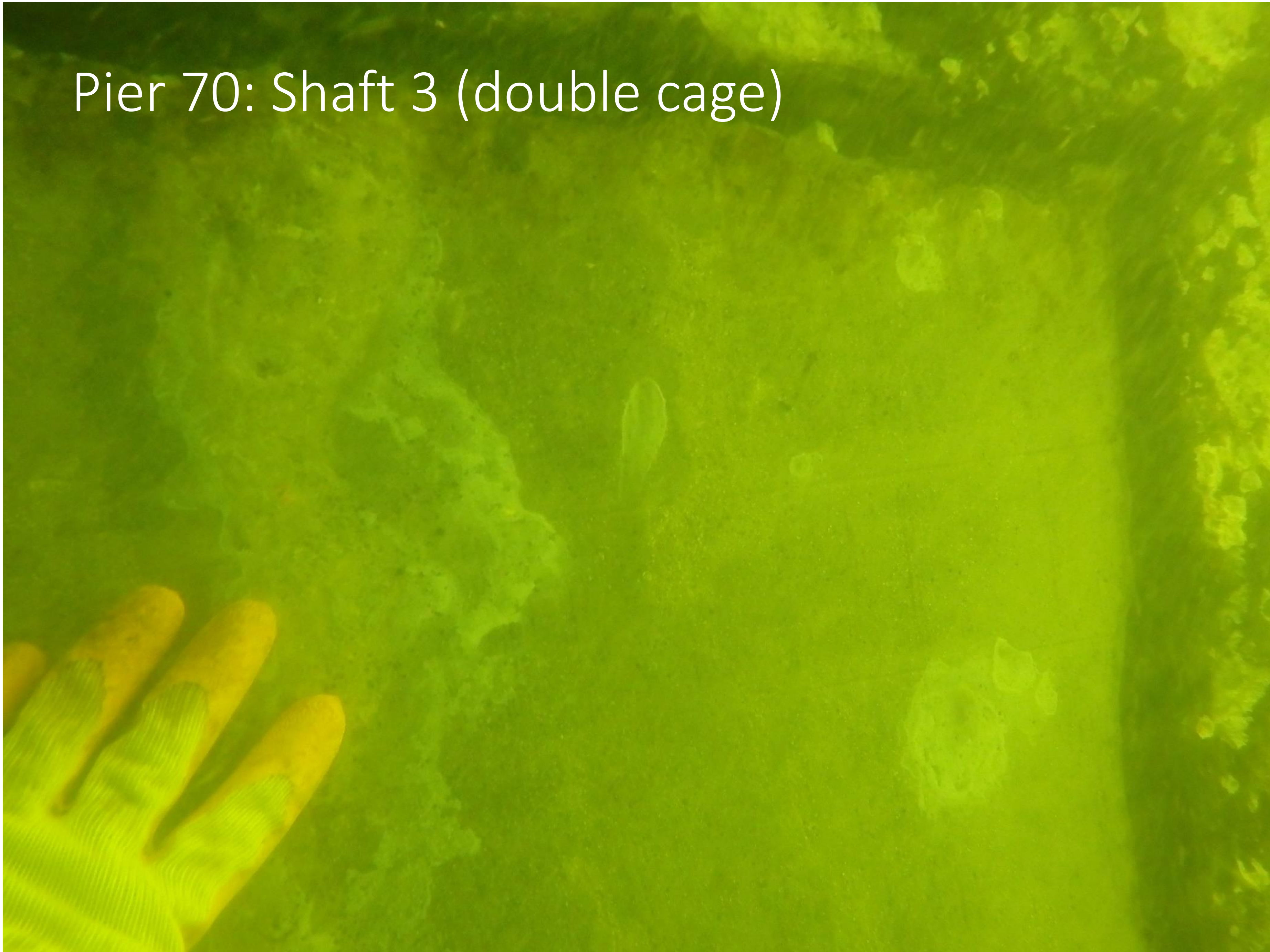

Pier 94: Shaft 4 (single cage)

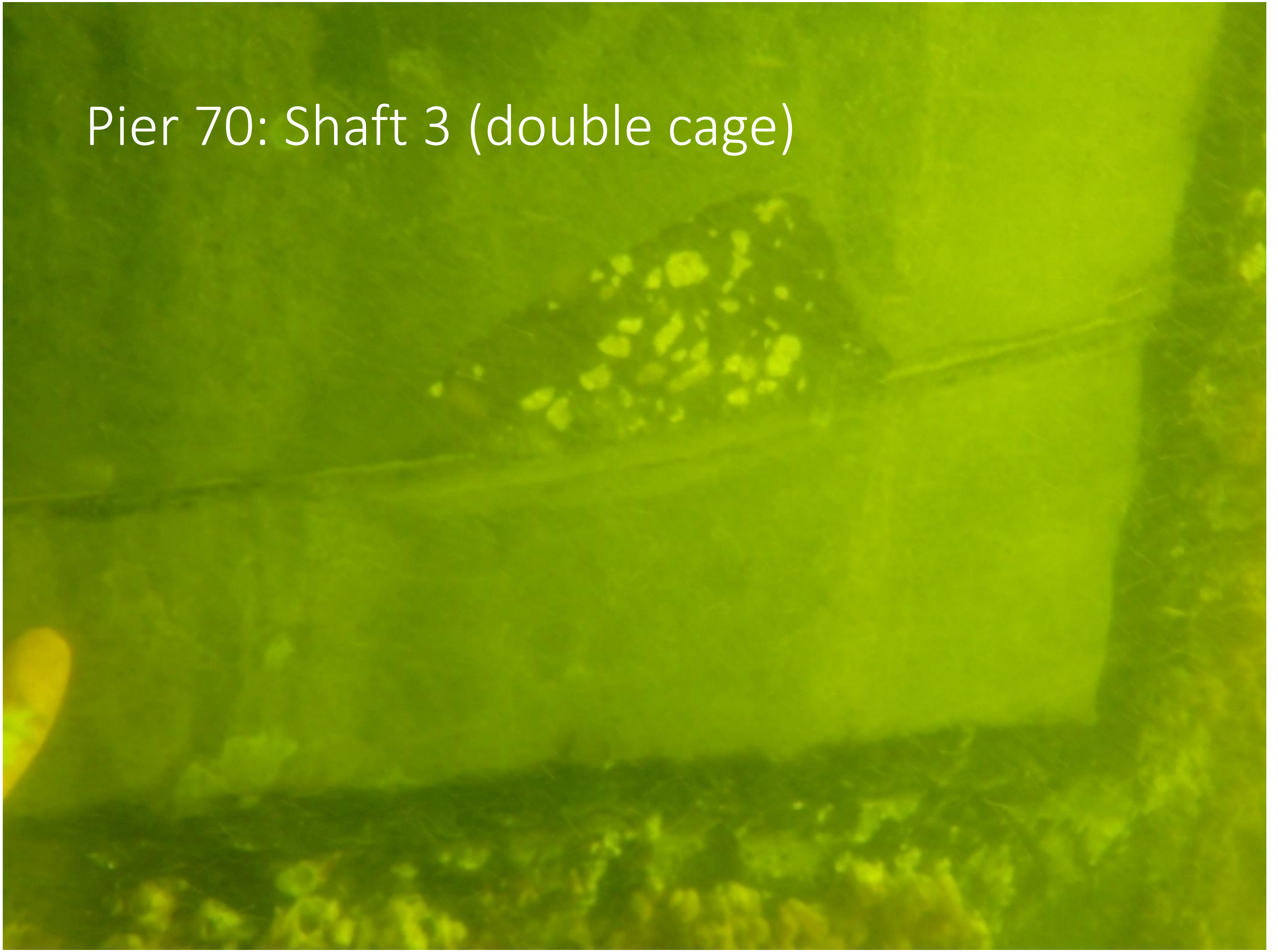
Pier 70: Shaft 1 (double cage)

Pier 70: Shaft 1 (double cage)



Pier 70: Shaft 3 (double cage)

