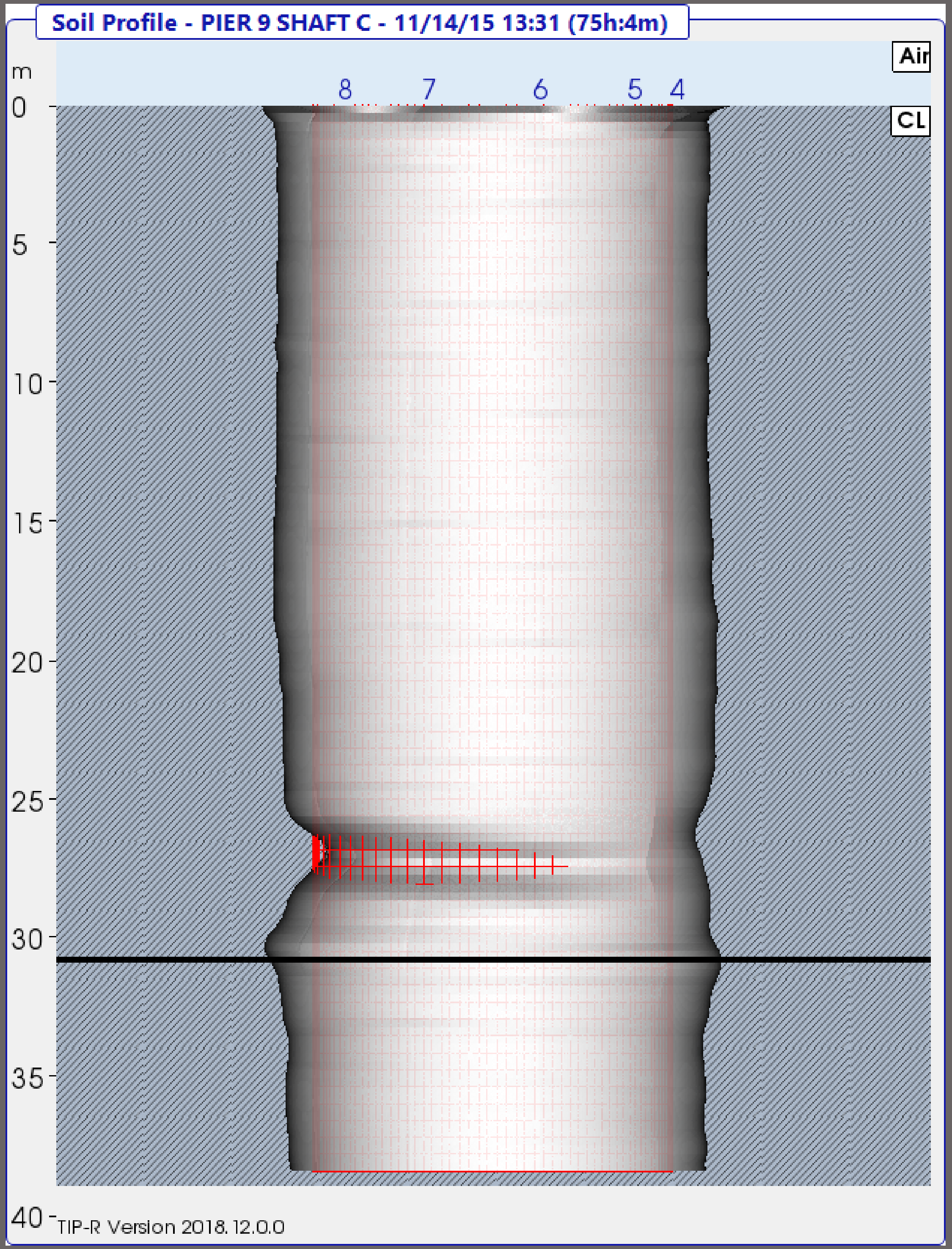

THERMAL INTEGRITY PROFILING

ASTM D7949

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TYPICAL INSPECTION

- Dry Cast
  - Generally visual inspection only

- Wet Cast
  - Since visual inspection is impossible some NDT is needed. Options include:
    - **PIT** (pulse echo) ASTM D5882
    - **CSL** (crosshole sonic logging) ASTM D6760
    - **Thermal Profiling** ASTM D7949

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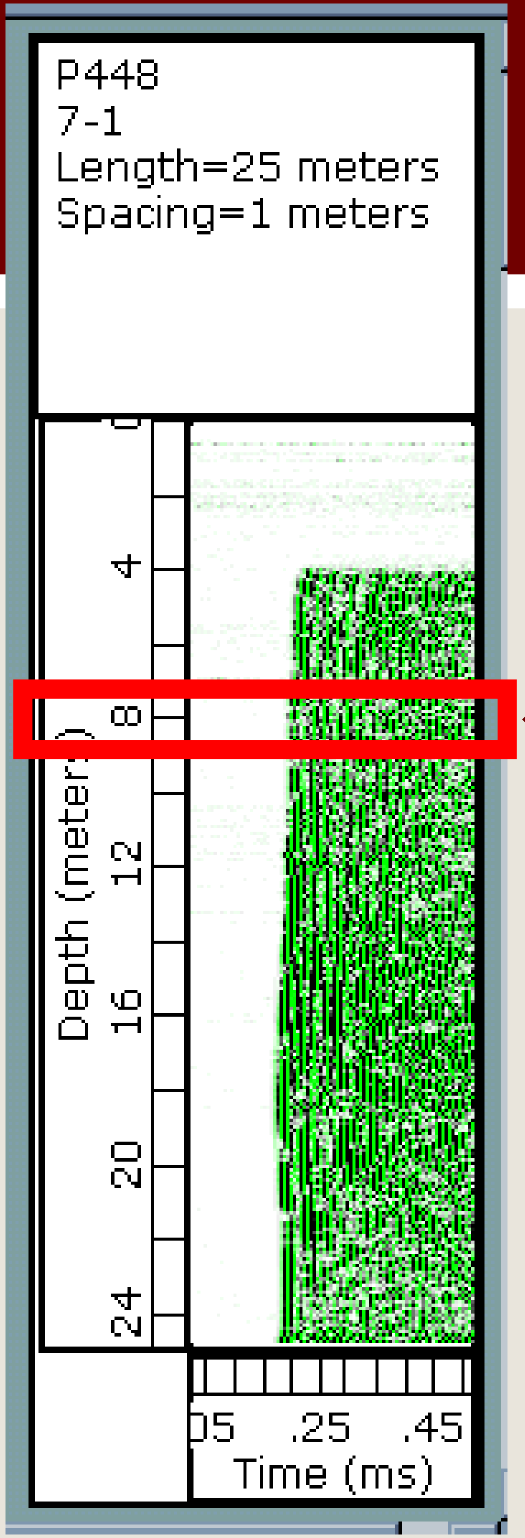
CSL CANNOT EVALUATE CONCRETE OUTSIDE CAGE



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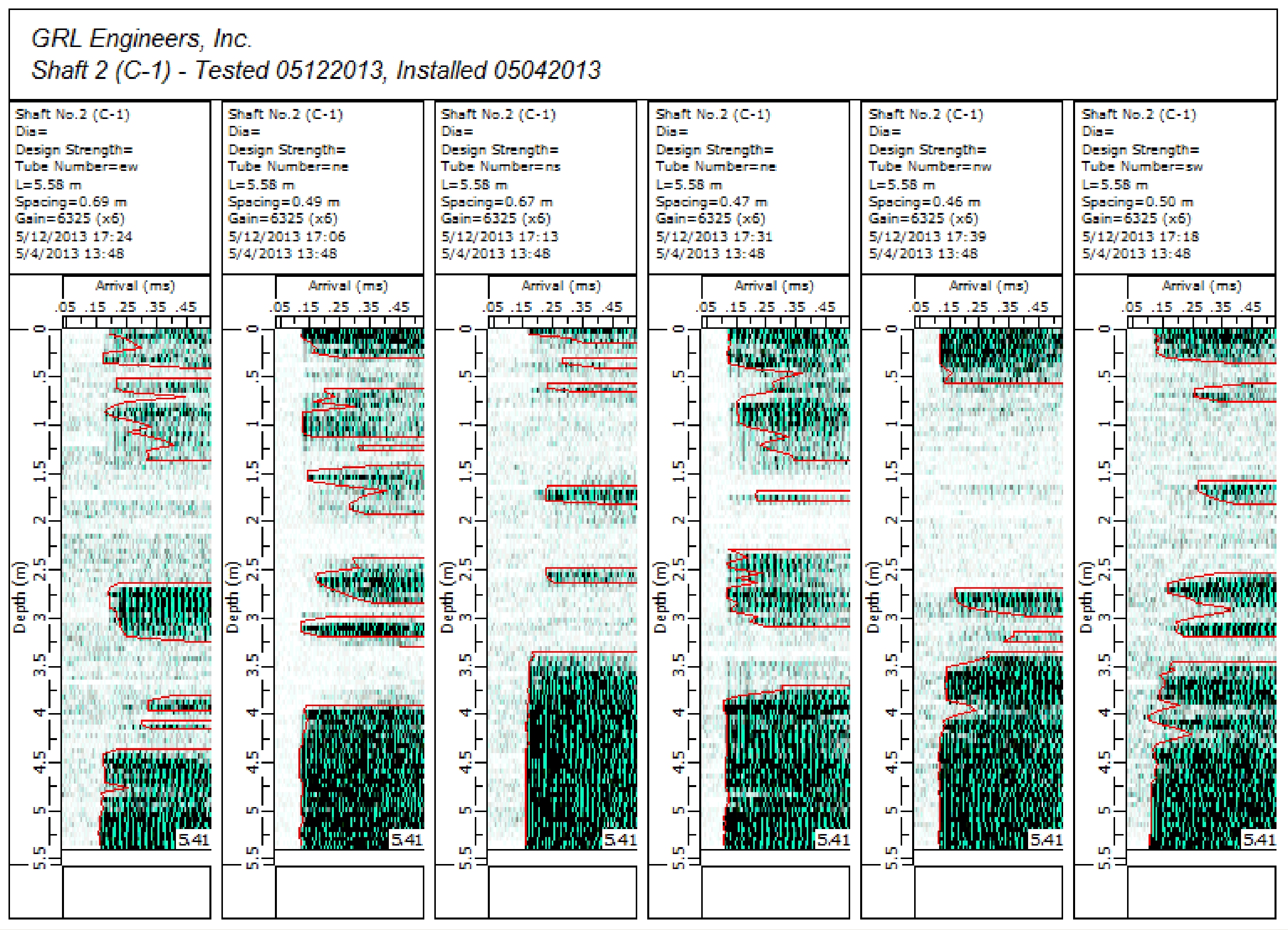
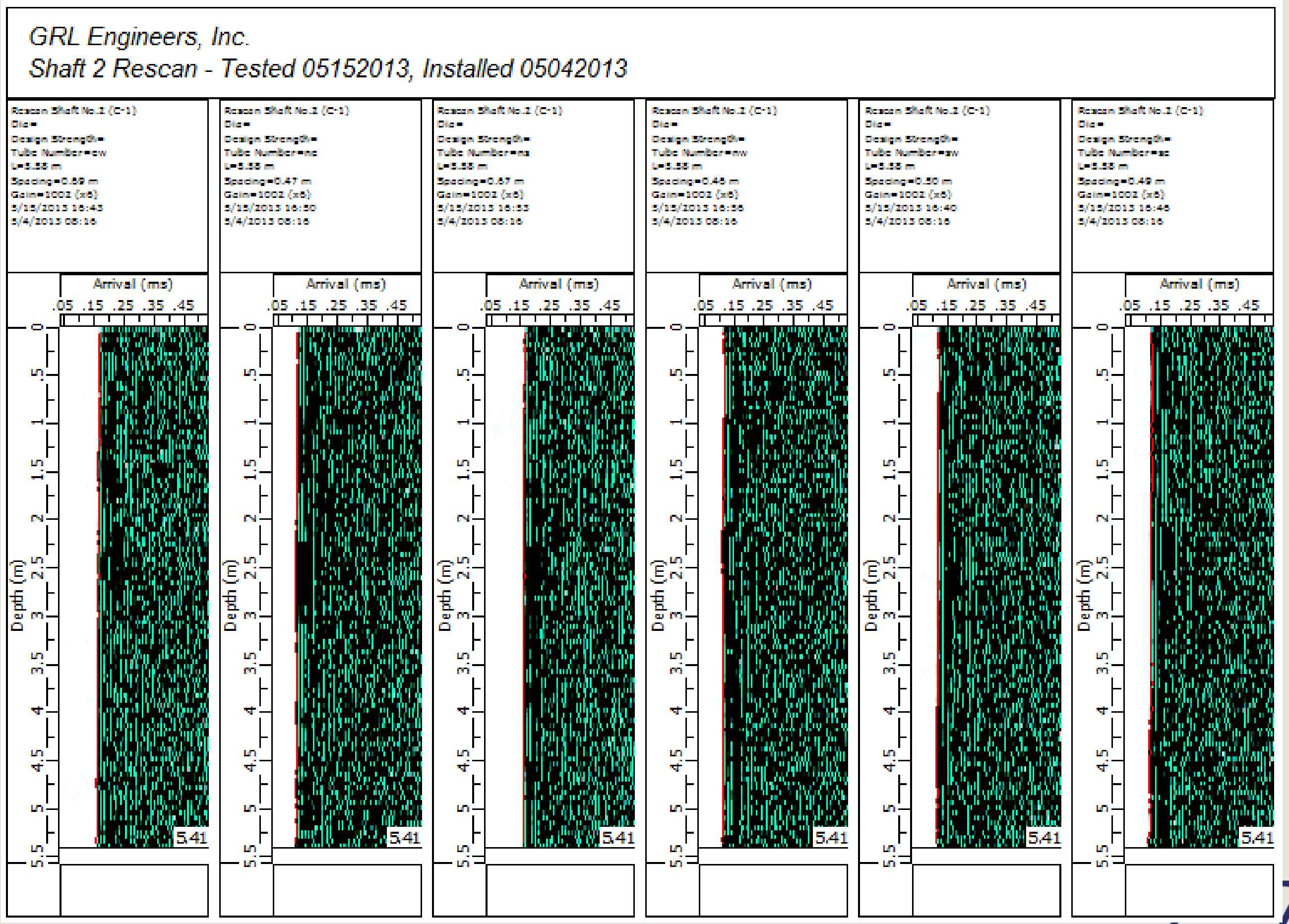
DEBONDING ISSUES WITH CSL

CSL test at 8 days

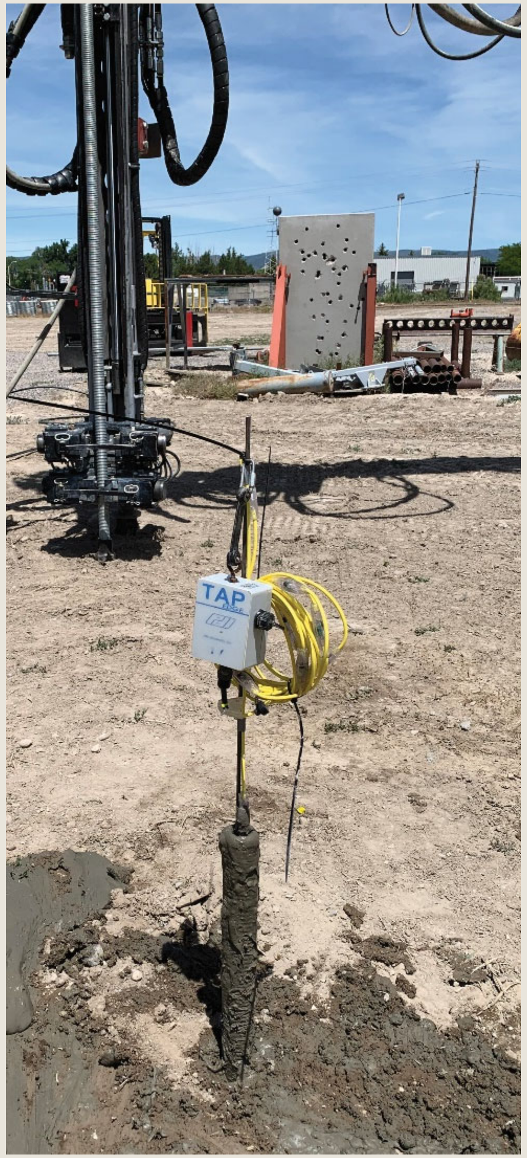


Re-test after remove PVC tubes



TIP APPLICATIONS

- Drilled shafts
- Auger cast-in-place piles
- Continuous flight auger piles
- Displacement piles
- Micropiles
- Secant pile walls
- Diaphragm walls



THERMAL INTEGRITY PROFILING

- Uses the heat generated by curing cement
- Instrument cage with sacrificial Thermal Wire® cables
- Temperature during curing relates to concrete quality, volume, and cover
  - Temperature reductions: necking or poor quality concrete
  - Temperature increases: bulges or increased concrete cover
  - Temperature differences between opposite wires: cage alignment
- Uses concrete volume to evaluate radius from temperature

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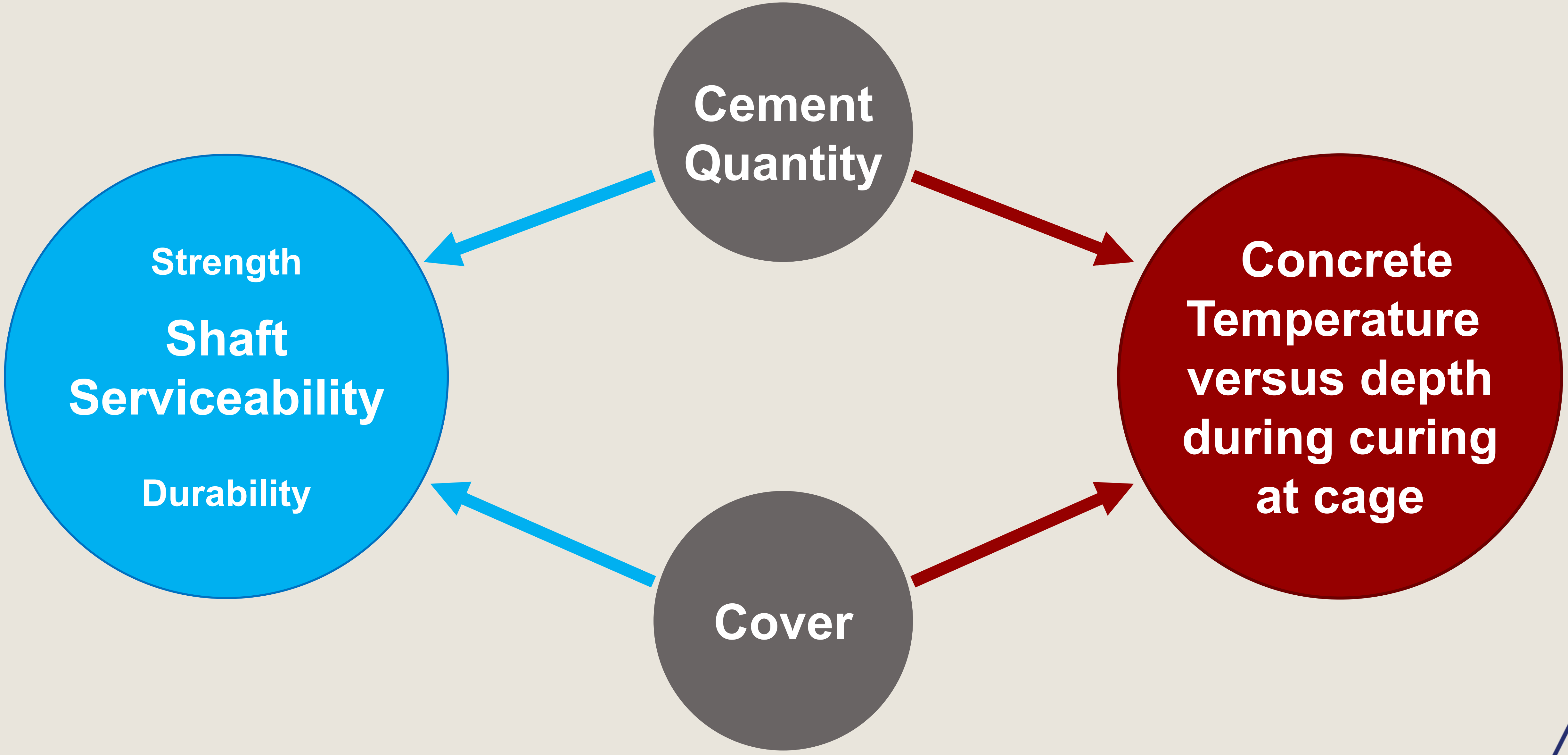
THERMAL INTEGRITY PROFILING



