THERMAL INTEGRITY PROFILING AS A DRILLED SHAFT QUALITY ASSURANCE TOOL

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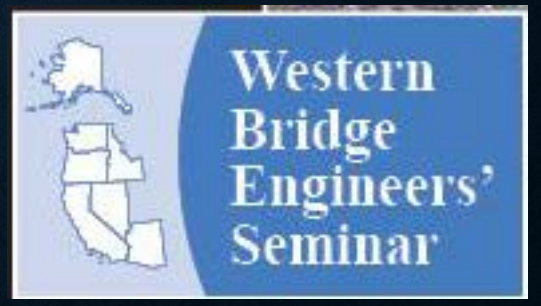
Washington State Department of Transportation



PRESENTATION OVERVIEW

- WSDOT's drilled shaft construction program
- Traditional shaft quality assurance at WSDOT
- Thermal Integrity Profiling Basics
- Implementation on Construction Contracts
- What we learned
- The way forward

WSDOT'S DRILLED SHAFT CONSTRUCTION PROGRAM

- WSDOT's started drilled shaft construction in late 70's.
- For past 10 years, average exceeds 100 shafts per year.
- Range from 4-12 feet in diameter and 40-200 feet in length.
- Vast majority (95%) constructed as "wet" shafts.

TRADITIONAL SHAFT QUALITY ASSURANCE AT WSDOT

- Primary QA has been cross-hole sonic log (CSL) testing
- 100% of the "wet" shafts are CSL tested
- Backed up by:
  - Inspector observations
  - Monitoring of concrete and slurry levels
  - Concrete yield plots

TRADITIONAL SHAFT QUALITY ASSURANCE AT WSDOT

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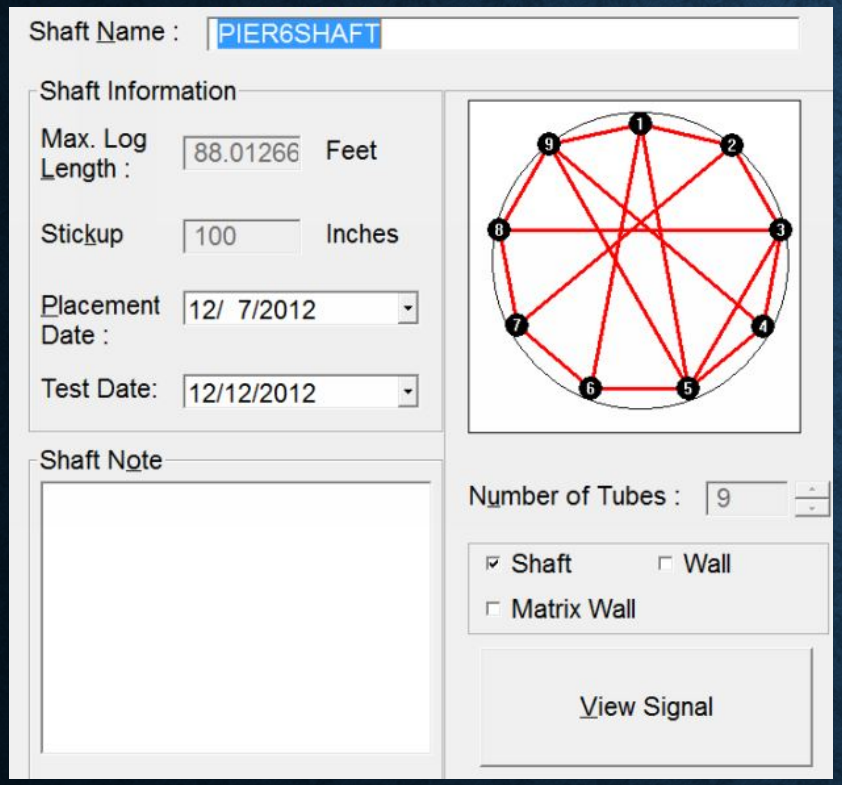
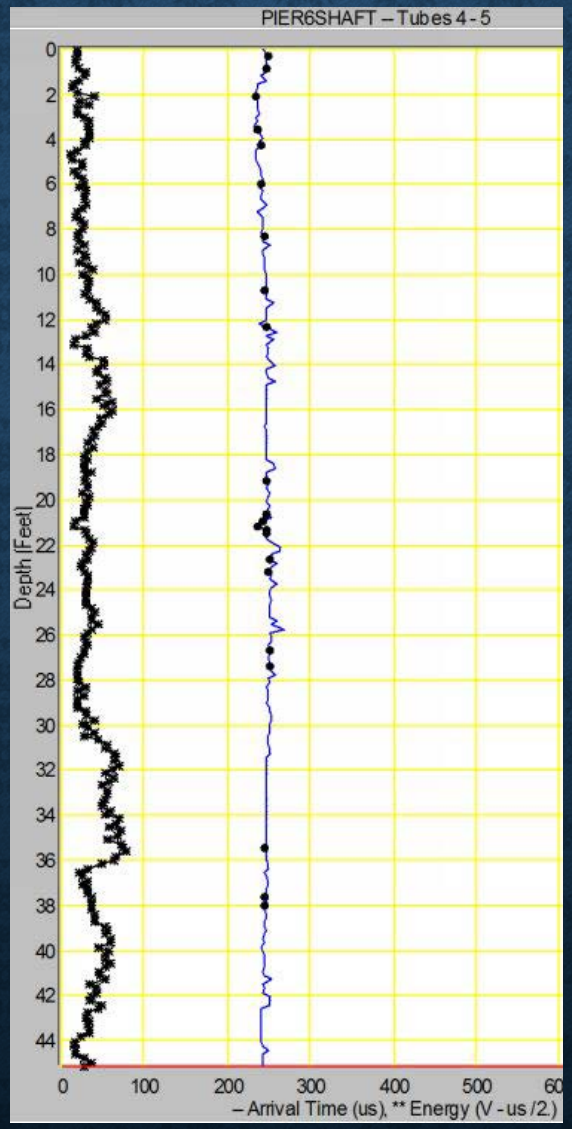
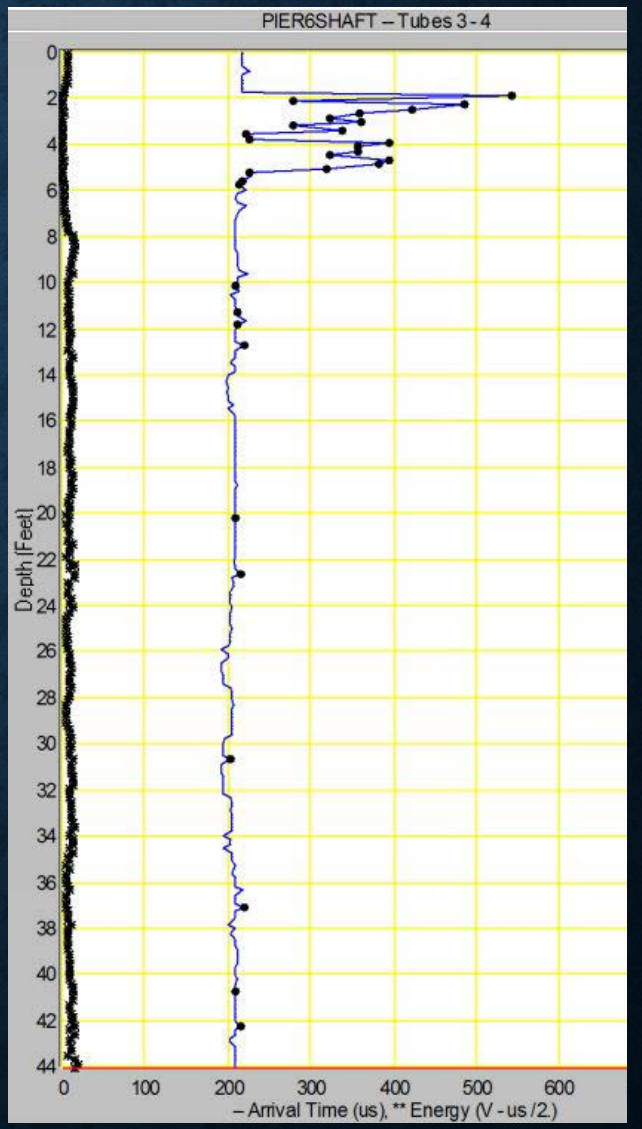






TRADITIONAL SHAFT QUALITY ASSURANCE AT WSDOT

- Limitations on CSL Testing:
  - Can be a "sensitive" test.
  - "False anomalies" aren't uncommon.
  - Only validates core of shaft.

