DRILLED SHAFTS: DESIGN, CONSTRUCTION, QA/QC TESTING

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Quality First in the First State

MID-ATLANTIC QUALITY ASSURANCE WORKSHOP

American Geotechnical & Environmental Services, Inc.

Outline

- Recent AASHTO/FHWA changes in design equations → QA/QC impact
- Construction: drilling Tools / machines
- Instrumentation for drilling (QA/QC)
- Testing (QA/QC) constructed shaft


BRAYMAN

Design Equations: the “old” vs new

<u>Ultimate side friction (example if controlled by 3 ksi concrete)</u>

AASHTO 2012 and earlier

$$q_s = 0.65\alpha_E p_a (q_u/p_a)^{0.5} < 7.8 p_a (f'_c/p_a)^{0.5}$$

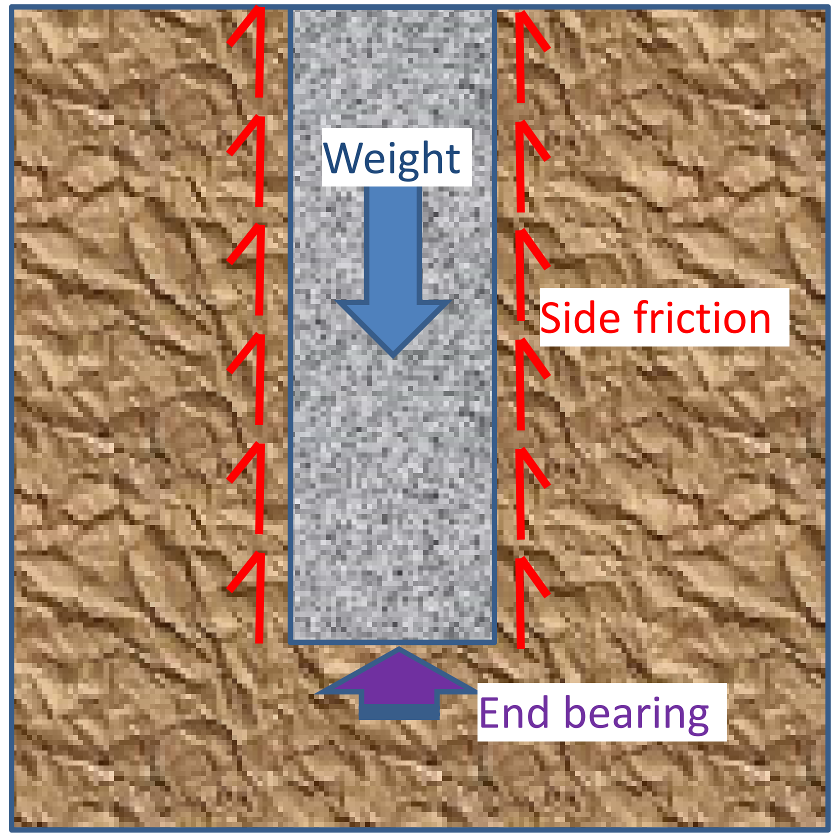
q_s= 19.7 ksf

AASHTO 2014

$$q_s/p_a = C\sqrt{q_u/p_a}$$

q_s= 30.3 ksf

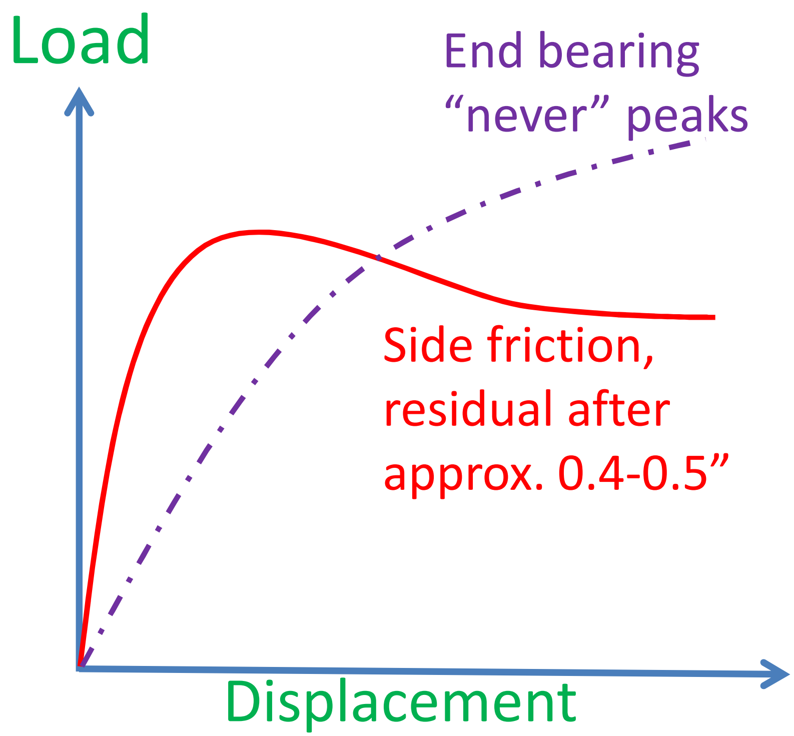
New value is **<u>1.54</u>** times the old!

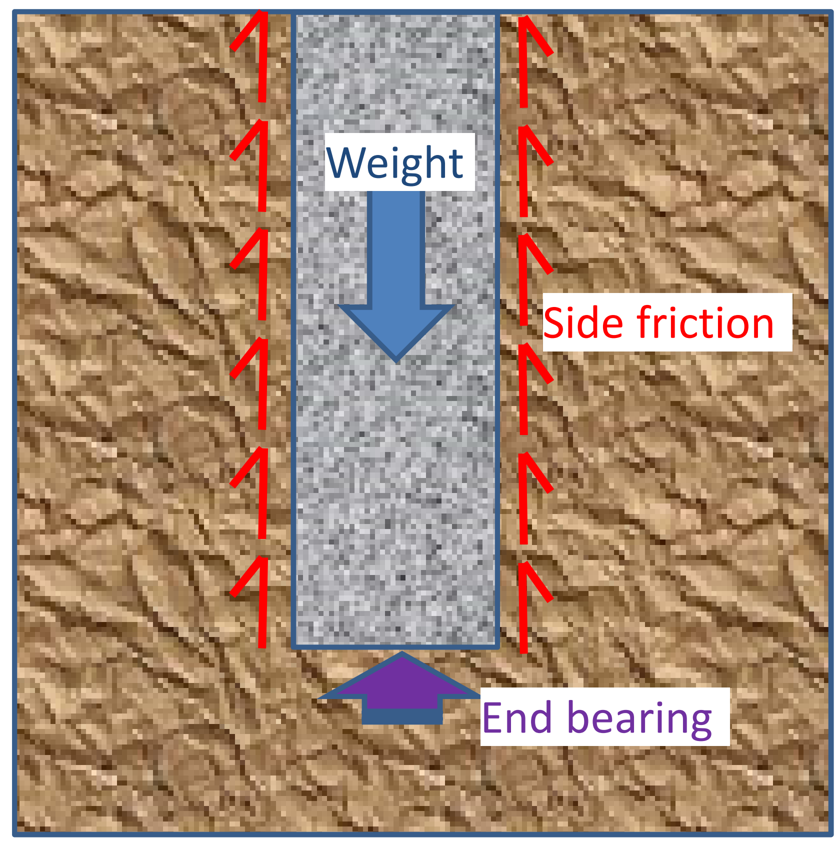


End bearing

- No change in equation, allows using combination of end bearing and side friction

- More State DOTs allowing this combination





- New equations require rock socket with “clean” side walls without the need of artificial roughening

- Does not apply if: walls show smearing, rapid deterioration or collapse, and/or require temporary support/pre-grouting

- If using end bearing: clean up procedure to be specified to ensure removal of sediments/loose material

→ Construction QA/QC is a critical item!!!!

Drilling Tools - Augers

Down Hole Hammer

Machines


NS596
MHL 360
15-78
TRUMBULL

Casing

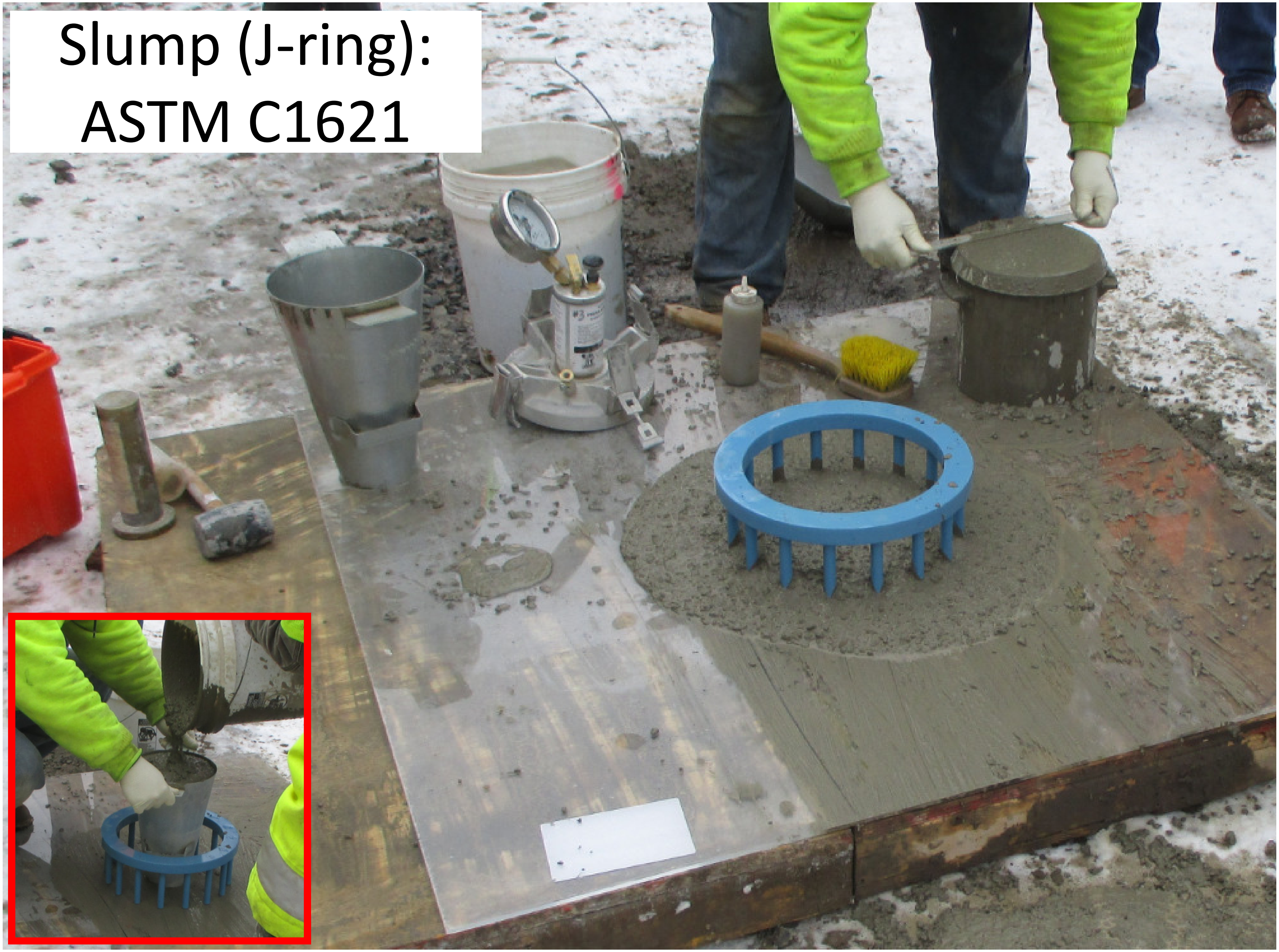
Reinforcement

Grouting

Traditional QA/QC items to record:

- Geometry (length, diameter)
- Elevations (working, bottom of Cap, bottom of shaft)
- Materials requirements (reinforcements / grout)
- Concrete: slump flow, air content, temperature, penetration test, UC strength, etc. → every 50 CY
- Advance / Drilling rate (ft/min)
- Spoils (material type vs. boring logs / design)
- Plumbness of shaft
- Spoil control
- Cleanliness at bottom of shaft