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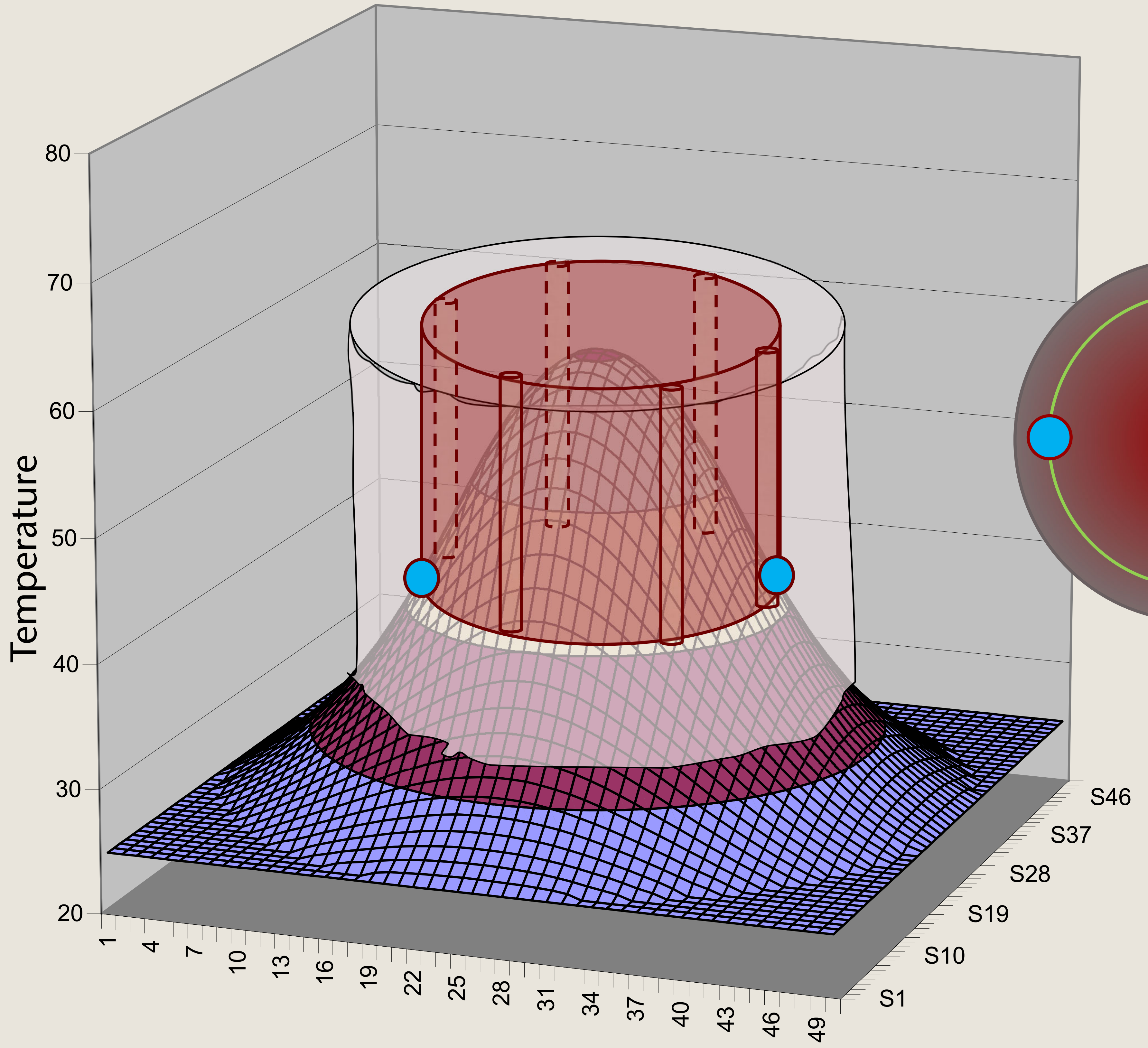

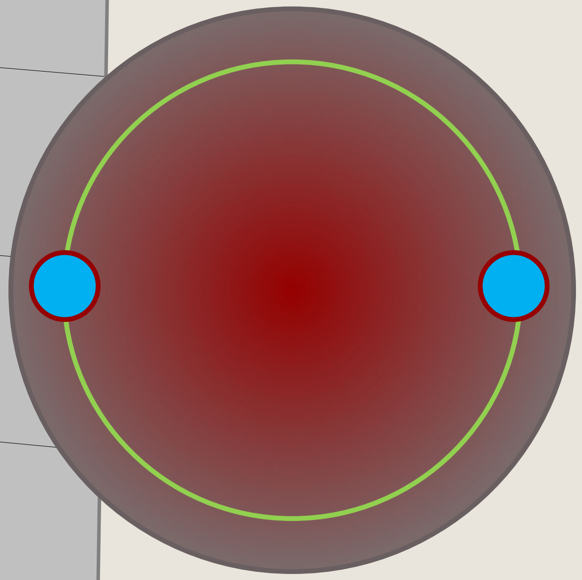

SHAFT HEAT SIGNATURE

The heat at the center of the shaft will be the greatest.

The temperature at the reinforcement cage behaves linearly with respect to radius

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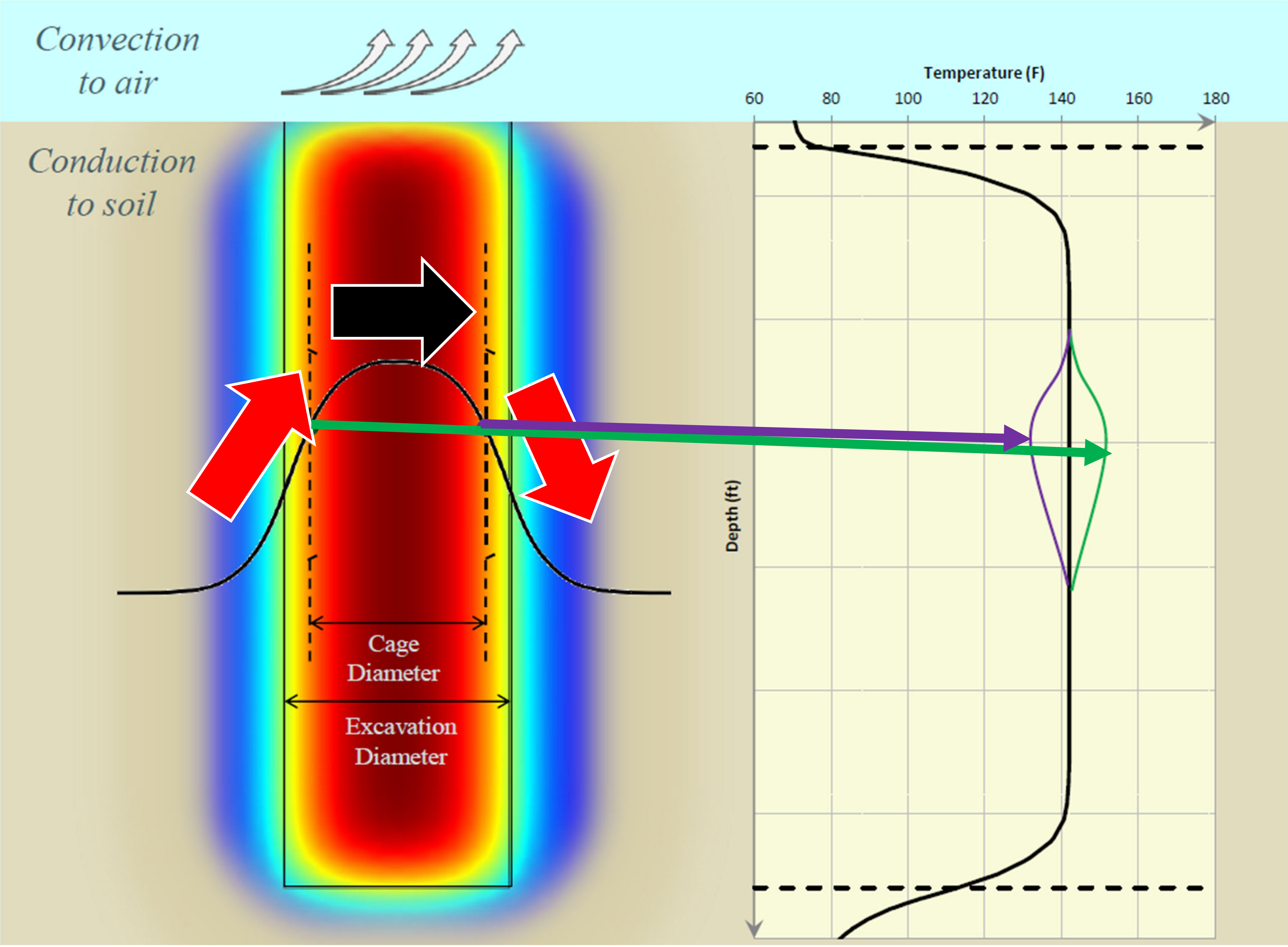

PROXIMITY TO CENTER OF CONCRETE EFFECTS TEMPERATURE

If the reinforcement cage shifts in any direction, the cage closer to the soil will measure a lower temperature, the cage closer to the center of the concrete will measure a higher temperature

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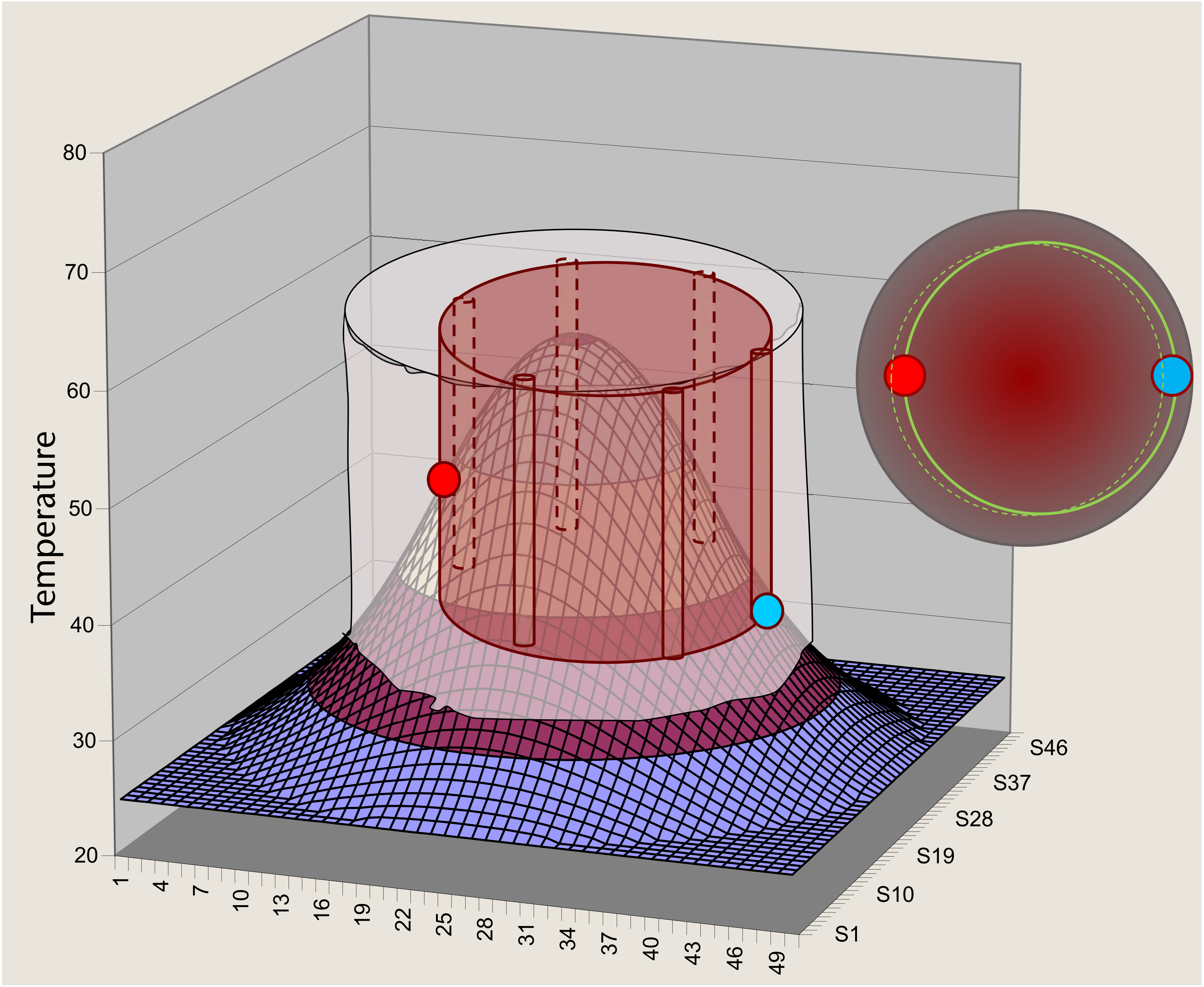
Temperature
80
70
60
50
40
30
20
1
4
7
10
13
16
19
22
25
28
31
34
37
40
43
46
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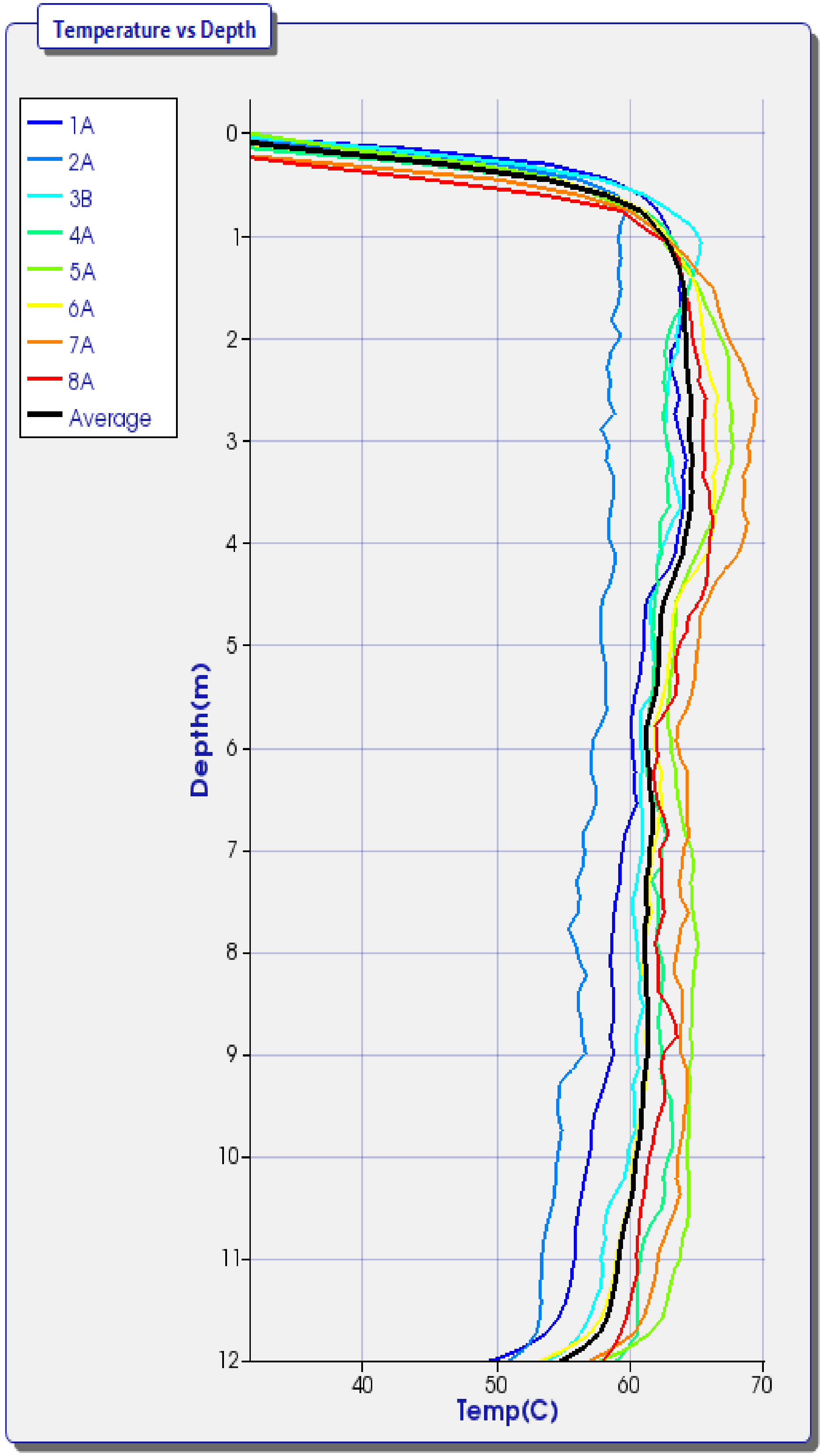
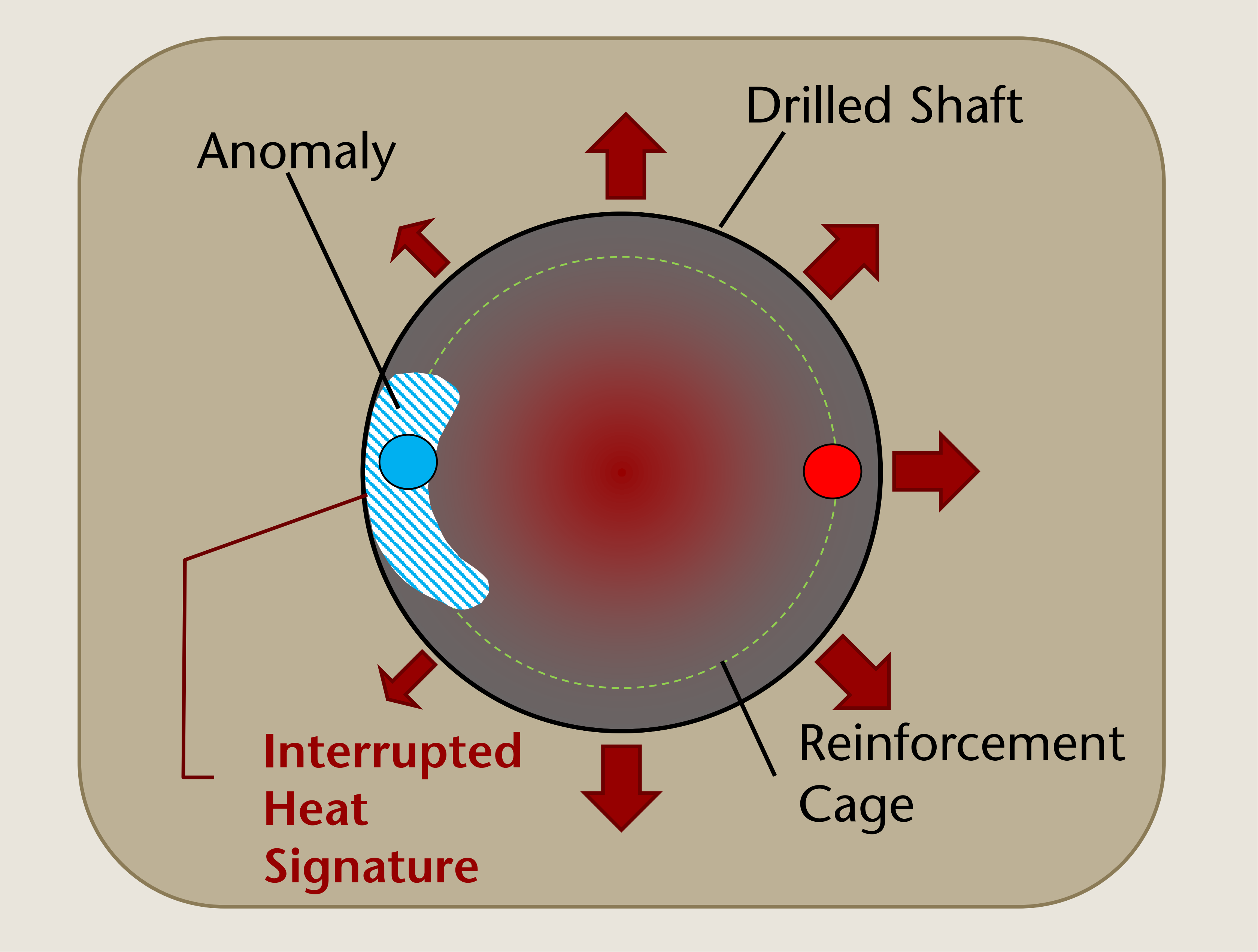
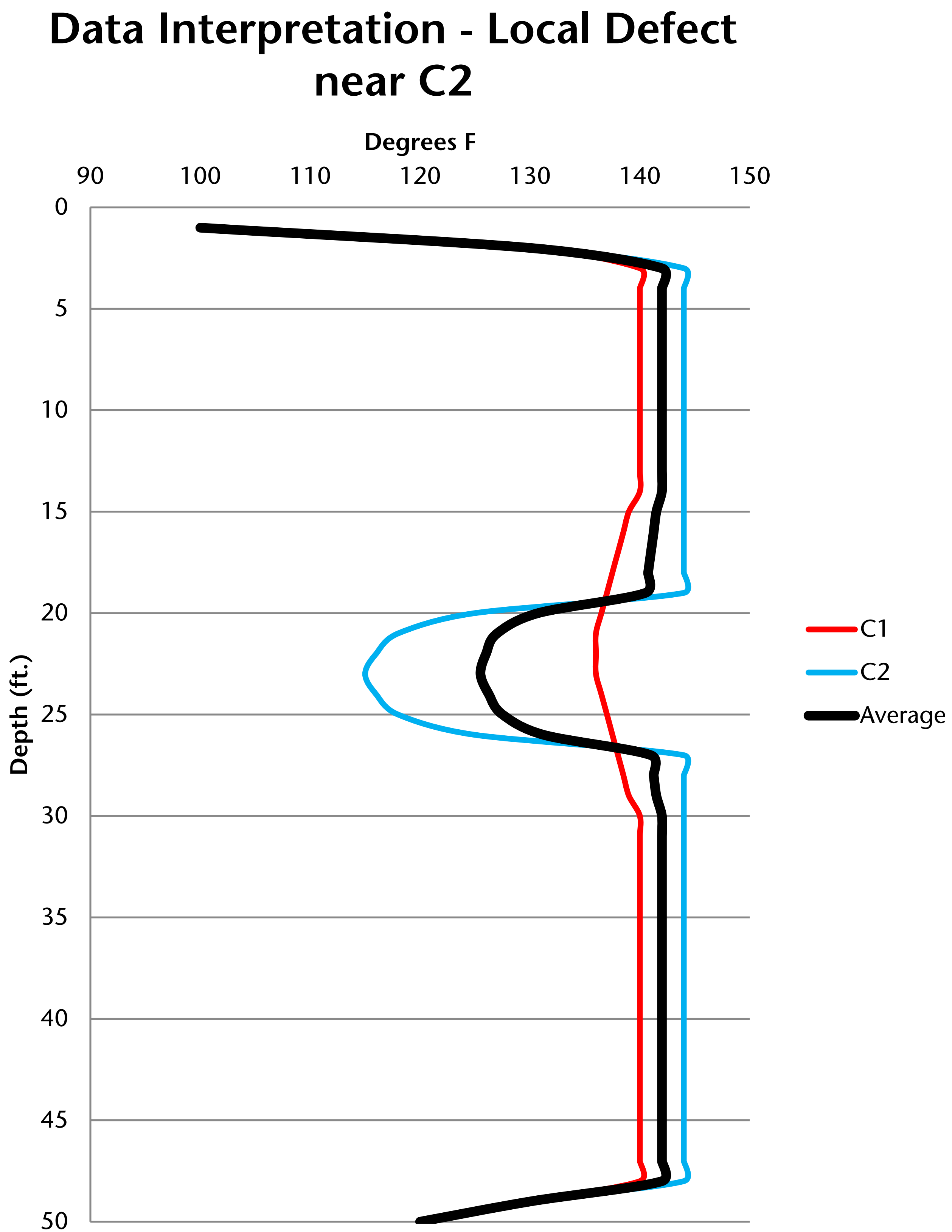
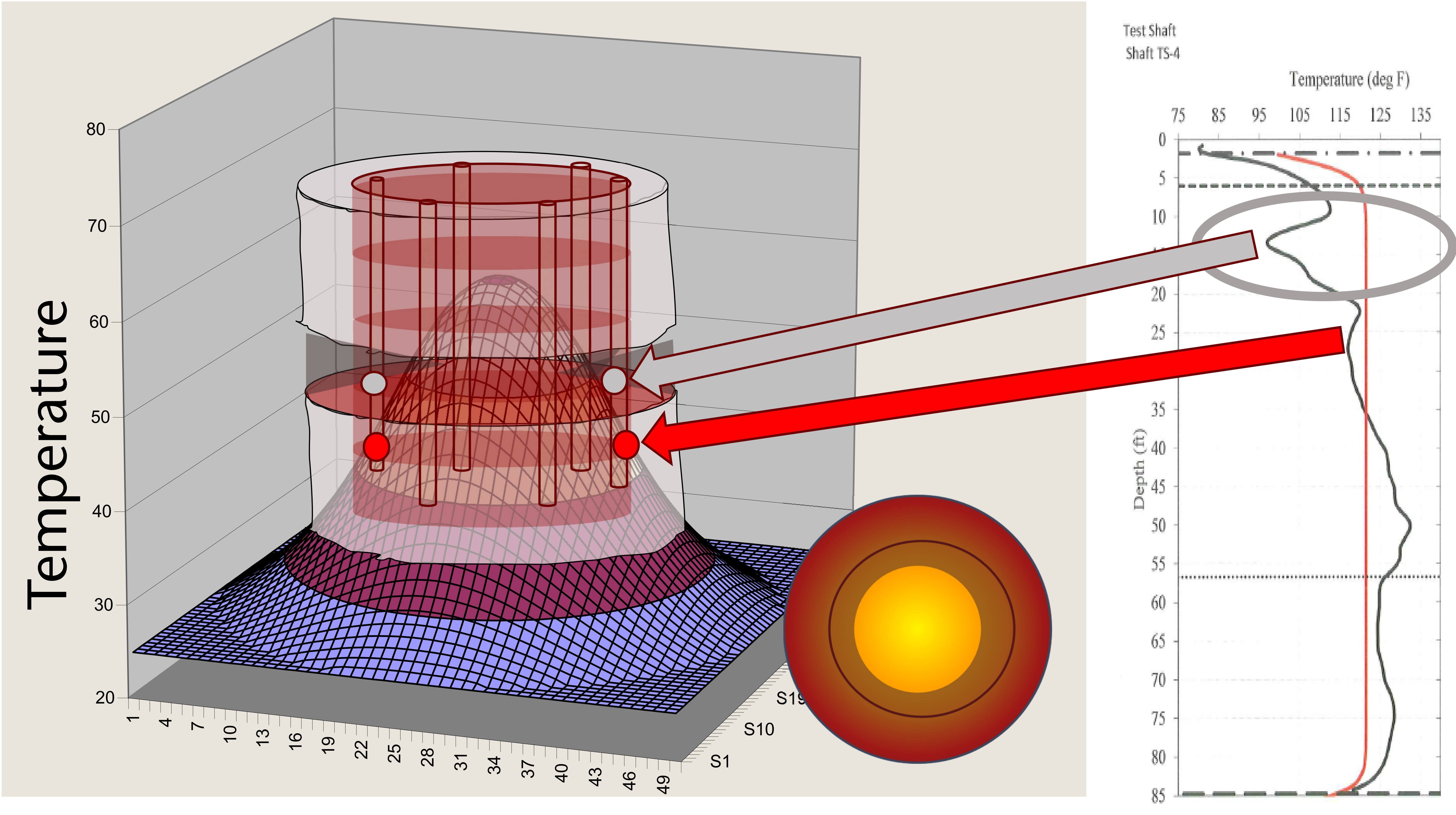
S1
S10
S19
S28
S37
S46