WSDOT has used Thermal Integrity Profiling on two recent projects.

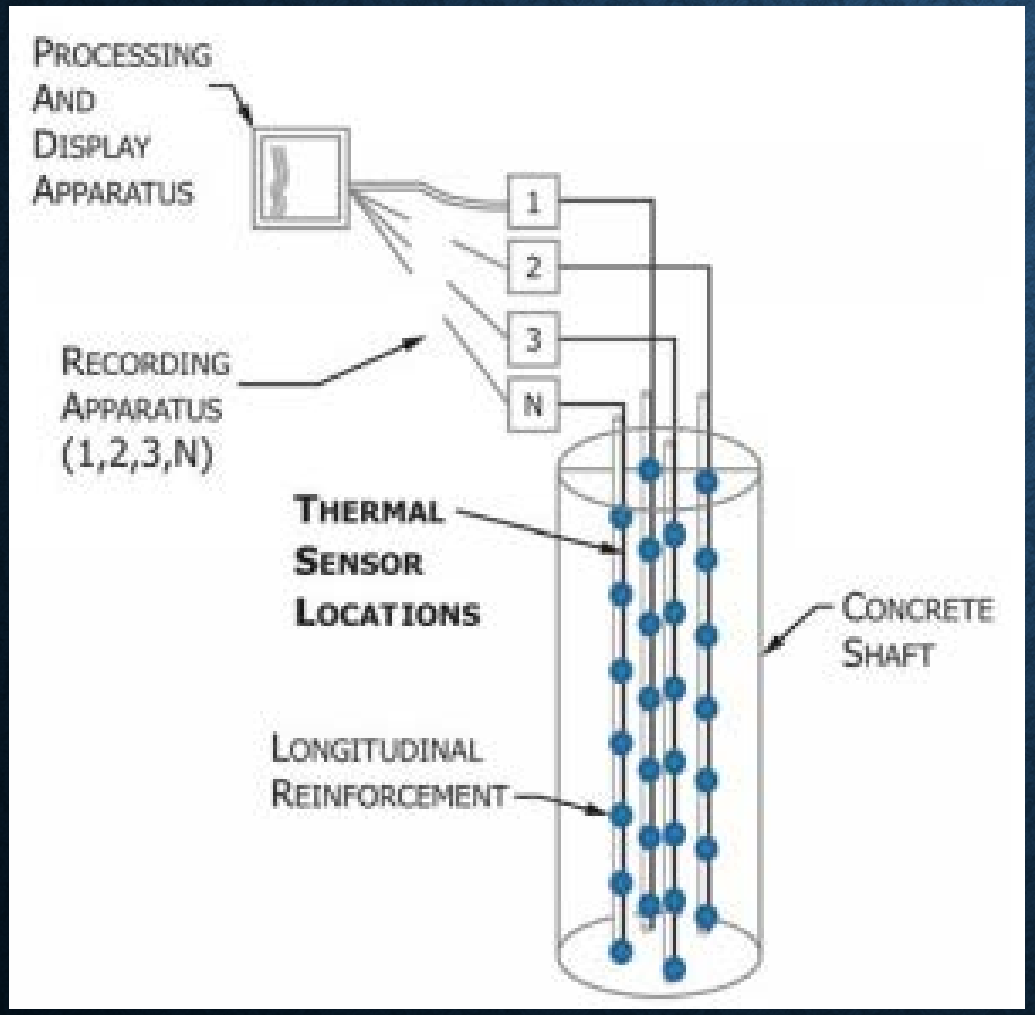
THERMAL INTEGRITY PROFILING BASICS

- Uses heat generated by hydrating concrete to determine quality.
- Measurements taken near shaft perimeter and uniformly around and along shaft.
- Adjustments for shaft geometry, concrete properties, water table, type of soils, presence of casing, etc.