Well established ASTM tests and requirements



Instrumentation (QA/QC) during Drilling

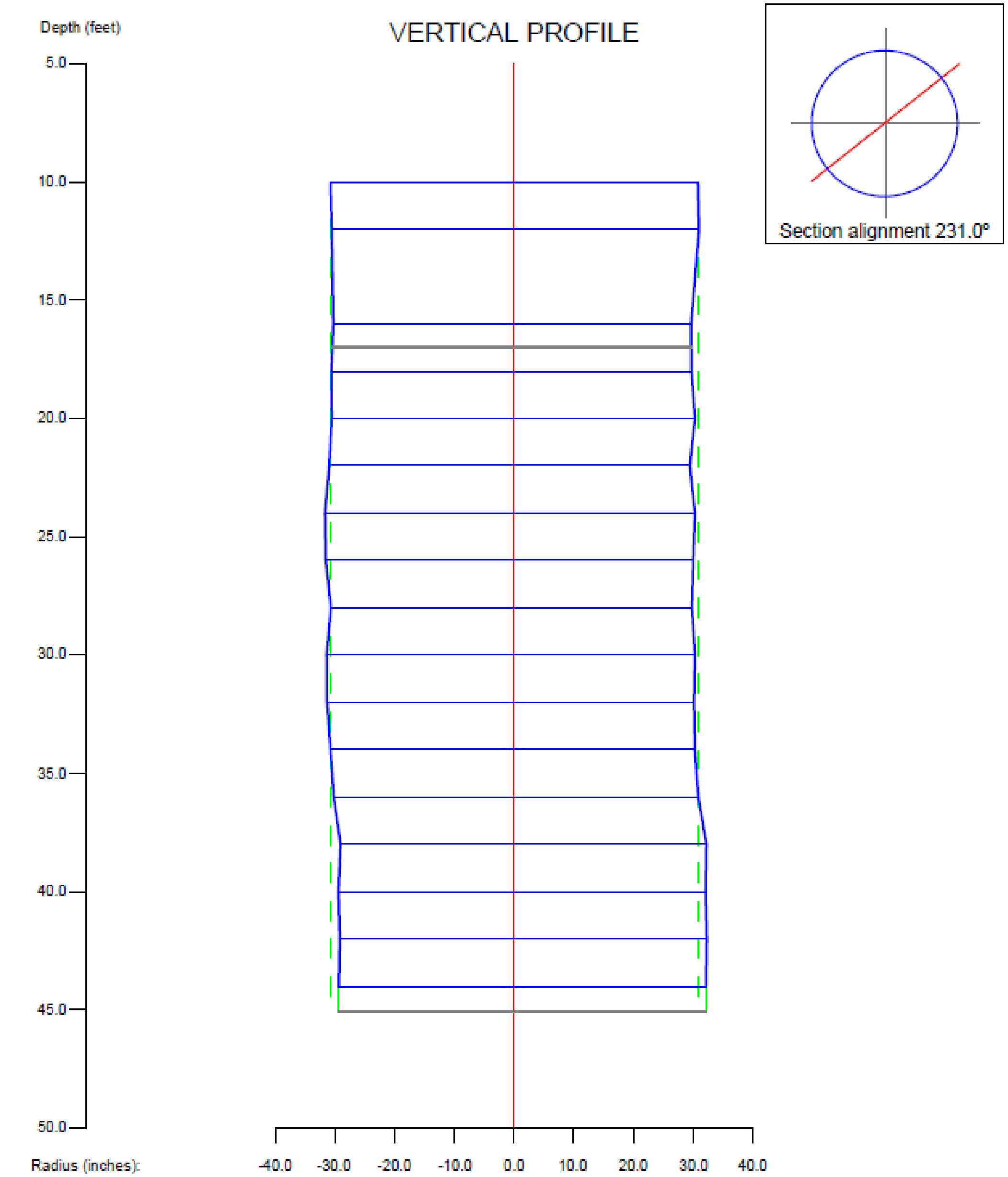
- Sonicaliper: 3D geometry

- MiniSID : quality of <u>bottom</u> of the shaft

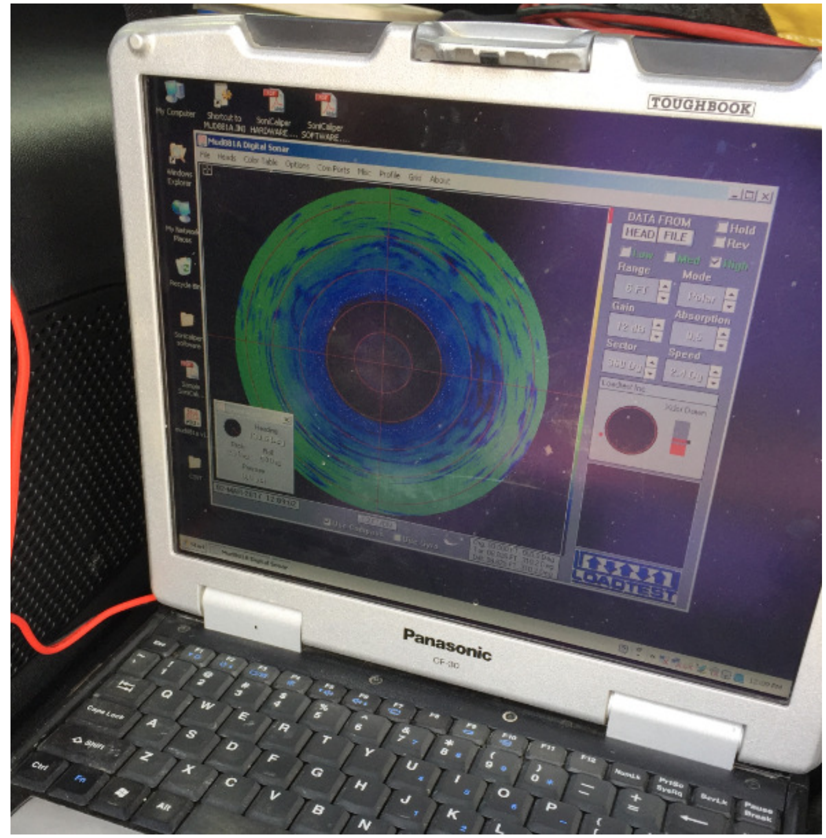
- Down hole camera (visual inspection): quality of <u>side walls</u> of the shaft

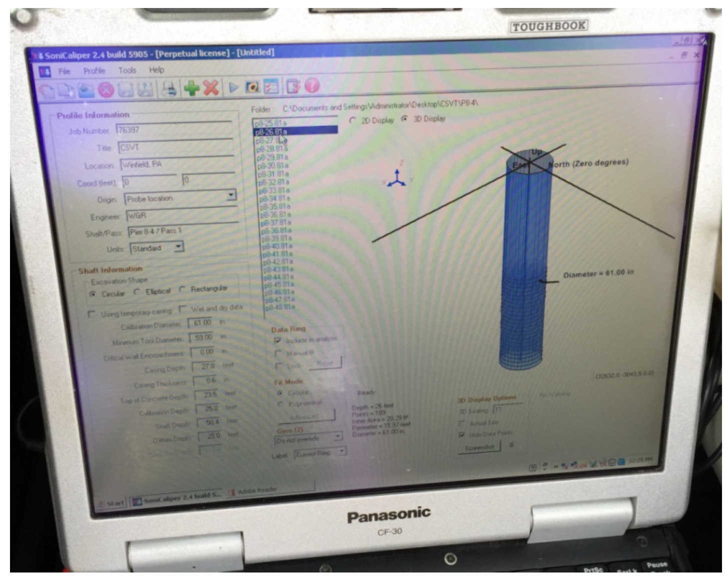
Sonicaliper: 3D geometry

PA, 1/16/2017



Project Number: 1576



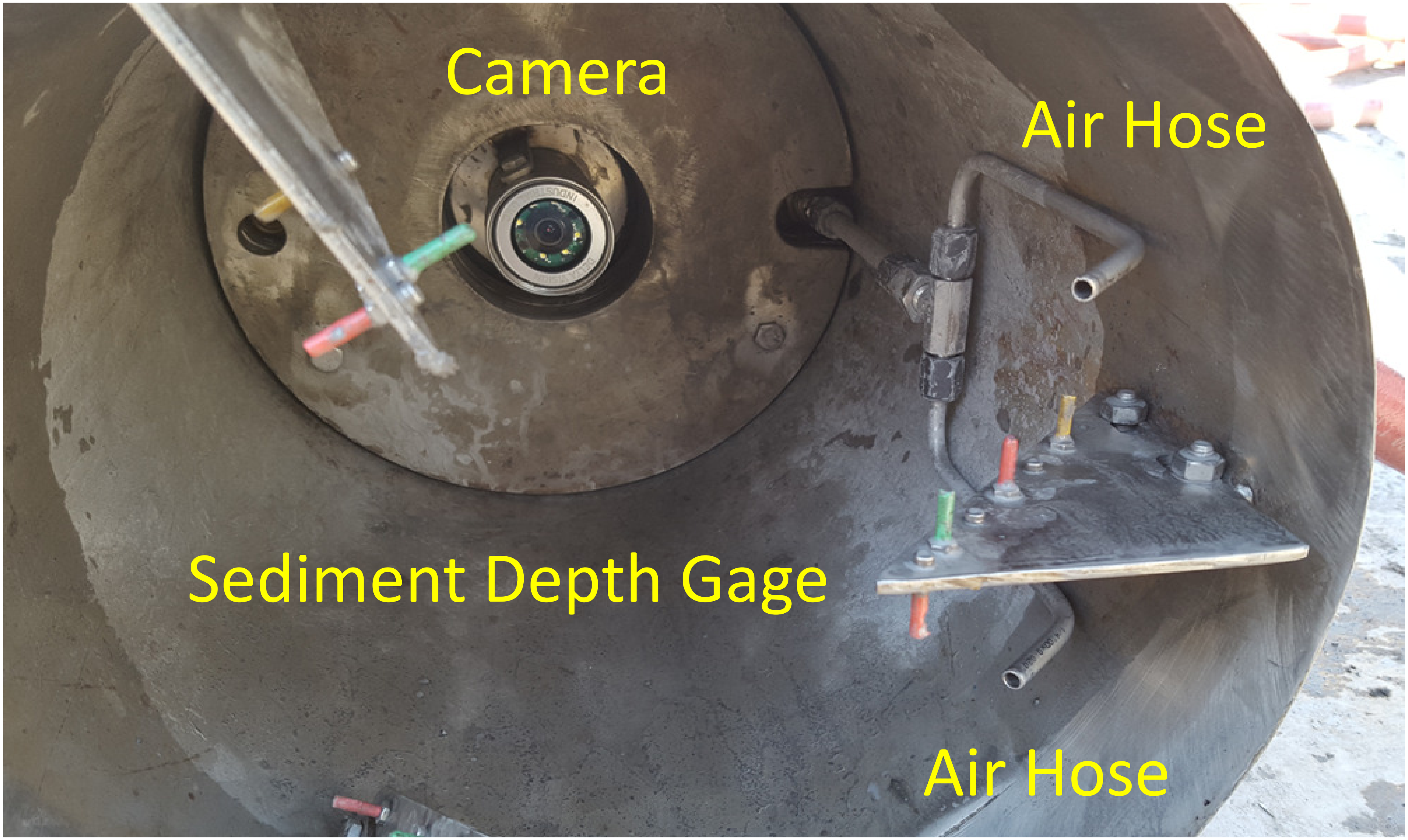


Miniature Drilled Shaft Inspection Device (MiniSID)

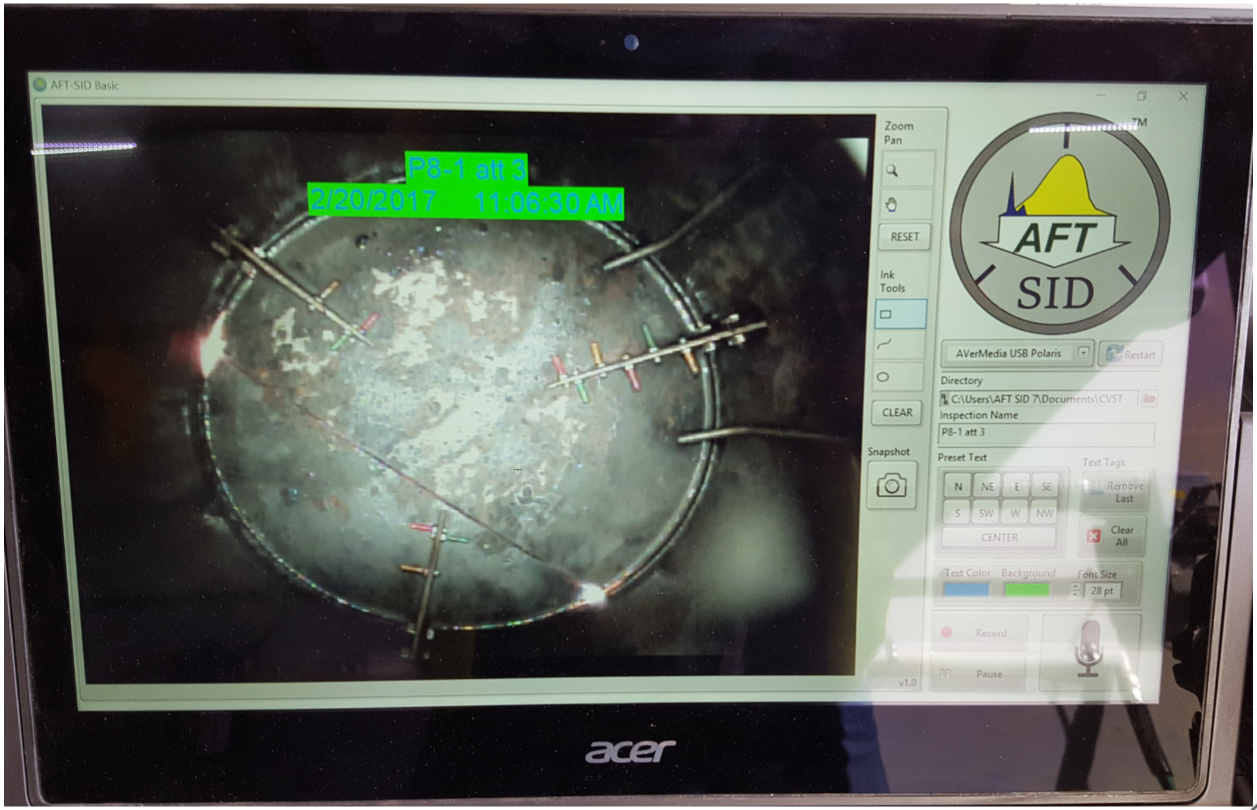

LABORERS
MORETRENCH
ENCH


Monitor
Connected Laptop
For Recording
Air / Water Control

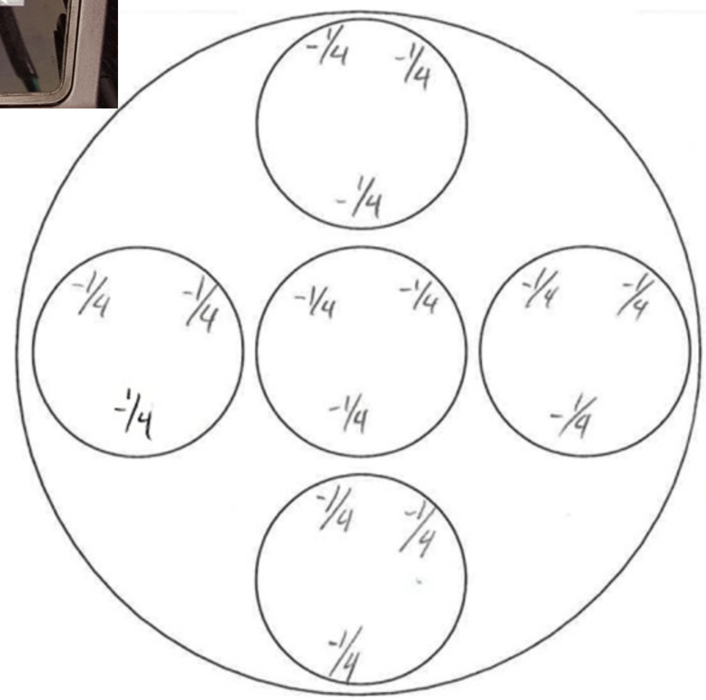
Mini SID - Looking from below (camera and depth gage)