Temperature vs Depth
1A
2A
3B
4A
5A
6A
7A
8A
Average
Depth(m)
Temp(C)
0
1
2
3
4
5
6
7
8
9
10
11
12
40
50
60
70

LOCALIZED DEFECTS






Temperature
80
70
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1
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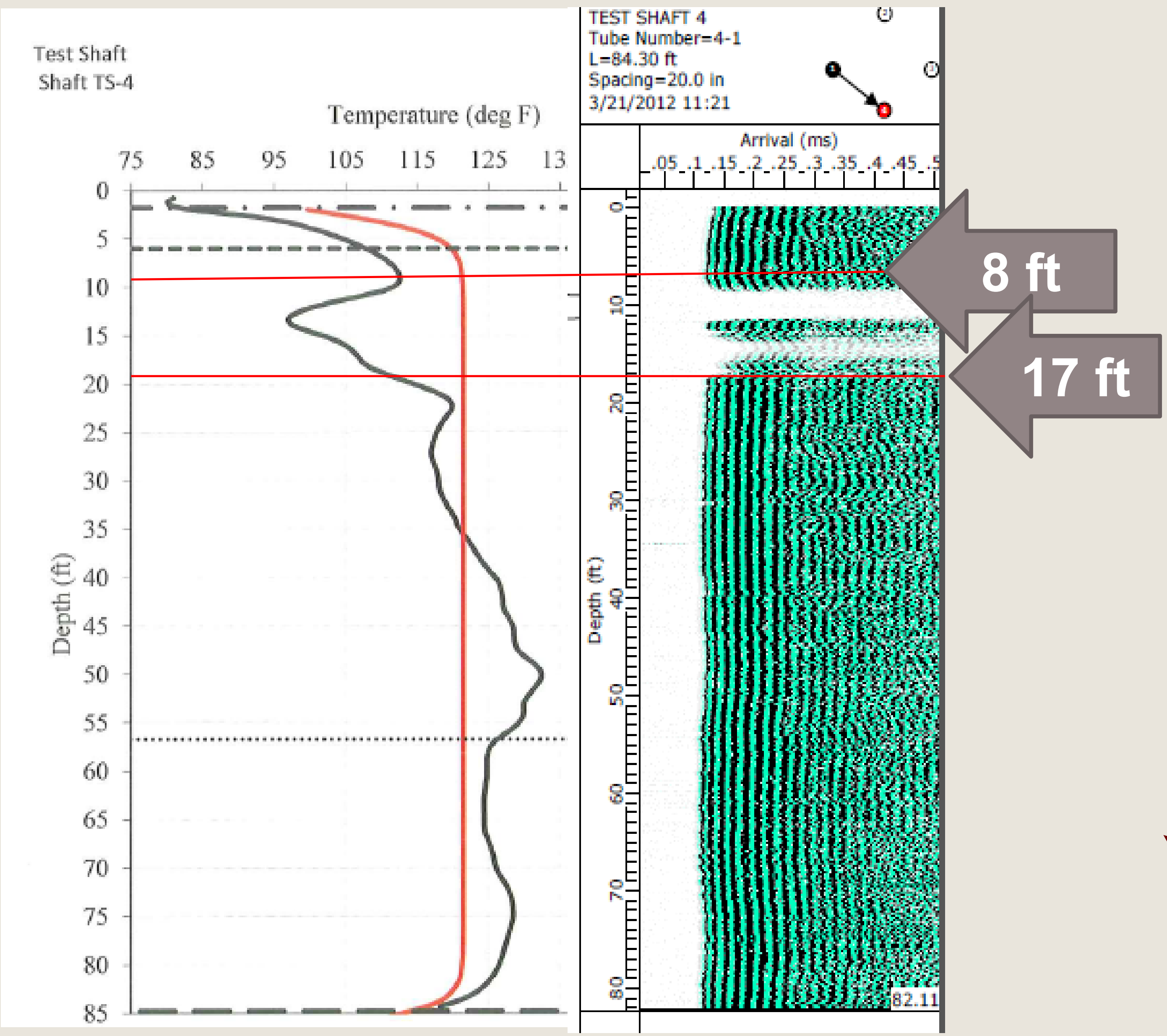
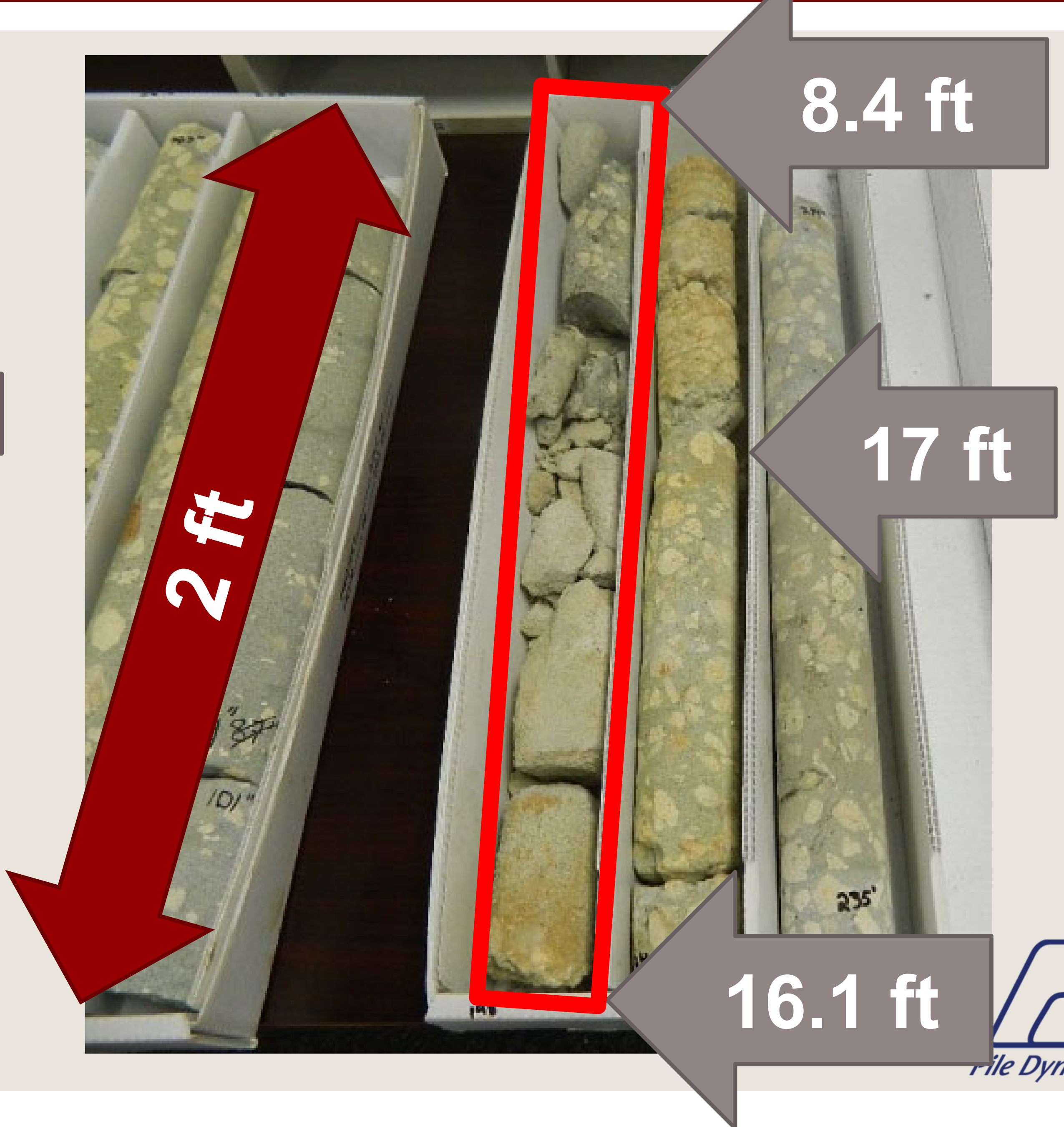
7
10
13
16
19
22
25
28
31
34
37
40
43
46
49
S1
S10
S19
Test Shaft
Shaft TS-4
Temperature (deg F)
75
85
95
105
115
125
135
Depth (ft)
0
5
10
20
25
35
40
45
50
55
60
65
70
75
80
85

LOCALIZED DEFECT





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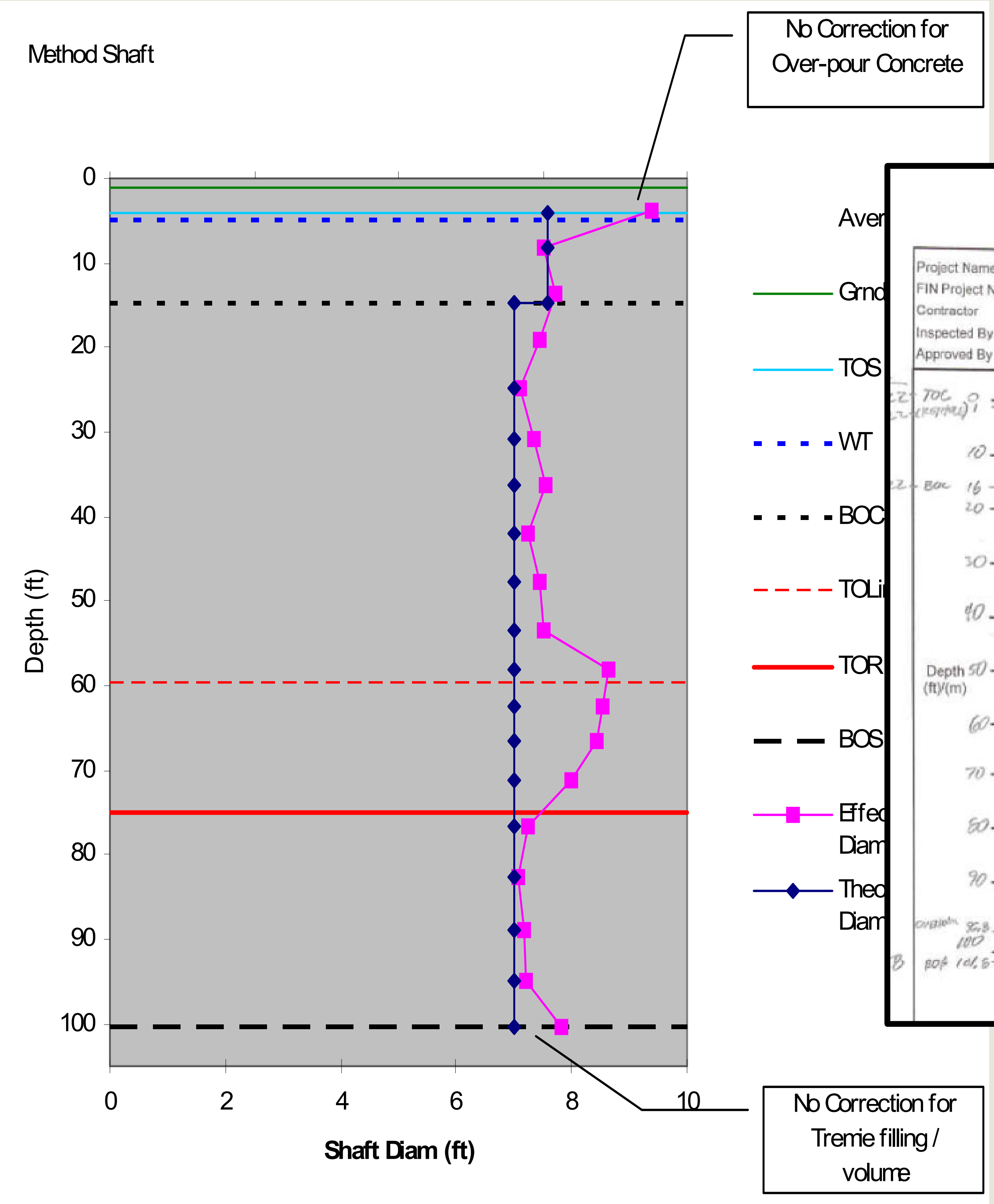

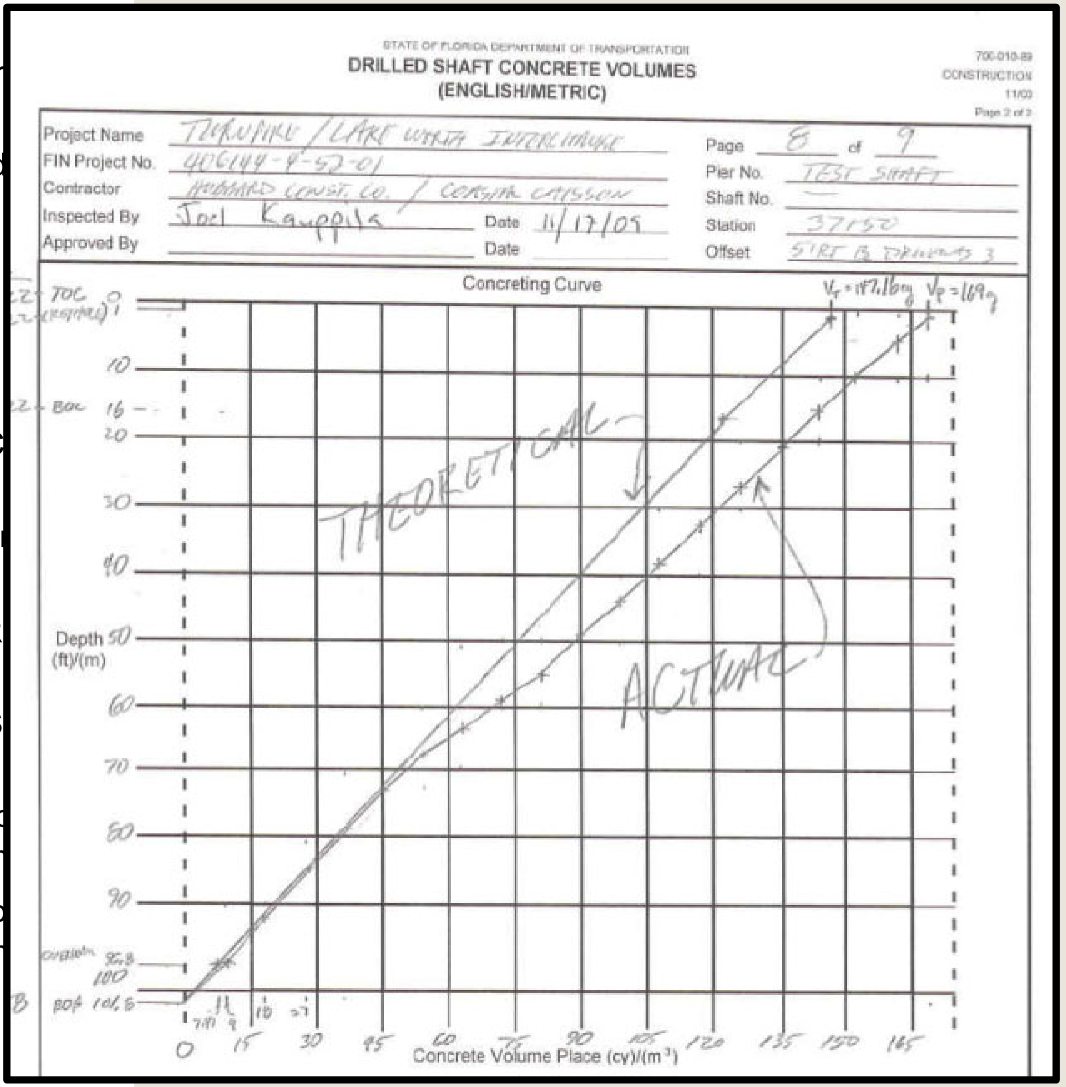

RADIUS BASED PLACED CONCRETE VOLUME

Truck volume and depth after each truck can establish the effective diameter for each shaft segment.