ASTM D7949 – Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations

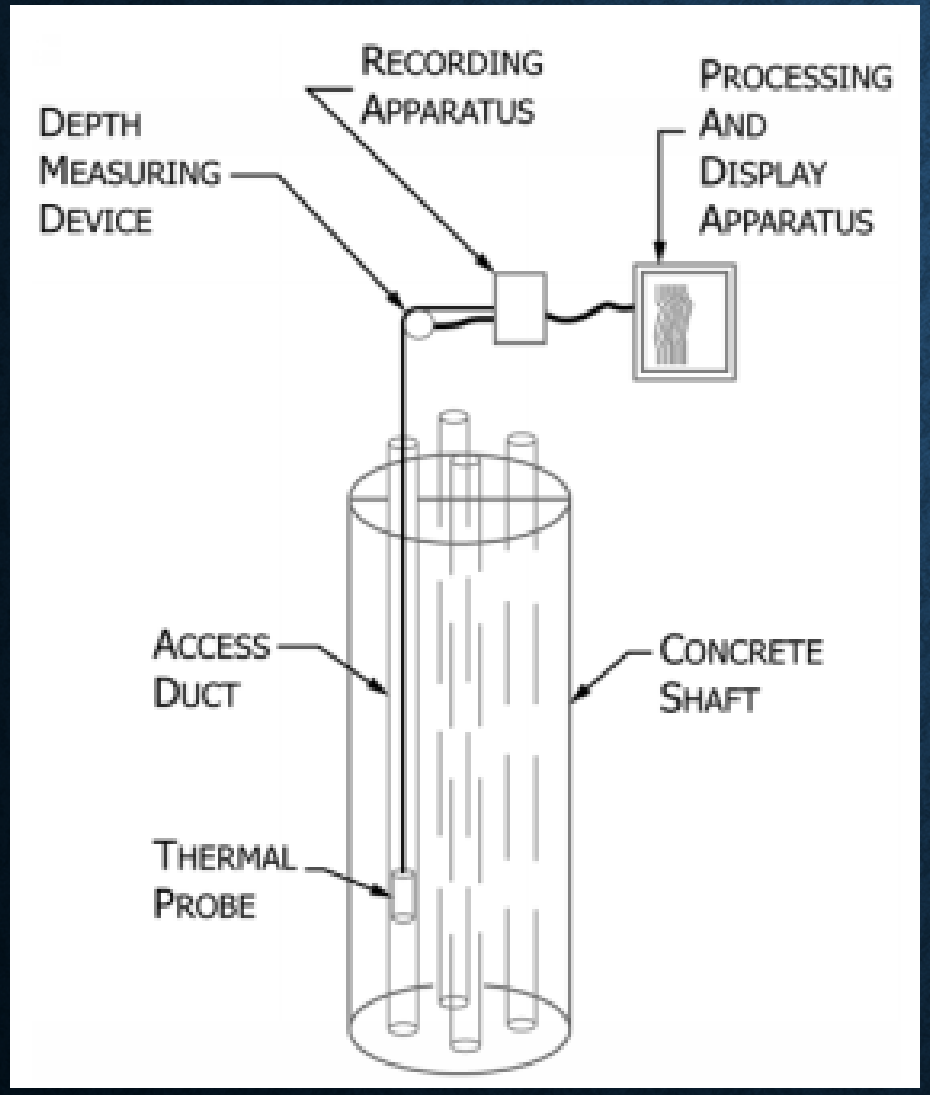
THERMAL INTEGRITY PROFILING BASICS

THERMAL WIRE METHOD



- One wire per foot diameter of shaft
- Sensors located every foot

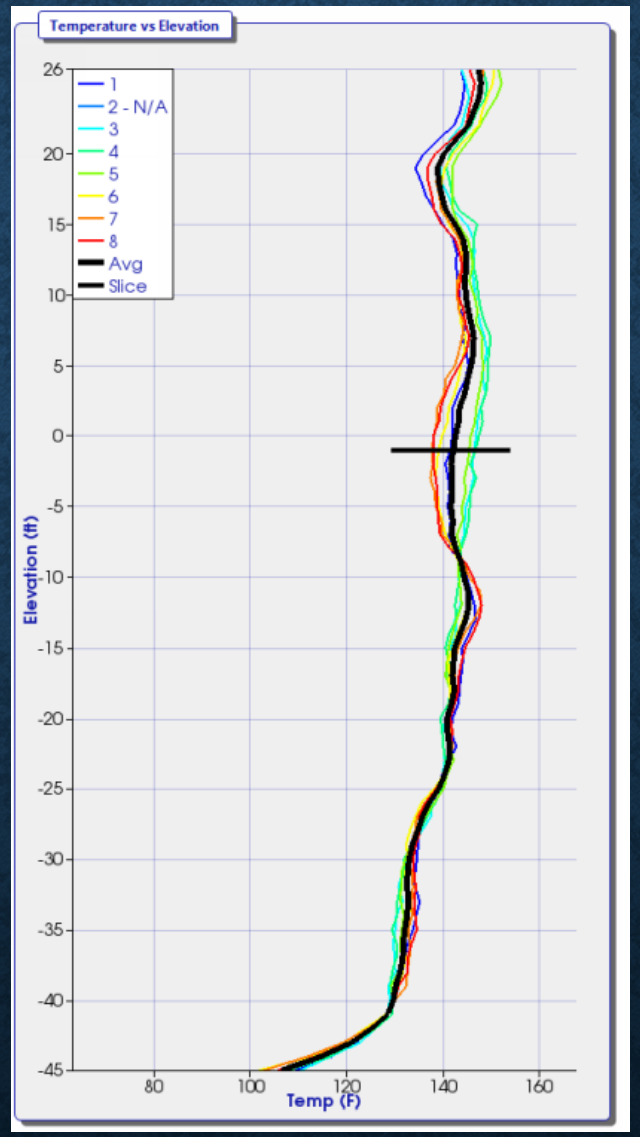
THERMAL INTEGRITY PROFILING BASICS
THERMAL PROBE METHOD

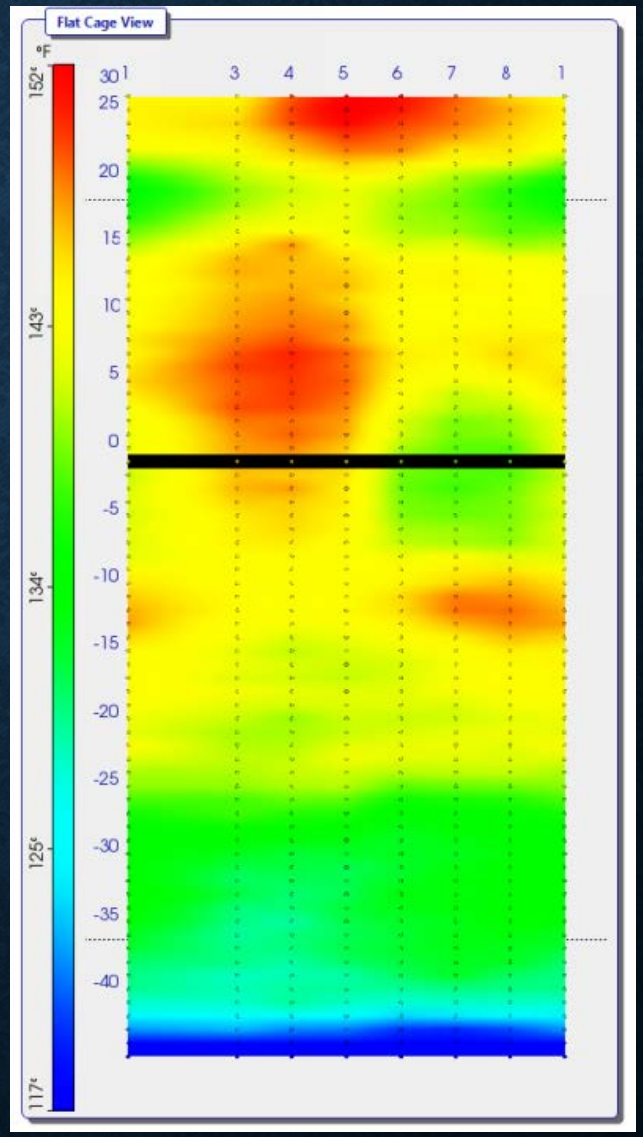


- One access duct per foot diameter of shaft
- Reusable thermal probe to get temperatures

THERMAL INTEGRITY PROFILING BASICS

- Basic output is temps at each node
- Data is further post-processed (discussed later)





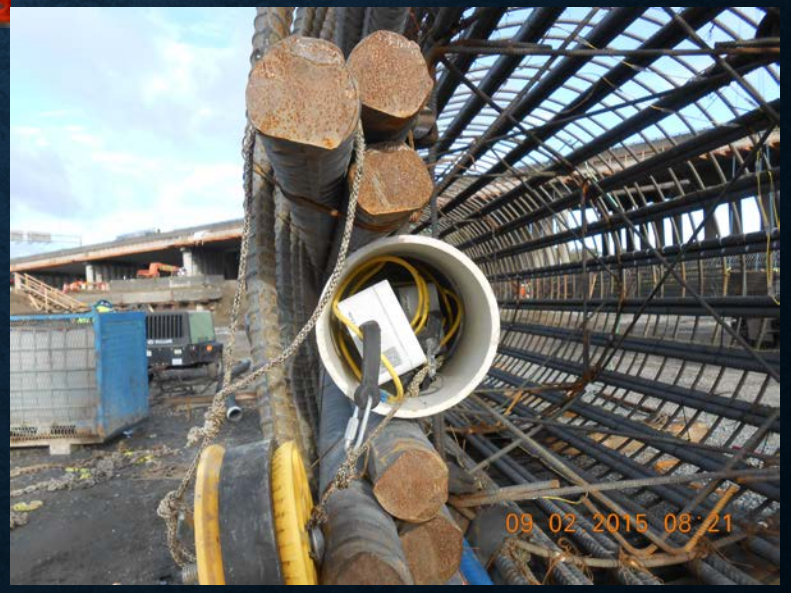
IMPLEMENTATION AT WSDOT

- Participated in research testing in 2010
  - Used the thermal probe method
- WSDOT purchased testing equipment and used for QA testing and shaft acceptance on two contracts
  - Selected the thermal wire method

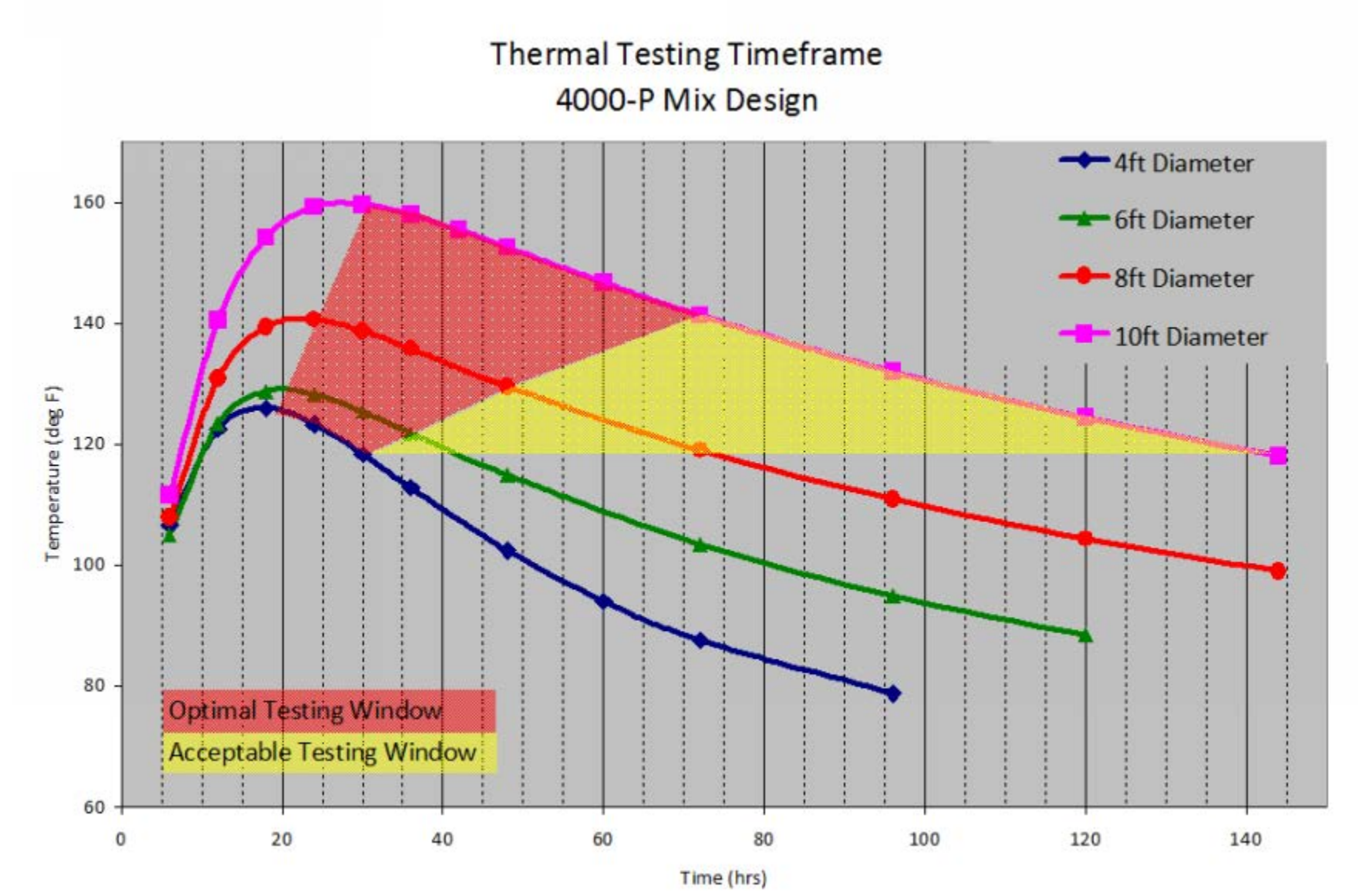
IMPLEMENTATION AT WSDOT
INSTALLING THE THERMAL WIRES