Sample Reading On Monitor

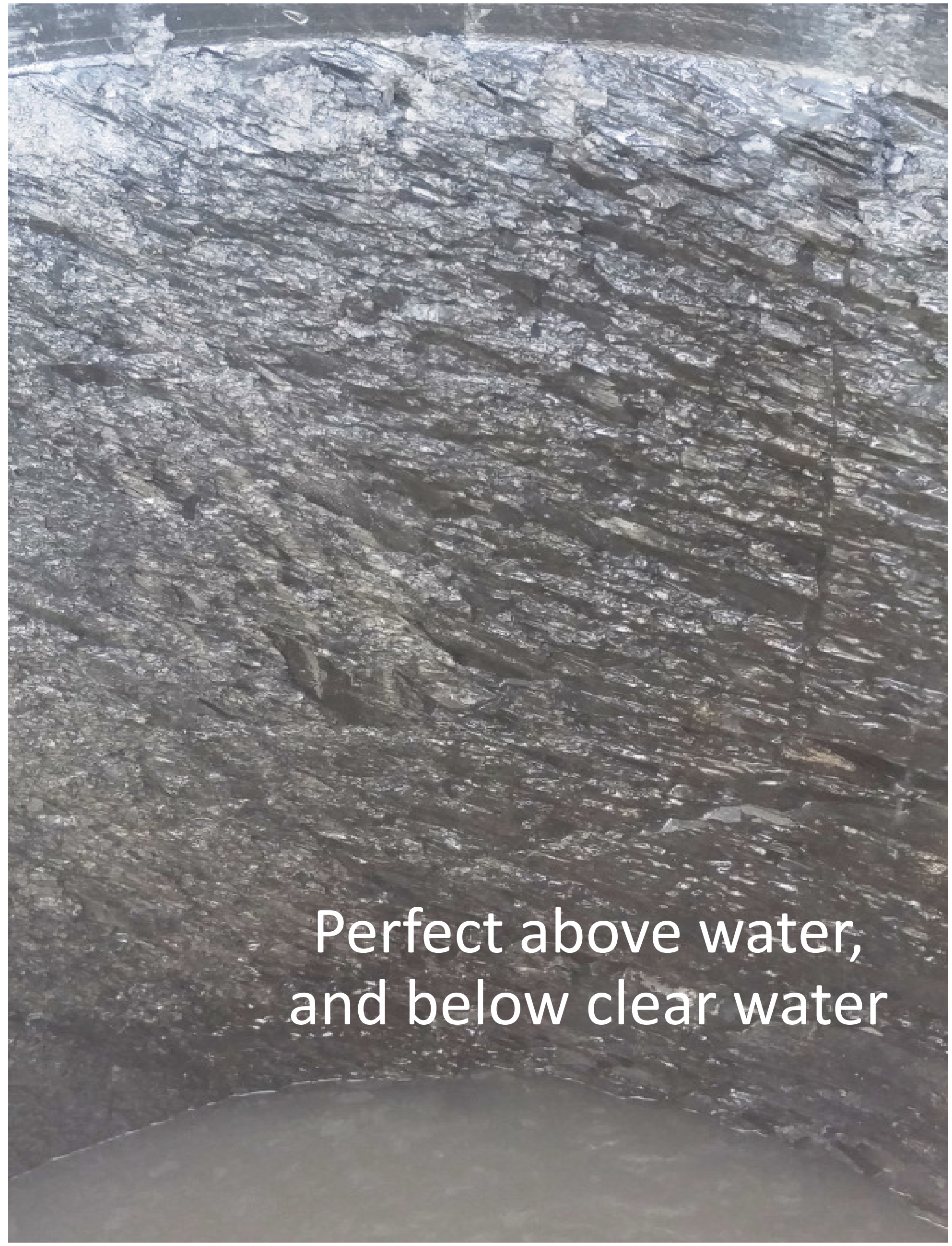


- 4 to 5 areas
- Based on specification, for example…
  - 50% lower than ½ or ¼ inch
  - Max. lower than 1 or ½ inch

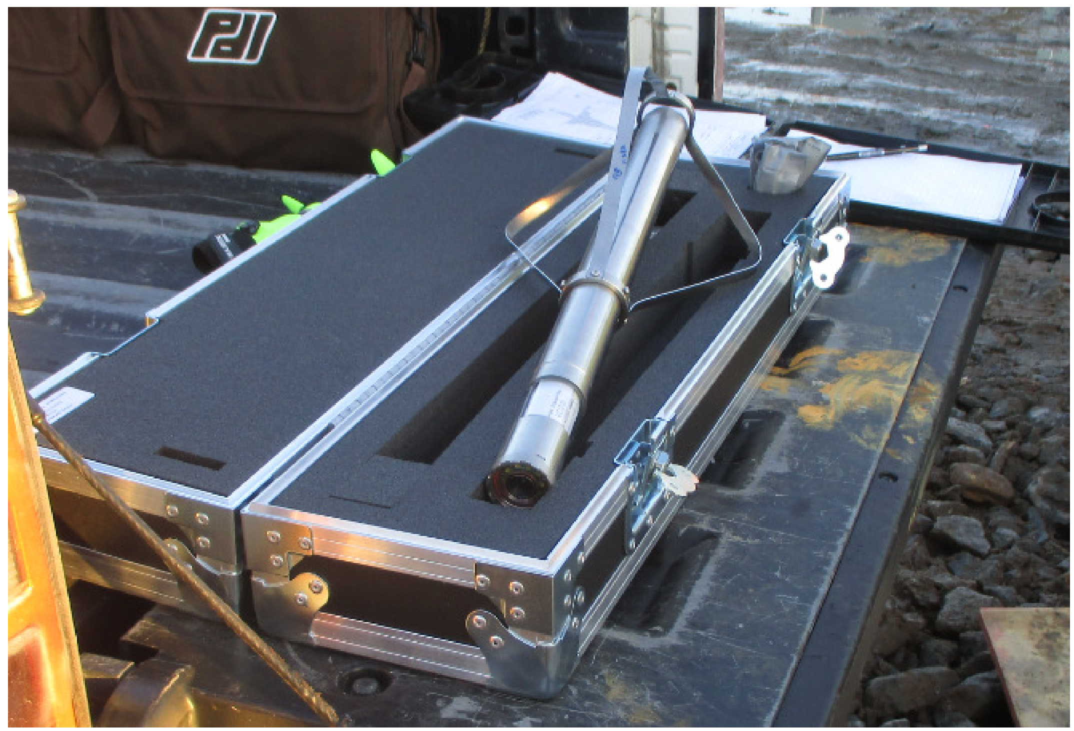


Cleaning the Shaft

Down Hole Camera




Aries Industries
WC1200
S/N WC1200. 16088632
www.ariesindustries.com



Testing Constructed Shaft

– Crosshole Sonic Logging (CSL)

– Thermal Integrity Profiler (TIP)

– Concrete coring

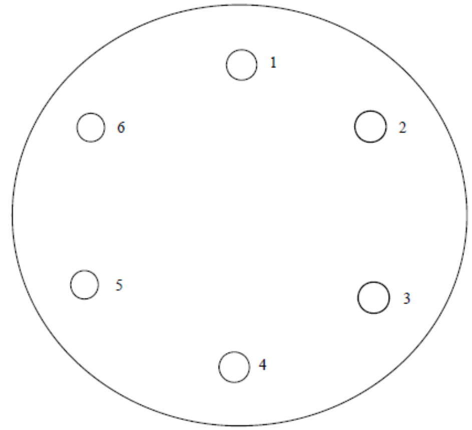
– O-Cell / Sensors (only for test shaft)

CSL

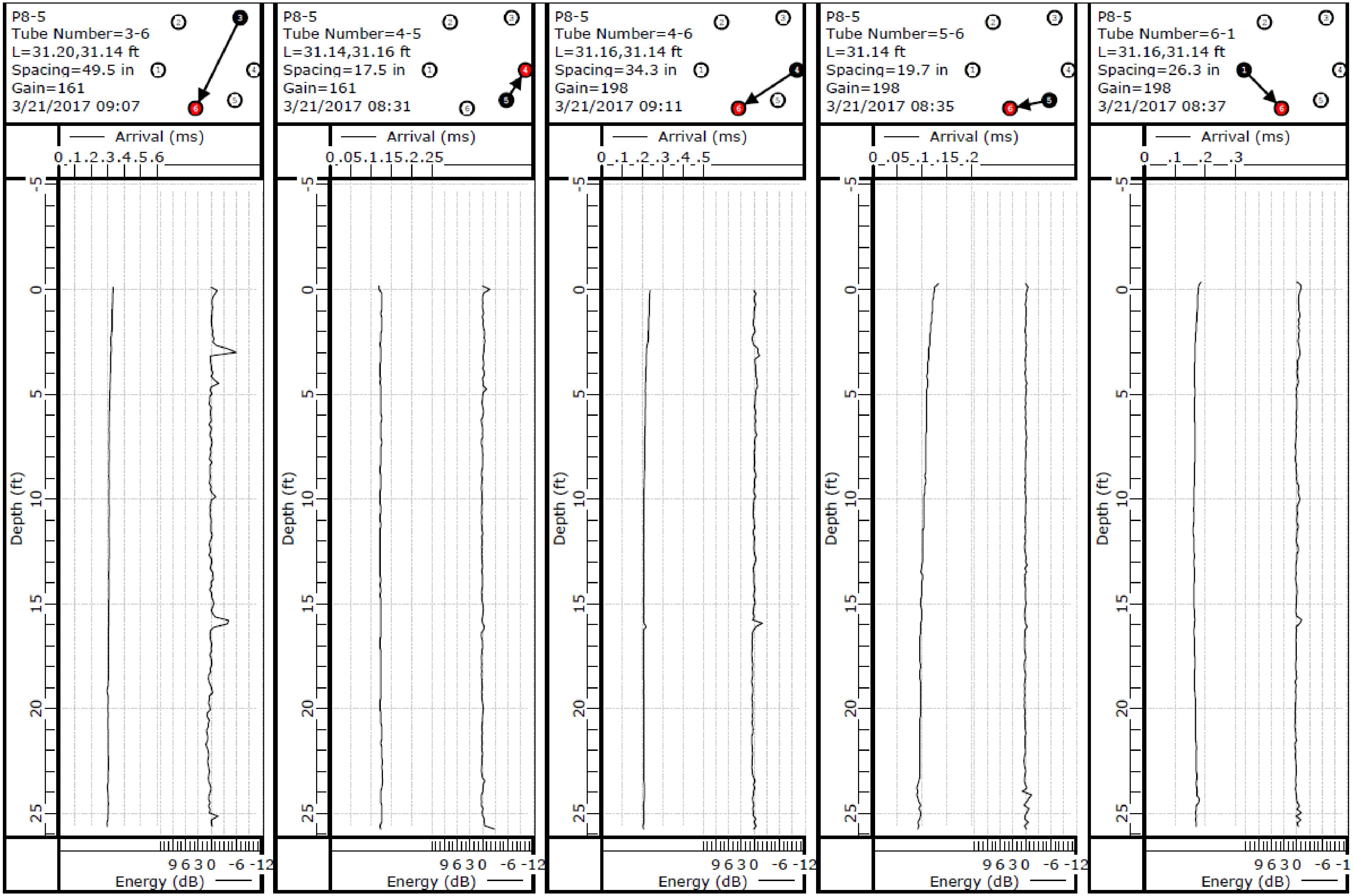
- Assesses concrete integrity by sending ultrasonic pulses through the drilled shaft from one access tube to another

- Transmitter and receiver probes are placed at the bottom of the access tubes and then slowly raised (one profile/ points approx. every 2")

- Typically 1 probe per foot of drilled shaft dimeter



CSL Pipes: typically steel or PVC



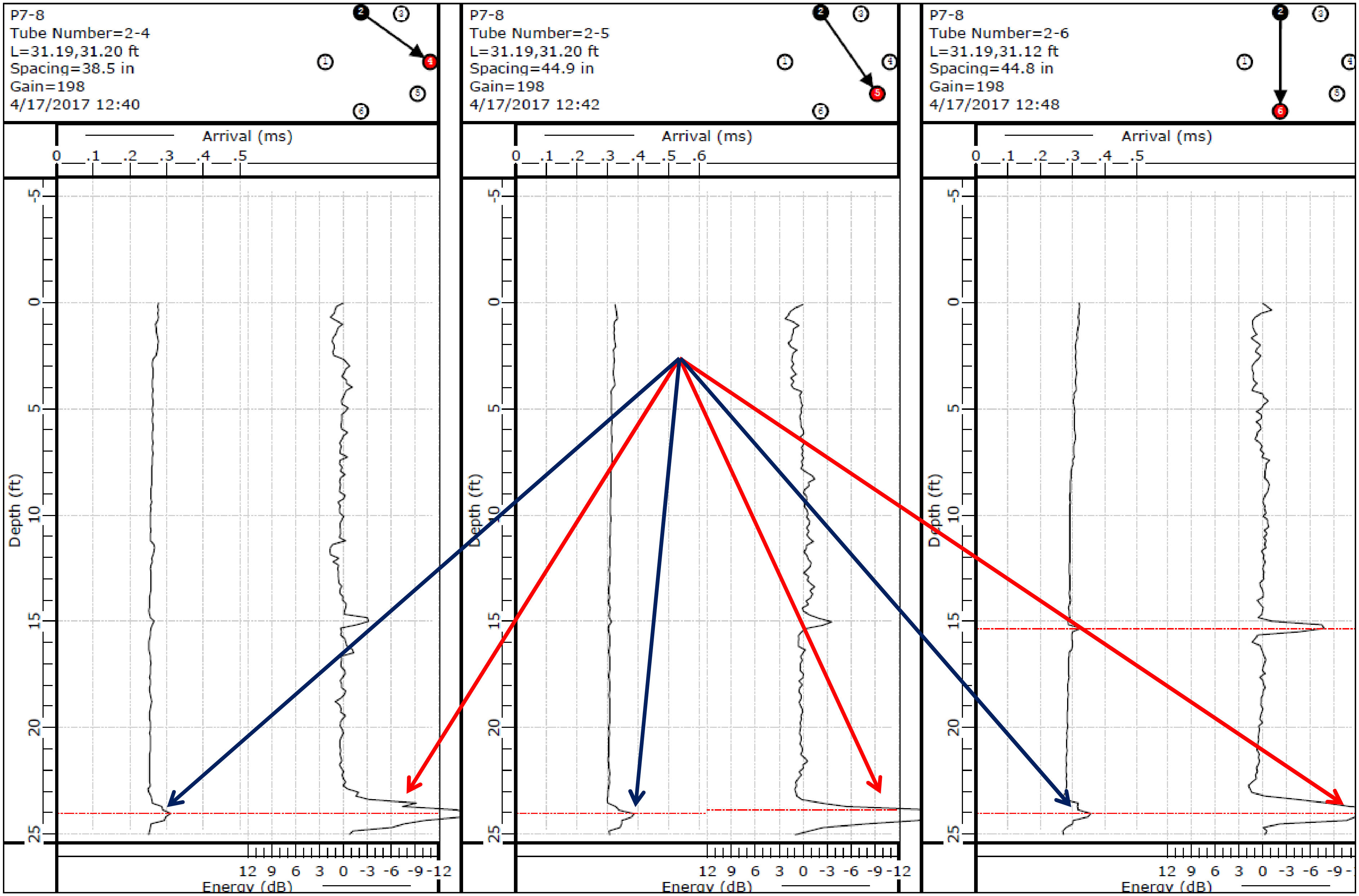
P8-5
Tube Number=3-6
L=31.20,31.14 ft
Spacing=49.5 in
Gain=161
3/21/2017 09:07
Arrival (ms)
0 .1 .2 .3 .4 .5 .6
Depth (ft)
-5
0
5
10
15
20
25
9 6 3 0 -6 -12
Energy (dB)
P8-5
Tube Number=4-5
L=31.14,31.16 ft
Spacing=17.5 in
Gain=161
3/21/2017 08:31
Arrival (ms)
0 .05 .1 .15 .2 .25
Depth (ft)
9 6 3 0 -6 -12
Energy (dB)
P8-5
Tube Number=4-6
L=31.16,31.14 ft
Spacing=34.3 in
Gain=198
3/21/2017 09:11
Arrival (ms)
0 .1 .2 .3 .4 .5
Depth (ft)
9 6 3 0 -6 -12
Energy (dB)
P8-5
Tube Number=5-6
L=31.14 ft
Spacing=19.7 in
Gain=198
3/21/2017 08:35
Arrival (ms)
0 .05 .1 .15 .2
Depth (ft)
9 6 3 0 -6 -12
Energy (dB)
P8-5
Tube Number=6-1
L=31.16,31.14 ft
Spacing=26.3 in
Gain=198
3/21/2017 08:37
Arrival (ms)
0 .1 .2 .3
Depth (ft)
9 6 3 0 -6 -1
Energy (dB)

Concrete Integrity Assessment	First Arrival Time (FAT) Delay (%)		Energy Reduction
Satisfactory	0 to 10%	and	< 6 dB
Anomaly	11 to 20%	and	6 dB to 9 dB
Flaw	21% < FAT < 30%	or	9 to 12 dB
Poor/Defect	30% < FAT	or	> 12 dB

PDI recommends that Flaws (P/F) should be addressed if they are indicated in more than 50% of the profiles. They recommend that Defects (P/D) should be addressed if they are indicated in more than one profile.