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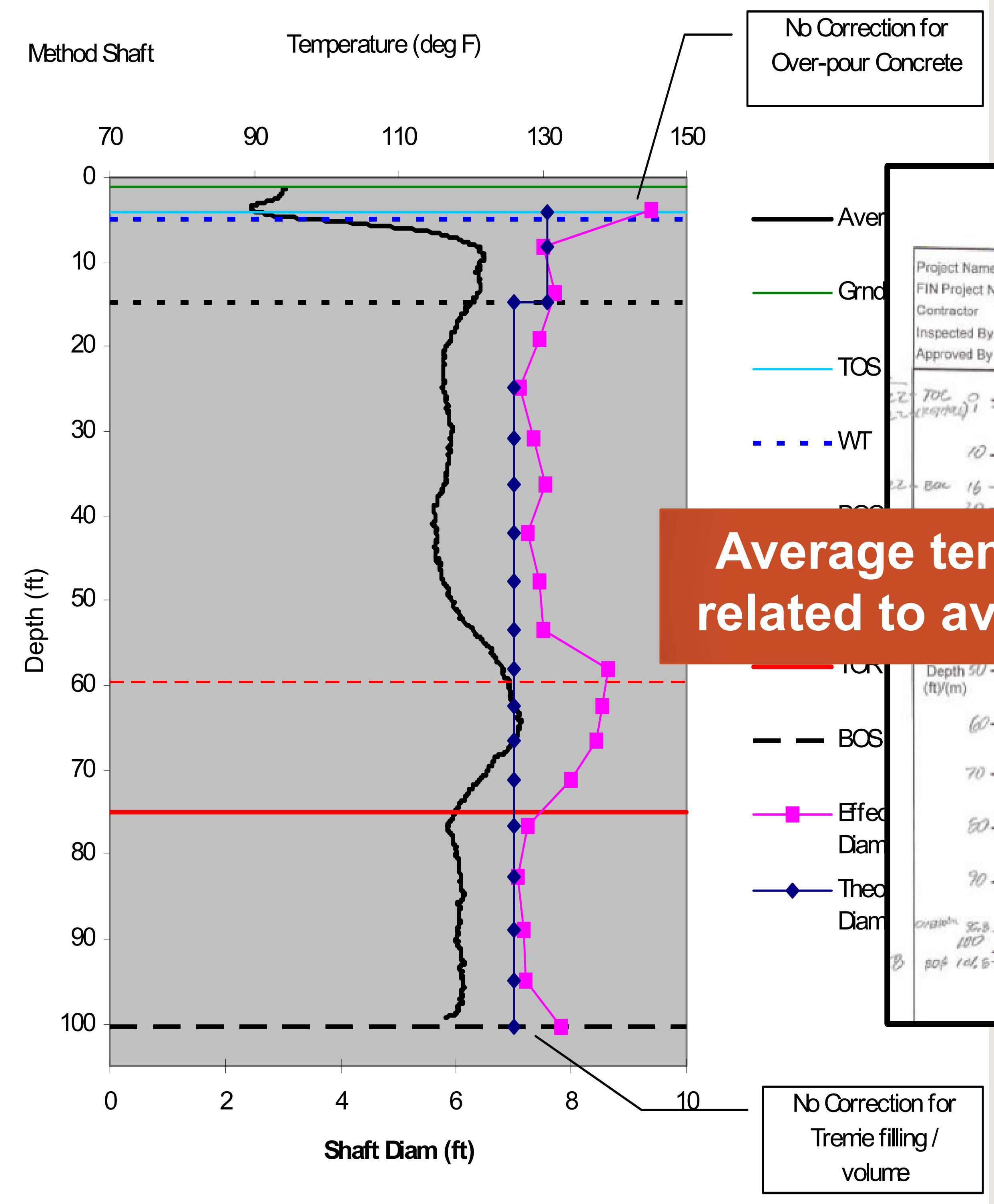
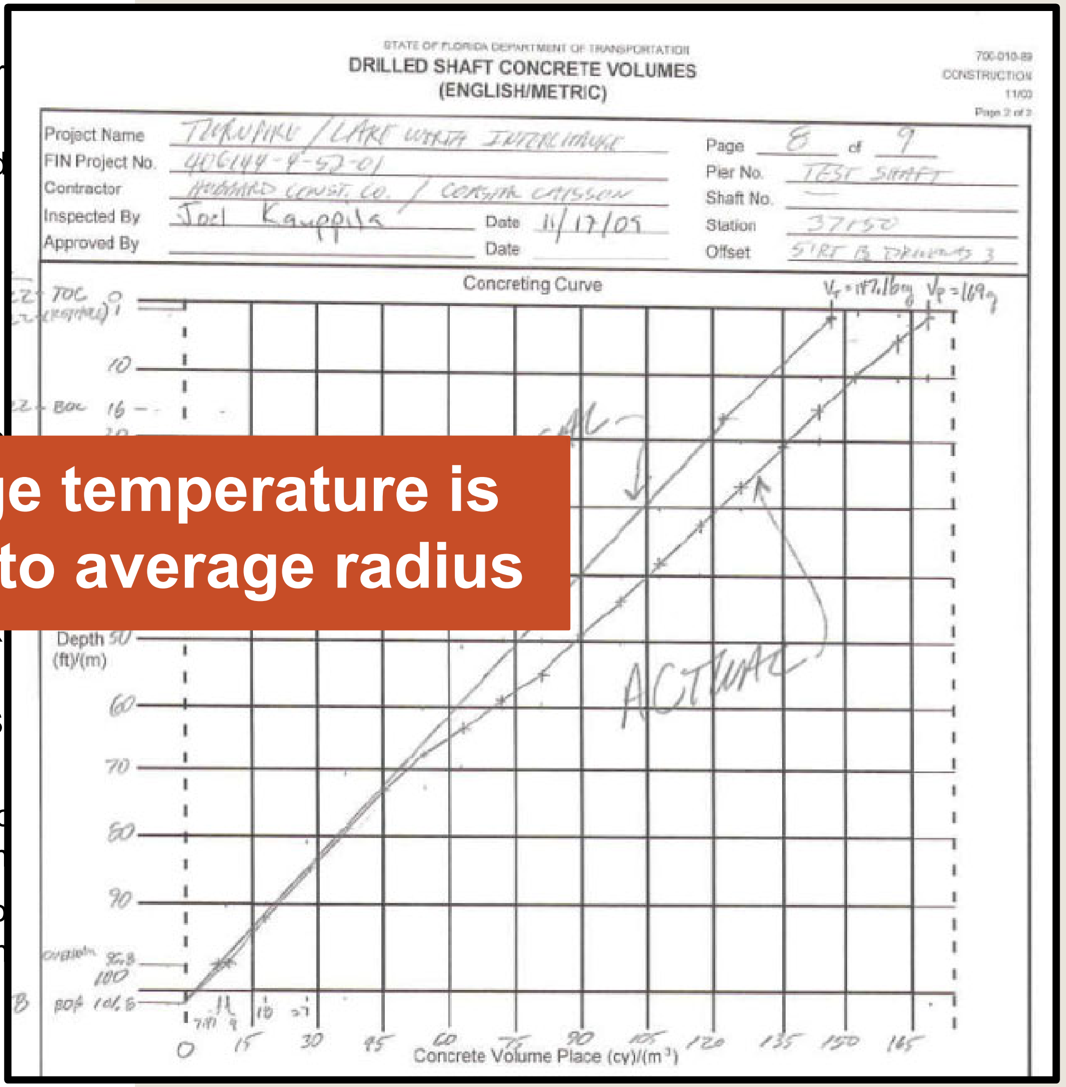
TEMPERATURE RADIUS RELATIONSHIP





Average temperature is related to average radius

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CONVERTING TEMPERATURE TO RADIUS

- Accurate **volume** information is **critical to the analysis**
  - Requires Thermal Field Log & Concrete Logs

- **Radius-Average: R-avg** (in.)
  - Calculated radius based on volume input over given length

- **Temperature-Average: T-avg** (°F)
  - Average temperature of all wires at selected time stamp

R-avg/T-avg = Temp to Radius Multiplier

- Units are (in/°F)

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TIP ANALYSIS
TOS & BOS ADJUSTMENT
REVIEW

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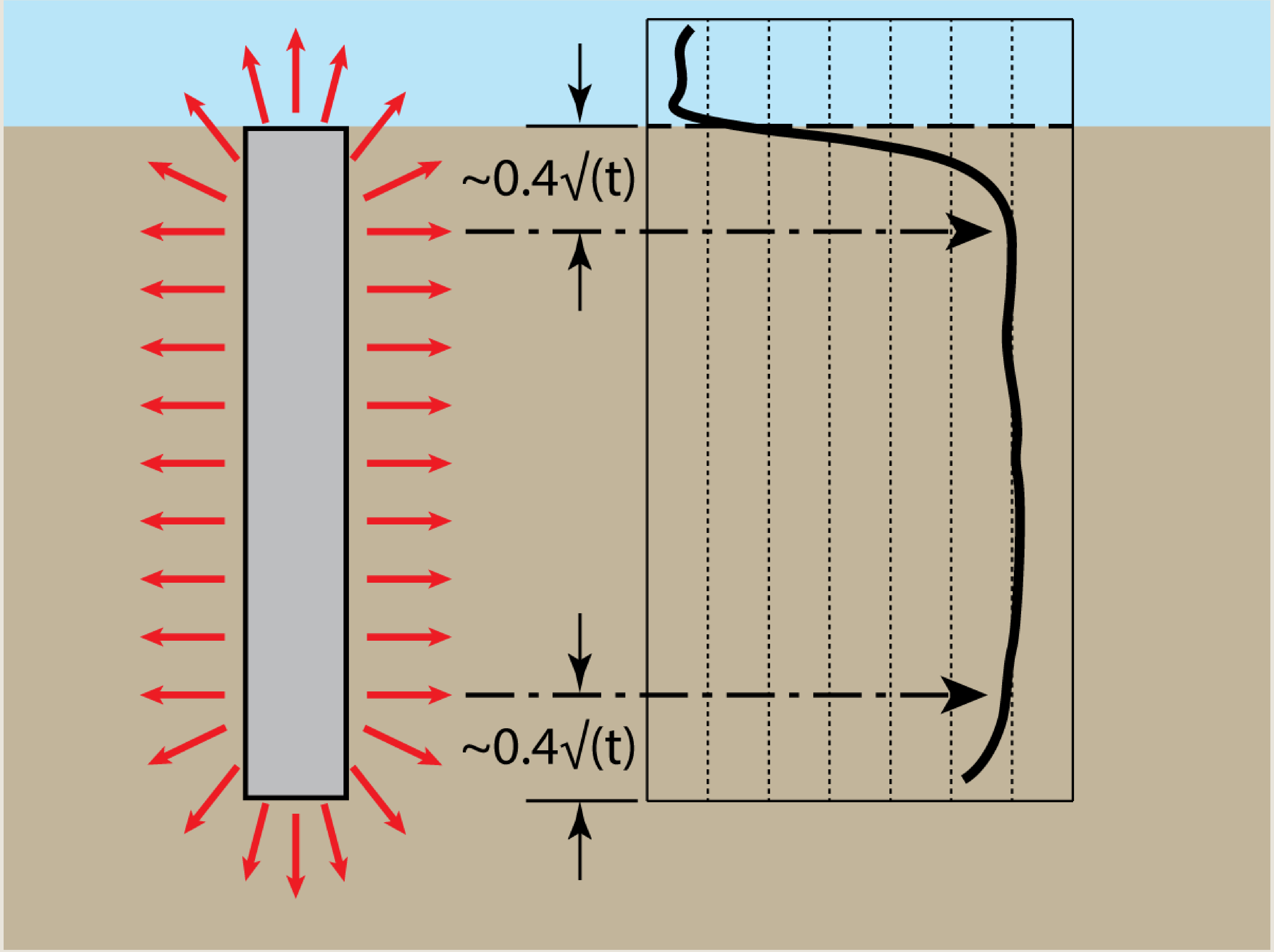
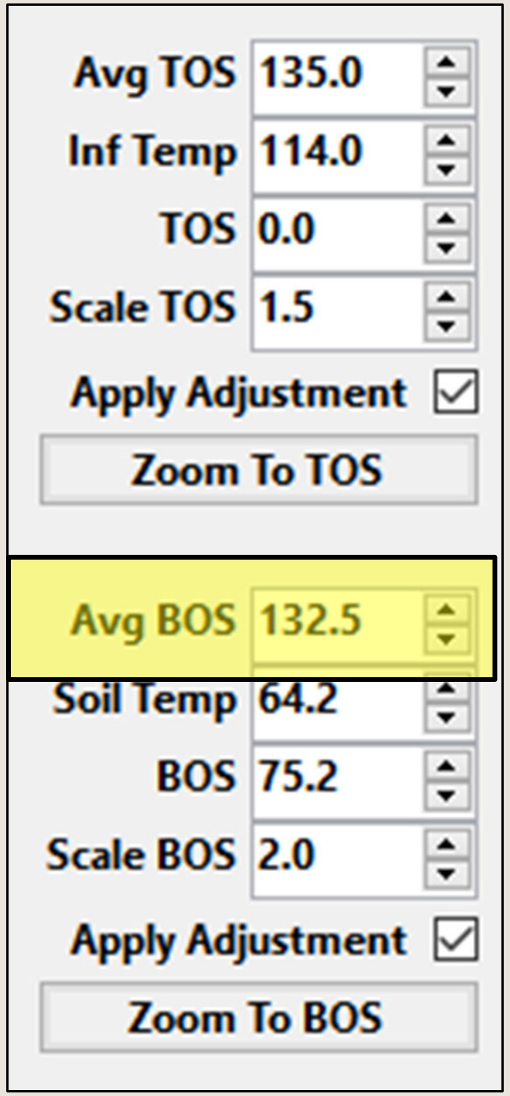


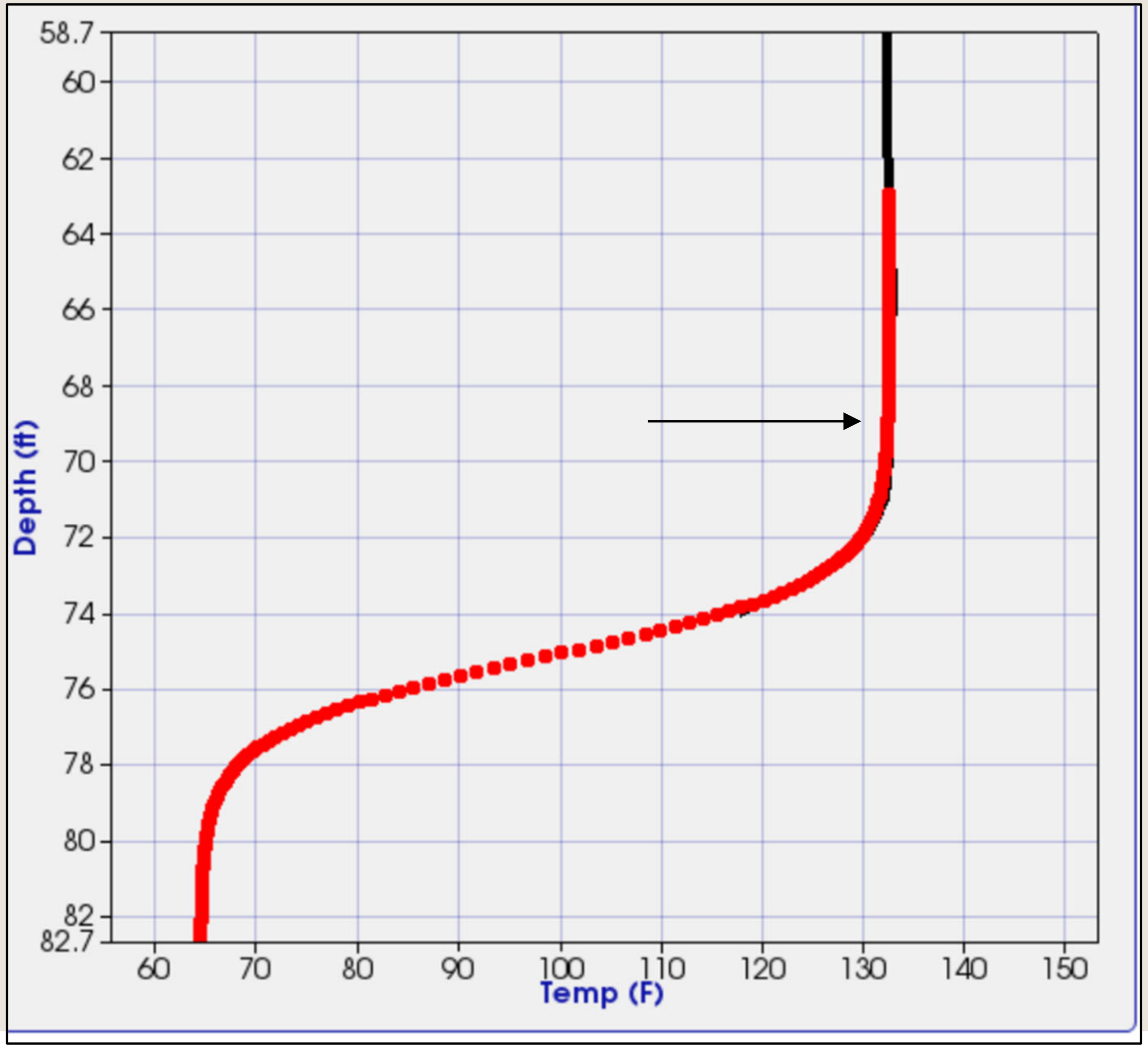
TEMPERATURE DISSIPATION

For a uniform shaft, temperature is constant, except 1 diameter at top and bottom roll-off

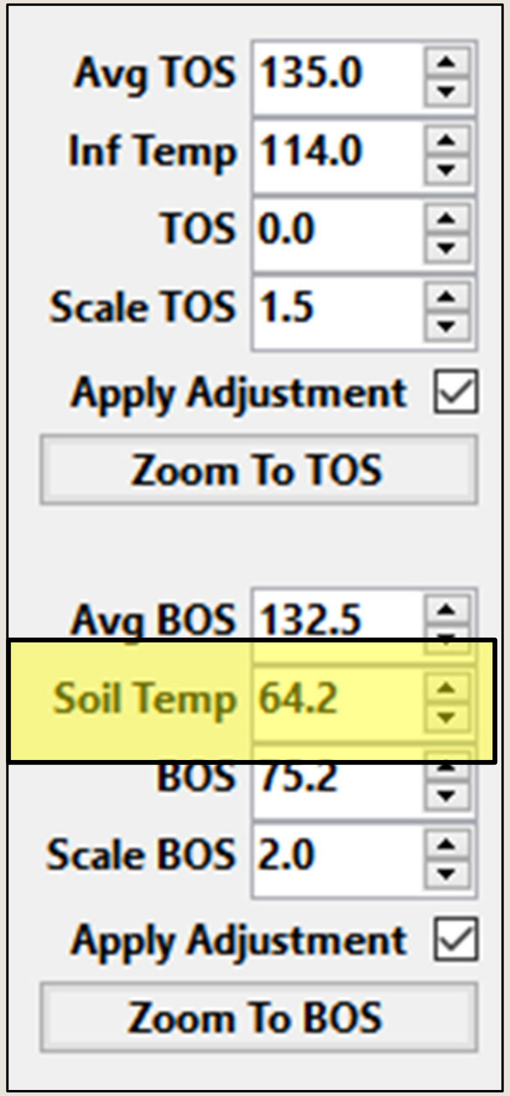
Recommended BOS Hyperbolic Adjustment Parameters



Avg BOS: Average temperature above roll-off region. Generally equal to the temperature observed one diameter up from the base of the shaft (up to 6 feet).