IMPLEMENTATION AT WSDOT

PROTECTING THE TAPS



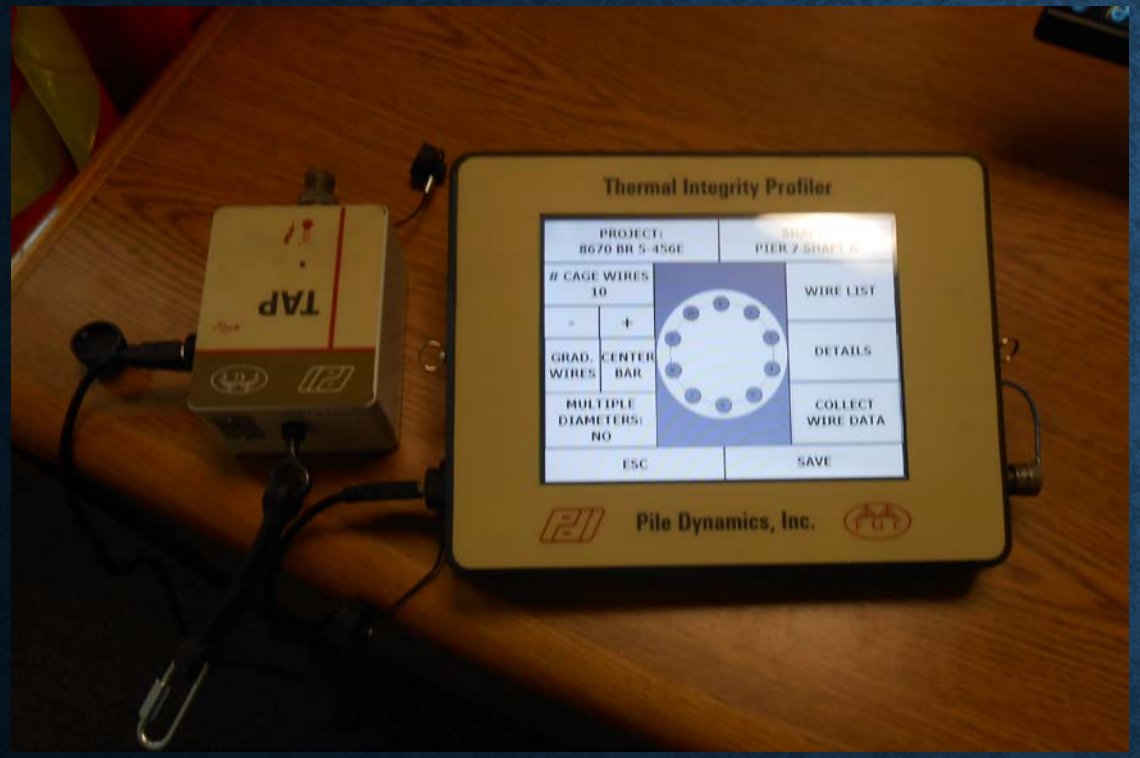
IMPLEMENTATION AT WSDOT
OBTAINING DATA READINGS

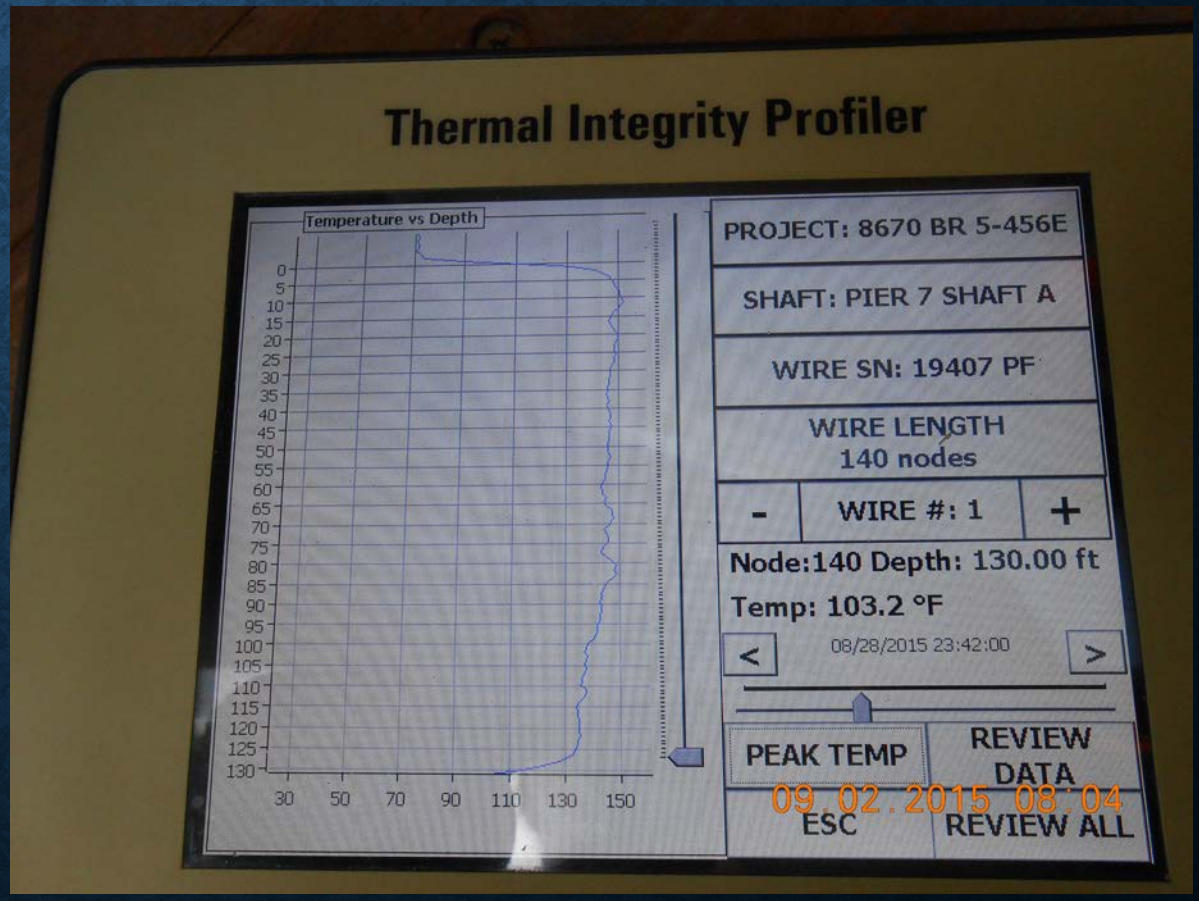


IMPLEMENTATION AT WSDOT
COLLECTING THE TAPS

- TAP's obtained:
  - Once slurry pumped down, and
  - Once sufficient time has elapsed
- If needed, TAP's can be reconnected.