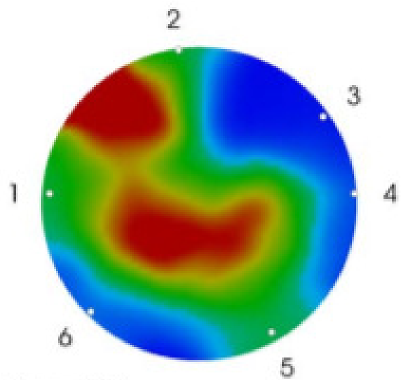
ASTM D6760 - 16

Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing

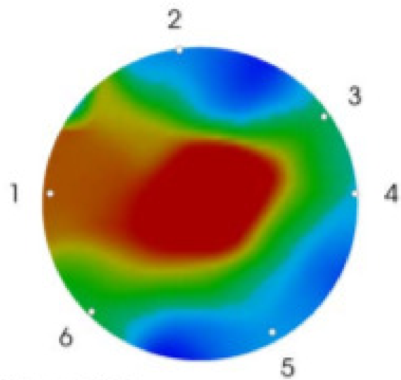

P7-8
Tube Number=2-4
L=31.19,31.20 ft
Spacing=38.5 in
Gain=198
4/17/2017 12:40
Arrival (ms)
Depth (ft)
Energy (dB)
P7-8
Tube Number=2-5
L=31.19,31.20 ft
Spacing=44.9 in
Gain=198
4/17/2017 12:42
Arrival (ms)
Depth (ft)
Energy (dB)
P7-8
Tube Number=2-6
L=31.19,31.12 ft
Spacing=44.8 in
Gain=198
4/17/2017 12:48
Arrival (ms)
Depth (ft)
Energy (dB)

Company Name: Pile Dynamics, Inc.
Project Name: DEMO-SHAFT
Pile Name: DEMO-SHAFT 1
Pile Length=60 m / Pile Diameter=2.5 m / Cage Diameter=1.9 m
MAR 17, 2016

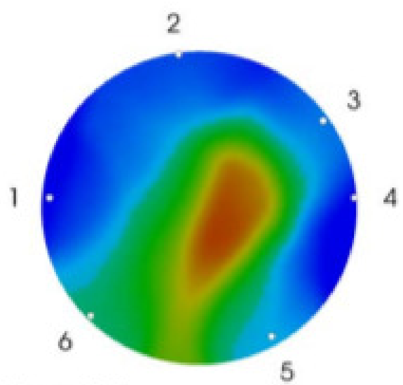
Pile Dynamics, Inc.



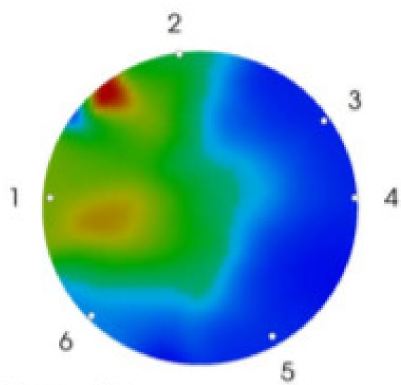
Eff. Area=27%
Depth=1.34 m



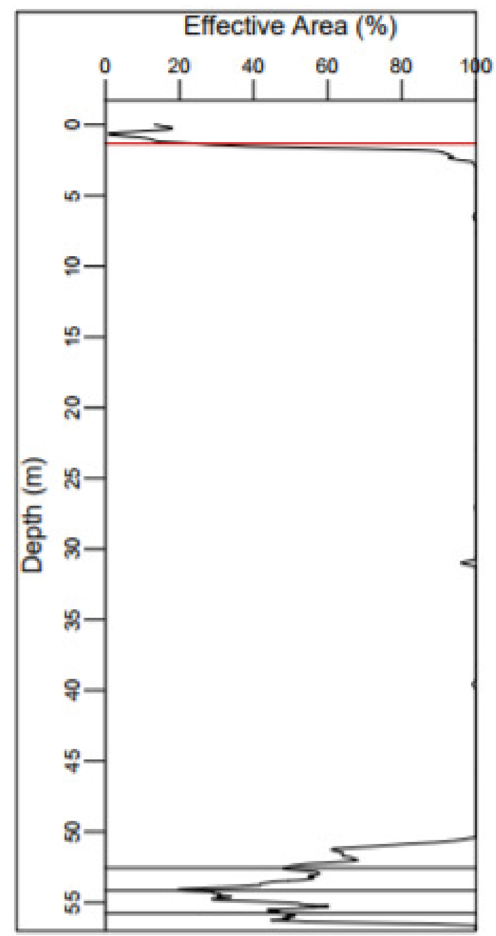
Eff. Area=16%
Depth=54.16 m

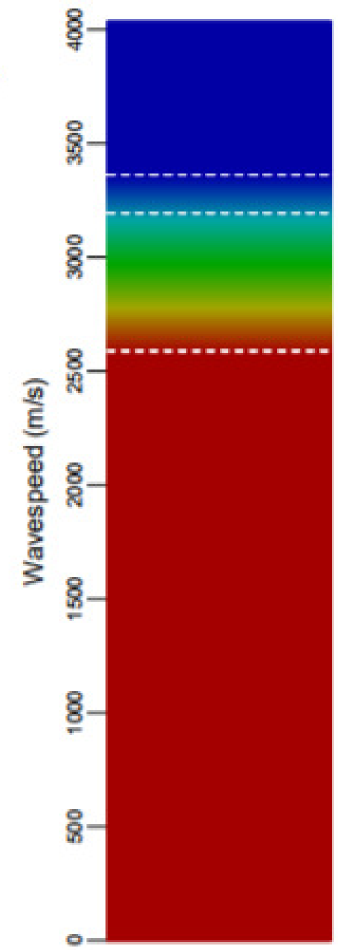


Eff. Area=43%
Depth=55.76 m



Eff. Area=48%
Depth=52.55 m





Effective Area is the percentage of cross-sectional area with wave speeds greater than the effective wave speed (EWS) selected by the user by the user, 3194 m/s

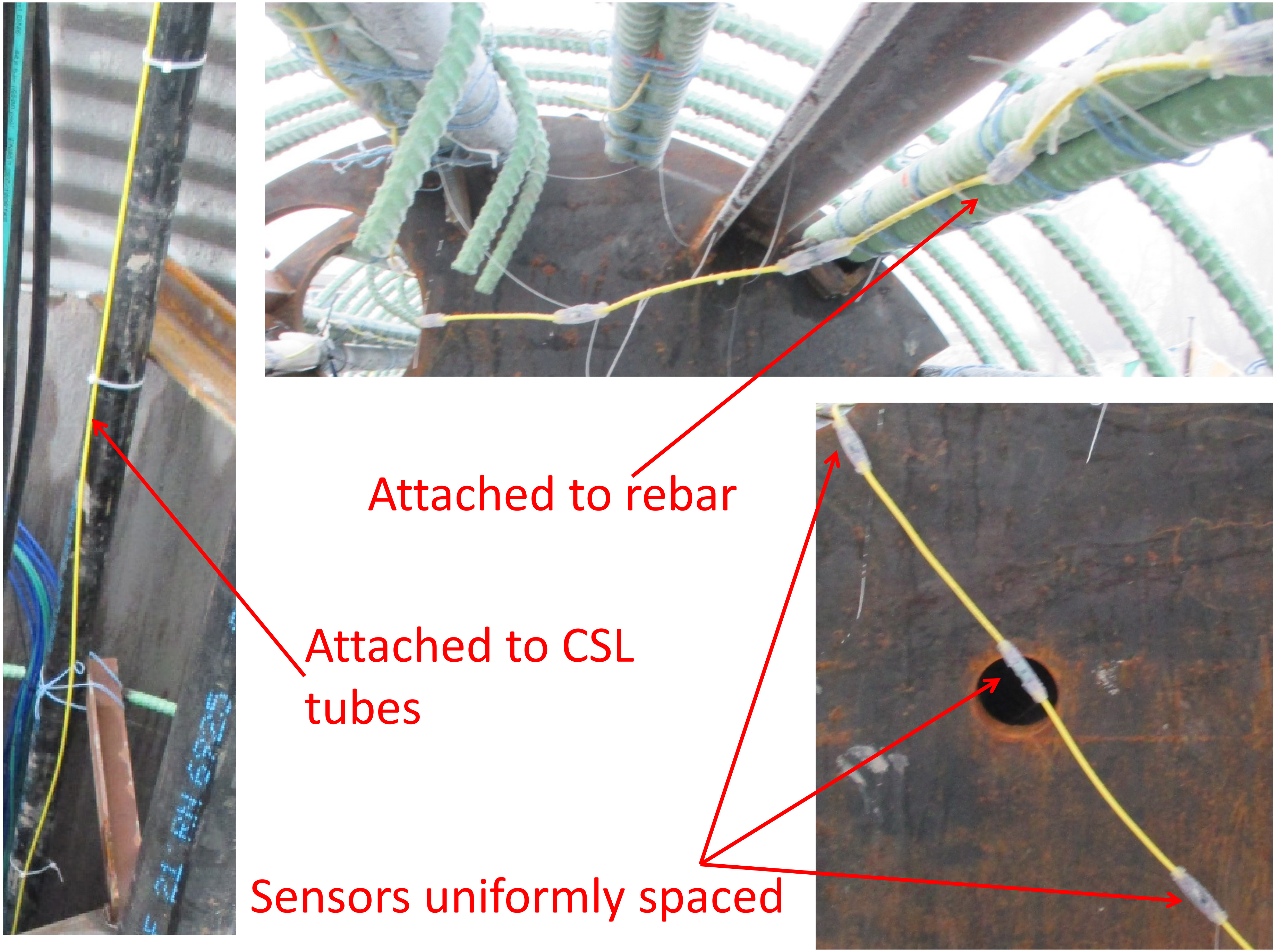
Pile Dynamics, Inc.

Thermal Integrity Profile (TIP)

- During curing: system measures concrete temperatures using embed cables

- Thermal Acquisition Ports (TAPs) connected to the ThermalWire®: store temperature data

- Cement hydrates during curing process: generated heat increases temperature inside the shaft