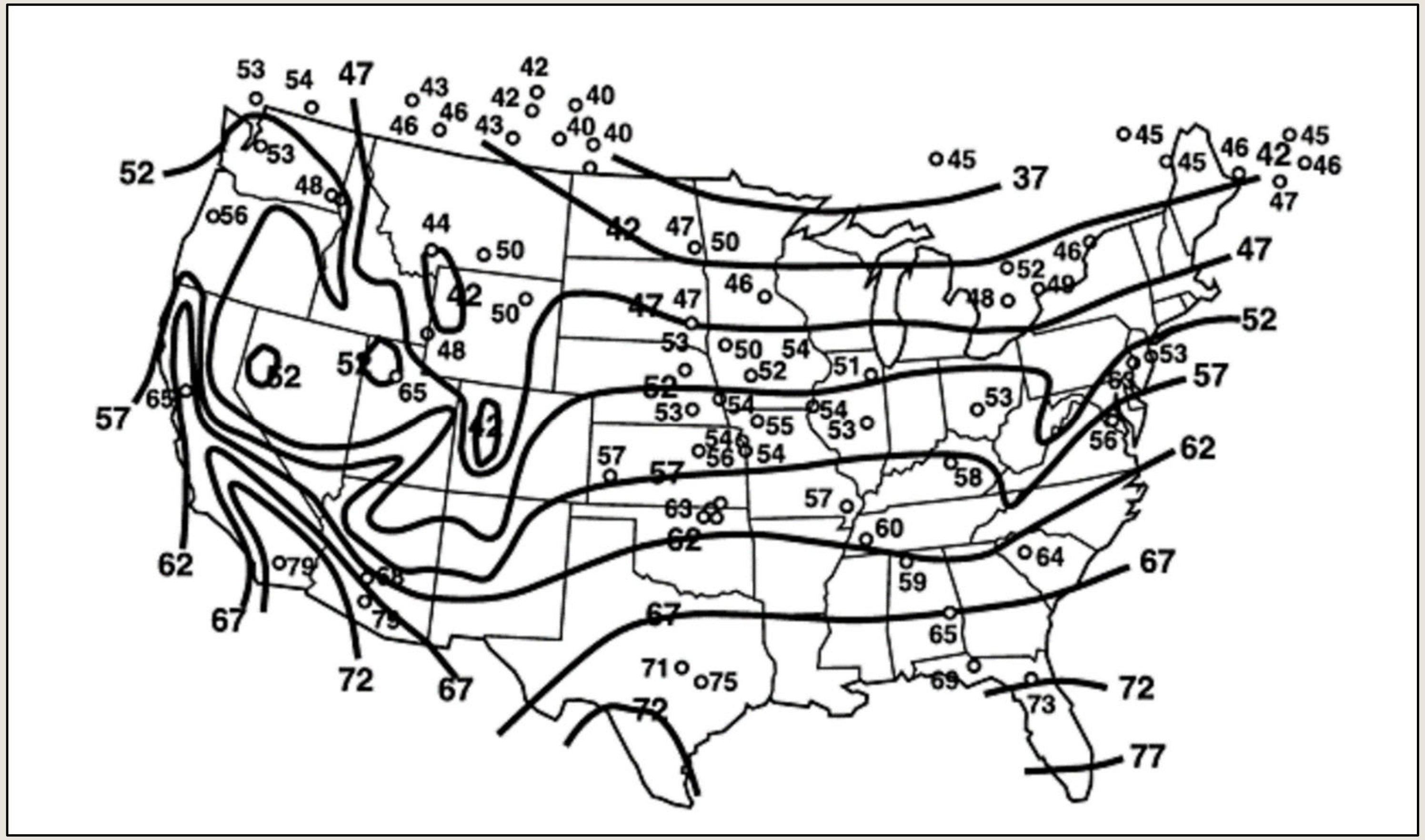


Recommended BOS Hyperbolic Adjustment Parameters



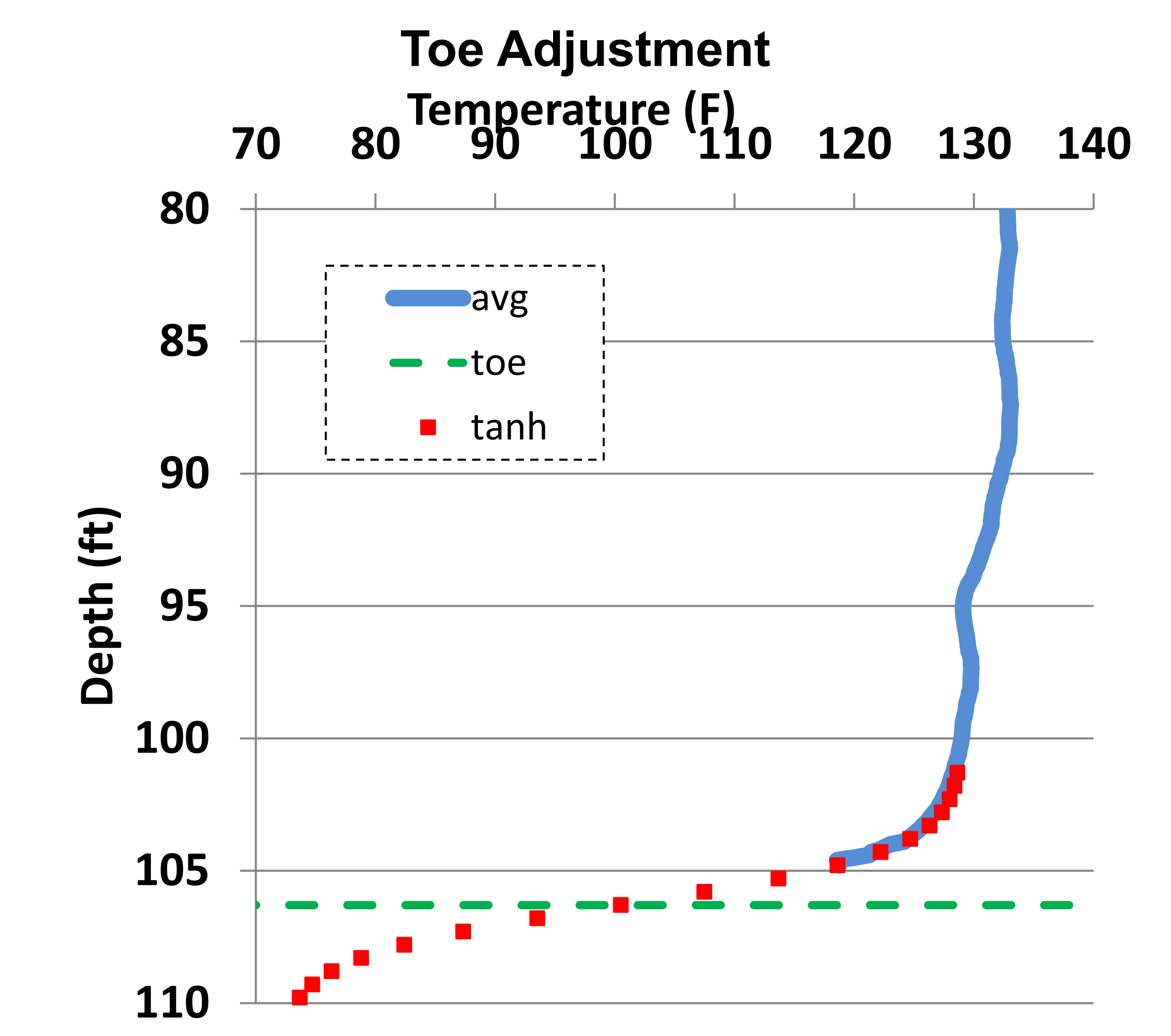
Soil Temp: Minimum temperature used in BOS hyperbolic fit. Soil temperature correlates with regional average annual air temperature. Regions with volcanic or geothermal sources may strongly influence temperature.

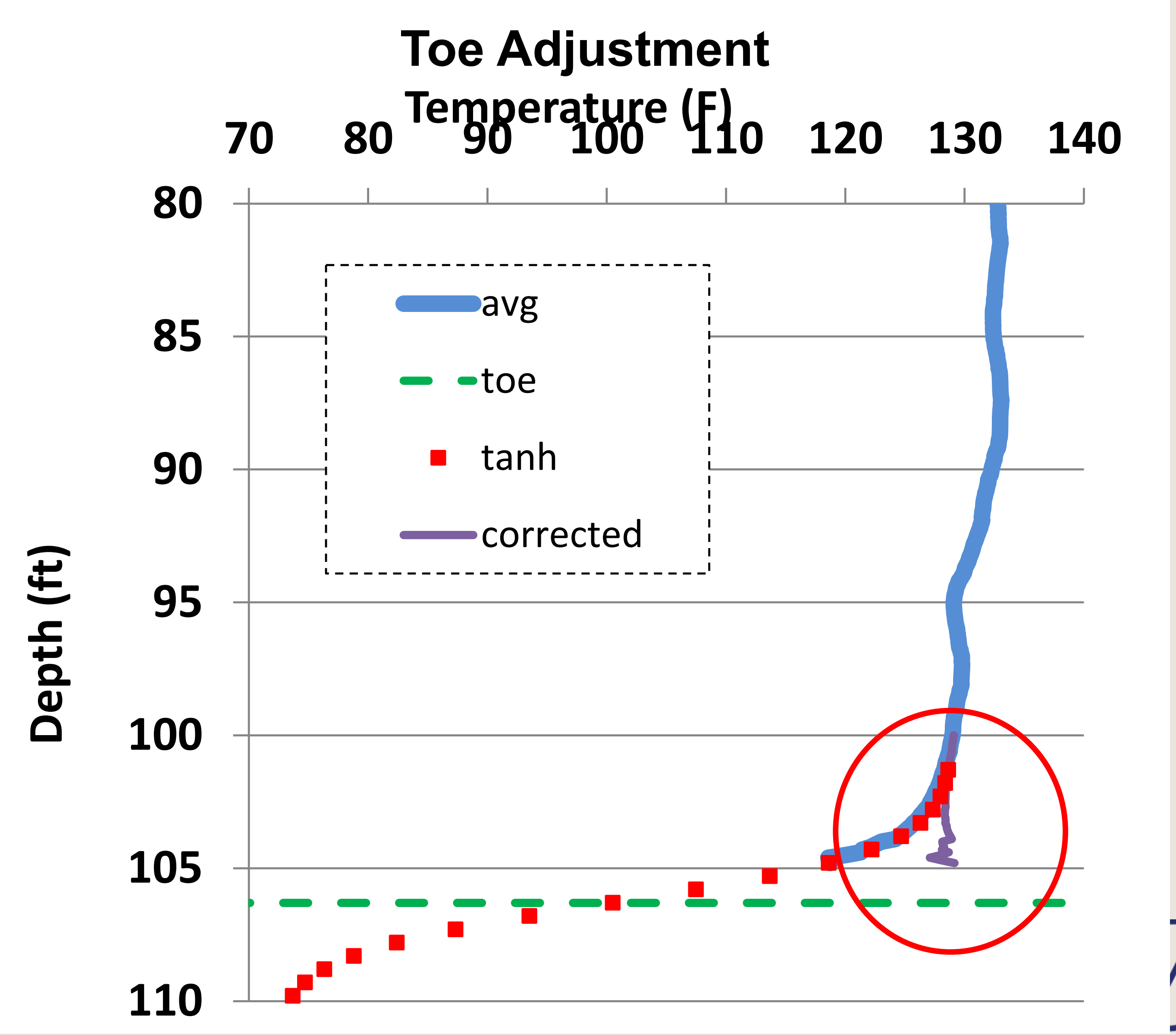
Regional Soil Temperature Map



https://www.builditsolar.com/Projects/Cooling/EarthTemperatures.htm

'ROLL-OFF' CORRECTION





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TOE ADJUSTMENT EXAMPLE

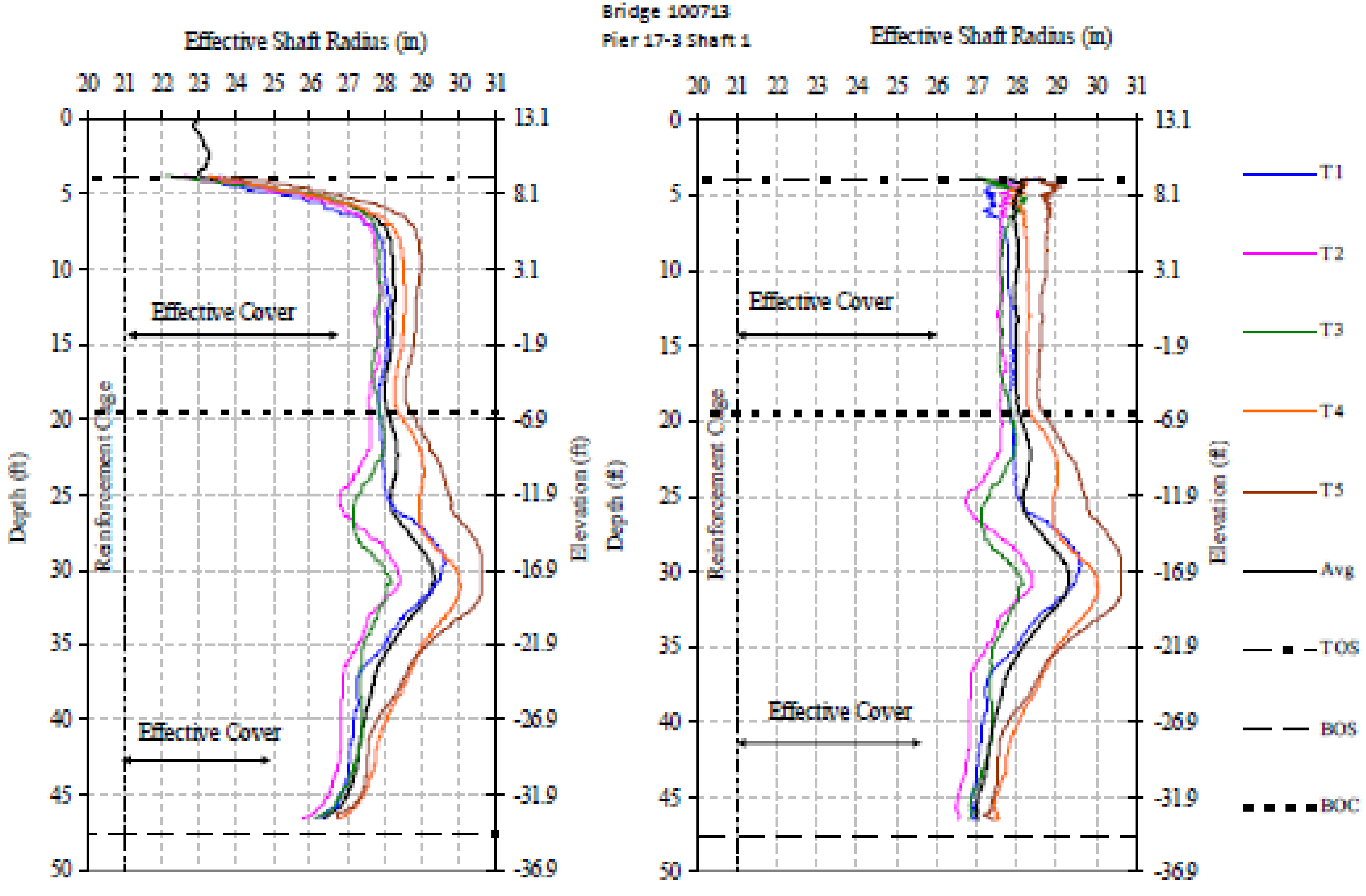
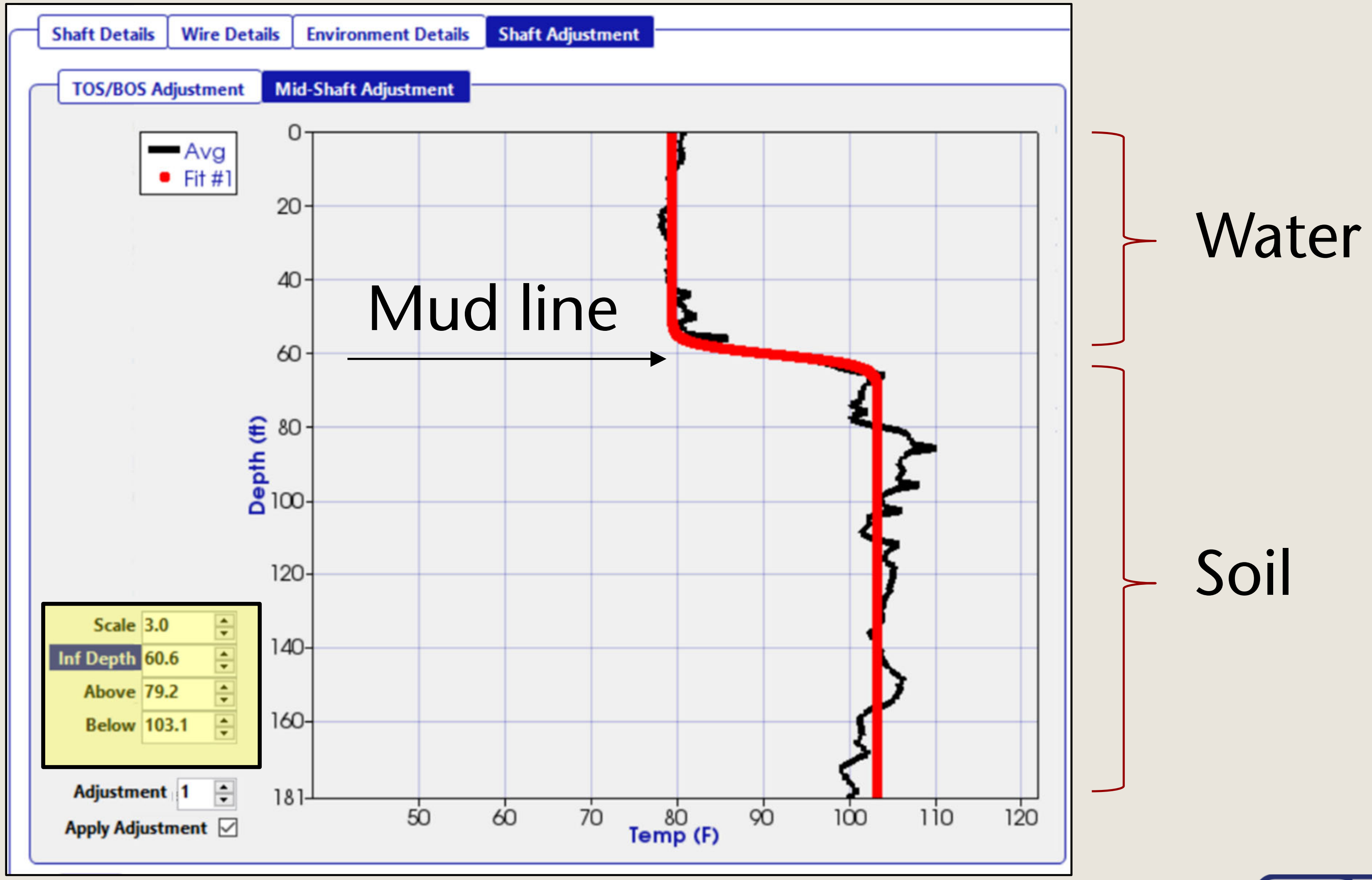


Figure 5. Effective shaft radius showing cage alignment, effective cover, and model correction for end effects.