IMPLEMENTATION AT WSDOT
DOWNLOADING THE THERMAL DATA





IMPLEMENTATION AT WSDOT

DATA SUPPLIED BY THE FIELD

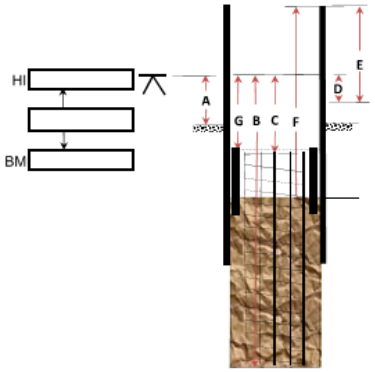
SHAFT INSTALLATION REPORT

PROJECT: **PORTLAND AVE to POT Rd- NB HOV** JOB NUMBER: **8670** DATE STARTED: 6/22/2015

BRIDGE: **5/456E** PIER: **1** SHAFT: **D** DIAMETER: **8.00 ft** DATE COMPLETED: 6/24/2015

FIELD MEASURMENTS

(A) to ground at casing =	
(B) to bottom of shaft =	
(C) to top of rebar =	
(D) to reference point =	
(E) to top of temp casing =	
(F) to top of concrete =	Varies
(G) to top of casing/silo =	N/A



QUANTITIES & DIMENSIONS

	Plan	AsBuilt
Casing Shoring	YES	
Perm. Casing O.D.	N/A	
Perm. Case Length	N/A	5.0 ft
Rebar Cage Dia.	6.75 ft	6.75 ft
Rebar Cage Length	97.46 ft	97.46 ft
Shaft Length	75.0 ft	75.6 ft
Excavation	146.7 CY	
Conc. Vol. Stage 1	146.7 CY	149.0 CY
Conc. Vol. Stage 2	N/A	
Total Thermal Wire	720.0 ft	720.0 ft
CSL Tubes (each)	8	8

SHAFT ELEVATIONS

	Plan	AsBuilt
Origional Grade		26.50
Reference Pt. Elev.		49.50
Top of Perm Casing	N/A	
Top of Shaft	26.00	26.00
Top of Rebar	48.71	48.71
Construction Joint	26.00	26.00
Bot. of Perm Casing	N/A	
Bottom of Shaft	-49.00	-49.50

SOIL STRATA DATA

SOIL TYPE	ELEV. CHANGE Predicted	Actual
n/a		
n/a		
n/a		

Water Level High N/A

Low

Soil data take from Test Boring Hole No.

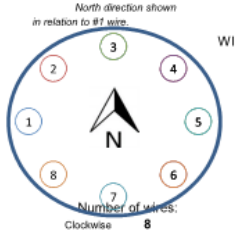
SLURRY TESTS

		Range for Water
Time		
Location		
PH		
Viscosity(s/q)		
Sand %	N/A	1.0 max
Density(pcf)	N/A	65 max

PERSONNEL & EQUIPMENT

Super: Dave Vistaunet
WSDOT: S. A. Lucero
Drill Rig: Libherr 883 drill crane
Drill Foreman: Elija Arnott
Drill Oiler: James Losnegard
Drill Operator: Caylin McClary

THERMAL INTEGRITY WIRES



WIRE #	SERIAL #	Wire Length (# nodes)	Nodes Above Concrete	Wire Tested After Install
1	17897 PF	75	0	Y
2	17899 PF	75	0	Y
3	17895 PF	75	0	Y
4	17893 PF	75	0	Y
5	19178 PF	75	0	Y
6	17892 PF	75	0	Y
7	17896 PF	75	0	Y
8	17898 PF	75	0	Y

WIRE TO WIRE DISTANCE (in)

1	2	5	1
1	3	5	2
1	4	5	3
1	6	5	4
1	7	5	6
1	8	5	7
		5	8

NOTES

Wet Shaft
Permanent Casing Diameter = 8.82'
17899 PF Wire Failed during concrete pour.
Current As Built Top of Permanent Casing Elev. = 26.5
Original Ground Elev. = 26.5

SHAFT CONRETE POUR LOG

PROJECT: **PORTLAND AVE to POT Rd- NB HOV**
BRIDGE: **5/456E** Pier: **1** SHAFT: **D**

Shaft Diameter (ft):	8.0
Shaft Vol. per LF (CY):	1.9
Shaft Diameter (ft):	8.0
Shaft Vol. per LF (CY):	1.9
Reference point elevation:	-49.0

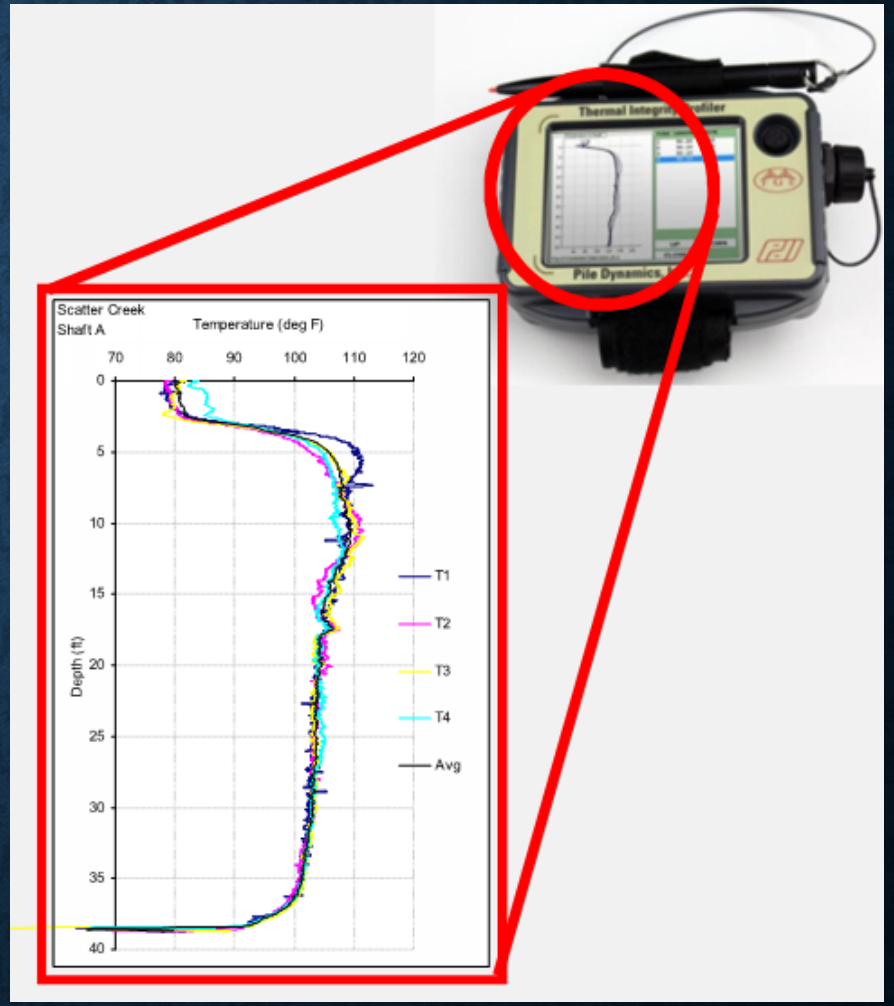
Measure Down Pt. Elev.	
Ground Elevation:	26.50
Construction Joint:	26.00
Bottom of Shaft:	-49.50

	Truck #	Time Start	Time End	Depth (ft) Start Elevation	Depth (ft) Ground to Top	Depth (ft) Top to Concrete	Depth (ft) End Elevation	Fill Ht.	Concrete Placed	Yards Per Foot	Temp. Casing Length	Comment
1	1	6:43	6:49	-49.5	81.7	77.1	-44.4	4.6	9	2.0	81.5	
2	2	6:49	6:55	-44.4	77.1	74.5	-46.4	4.6	9	2.0	81.5	
3	3	6:55	7:01	-46.4	74.5	71.0	-45.5	4.6	9	2.0	81.5	
4	4	7:04	7:10	-45.5	71.0	70.5	-48.5	4.6	9	2.0	81.5	
5	5	7:10	7:15	-48.5	70.5	70.6	-49.1	4.6	9	2.0	81.5	
6	6	7:15	7:21	-49.1	70.6	70.3	-48.7	4.6	9	2.0	81.5	
7	7	7:21	7:27	-48.7	70.3	68.0	-46.7	4.6	9	2.0	81.5	
8	8	7:54	8:01	-46.7	53.0	56.5	-52.5	4.6	9	2.0	66.9	
9	9	8:01	8:07	-52.5	56.5	56.0	-48.5	4.6	9	2.0	66.9	
10	10	8:07	8:15	-48.5	56.0	57.0	-50.0	4.6	9	2.0	66.9	
11	11	8:15	8:22	-50.0	57.0	57.0	-49.0	4.6	9	2.0	66.9	
12	12	8:22	8:30	-49.0	57.0	54.5	-46.5	4.6	9	2.0	66.9	
13	13	8:58	9:04	-46.5	28.5	31.0	-51.5	4.5	9	2.0	41.3	
14	14	9:04	9:10	-51.5	31.0	30.5	-48.5	4.5	9	2.0	41.3	
15	15	9:10	9:17	-48.5	31.0	31.0	-49.0	4.5	9	2.0	41.3	
16	16	9:17	9:22	-49.0	31.0	37.5	-55.5	4.0	9	2.3	41.3	
17	17	9:29	9:35	-55.5	37.5	38.5	-50.0	2.5	9	3.6	41.3	
18	18											
19												