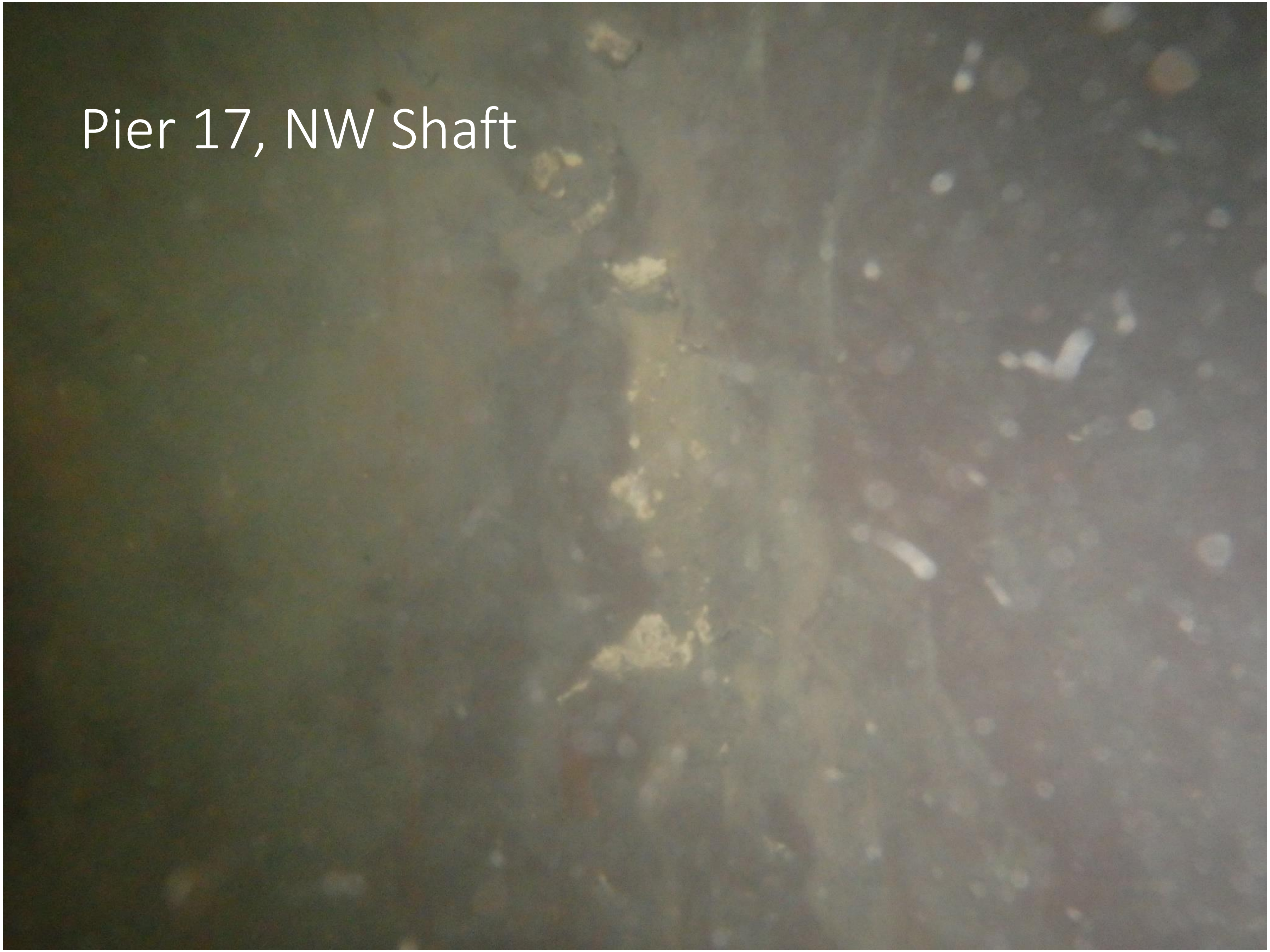



Pier 70: Shaft 3 (double cage)

Attappulgite-cast Shafts

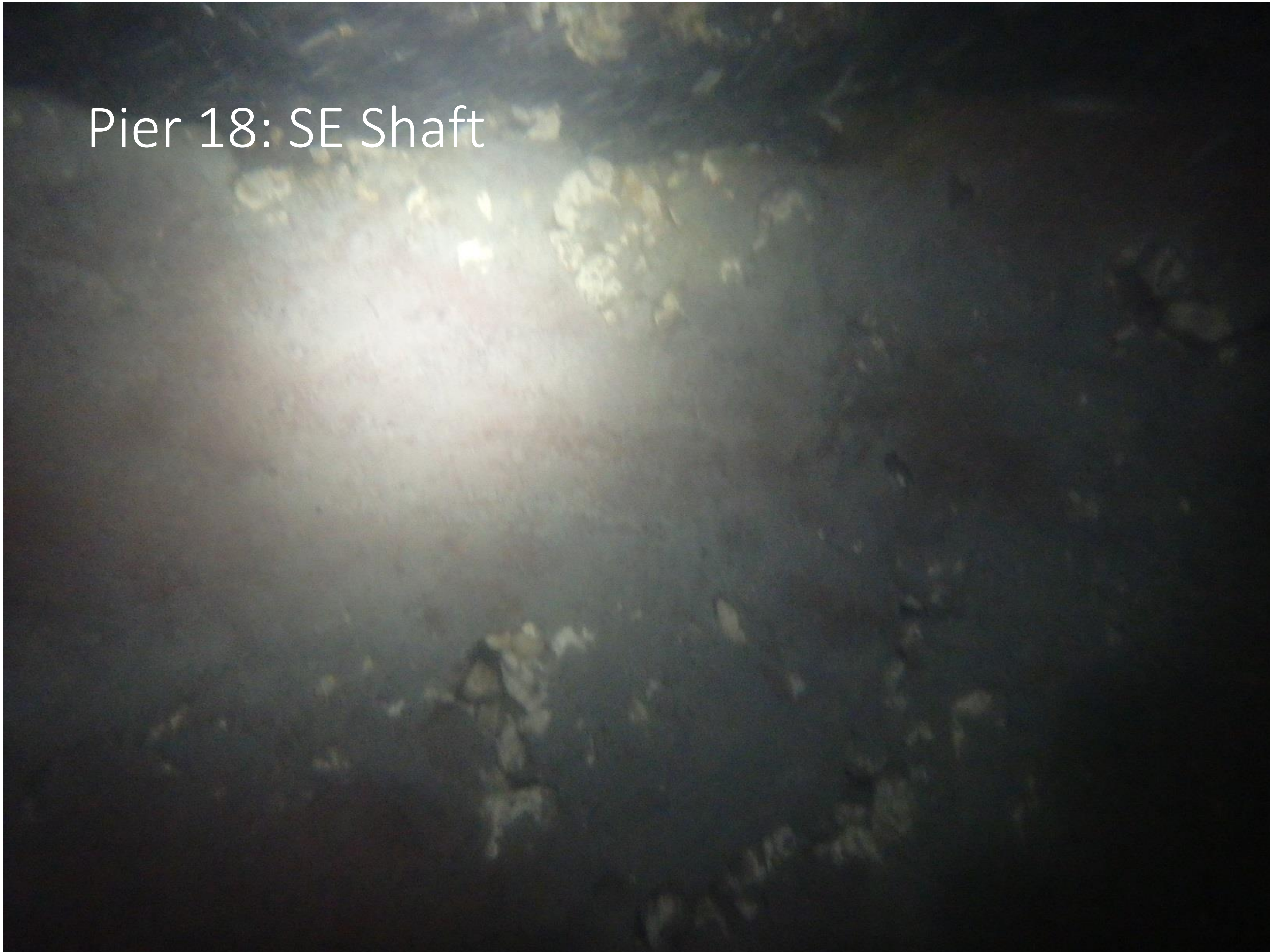
(~1-1.5 lb/gal)

Bridge of Lions
SR A1A over Intracoastal Waterway
St. Augustine
(salt water)