MID-SHAFT ADJUSTMENTS

- Use when changes in the temperature profile are caused by changes in boundary conditions and varying rates of heat dissipation rather than changes in shaft cross-section or quality



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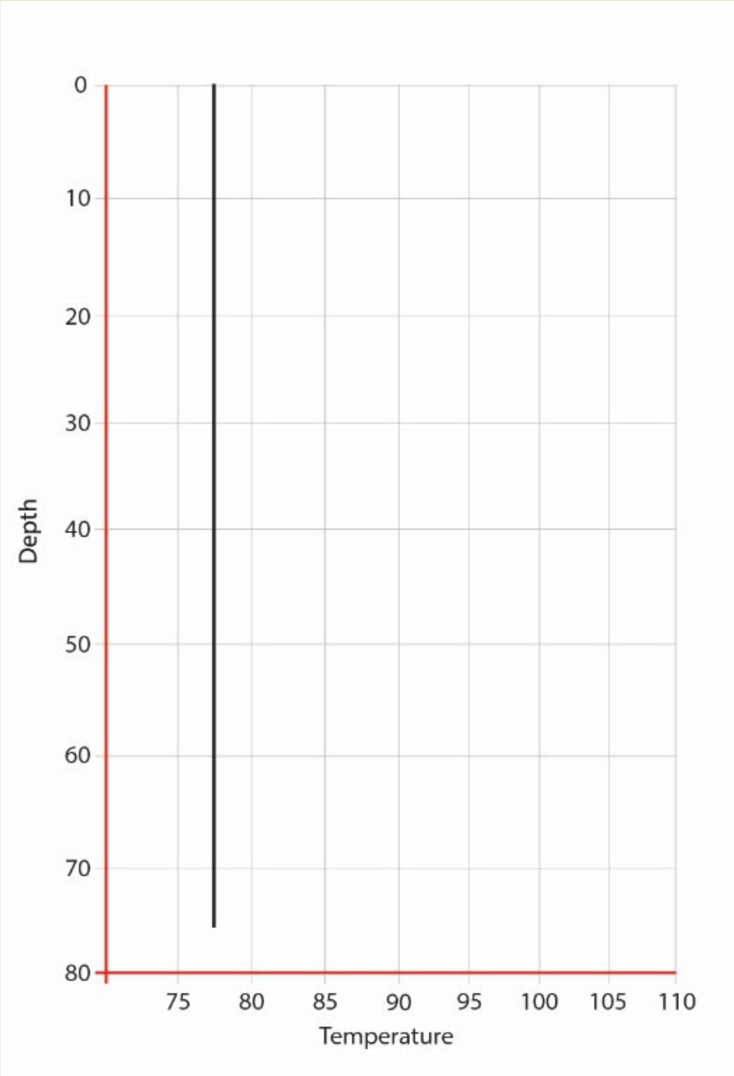
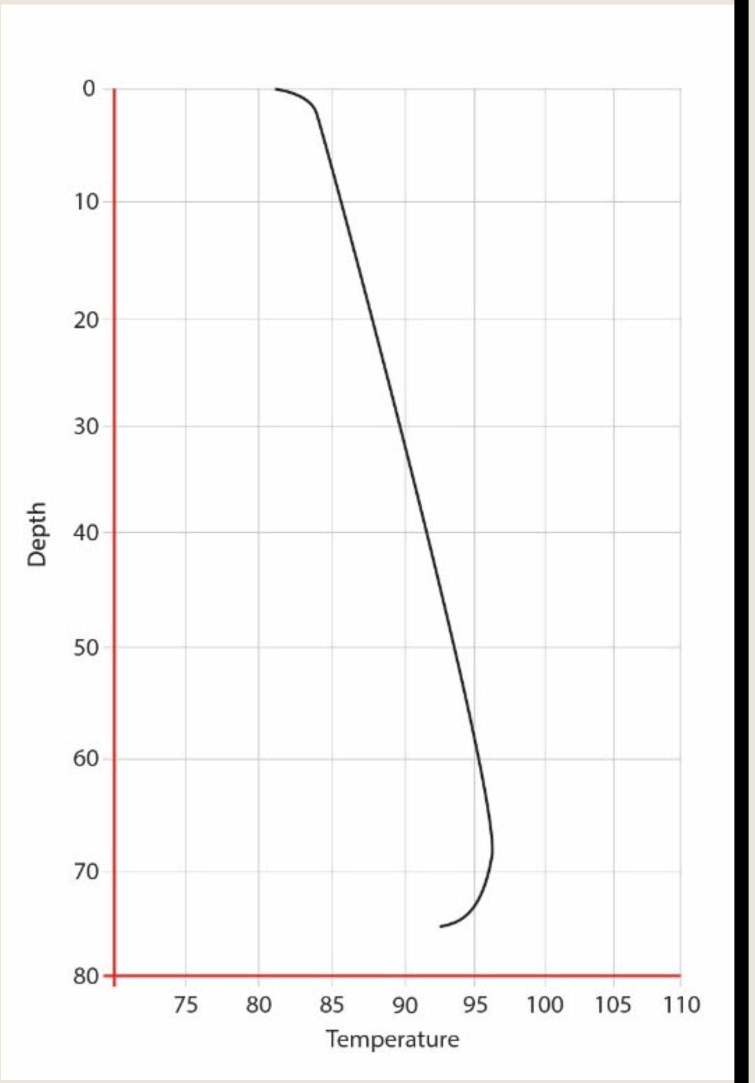
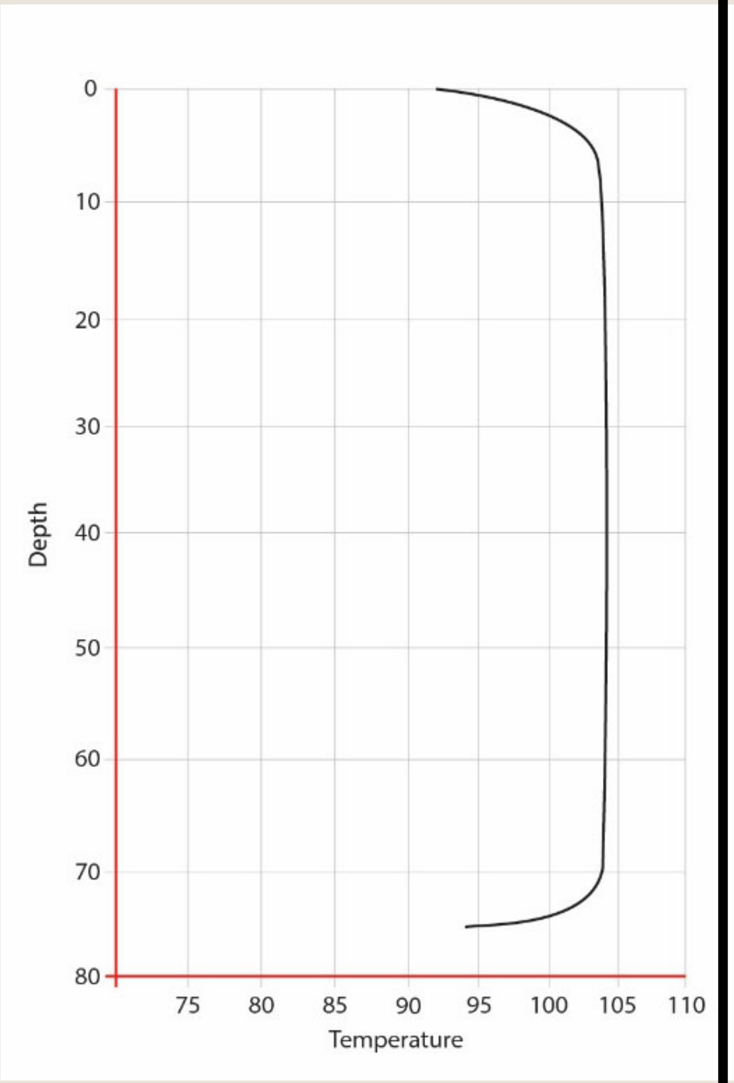
SELECTION OF ANALYSIS TIME



Time: After Placement



Time: < Half Peak Temperature



Time: ≥ Half Peak Temperature

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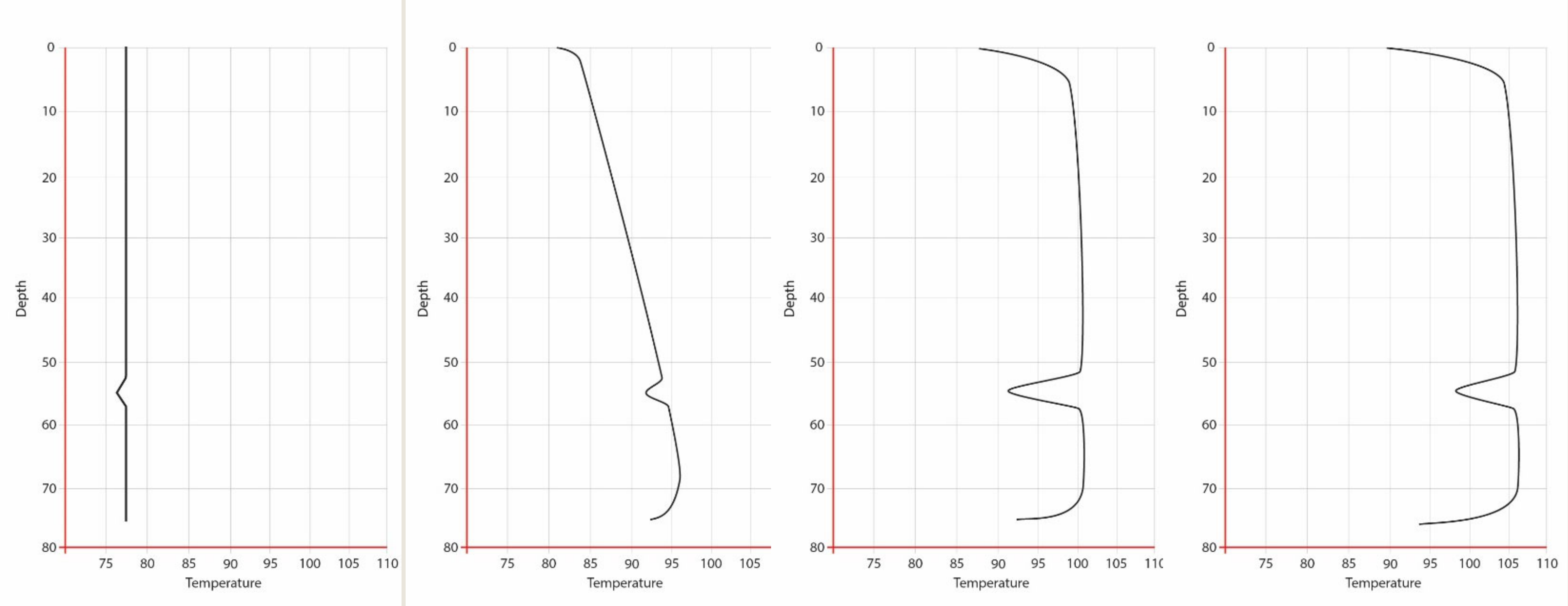
SELECTION OF ANALYSIS TIME

Peak Temperature: 40 hrs



Time: After Placement

Time: 10 hrs

Time: 20 hrs

Time: 40 hrs

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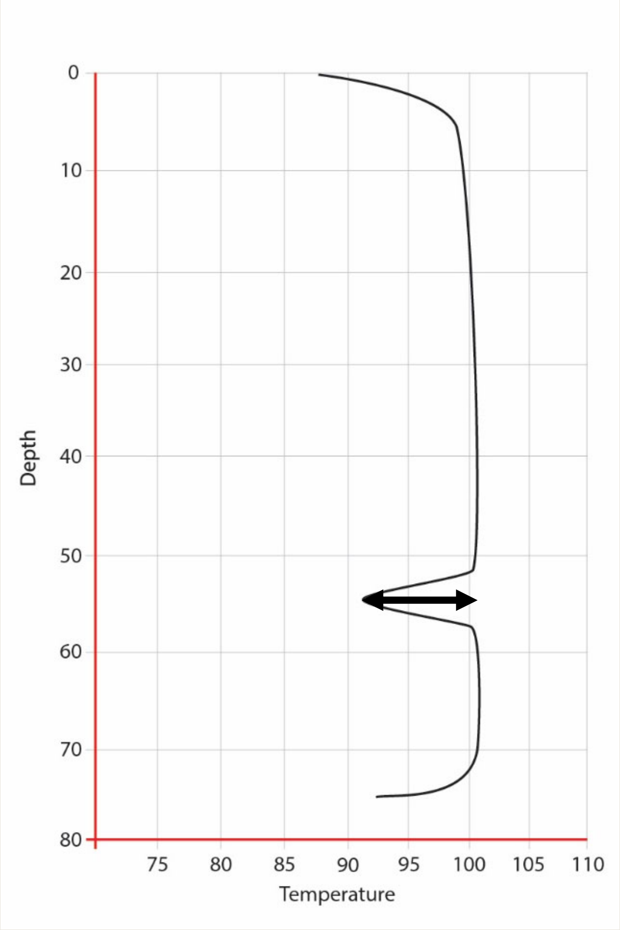
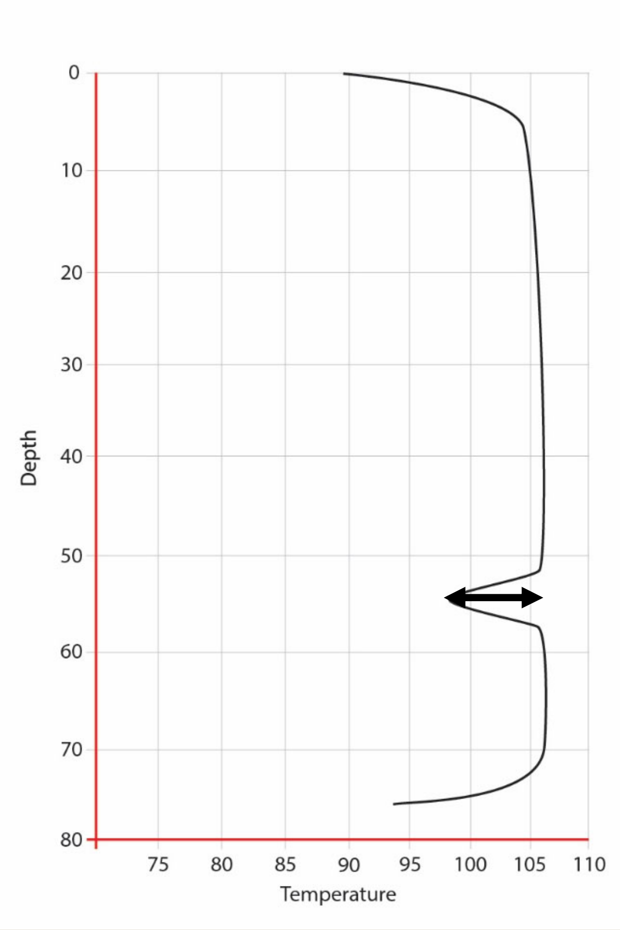
SELECTION OF ANALYSIS TIME

Half Peak Temperature: 20 hrs



10°F reduction from avg.

Peak Temperature: 40 hrs



7°F reduction from avg.

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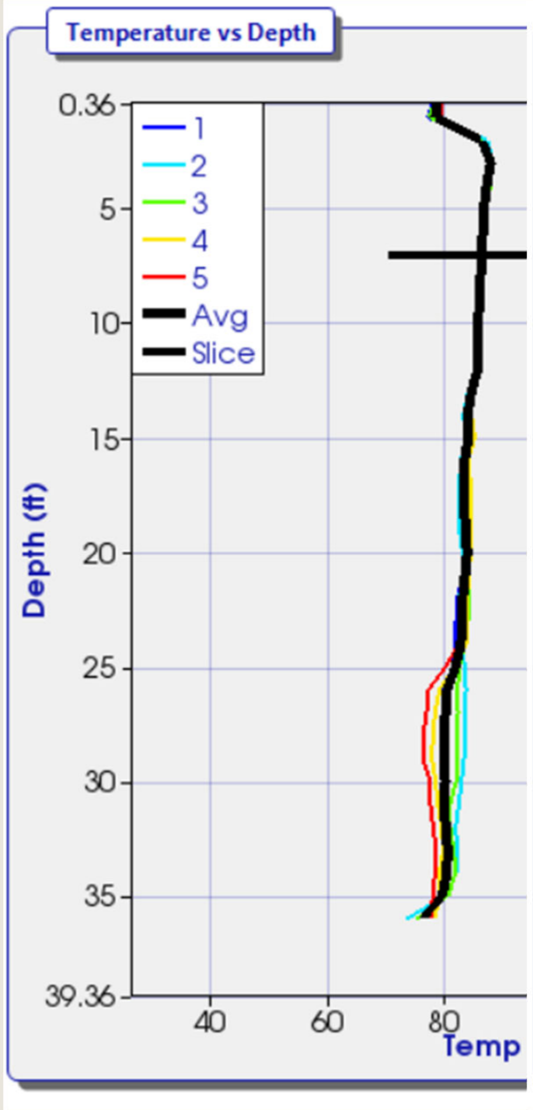
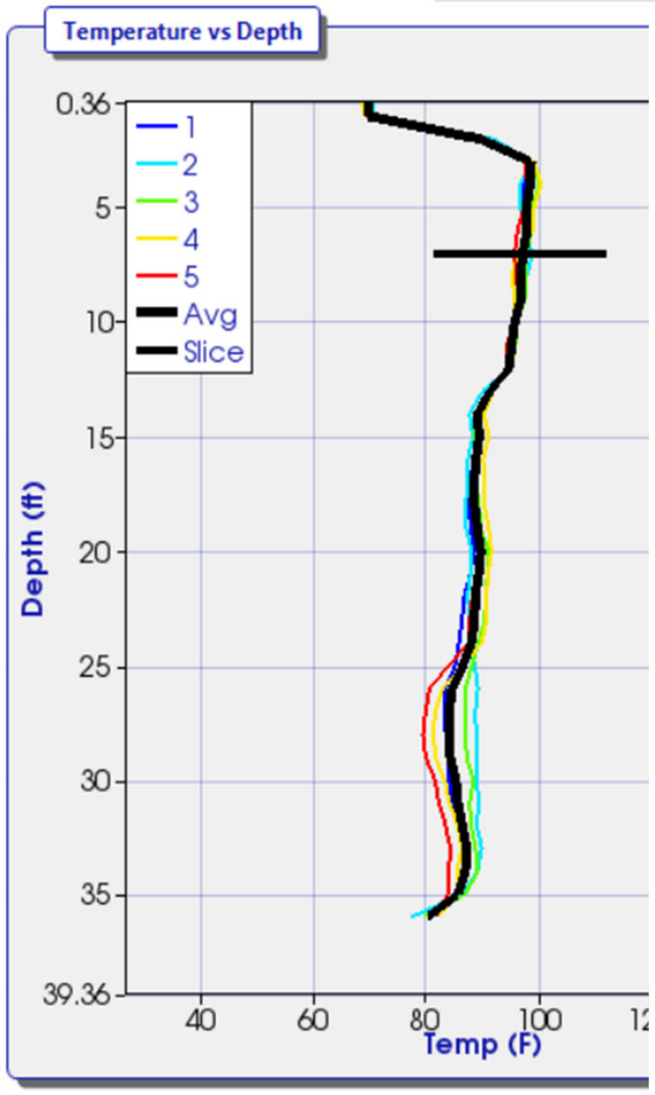
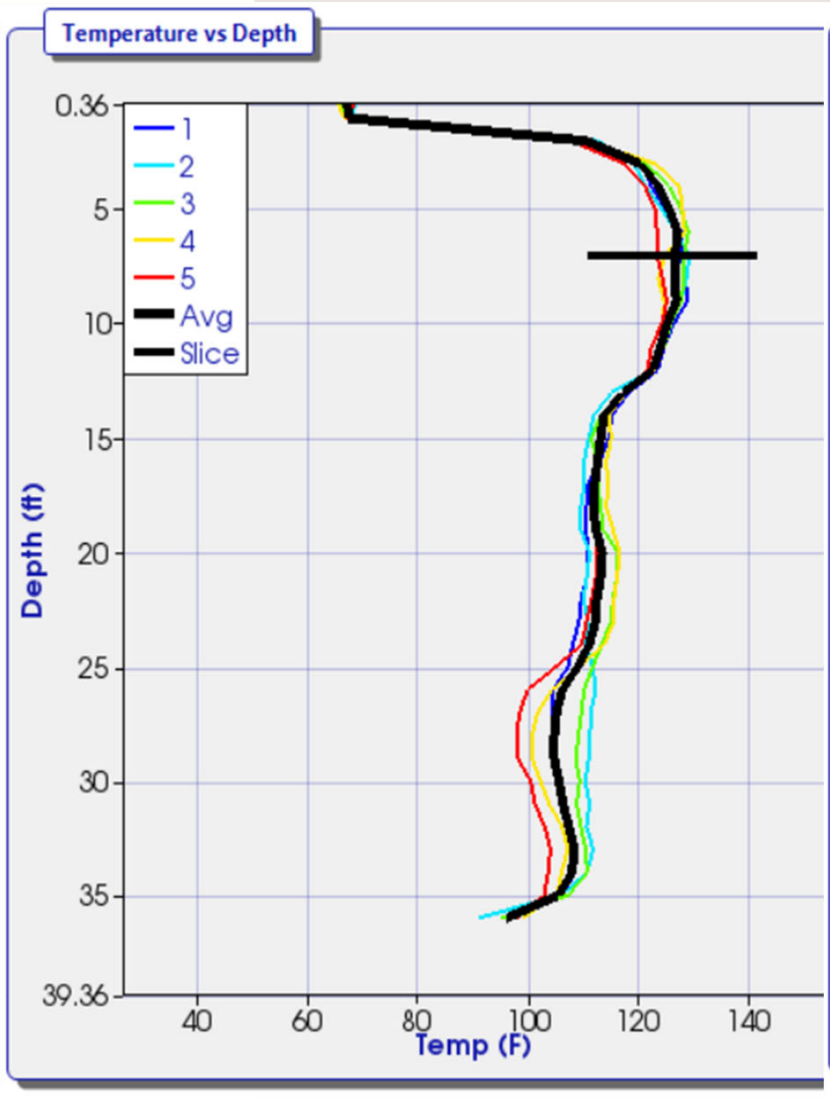
THERMAL INTEGRITY PROFILING