IMPLEMENTATION AT WSDOT
POST-PROCESSING AND RESULTS

LEVEL 1 – Performed in the field using TIP Main Unit
- Verify shaft length – Identify top and bottom
- Locate immediate areas of concern

LEVEL 2 – Added Element – Field Records
- Find relationship between concrete volume and measured temperature
- Predict as-built shaft radius, shape, and cover



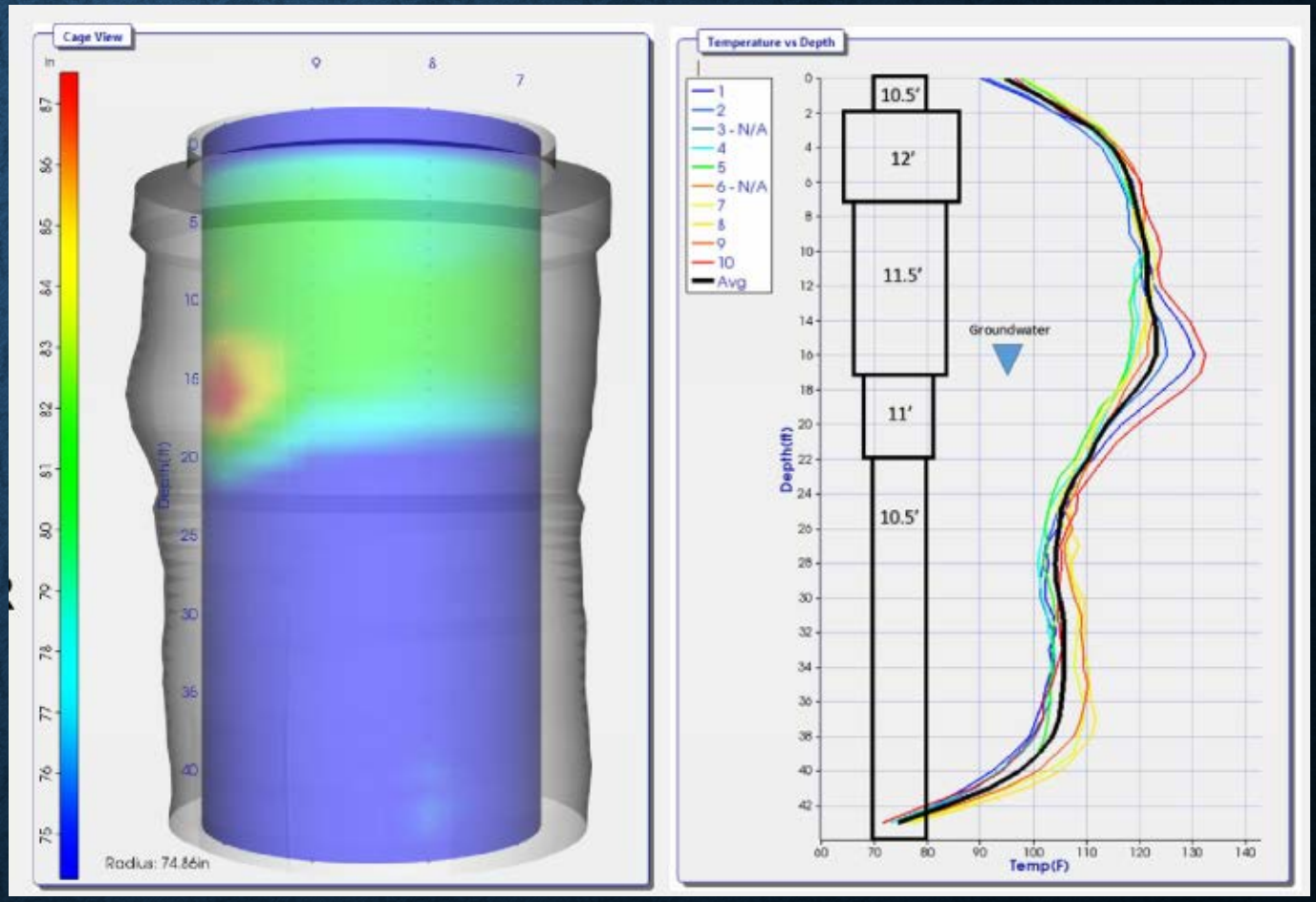
Level 1 Analysis

Information and graphics courtesy of Pile Dynamics Inc.

IMPLEMENTATION AT WSDOT
POST-PROCESSING AND RESULTS

LEVEL 3 – Thermal Modeling using TIP Reporter

- Completed with desktop software
- Top & Bottom Roll Off Corrections
- Analyze Radius vs. Depth



Level 3 Analysis

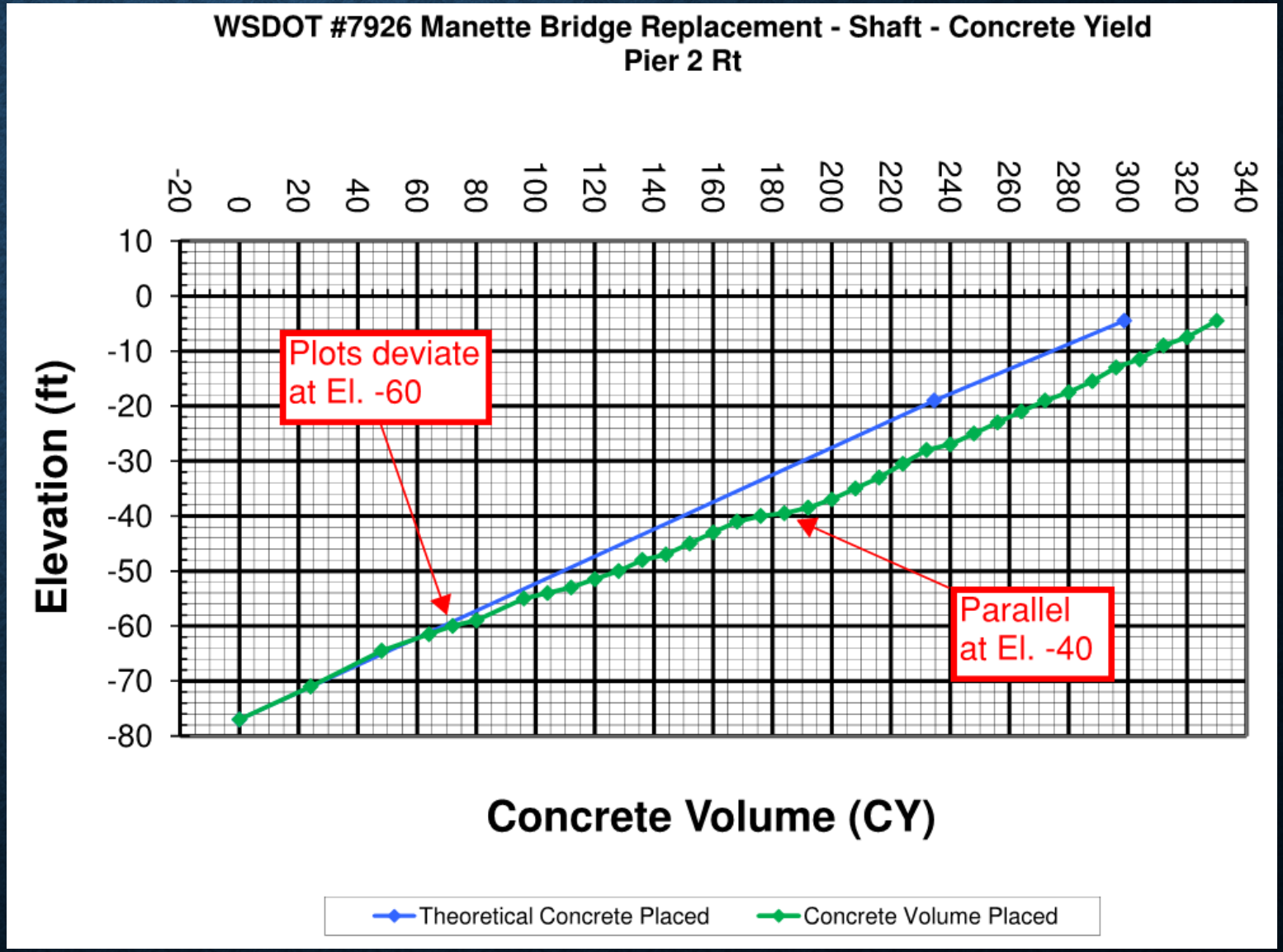
Information and graphics courtesy of Pile Dynamics Inc.