Pier 17, NW Shaft

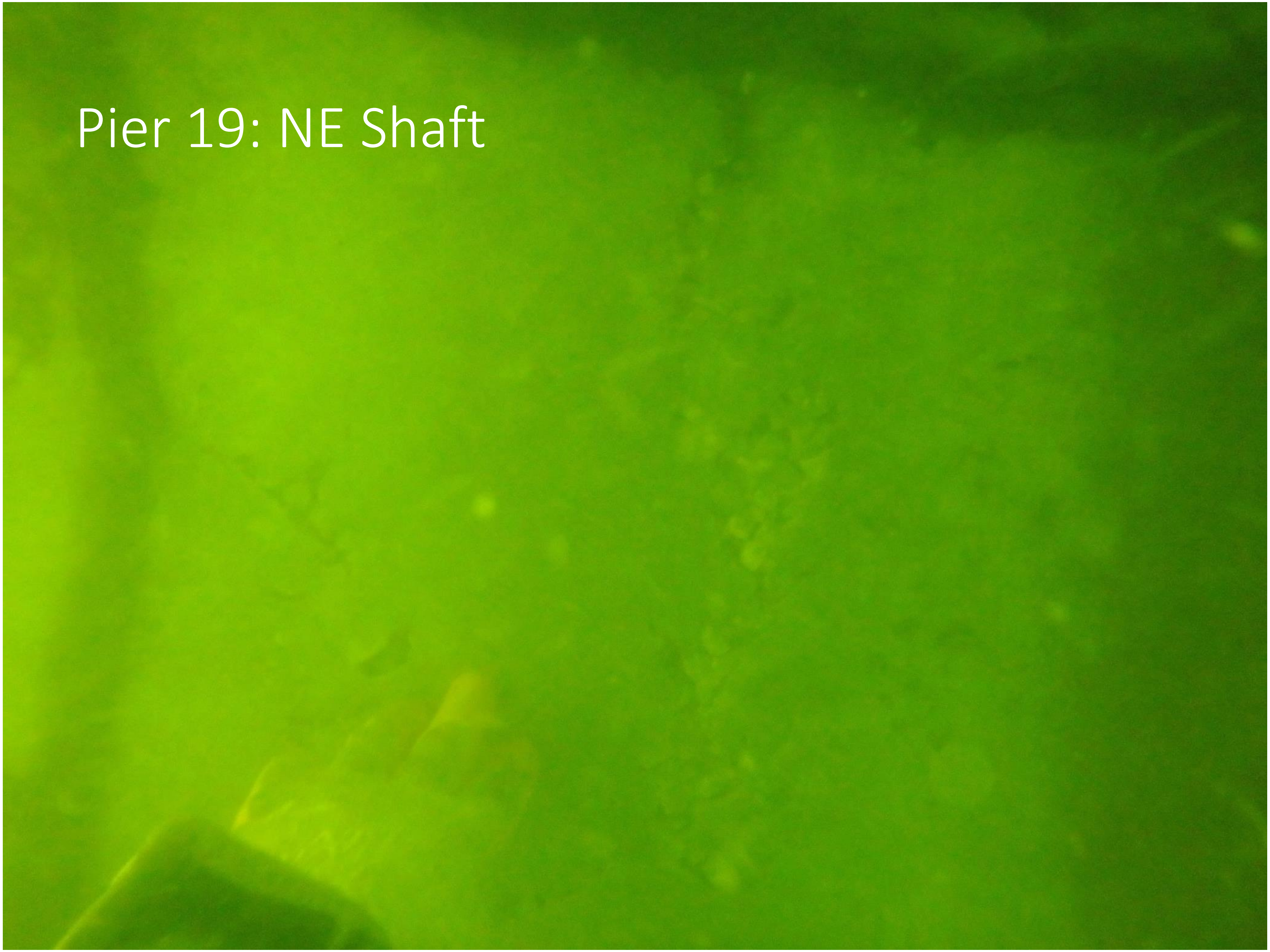

Pier 17: SW Shaft

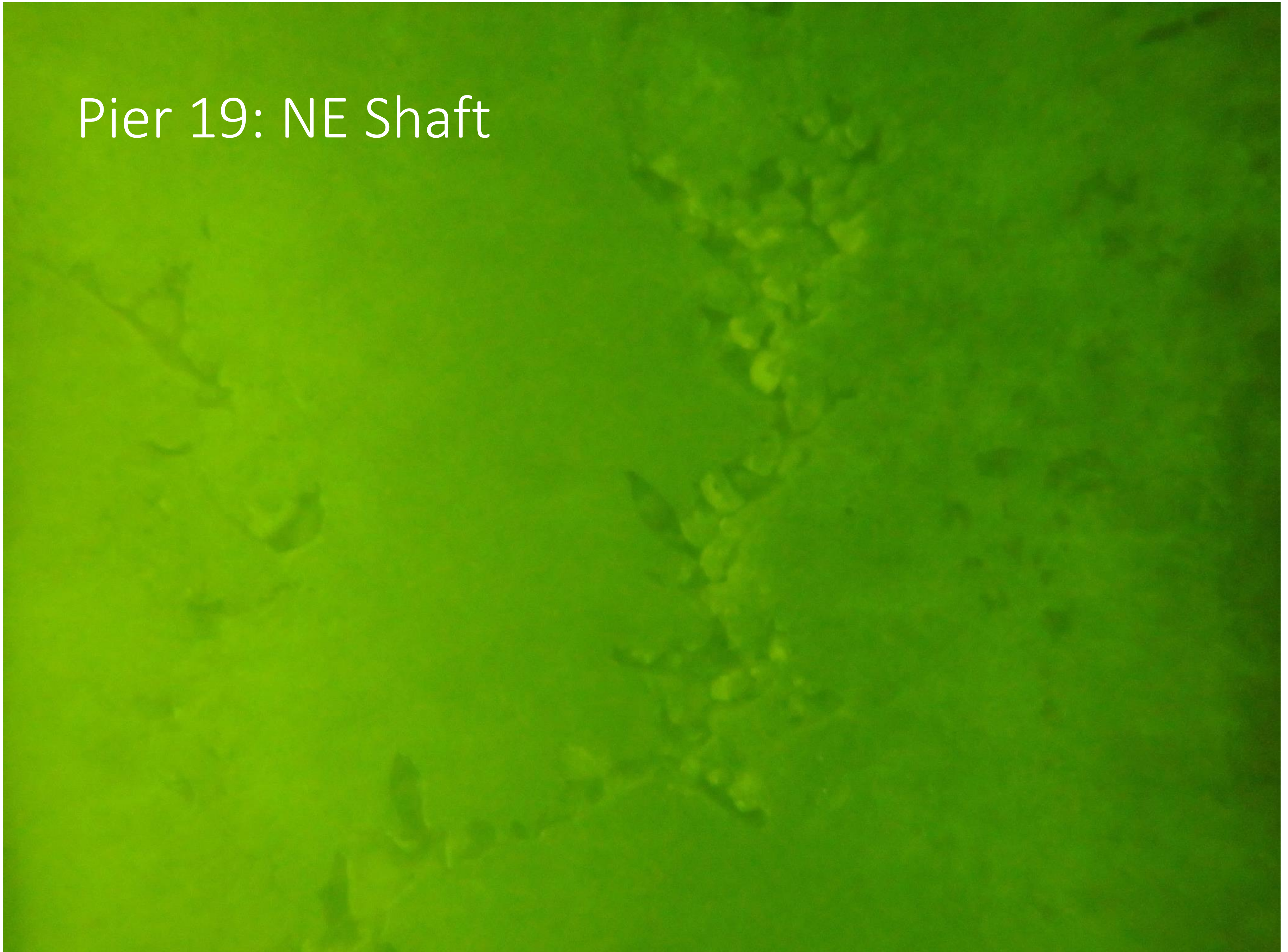
Pier 18: SE Shaft




Pier 18: SE Shaft

Pier 19: NE Shaft




Pier 19: NE Shaft


Pier 19: SE Shaft

Bentonite-cast Shafts

(~0.5 lb/gal)

SR 20 over Apalachicola River

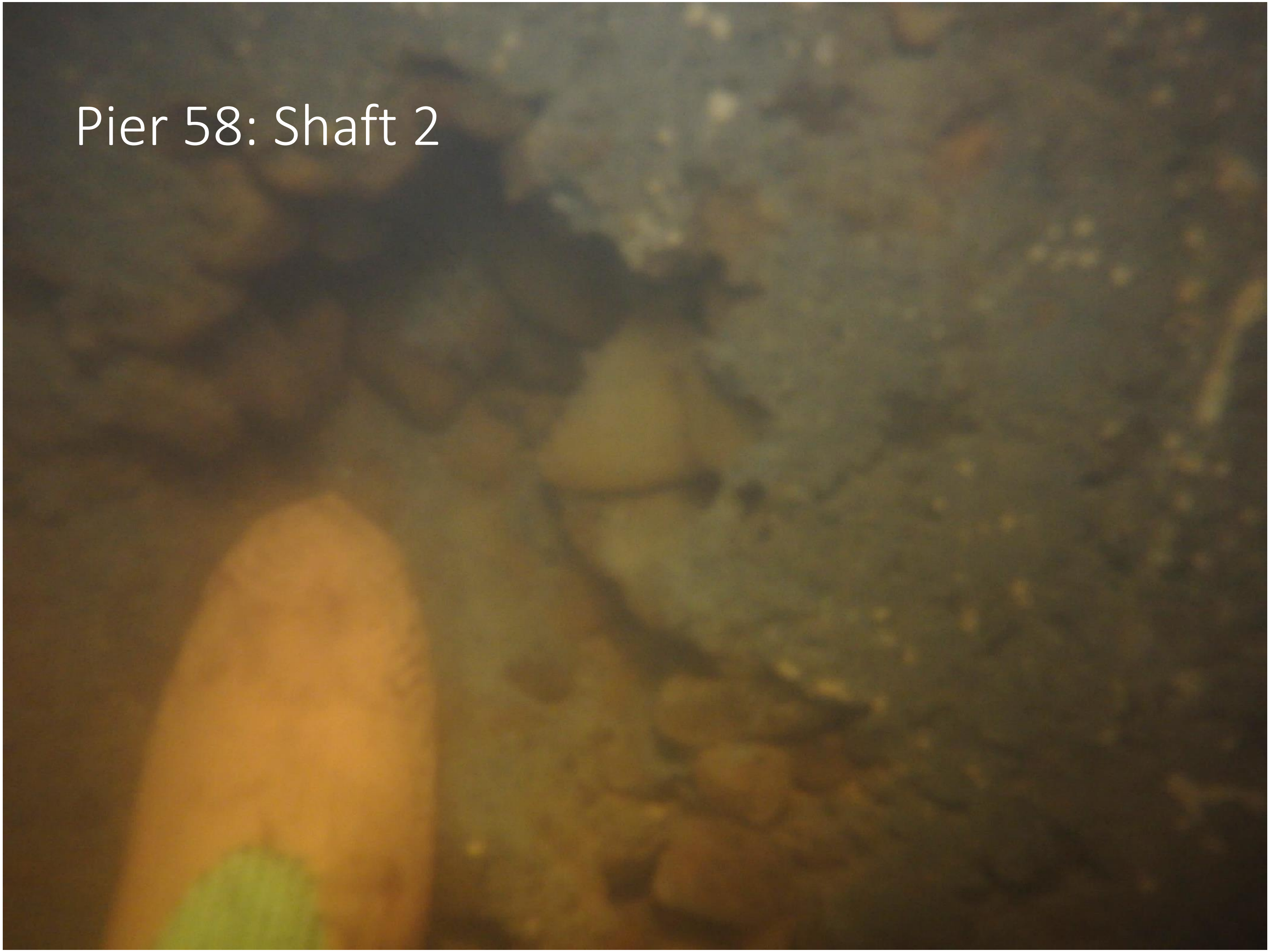
Blountstown

(fresh water)