Attached to rebar
Attached to CSL tubes
Sensors uniformly spaced

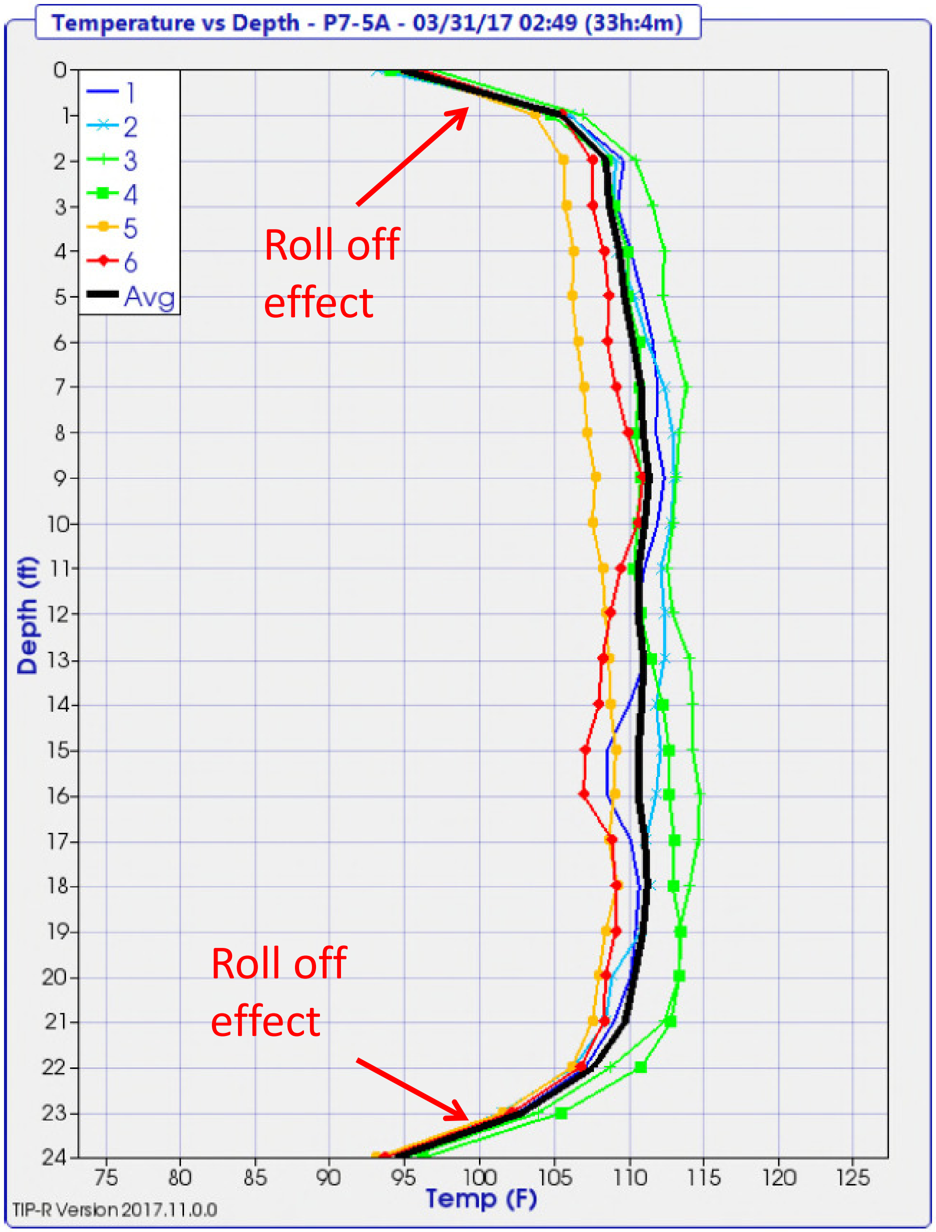

Thermal Wire® Tester

- Shaft radius vs depth: calculated based on measured average peak temperature

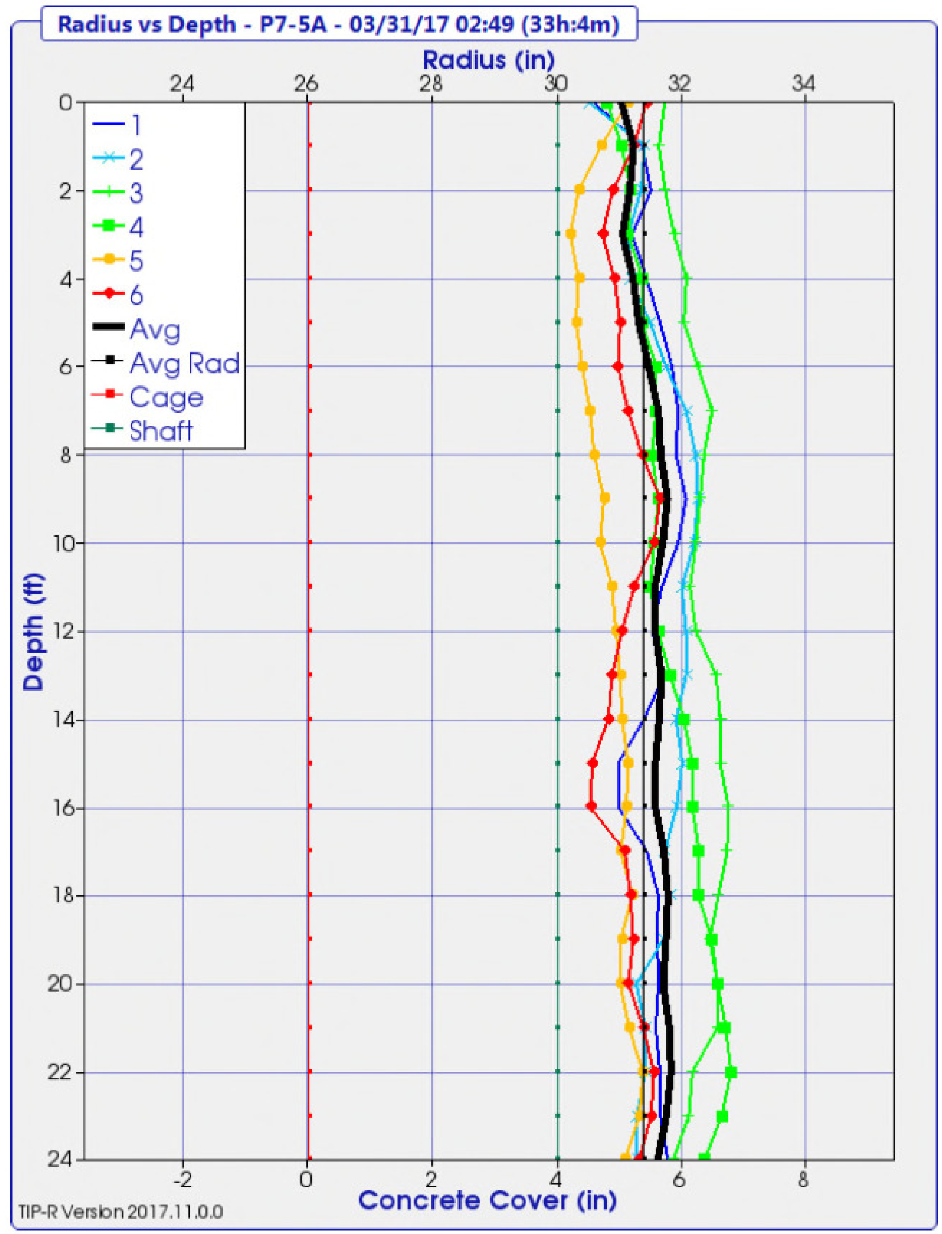
- Integrity: based on measured concrete volume input and the average peak temperature

- If measured average temperature vs depth is consistent: uniform shape and quality

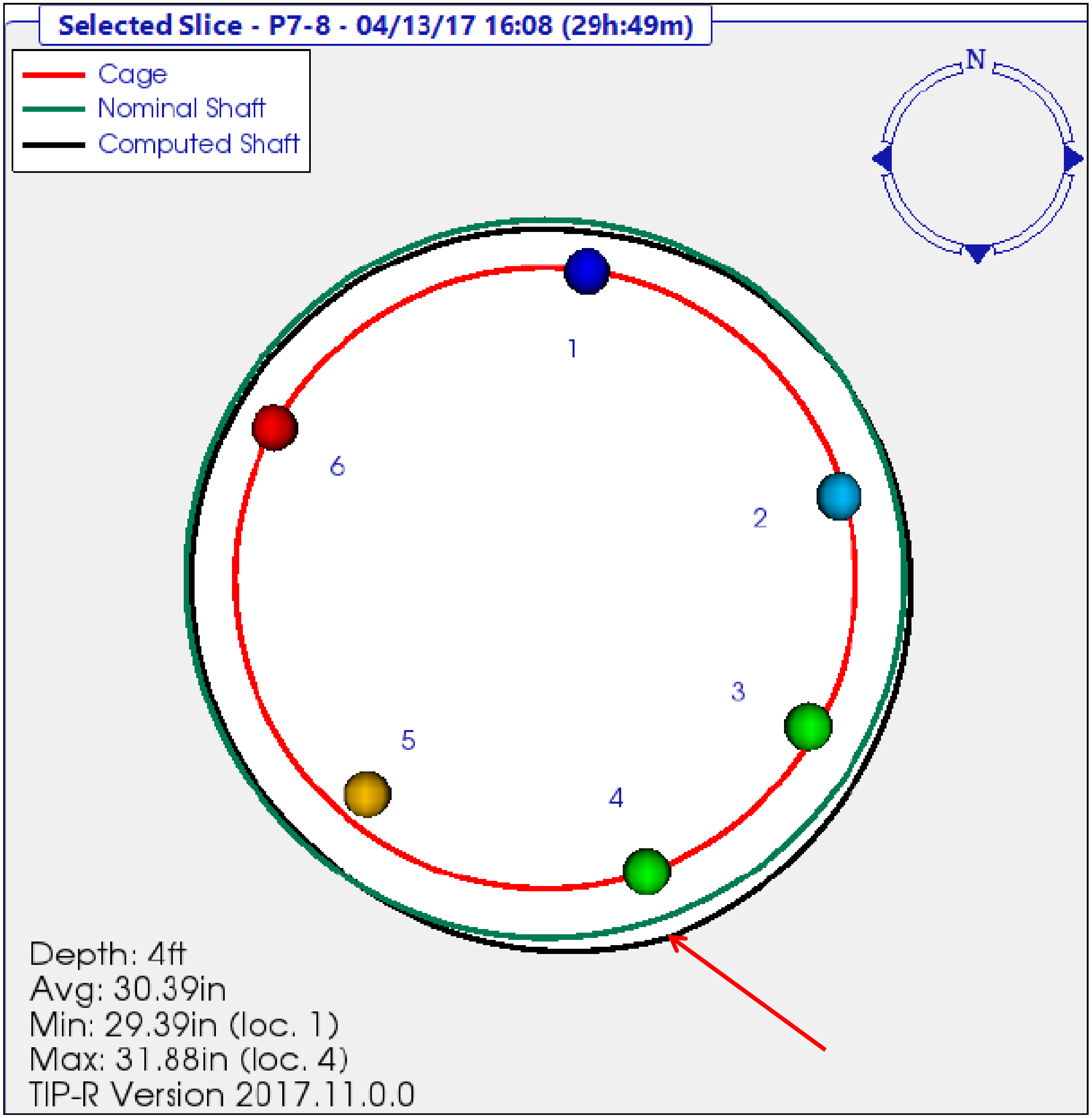
- Bulges: localized increases in average temp.
- Poor concrete quality or necking: localized decreases in average temperature
- Areas of soil intrusion/inclusion: lower local temperatures.
- ASTM D7949 – 14 Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations

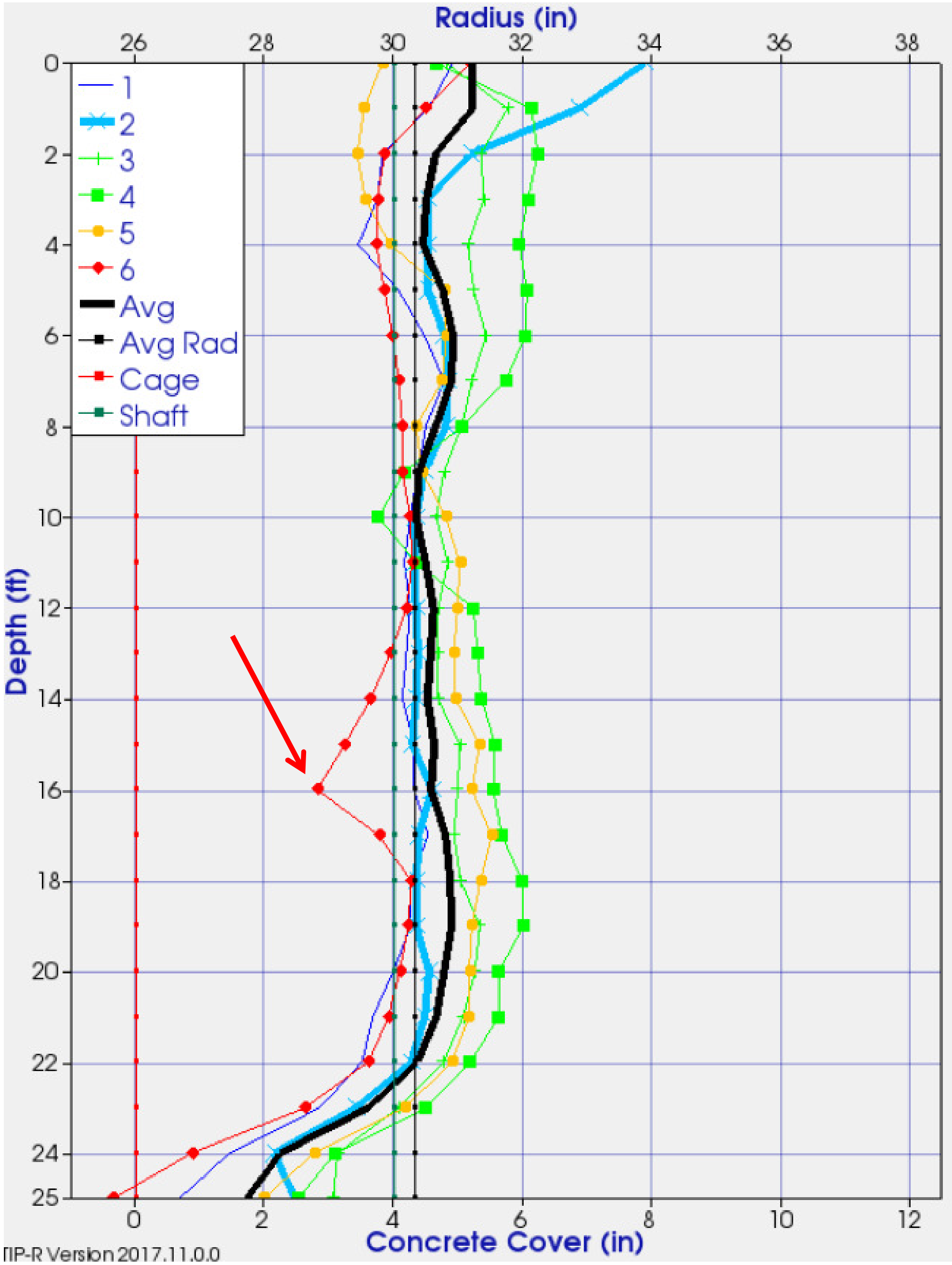


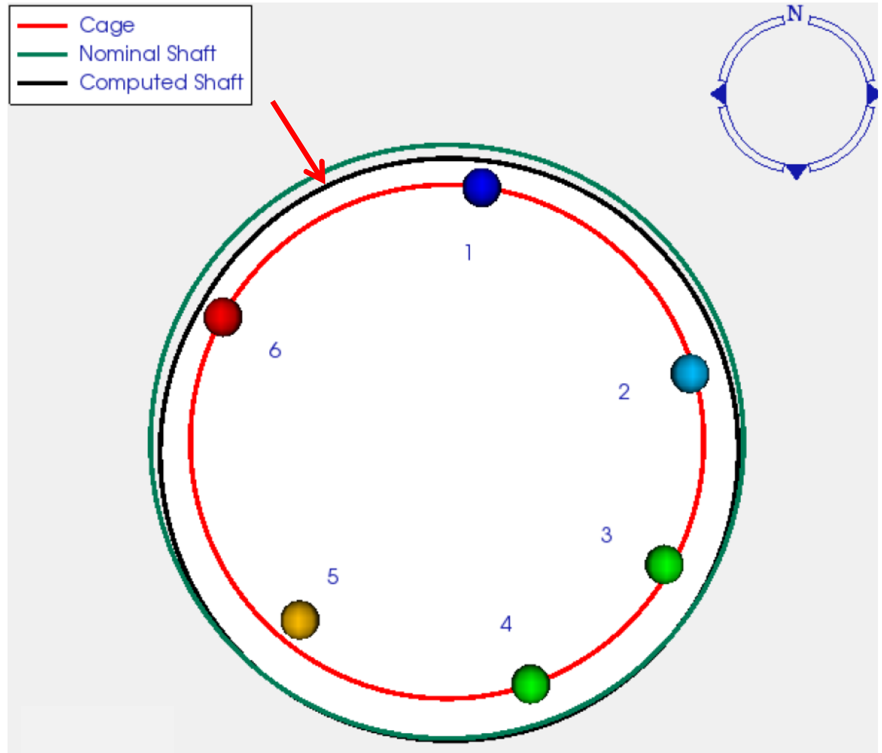
Temperature vs Depth - P7-5A - 03/31/17 02:49 (33h:4m)
Depth (ft)
Temp (F)
1
2
3
4
5
6
Avg
Roll off effect
Roll off effect
TIP-R Version 2017.11.0.0