WHAT WE LEARNED

SOME EXAMPLES FROM WSDOT PROJECTS

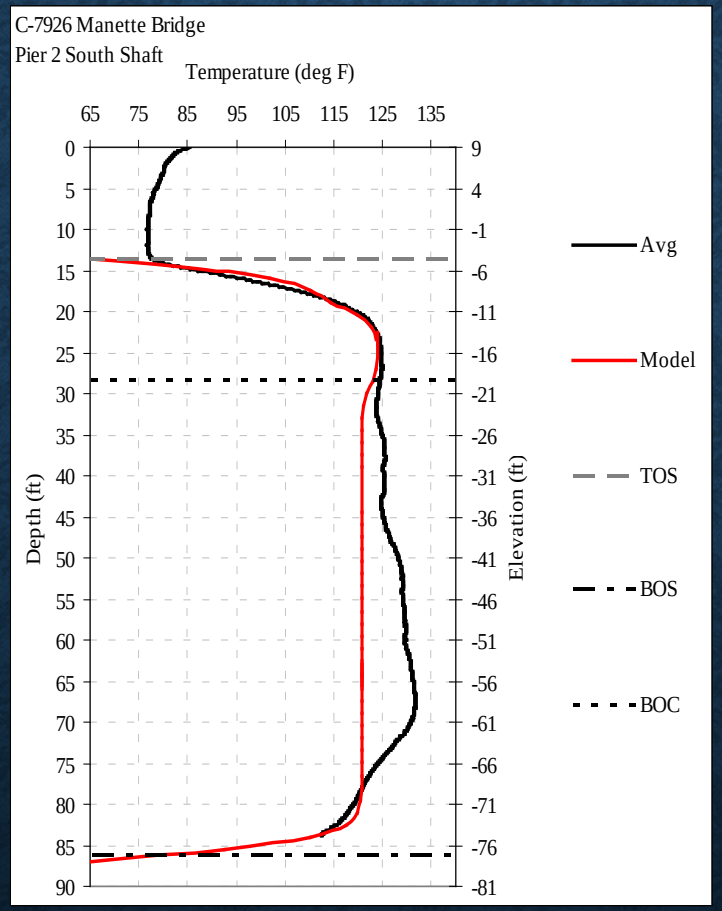
WHAT WE LEARNED
MANETTE BRIDGE SOIL CAVING

- After placing cage, 40 CY of material sluffed into shaft
- Cage was extracted and soils removed
- Used TIP to evaluate actual shaft geometry

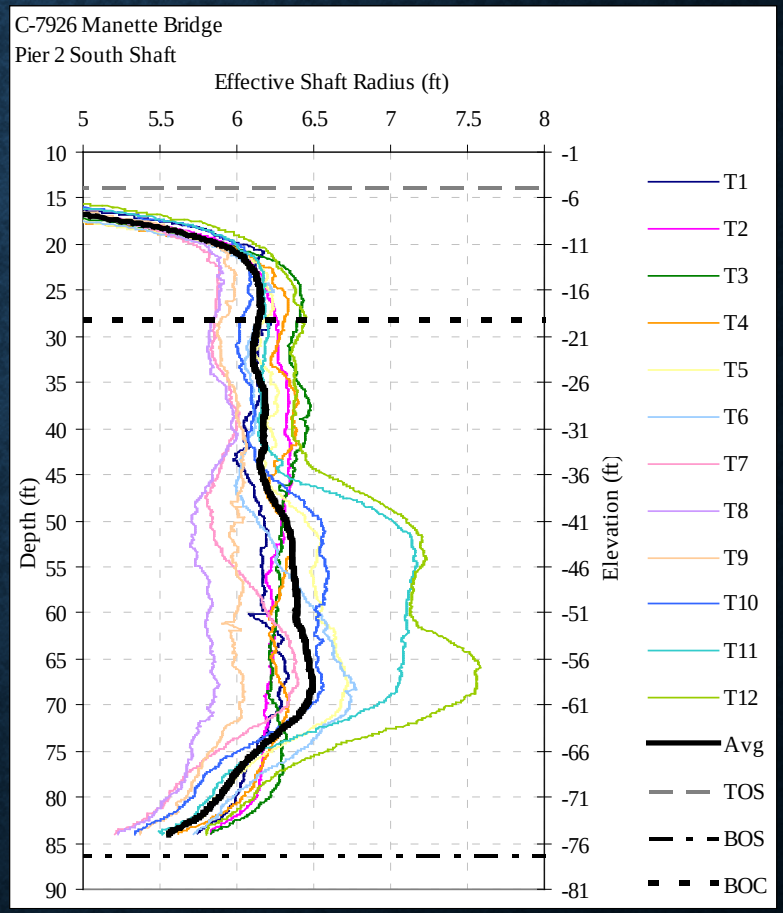


WHAT WE LEARNED
MANETTE BRIDGE SOIL CAVING

- Results showed as-built geometry
  - Limits of voiding
  - Effective radius at all shaft locations
- Good correlation with concrete yield plot



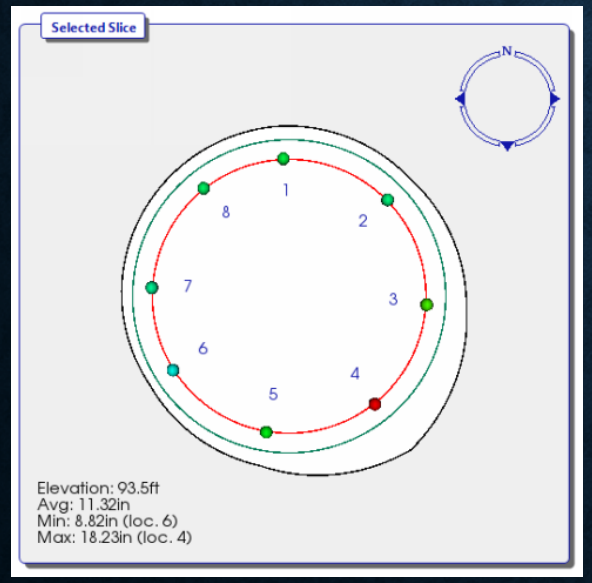
Actual vs. Modeled Temps.