Pier 58 Shaft 1


Pier 58: Shaft 2

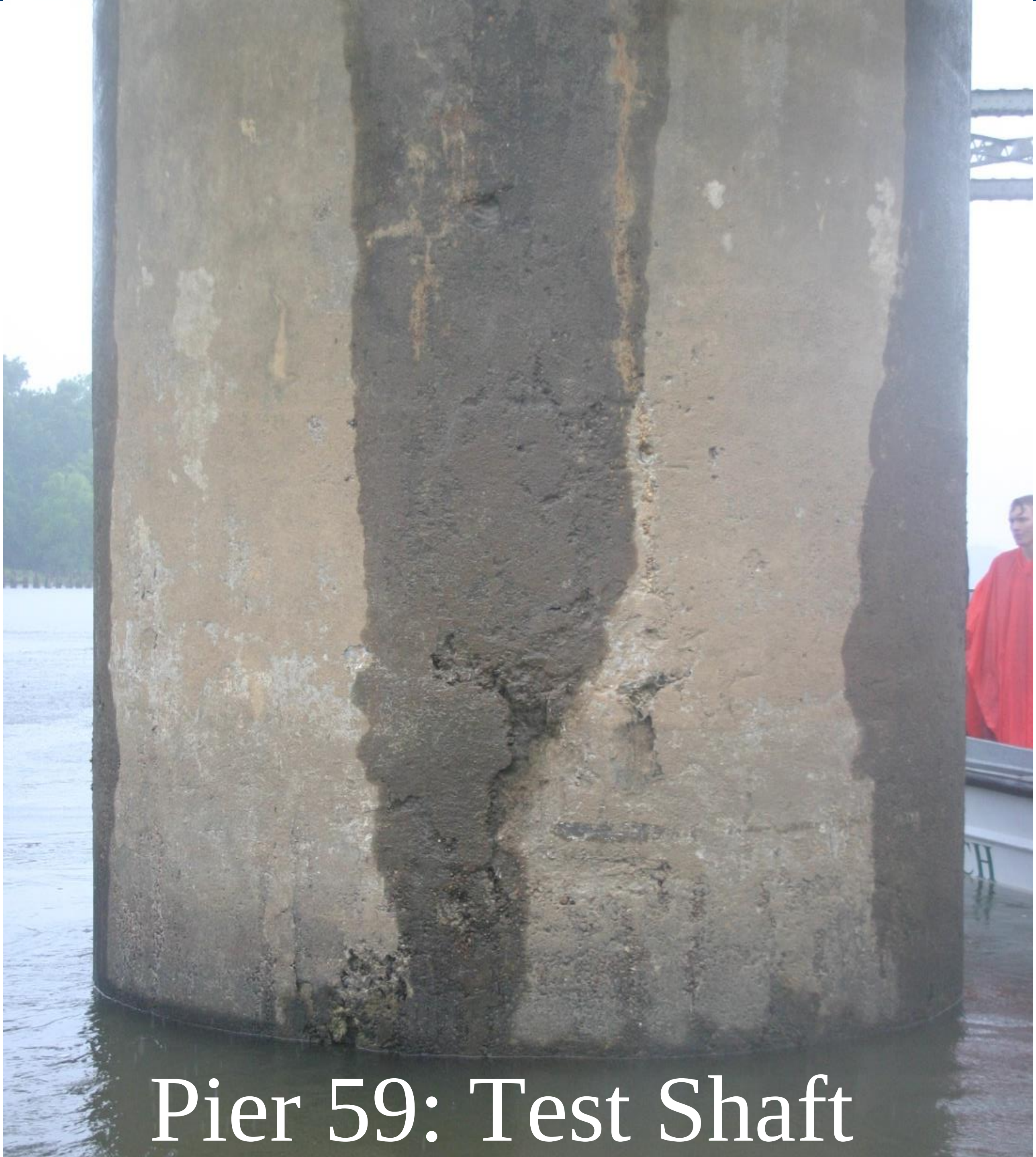

Pier 58: Shaft 2


Pier 58: Shaft 2


Pier 58: Shaft 2

Pier 59, Shaft 1


Pier 59: Test Shaft

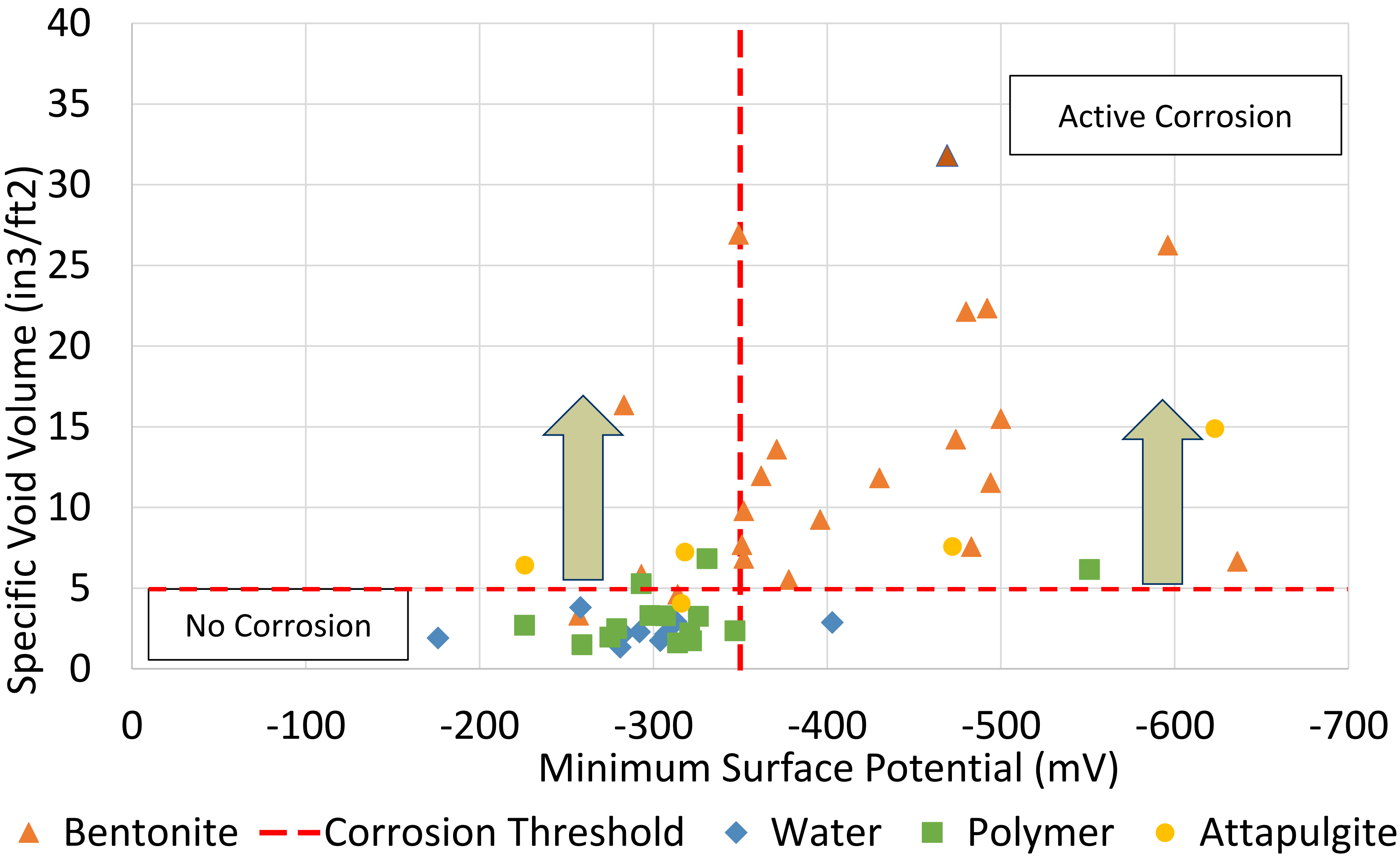


Pier 59: Test Shaft

Surface Condition
(failure ratios: measured and observed)