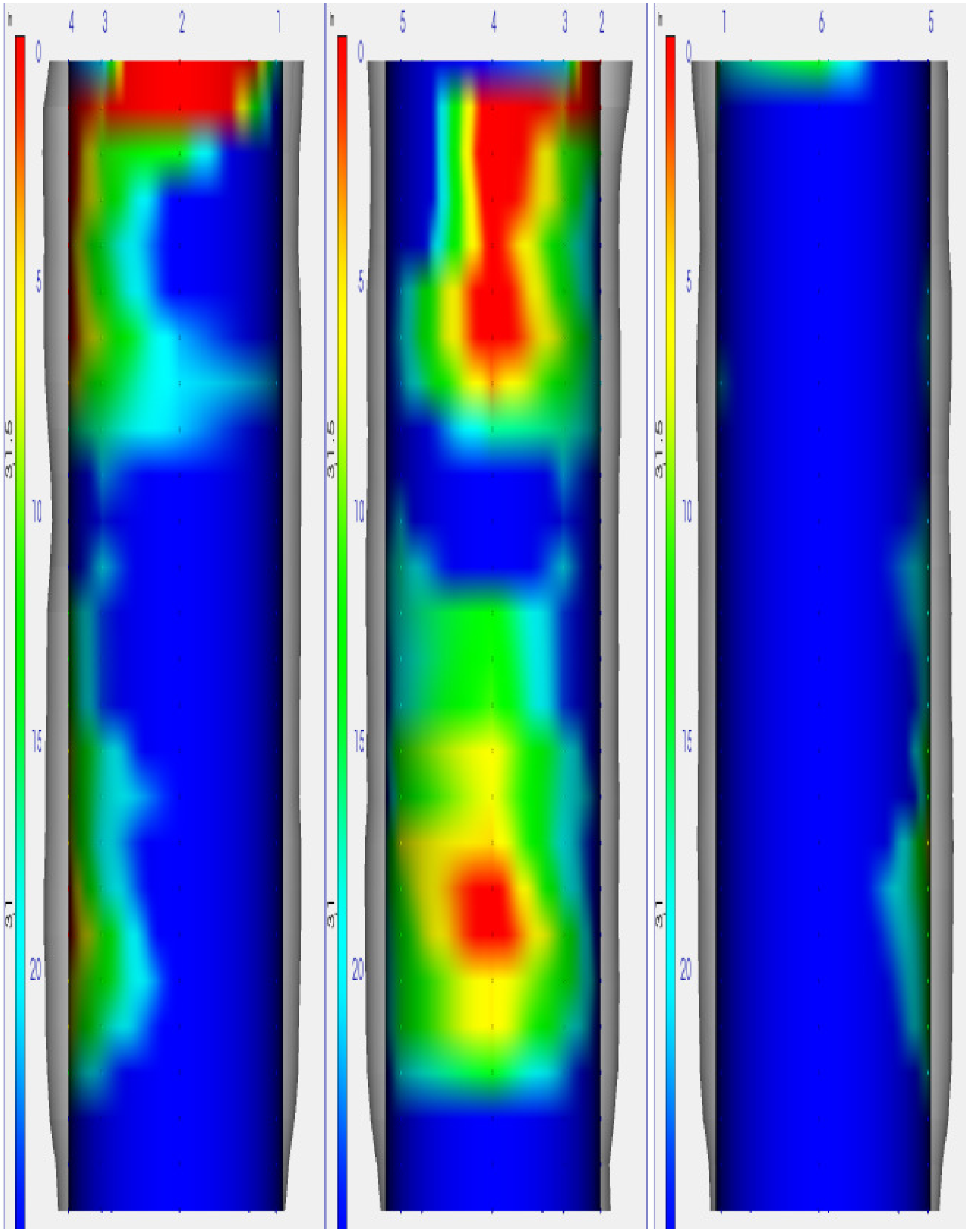
Radius vs Depth - P7-5A - 03/31/17 02:49 (33h:4m)
Radius (in)
Depth (ft)
Concrete Cover (in)
1
2
3
4
5
6
Avg
Avg Rad
Cage
Shaft
TIP-R Version 2017.11.0.0


Selected Slice - P7-8 - 04/13/17 16:08 (29h:49m)
Cage
Nominal Shaft
Computed Shaft
N
1
2
3
4
5
6
Depth: 4ft
Avg: 30.39in
Min: 29.39in (loc. 1)
Max: 31.88in (loc. 4)
TIP-R Version 2017.11.0.0



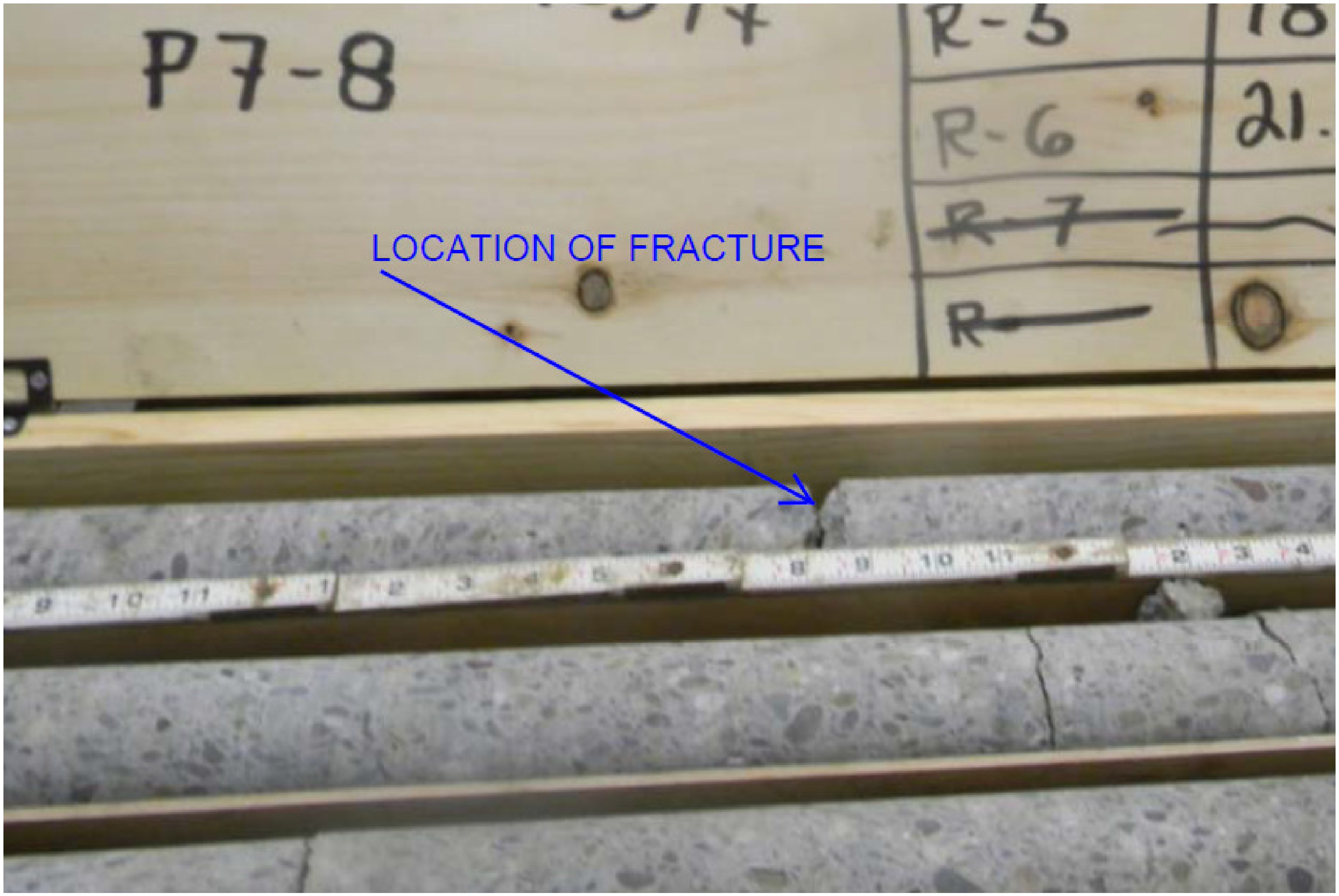


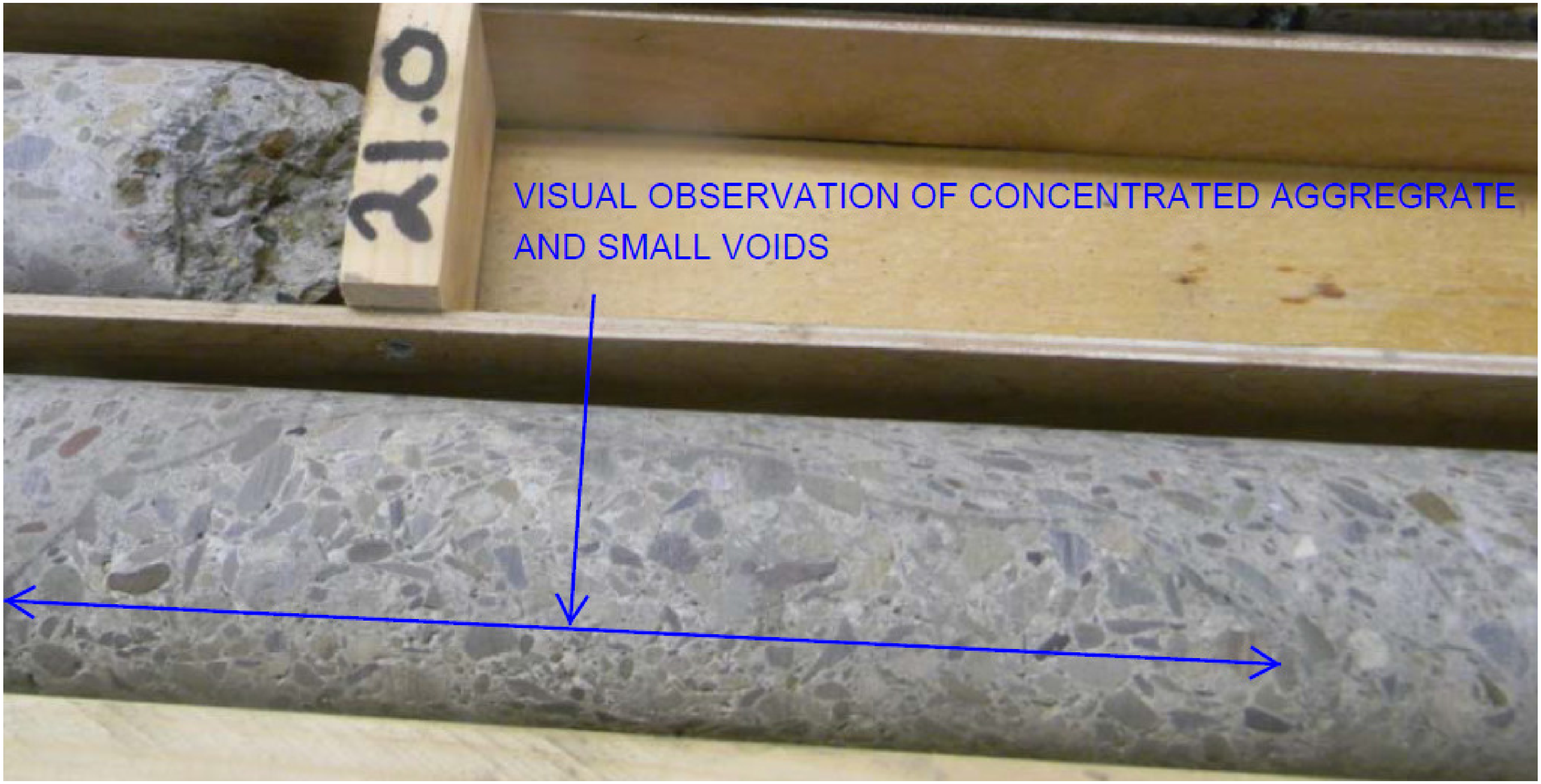
Advantage vs. CSL: "outside the rebar"


4 3 2 1
5 4 3 2
1 6 5
0
5
10
15
20
31.5
31

Concrete Coring

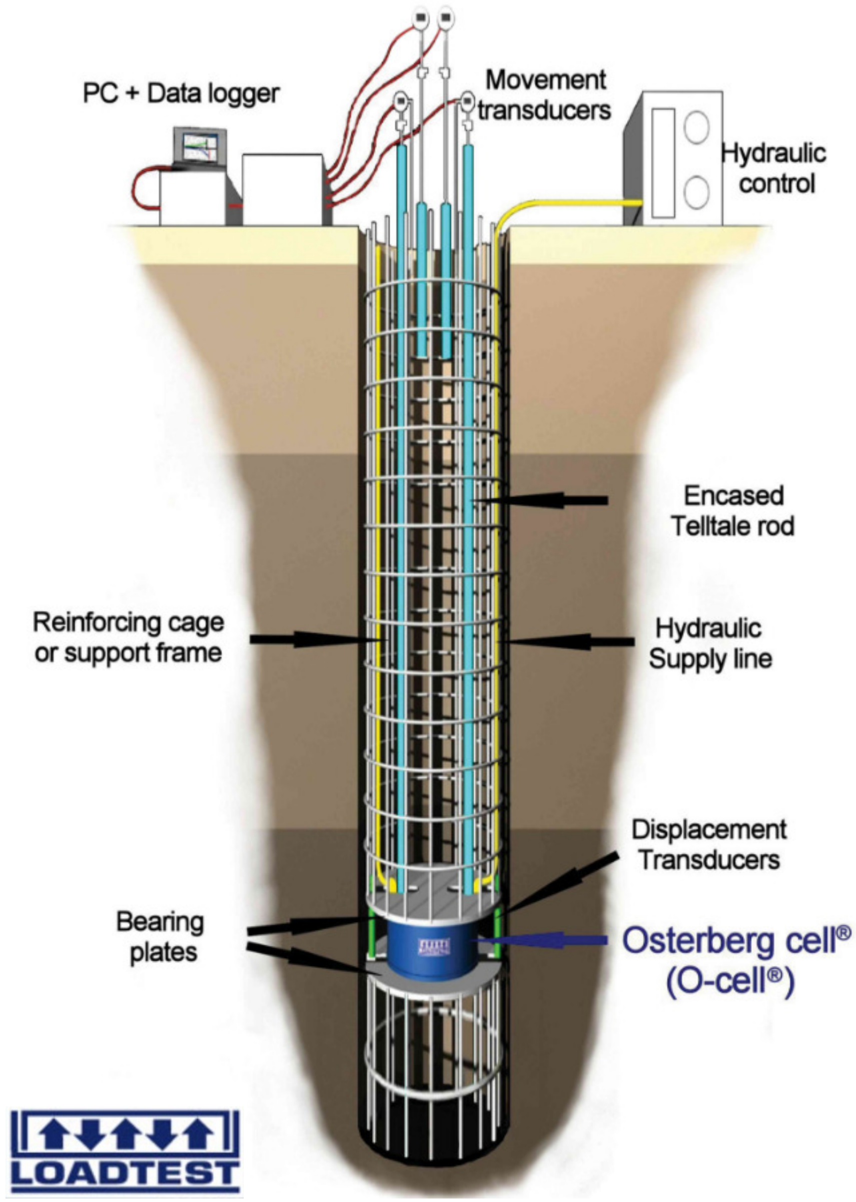
- Intended areas:

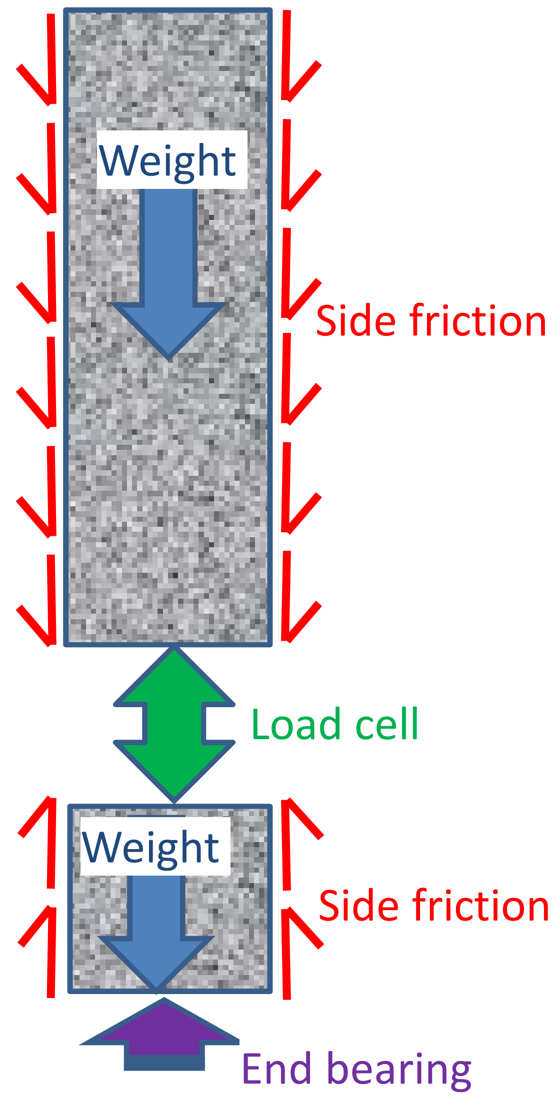


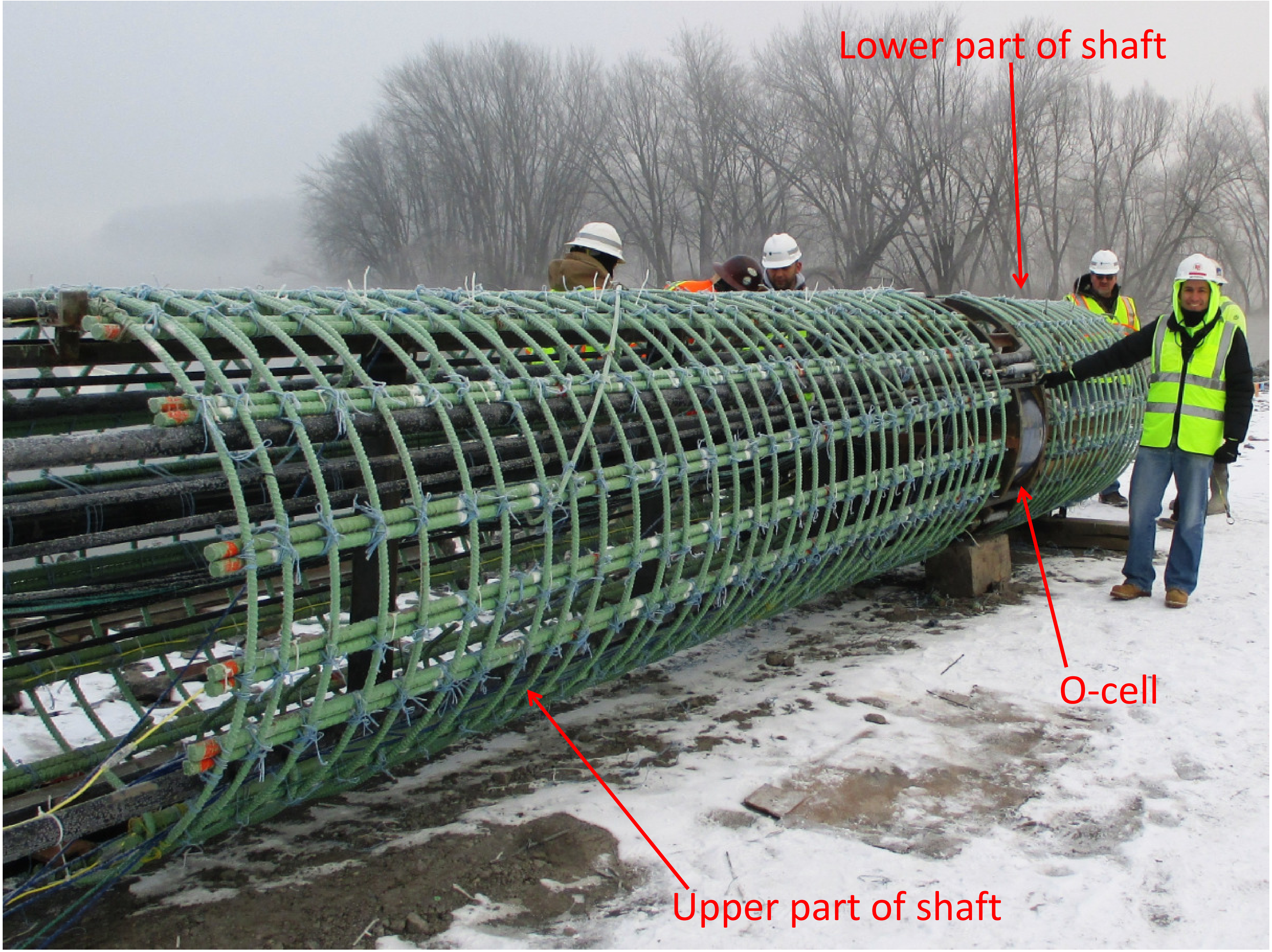


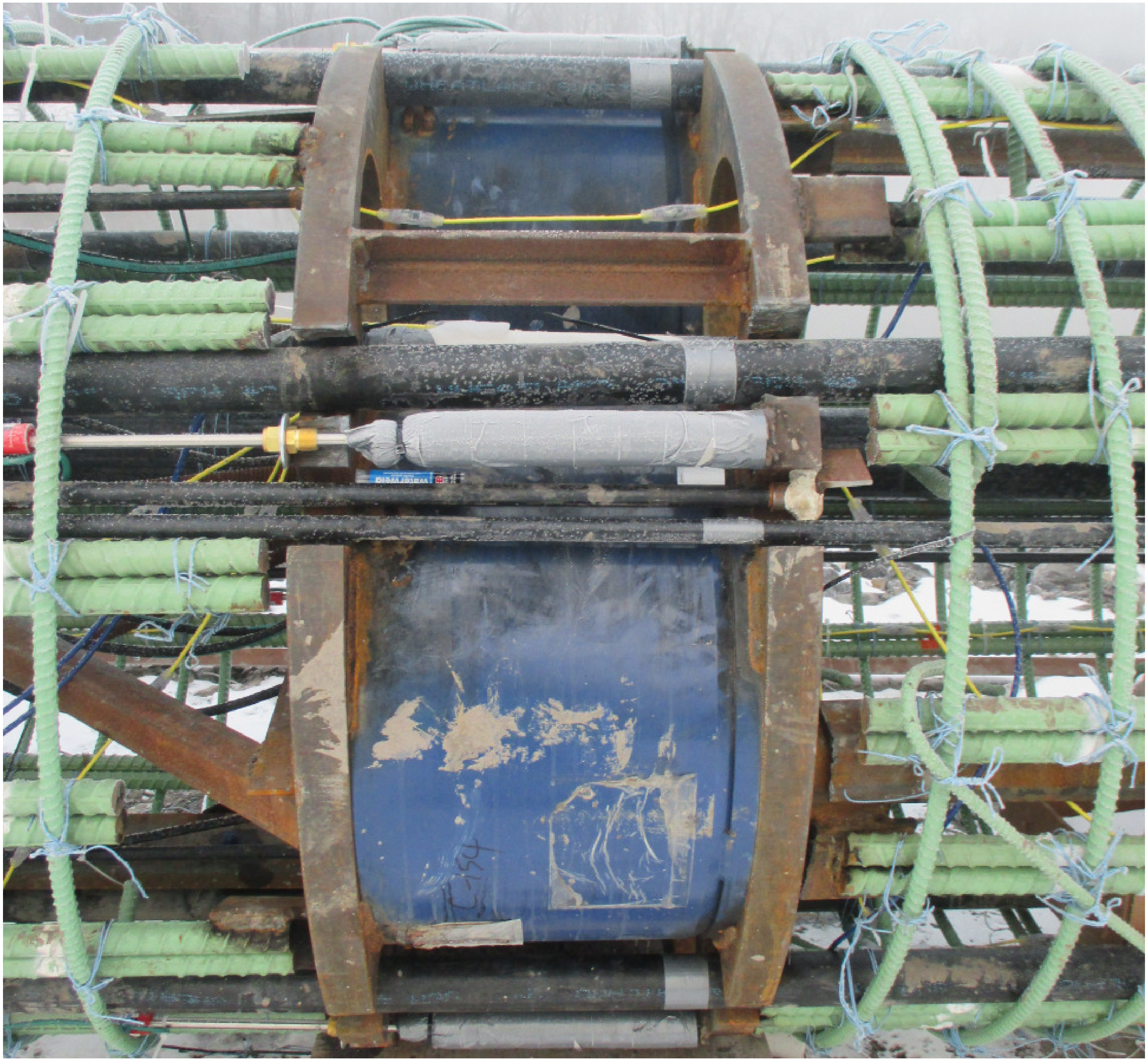
Besides visual observation, option to perform unconfined compression testing

O-cell Load Test (Bidirectional load test)



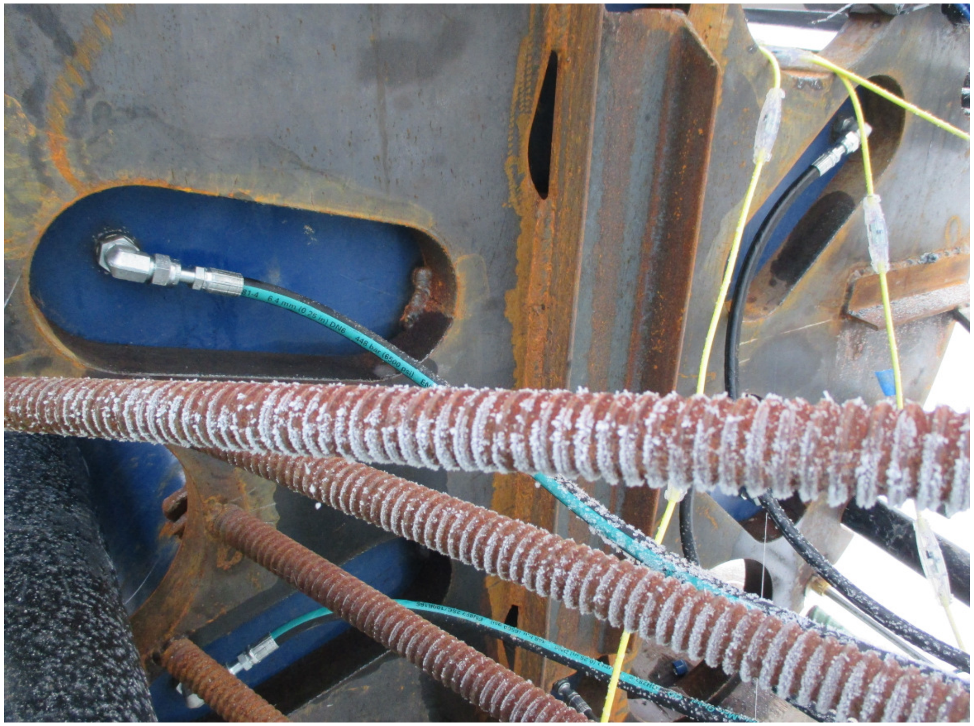


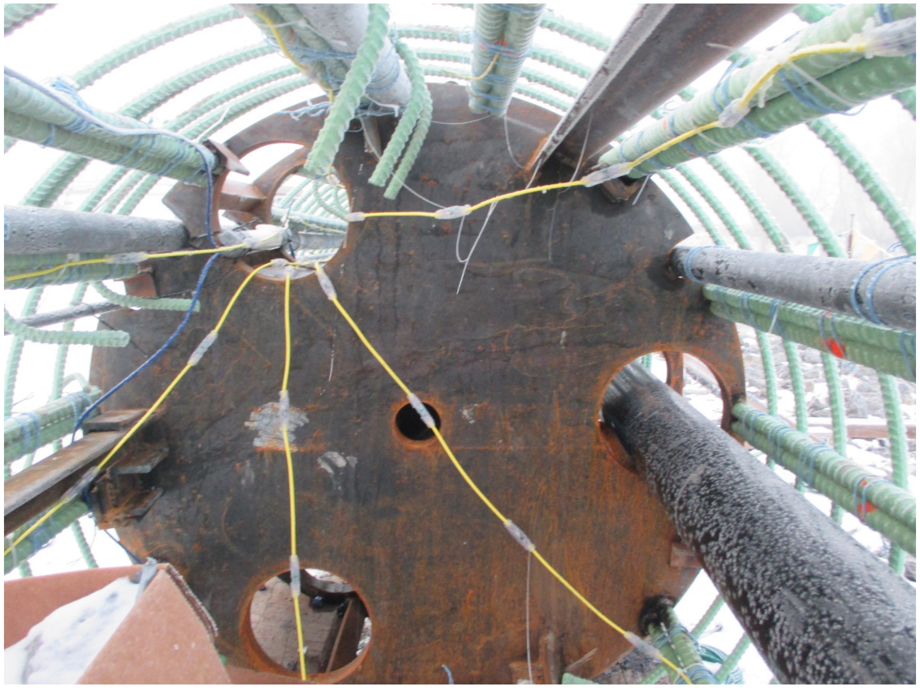

Lower part of shaft
O-cell
Upper part of shaft



Complete shaft instrumentation for load and displacement:

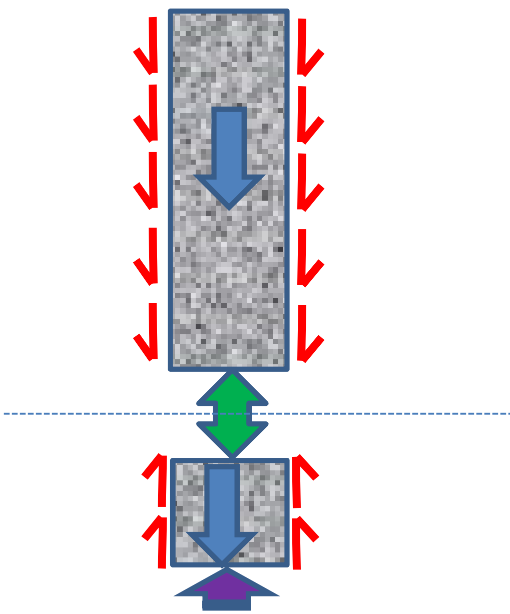
- Strain gages/ LWDTs
- Tell tales
- etc