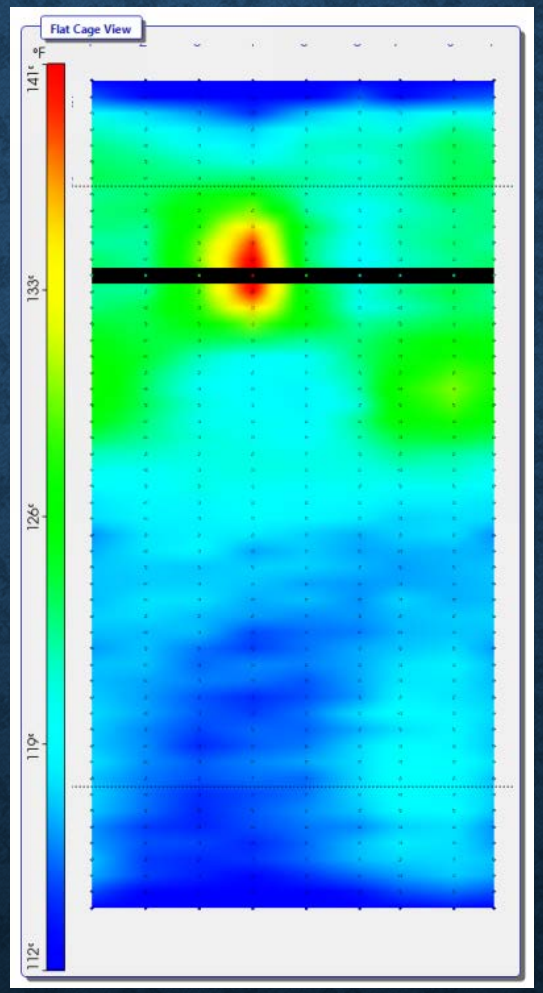


Predicted Shaft Radius

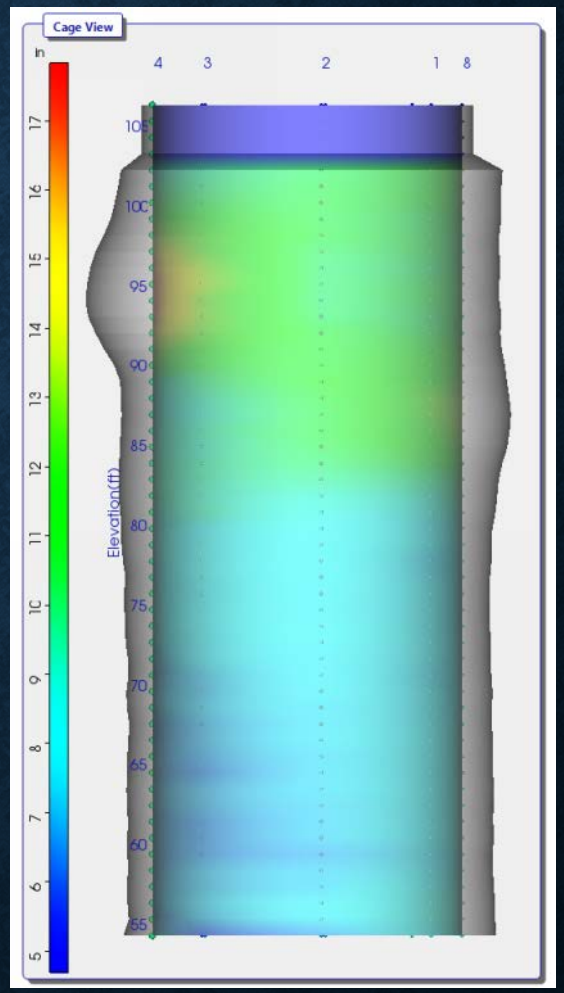
WHAT WE LEARNED
I-5 M-STREET TO PORTLAND "BULGE"

- "Bulge" of concrete identified.
- Potential for affecting seismic design.
- Allowed Engineer to review for structural acceptance.





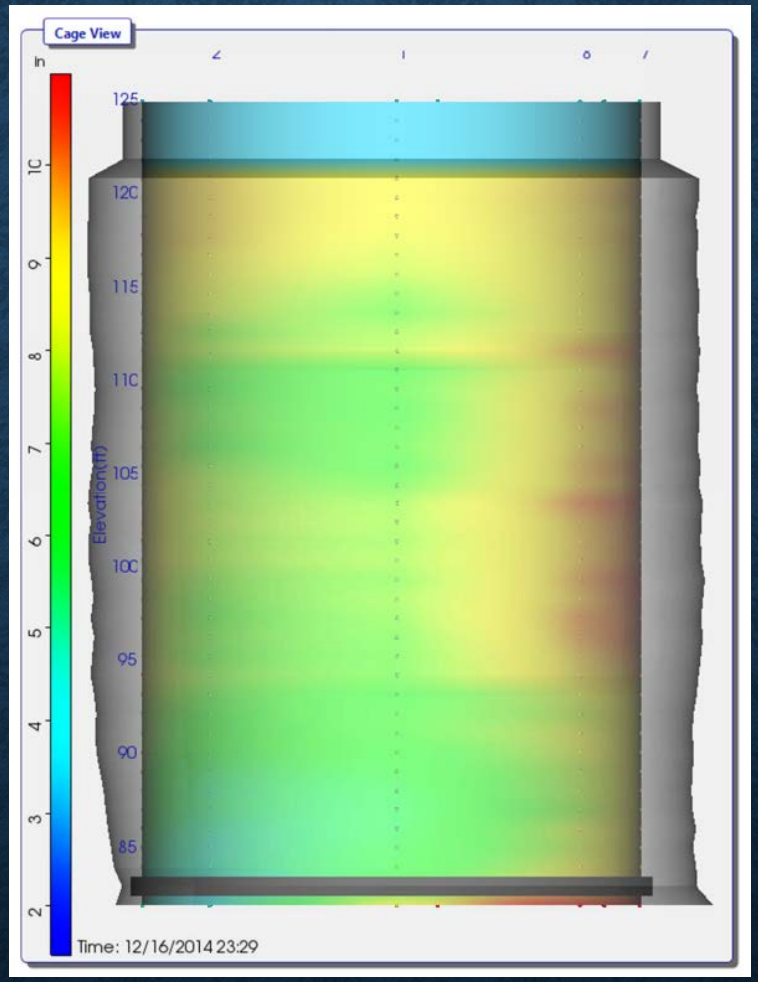
Flat view of Temps.



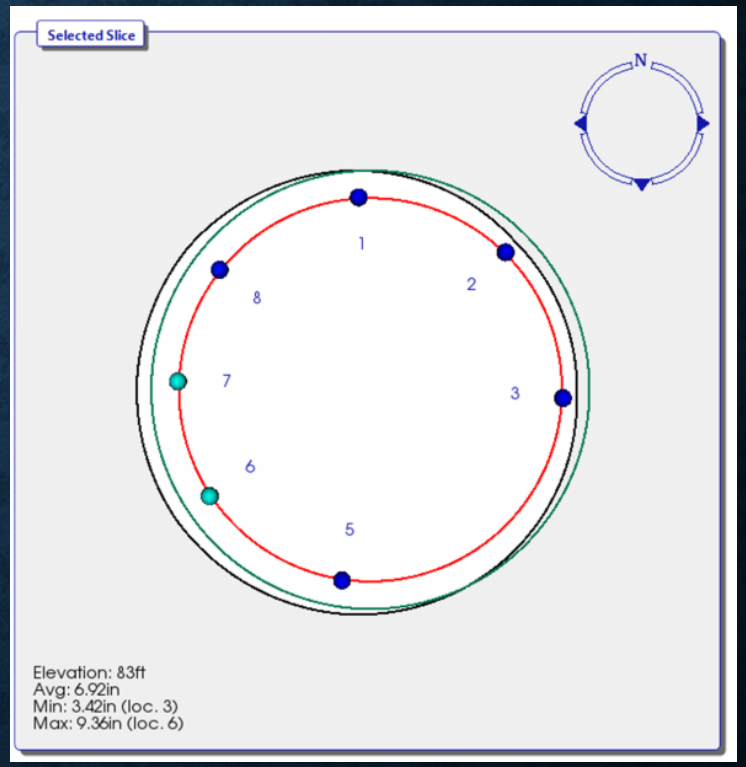
Estimated concrete cover

WHAT WE LEARNED
I-5 M-STREET TO PORTLAND CAGE RACKING

- Detailed for 6” cover
- Testing identified cage racking near shaft tip
- Min. cover approx. 3.5”
- Due to low corrosion potential at shaft tip, shaft was accepted.



Estimated concrete cover



Section near shaft tip

THE WAY FORWARD
PROS AND CONS OF THERMAL INTEGRITY PROFILING

Pros

- Indicates quality of shaft core and cover
- Testing as early as 24 hours after placement
- Builds a 3D model of shaft geometry

Cons

- A bit of a "black box"
- Thermal wires prone to damage/failure
- Thermal wires are a proprietary product

THE WAY FORWARD
OTHER OBSERVATIONS

- Cost-wise, comparable to CSL testing.
  - CSL tubes and thermal wires have similar costs
  - Equivalent labor for each method
- TIP methods/materials are improving!
  - New wire just released to reduce failures
- TIP data often leads to more acceptance evaluation
  - This is a good thing.

THE WAY FORWARD
FUTURE USE AT WSDOT

- WSDOT is generally pleased with the TIP methods
- Provides deeper review than CSL testing
- Currently reviewing/updating specifications
- Likely expand use to additional projects
  - Still want to keep CSL testing
  - May reserve TIP for larger, deeper shafts

THERMAL INTEGRITY PROFILING AS A DRILLED SHAFT QUALITY ASSURANCE TOOL

Comments/Thoughts?

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