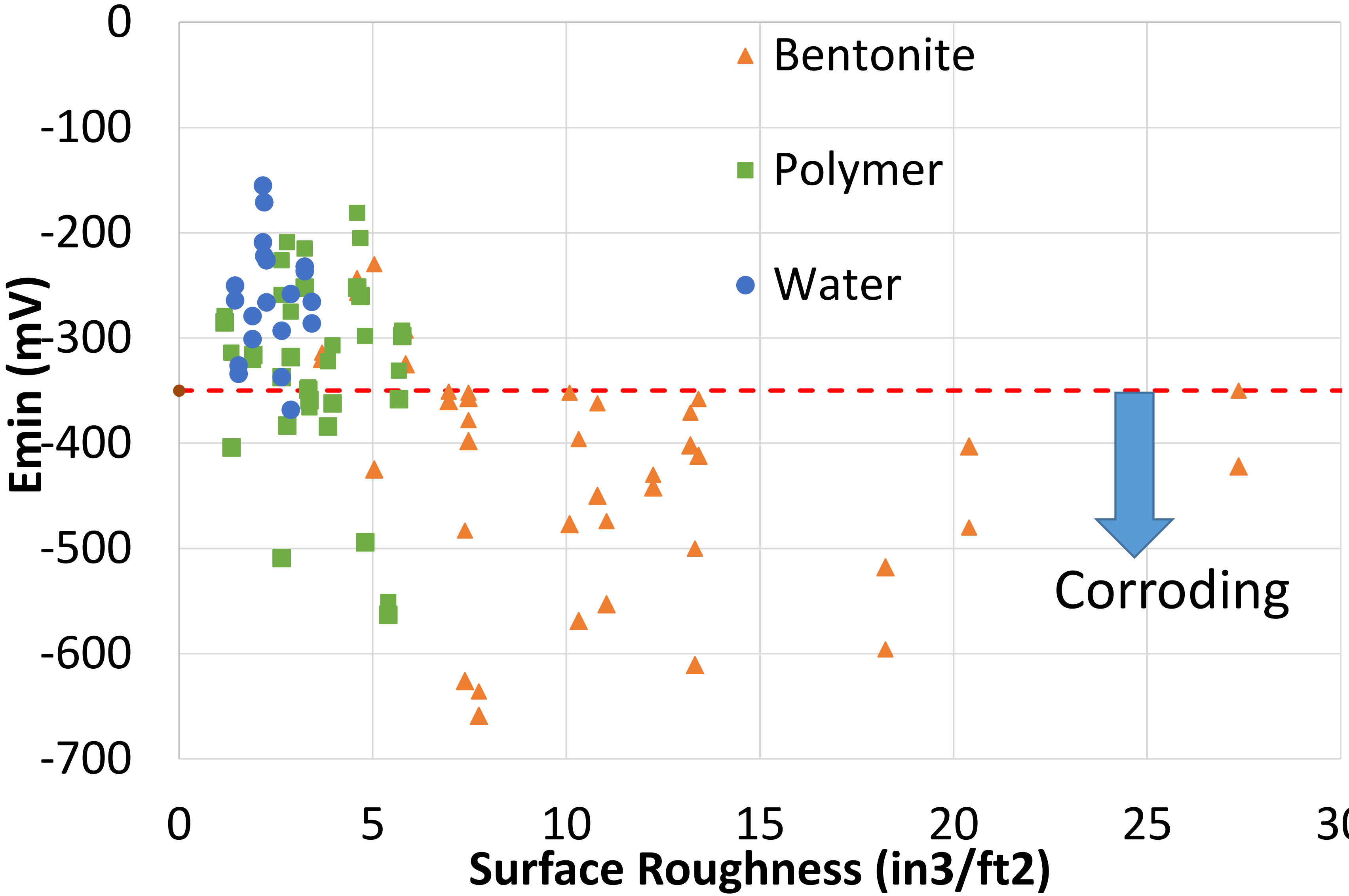
Specimen Source	Water		Attapulgite		Bentonite		Polymer	
Lab measured corrosion	1:10	10%	2:5	40%	18:21	86%	9:15	60%
Field observed surface blemishes	1:8	12.5%	5:11	45%	13:13	100%	n/a	n/a
	2:2	100%						

Specific Surface Roughness
(Need to quantify)

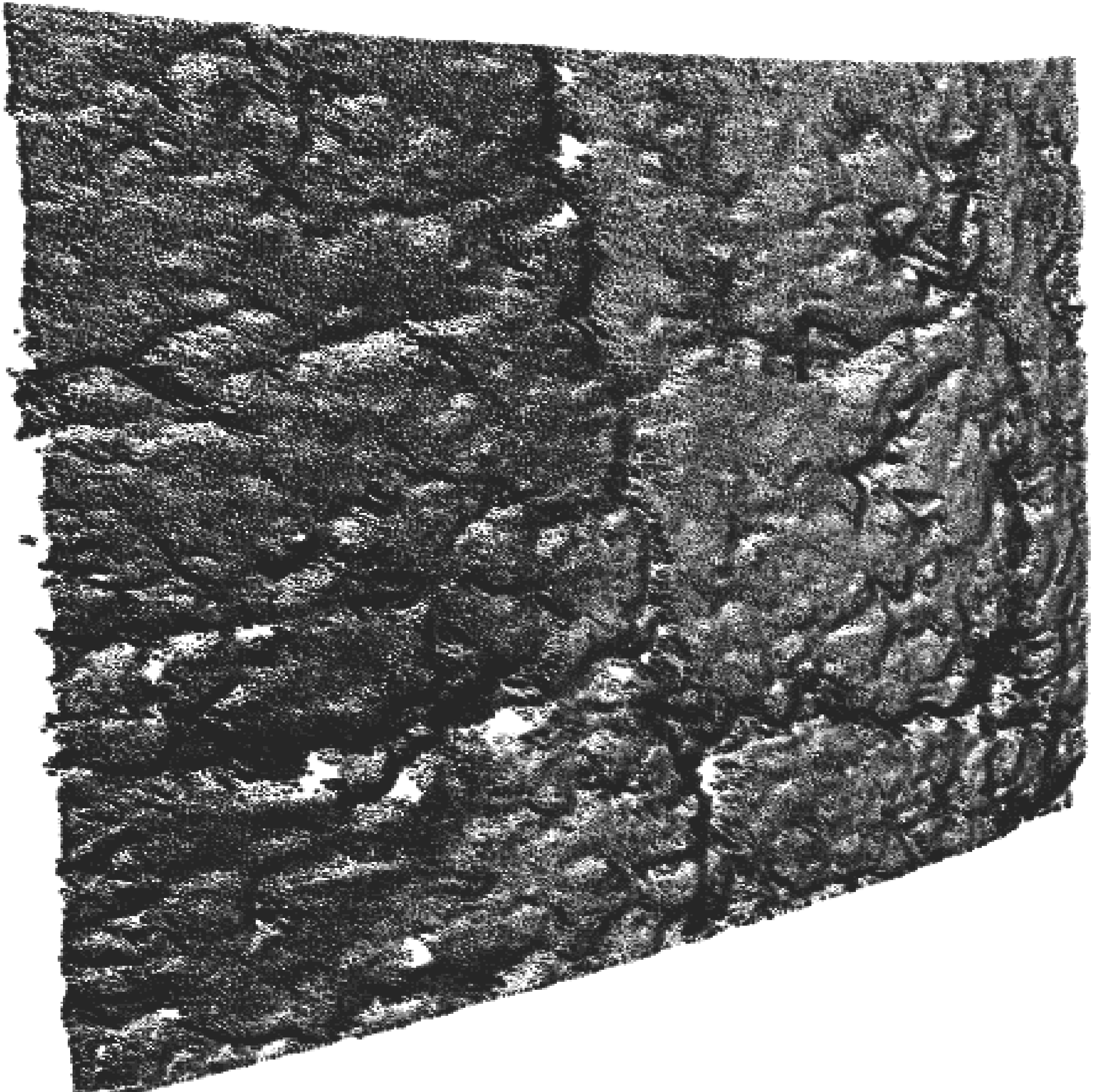


Surface Roughness vs Corrosion Activity

(Two years later; Mobley, 2019)