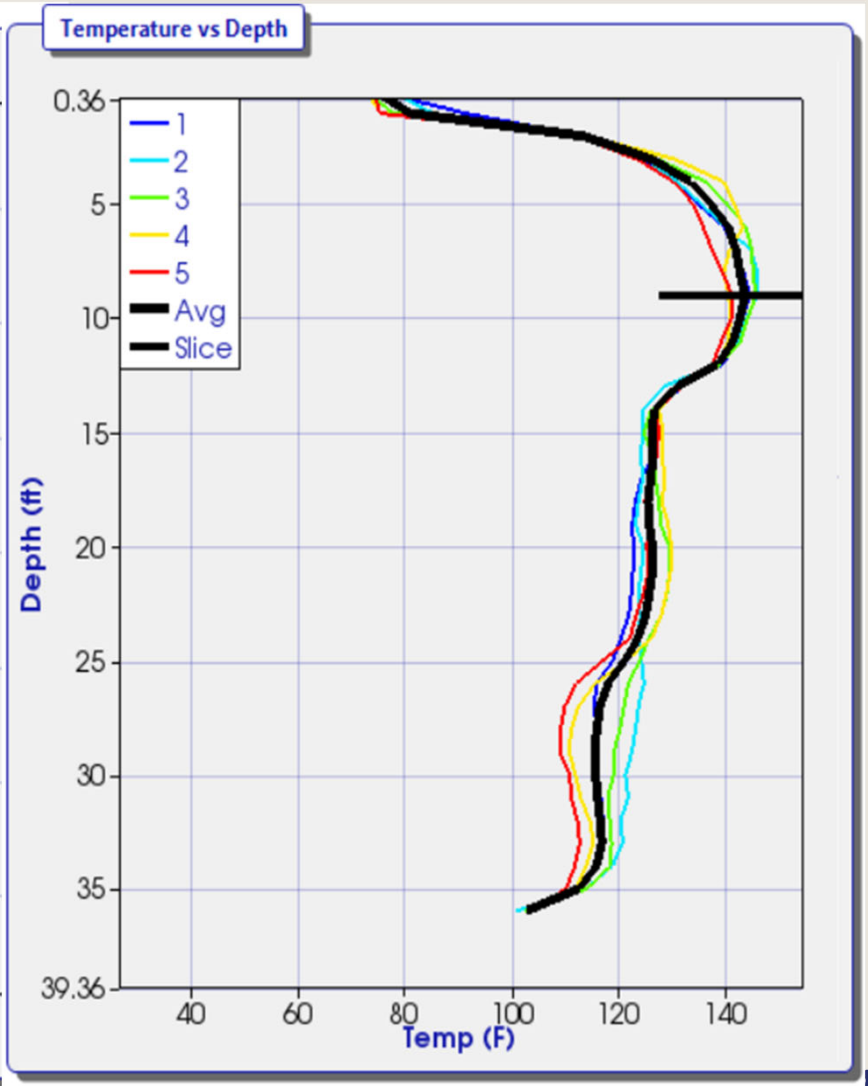
1 hour



4.5 hours



8 hours



18 hours

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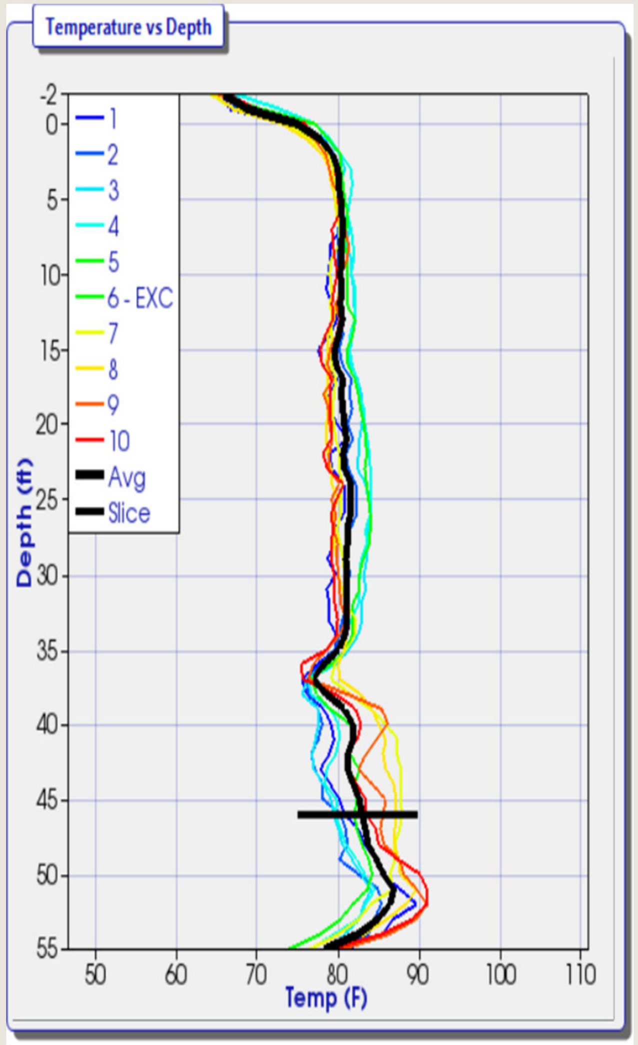
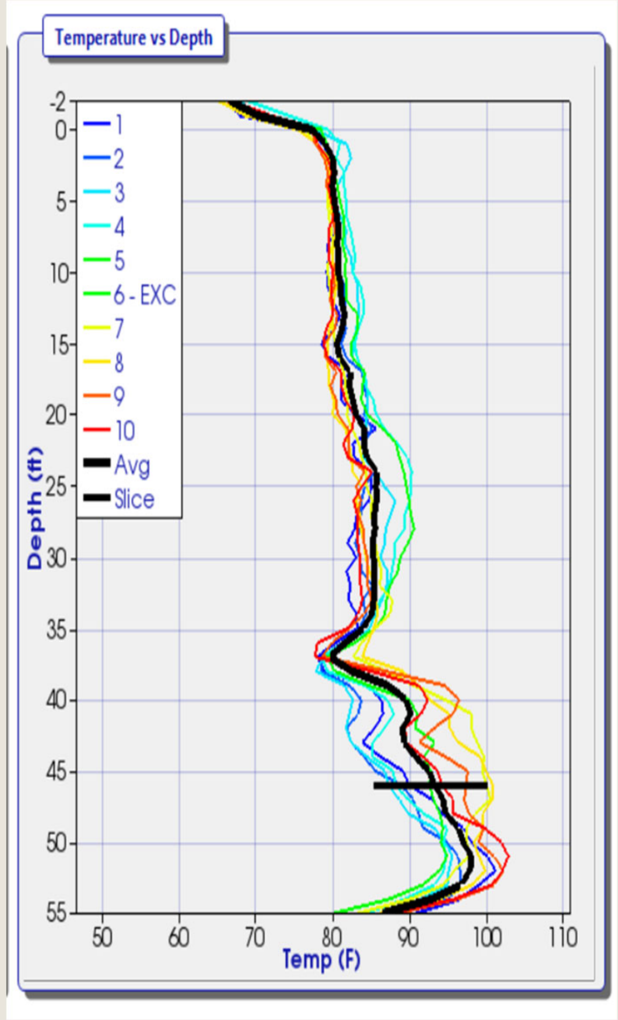
THERMAL INTEGRITY PROFILING

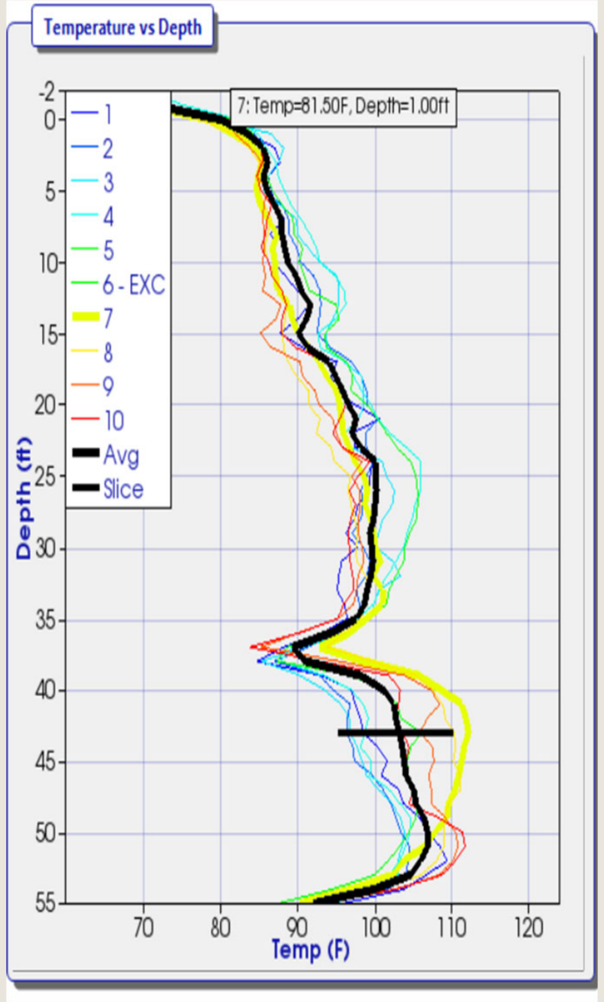
2 hours



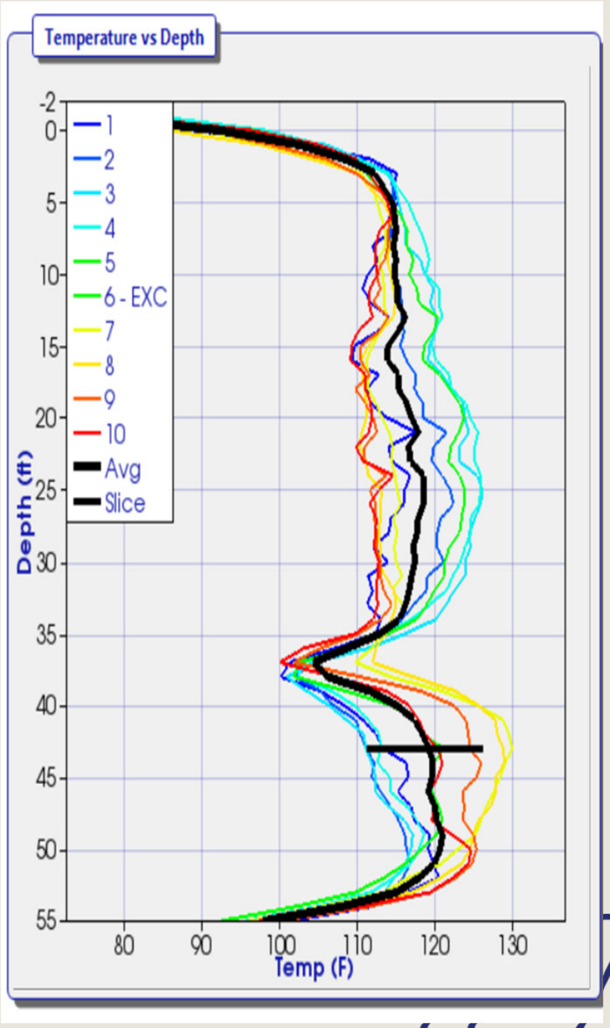
4.5 hours



8 hours



18 hours



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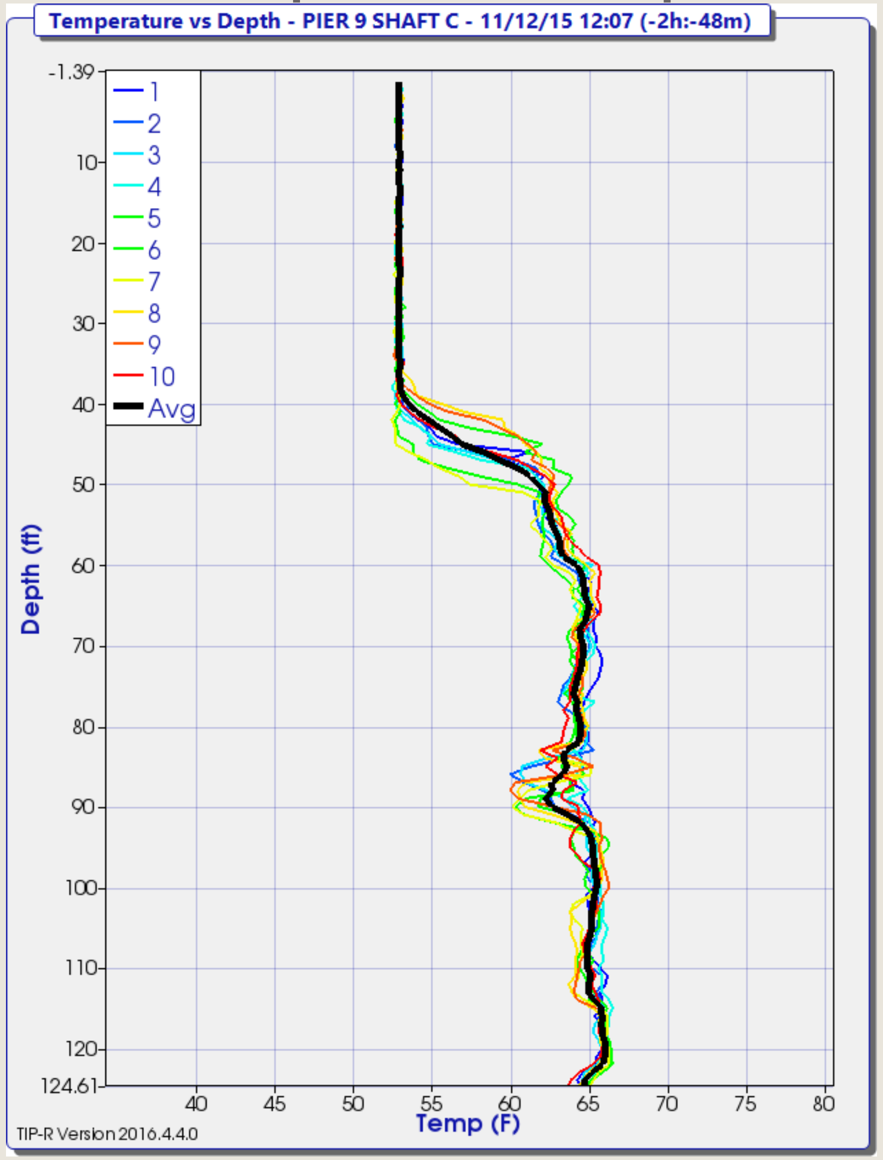
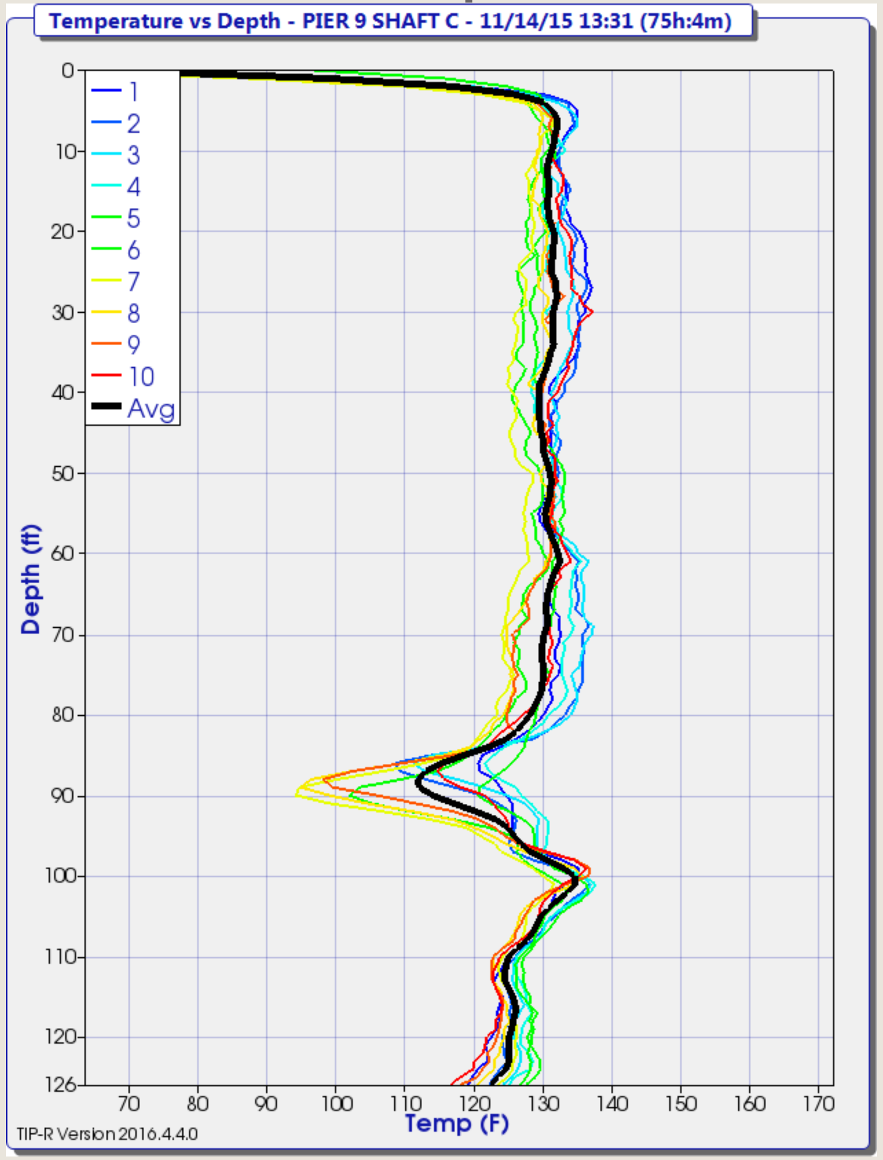
EARLY MEASUREMENTS ALREADY REVEAL DEFECT

Prior to pour completion



Peak Temperature



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ATTACHING CABLES

Securing Cable

- General recommendation is to place one wire per one foot diameter
- Use diametrically opposite pairs to assess alignment
- Wire can be zip tied or wire tied to the reinforcement cage

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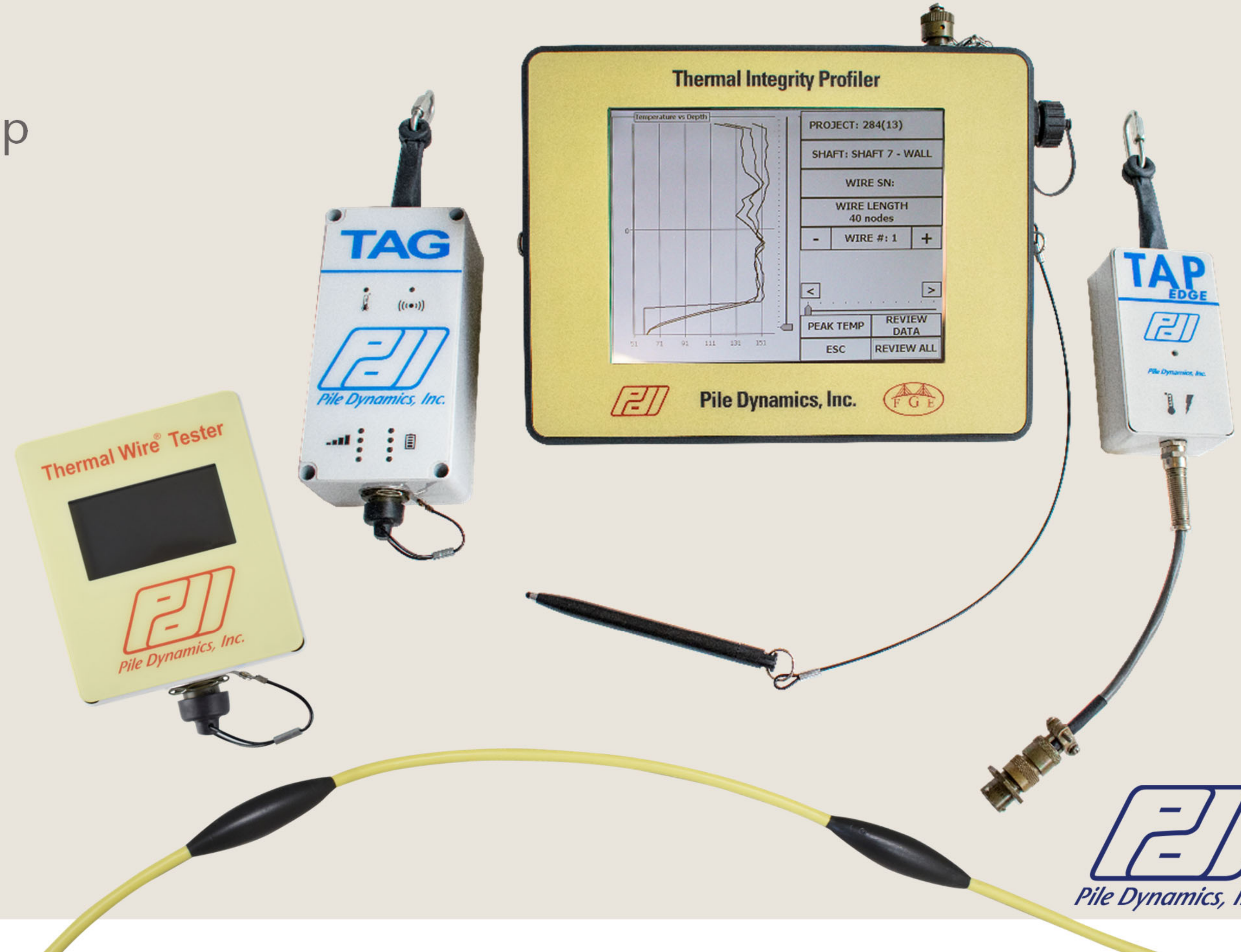
WHAT DOES A TIP SYSTEM INCLUDE?