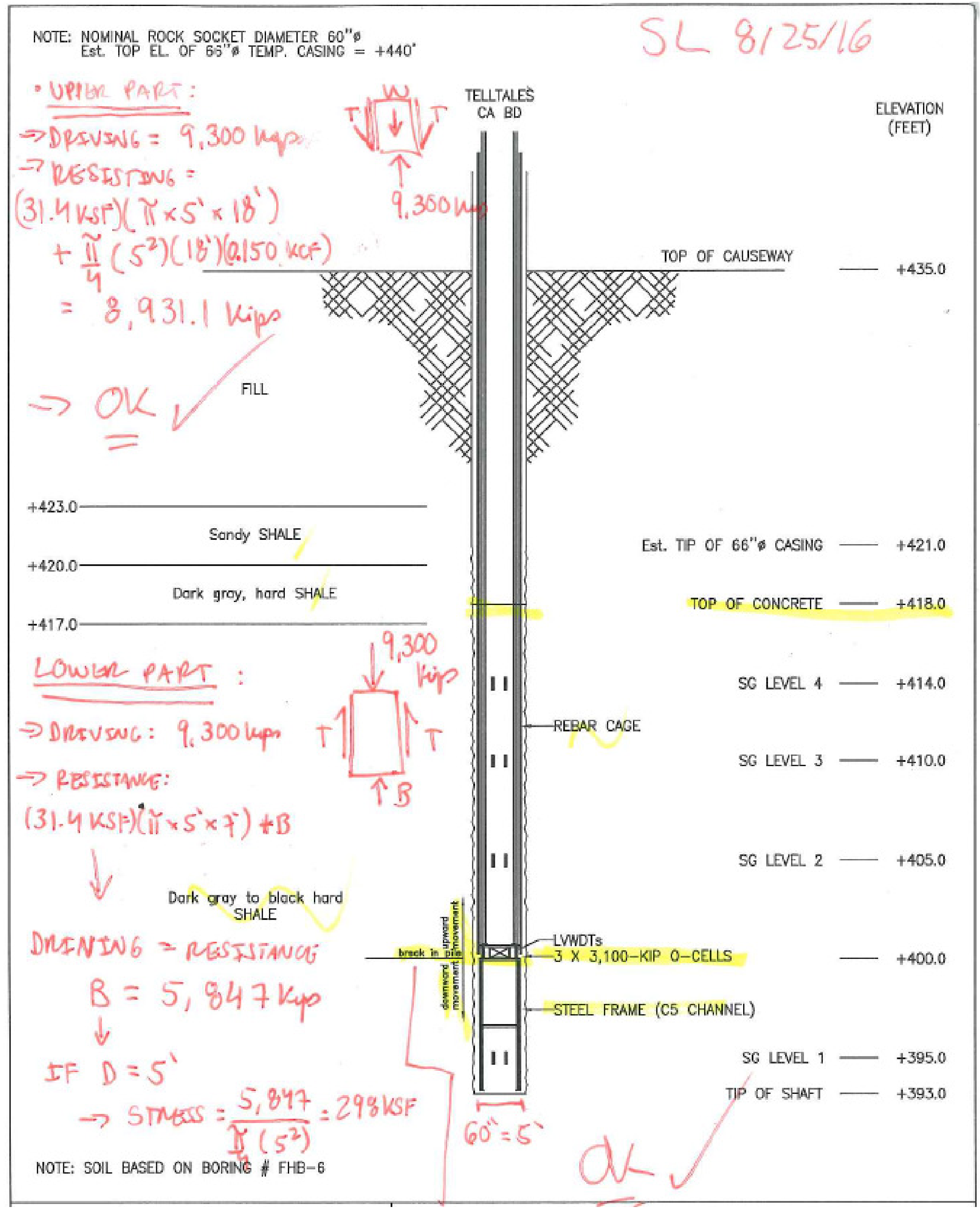




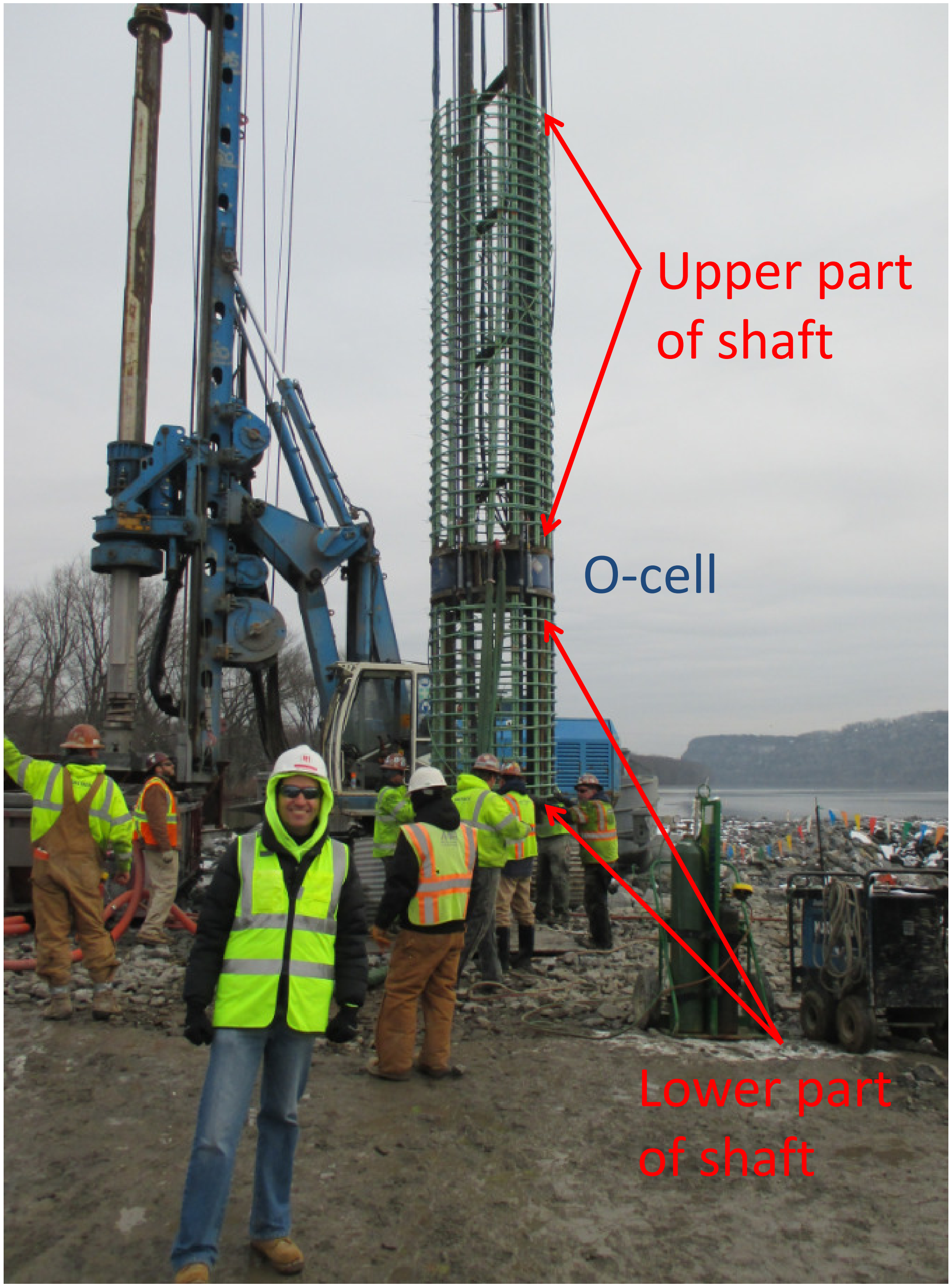
Selecting the right dimensions and the right cell:

- Use **ultimate** Geotech side shear and end bearing stresses
- Load > Expected resistance

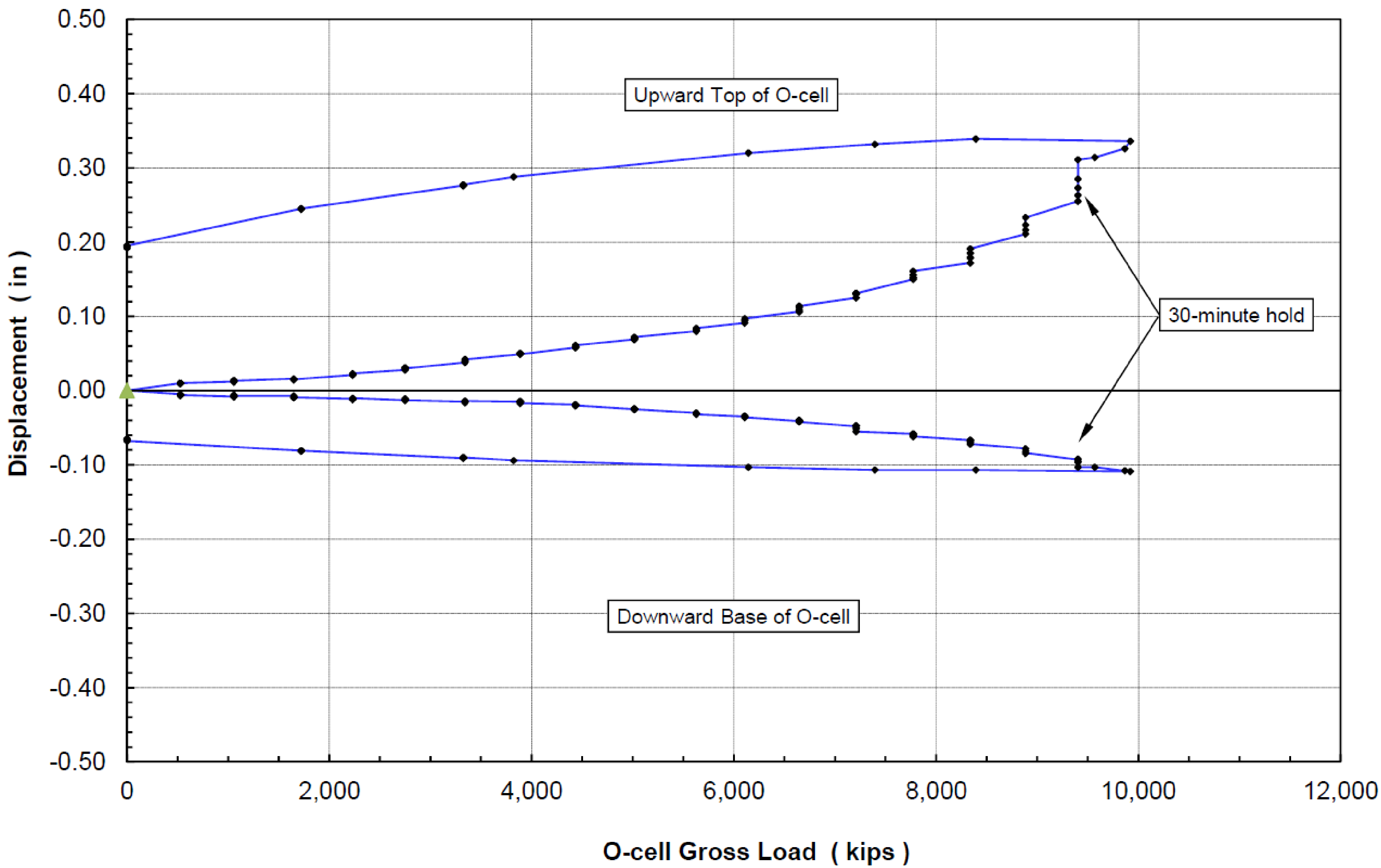




Lifting the instrumented shaft (including installed O-cell)


Upper part
of shaft
O-cell
Lower part
of shaft


LOADTEST
MORETRENCH
MORETRENCH



Upward Top of O-cell
30-minute hold
Downward Base of O-cell
Displacement (in)
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
0
2,000
4,000
6,000
8,000
10,000
12,000
O-cell Gross Load (kips)

Comparison of Test Results	Ultimate Capacity		Displacement at Failure	
	Predicted (kips) [MN]	Measured (kips) [MN]	Predicted (in) [mm]	Measured (in) [mm]
Upper portion (above O-cell): skin friction only	9,300 [41.4]	9,371 [41.7]	0.40 [10]	0.31 [7.9]
Lower portion (below O-cell): skin friction + end bearing	9,300 [41.4]	9,402 [41.8] (no failure observed)	0.40 [10]	0.10 [2.6] (no failure observed)

FEATURE ARTICLE

Production shaft drilling

Predicting Geotechnical Drilled Shaft Capacity: Are We Close?

Recently modified design equations used in the transportation industry to calculate side friction and end bearing capacity for drilled shafts are now providing more realistic estimations of capacities than did previous methods. Using multiple case studies and test results from various projects, a more realistic design approach was formulated by the Federal Highway Administration (FHWA), which resulted in greater values of ultimate capacity for side friction and end bearing and in a more efficient design overall.

In 2010, the FHWA published *GEC-10 – Drilled Shafts: Construction Procedures and LRFD Design Methods*, which illustrates a different method of calculating side friction and end bearing resistance and results in greater values for design. In 2014, the Association of State Highway and Transportation Officials (AASHTO) adopted the method put forth by FHWA, which was included in its *LRFD Bridge Design Specifications, 7th Edition*. The Pennsylvania Department of Transportation (PennDOT) recently adopted and incorporated the similar methodology as AASHTO for calculating side friction and end bearing for drilled shafts in rock, and these changes are reflected in the 2015 edition of the PennDOT *Design Manual, Part 4 (DM-4)*. This article discusses the past and current design methodology along with a project case study with results from Osterberg Cell (O-cell) load testing, which presents a comparison between the design resistances of ultimate side friction and end bearing and the measured capacities at failure.

The Old and the New

Editions of the *AASHTO LRFD Bridge Design Manual* from 2012 and earlier estimated ultimate side resistance, q_s, in rock using the following equation (modified from Horvath and Kenney, 1979):

$$q_s = 0.65\alpha_E p_a (q_u/p_a)^{0.5} < 7.8 p_a (f'_c/p_a)^{0.5}$$

where: q_u is the uniaxial compressive strength of the rock in ksf; p_a is the atmospheric pressure in ksf; α_E is the reduction factor to account for jointing in rock; and f'_c is the compressive strength of the concrete in ksi. For intact rock, previous versions of the AASHTO manual required that the ultimate end bearing resistance, q_p, was calculated using the following equation: $q_p = 2.5q_u$

Editions of PennDOT *DM-4* from 2012 and earlier adhered to the same methodology as AASHTO, with slight modifications for calculating the value of α_E, based on the rock quality designation (RQD) and open or closed joints.

In editions of the AASHTO manual prior to 2014, the method for determining the interaction between side friction and end bearing resistance was not practical and often resulted in conservatively neglecting one of these two resistance components. Moreover, the AASHTO manual did not provide a clear guideline for calculating side friction and end bearing resistance when both components were considered:

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DEEP FOUNDATIONS • SEPT/OCT 2017 • 81

Production shaft dril

Predicting Geotechnical Drilled Shaft Capacity: Are We Close?

Recently modified design equations used | Department of Transportation (PennDOT) | atmospheric pressure in ksf; α_E is

Acknowledgements

pennsylvania
DEPARTMENT OF TRANSPORTATION

PJ DICK
TRUMBULL
LINDY PAVING

BRAYMAN construction corporation
Innovative Solutions Since 1947

HNTB

MORETRENCH

SAI Consulting Engineers

LOADTEST

GZA

STV 100 Years

GRL engineers, inc.
Dynamic Measurements and Analyses