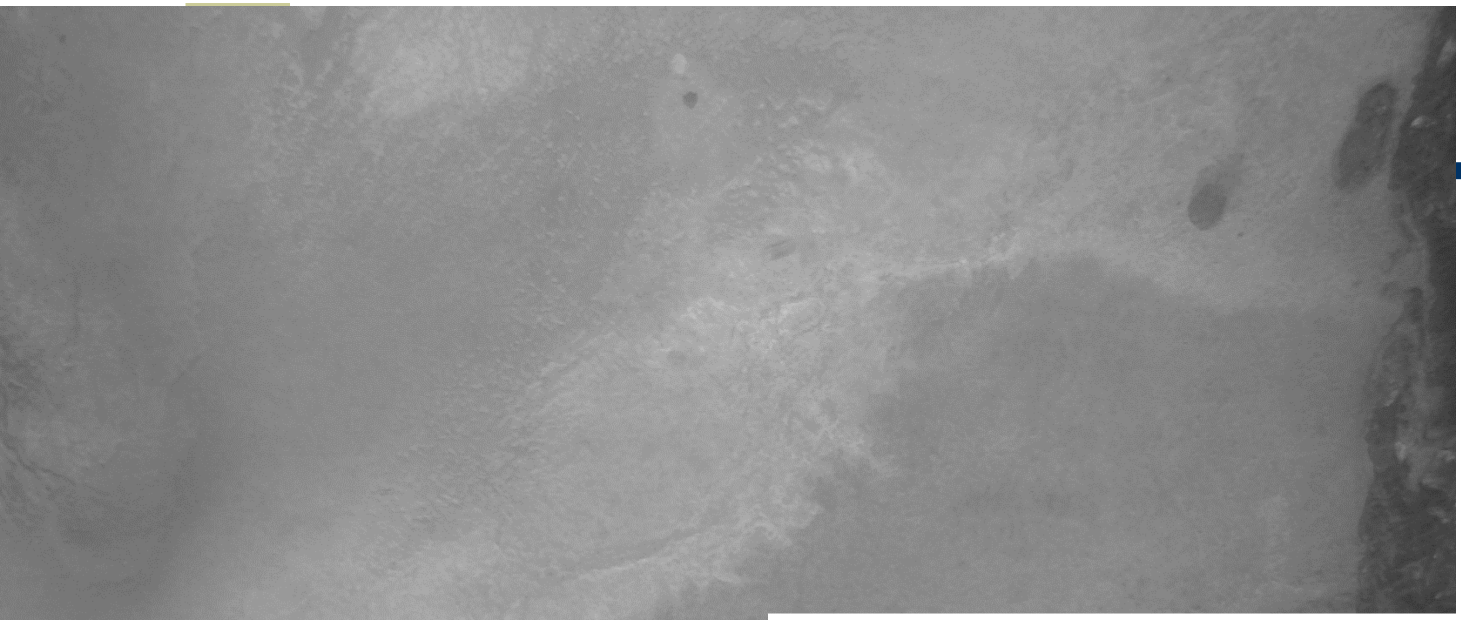


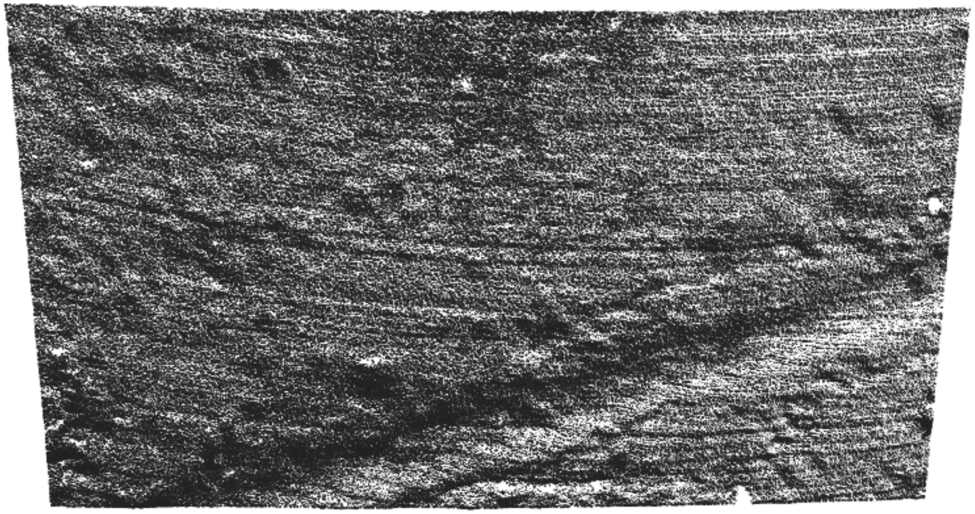
Underwater Laser Scanning




3
1
2

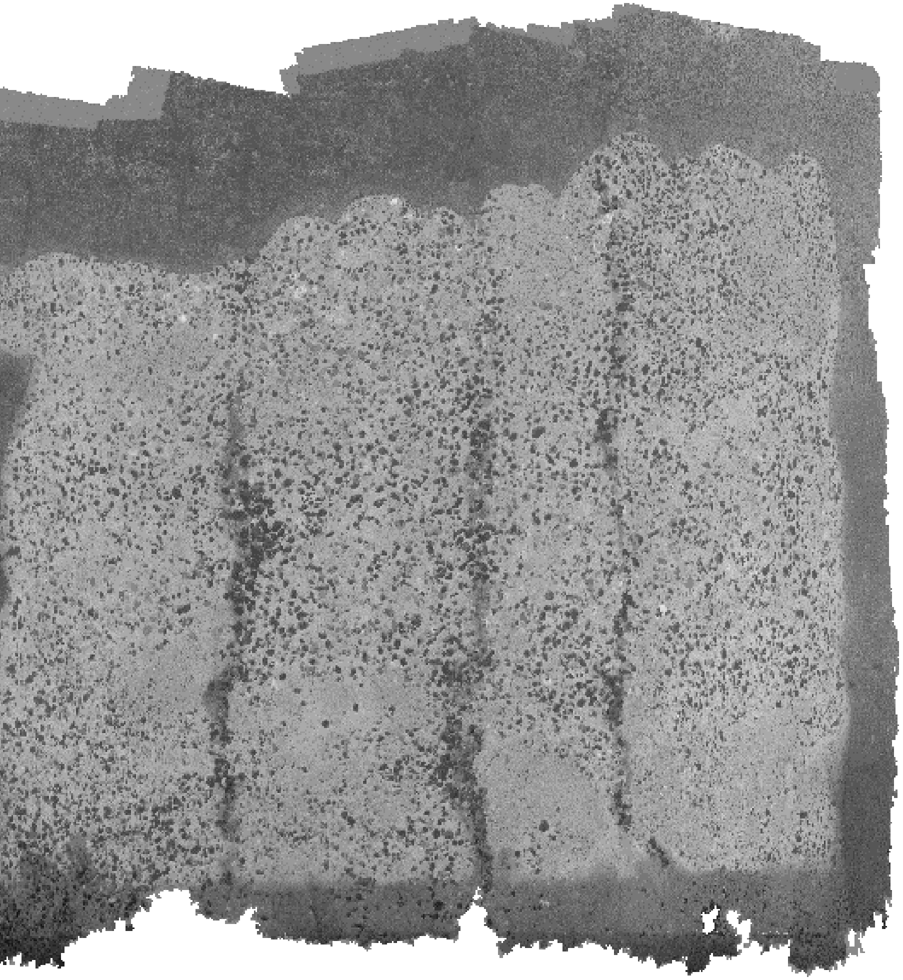
Gandy Bridge Pier 94
Southwest shaft





Caryville Bridge Pier 13

South shaft

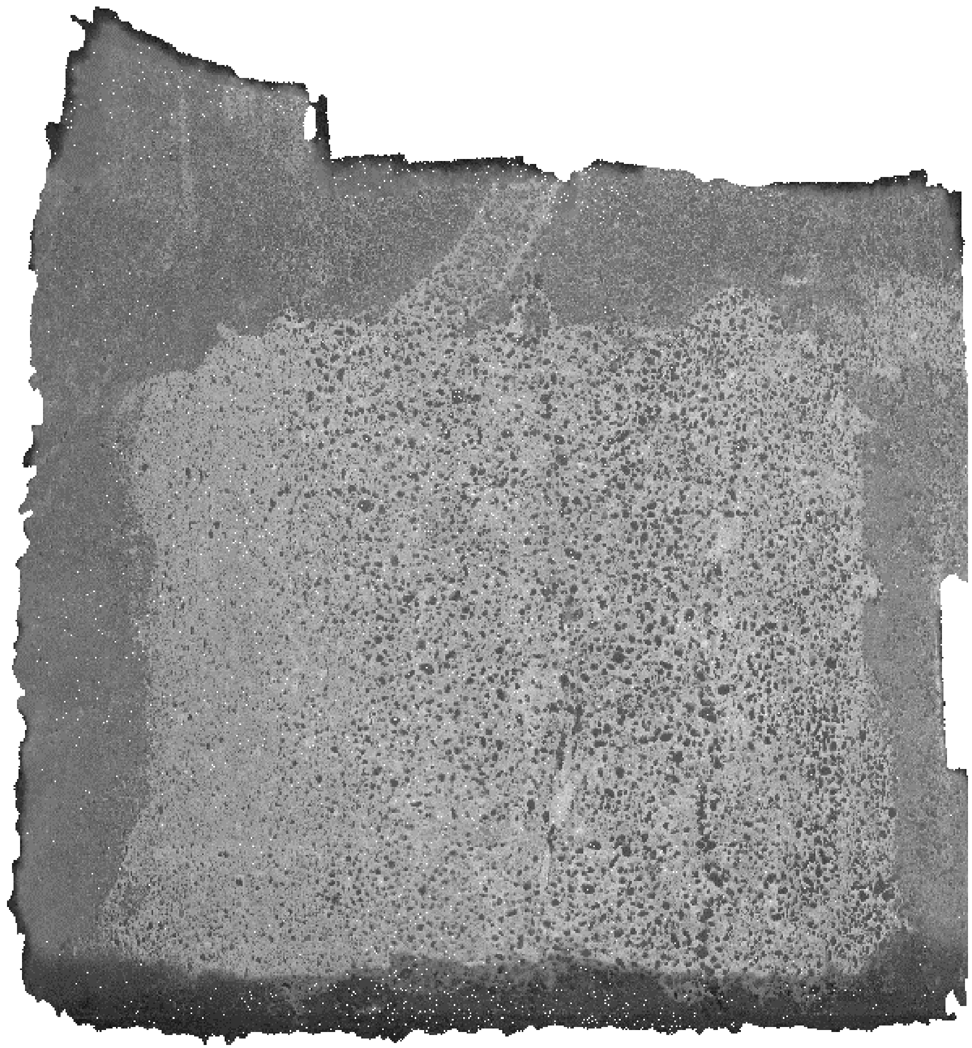


North shaft

Caryville Bridge Pier 14

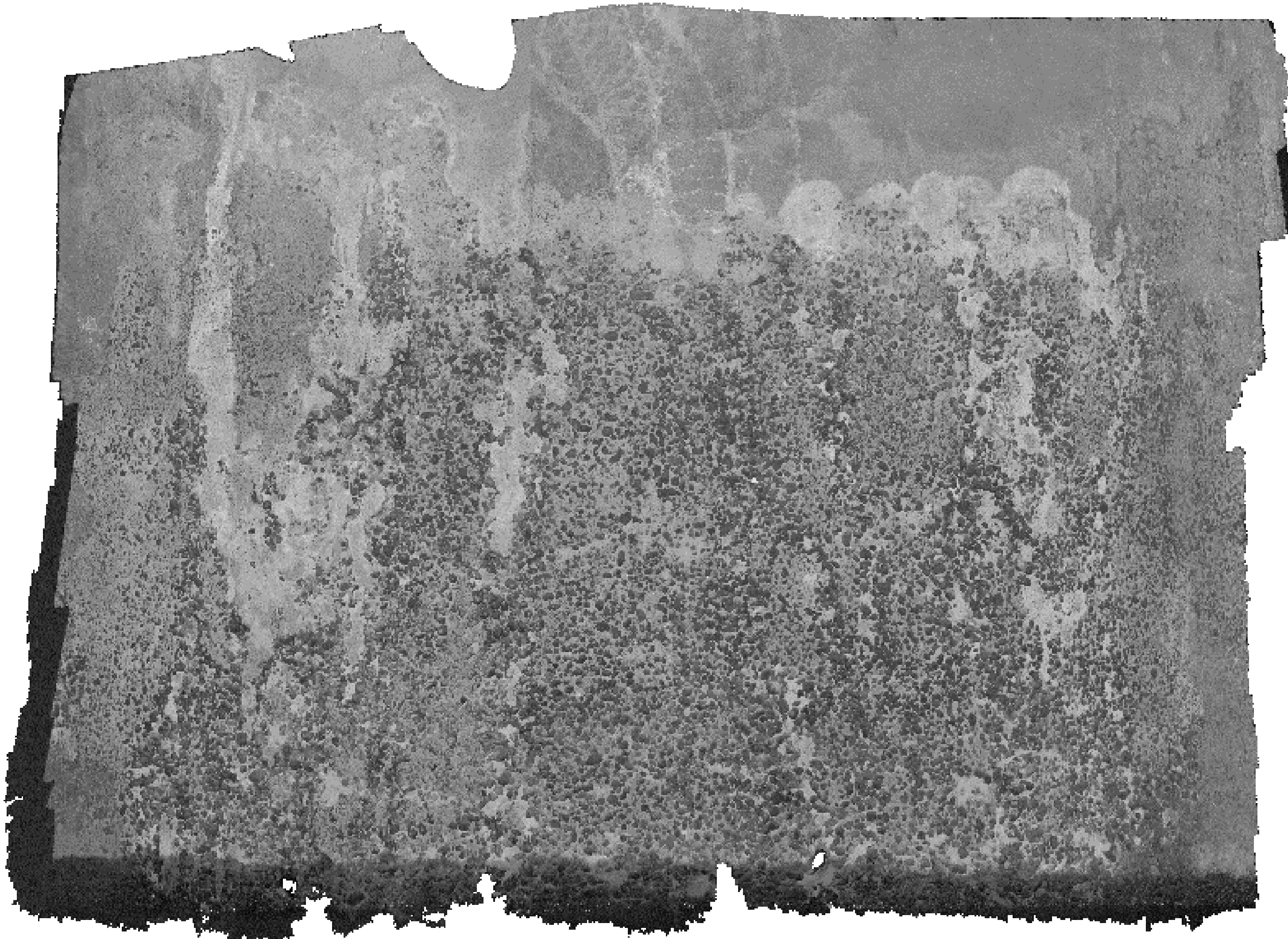
South shaft

North shaft



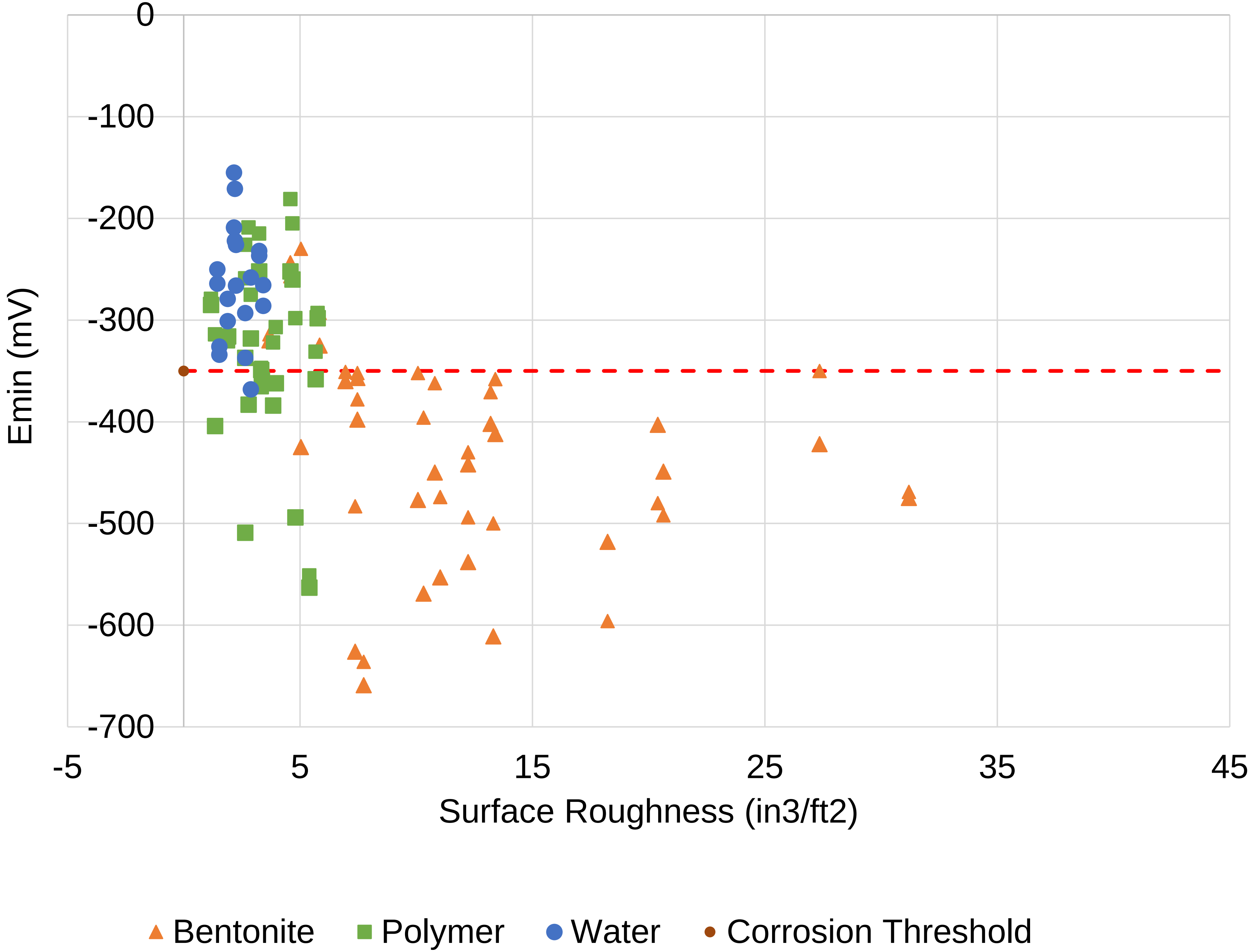
Blountstown Bridge Pier 59 North

Blountstown Bridge Pier 59 North

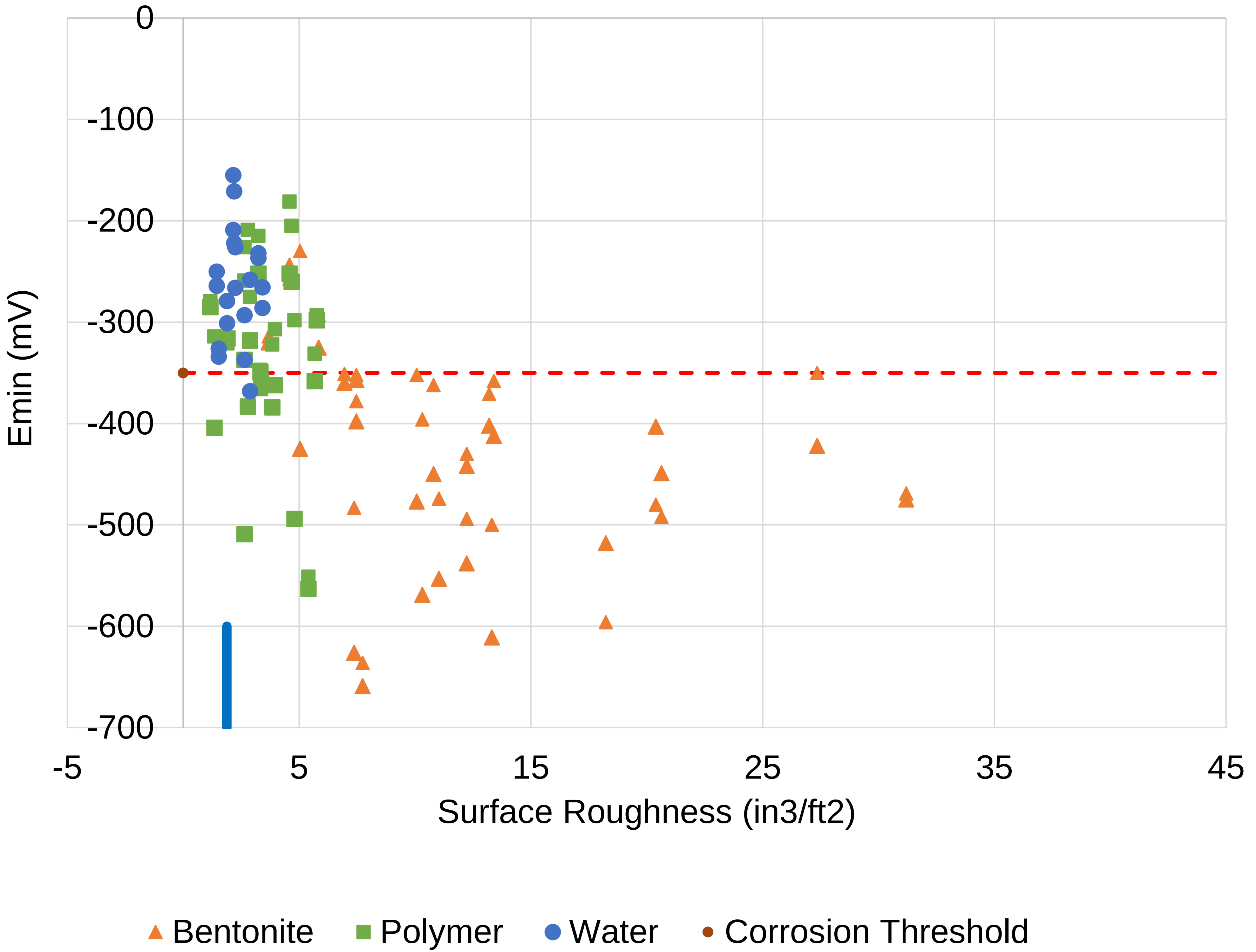


Digital Surface Roughness

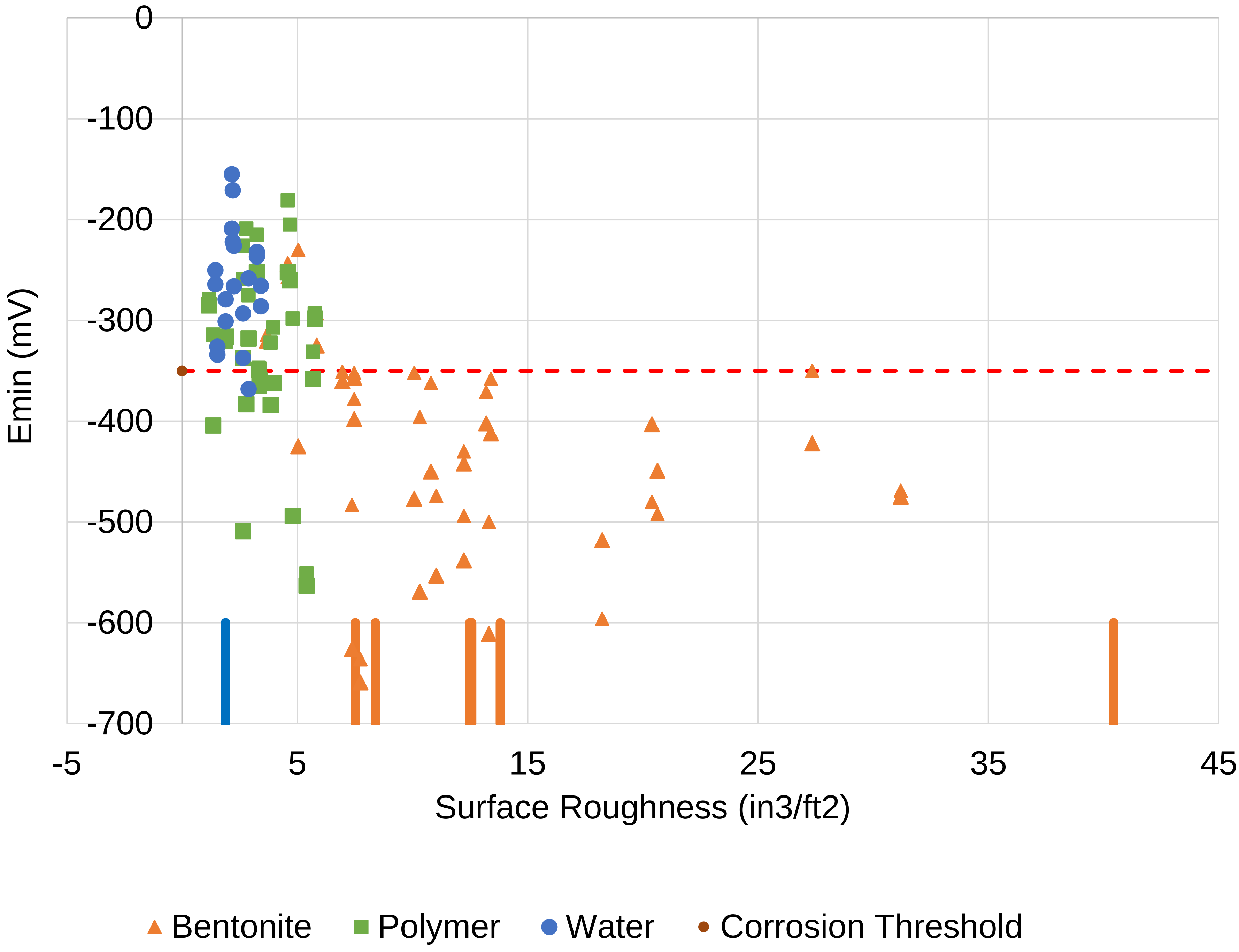
Shaft ID	Surface Void Volume	Slurry Type
Pier 13 North	13.81	Bentonite
Pier 13 South	8.39	Bentonite
Pier 14 North	7.52	Bentonite
Pier 14 South	12.57	Bentonite
Pier 59 North	12.49	Bentonite
Pier 59 South	40.44	Bentonite
Pier 94 Southwest	1.89	Water
Lab verification	45.42	Bentonite



0
-100
-200
-300
-400
-500
-600
-700
Emin (mV)
-5
5
15
25
35
45
Surface Roughness (in3/ft2)
Bentonite
Polymer
Water
Corrosion Threshold



0
-100
-200
-300
-400
-500
-600
-700
Emin (mV)
-5
5
15
25
35
45
Surface Roughness (in3/ft2)
Bentonite
Polymer
Water
Corrosion Threshold


0
-100
-200
-300
-400
-500
-600
-700
-5
5
15
25
35
45
Emin (mV)
Surface Roughness (in3/ft2)
Bentonite
Polymer
Water
Corrosion Threshold

Summary

- Effects of tremie placed concrete in a slurry environment were evaluated.
- Surface roughness (behind smooth casing) is a strong indicator of cover integrity / durability / active corrosion
- Field and laboratory observations of shafts cast in mineral slurry qualitatively and quantitatively appear to be the same.

Conclusions

- Water cast shafts had very low occurrences of problems.
- Slurry cast shafts had high probability of problems:
  - Rebar bond strength is statistically half that of water or dry casting conditions (code based).
  - Corrosion was active in 86% of bentonite cast shafts and 100% when surface roughness exceeded $5in^3/ft^2$
  - Corrosion was active in 60% of polymer cast shafts after two years but surface roughness was visibly perfect.

Recommendations / Implementation

- Discourage or eliminate bentonite and polymer slurry displacement in aggressive environments (temporary casing method only).
- Increase (double) reinforcing bar development length for slurry casting environments.
- Evaluate current bridge inventory for eminent failure potential (active corrosion or high bending moment applications)

Questions