- TIP Main Unit
  - Data Collector/Cloud Setup
- Thermal Wire
- TAG
  - Data Aggregator/Logger
- TAP-EDGE
  - Data Logger
- TIP Cable Tester Box
- TIP-Reporter Software
  - Analysis



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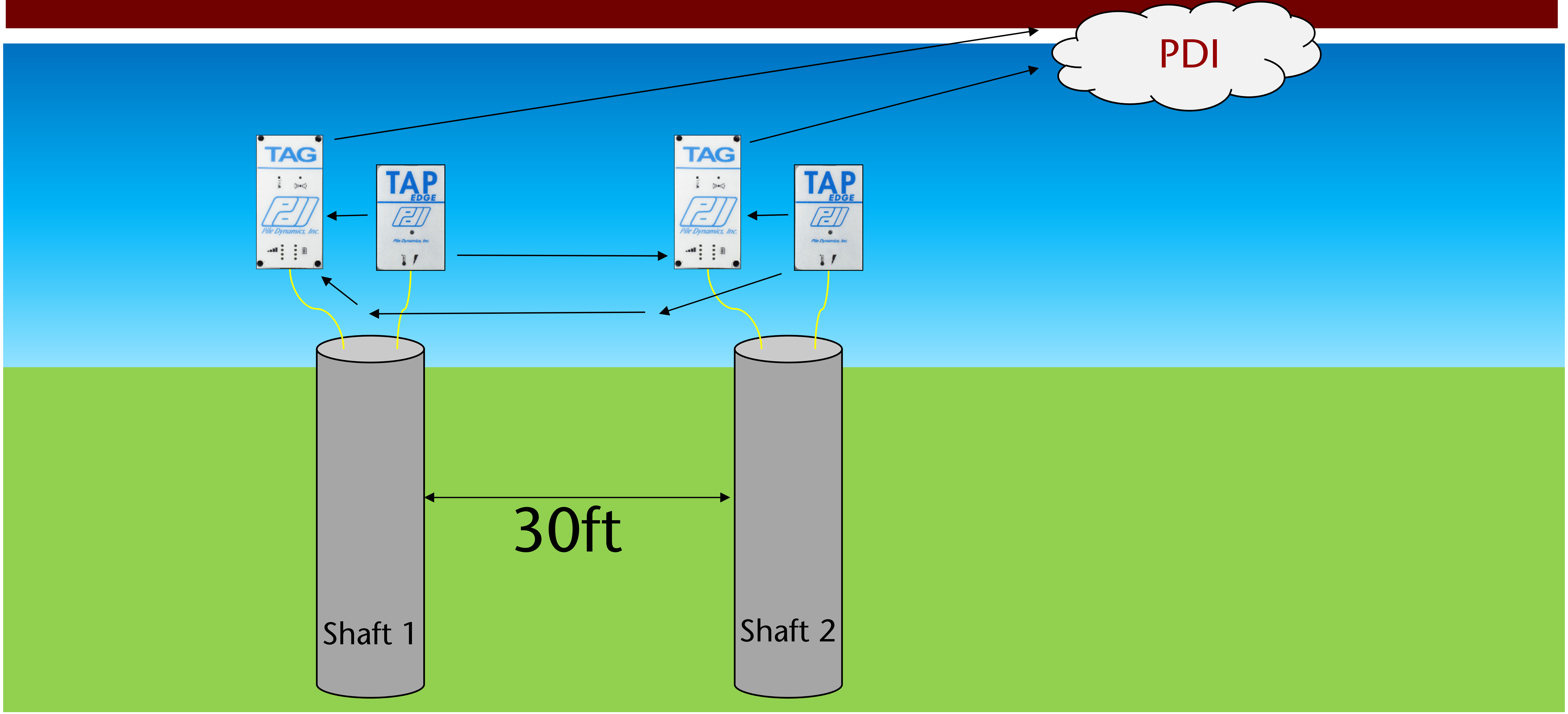
DATA COLLECTION USING TAG/TAP-EDGE



CONSIDERATIONS FOR ACCEPTANCE CRITERIA

- Load carrying requirements can be controlled by:
  - Geotechnical side shear
  - Compression
  - Structural bending
- These are directly related to:
  - Circumference surface area of the shaft
  - Cross sectional area
  - Moment of Inertia
- Each have different effects:
  - Circumference is linear with radius
  - Area related to square of radius
  - Moment of Inertia related to fourth power of radius
    - Is defect in zone of flexure?

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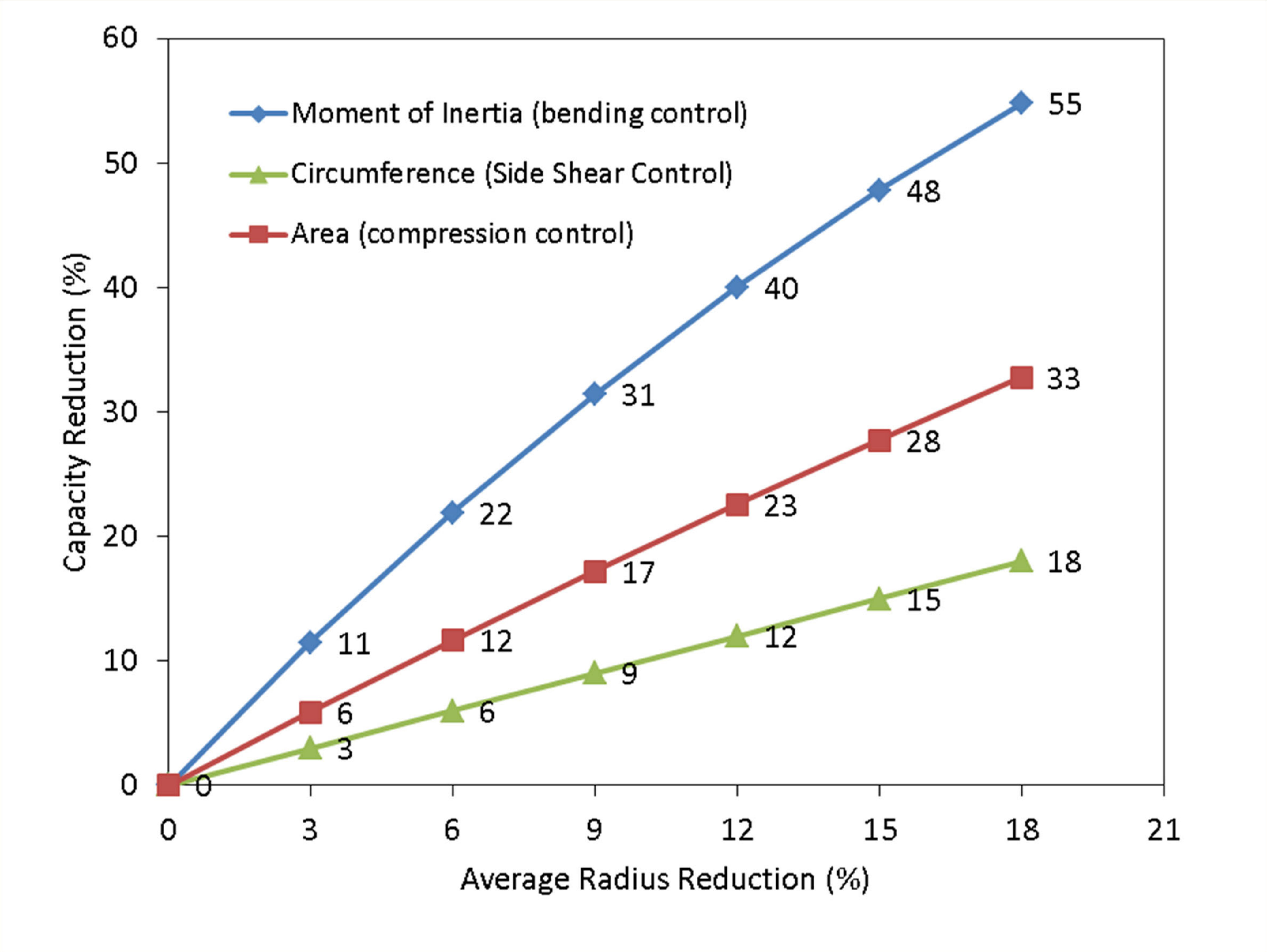
STRENGTH LOSS VS. RADIUS REDUCTION



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PROPOSED TIP CRITERIA

- **Satisfactory (S)**
  - < 6% Radius Reduction and
  - Cover Criteria Met
- **Anomaly requiring further Evaluation (E)**
  - Radius Reduction > 6% or
  - Cover Criteria Not Met
  - (a uniform 6% reduced radius is a 12% area reduction)

- minimum cover – 4 inch - AASHTO
- minimum cover – 3 inch - ACI

Need larger design cover to allow for cage eccentricity so net cover is sufficient

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FIELD EXAMPLES

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EXAMPLE 1 – TIME SAVINGS

- ~ 350 Drilled Shafts
  - Length 39 to 56 ft
  - Temporary Casing Installed to 26 ft
    - Groundwater at 4 ft below pile top
  - 4 to 8 ft diameters
  - All shafts TIP tested

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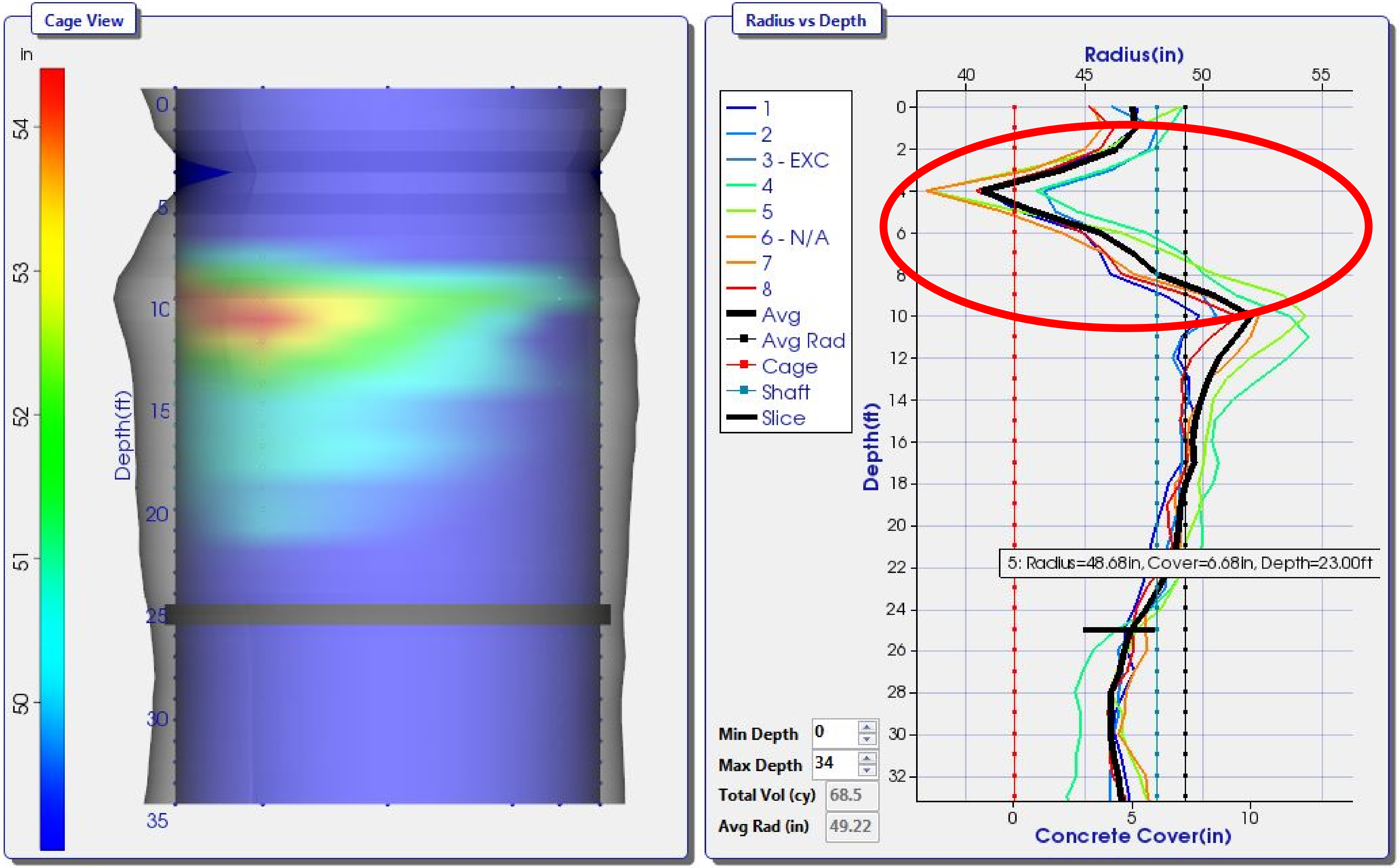

EXAMPLE 1

Shaft 1

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EXAMPLE 1

First six shafts had identified problems near top

All were cored and confirmed quicky

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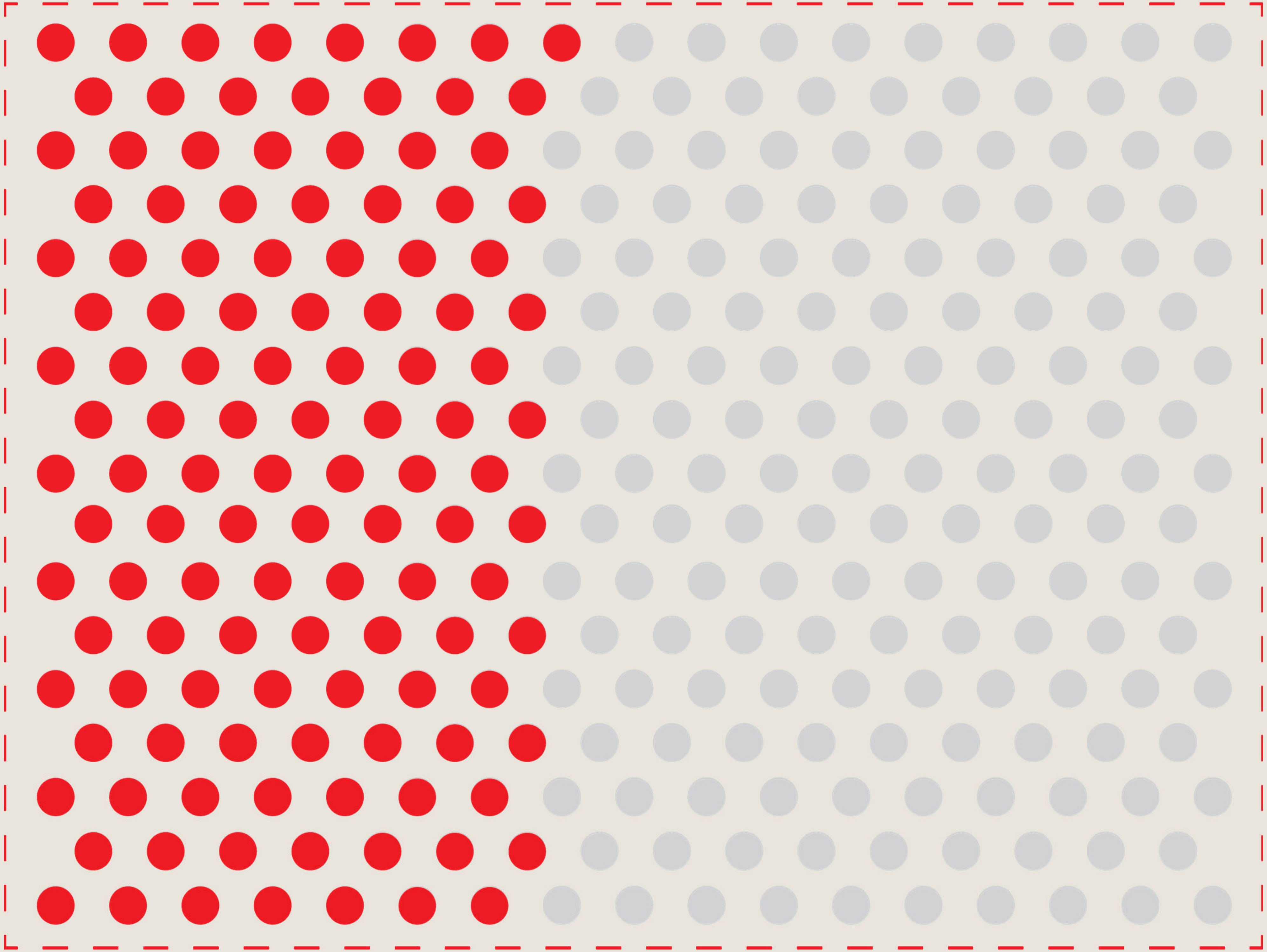

EXAMPLE 1

TIP allowed for correction of construction methods before it became catastrophic

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EXAMPLE 1 SUMMARY

- 100% TIP testing on all shafts
- TIP identified 6 shafts with defects all in upper 5 feet
  - groundwater at approximately 4 feet below top of shaft is washing out the concrete when the casing is pulled
- Coring has revealed voids in all 6 shafts where TIP identified a problem
- Construction techniques modified to avoid further issues
- Early detection saved considerable cost and delays for the project

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EXAMPLE 2

I-5 Bridge over
Puyallup River
Tacoma,
Washington

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TIP EXAMPLE 2

- Wet cast Shaft in Washington State
- 118" diameter
- 10 TIP wires installed
- Cage Diameter 102"
- 126' shaft length
- TIP testing begins immediately after casting
  - Data recorded during pour as well as cure
  - Data recorded for approximately 90 hours after casting
  - Shaft peak temperature occurs approximately 40 hours after casting
  - Shaft analysis done at time of one half peak temperature (20 hours)

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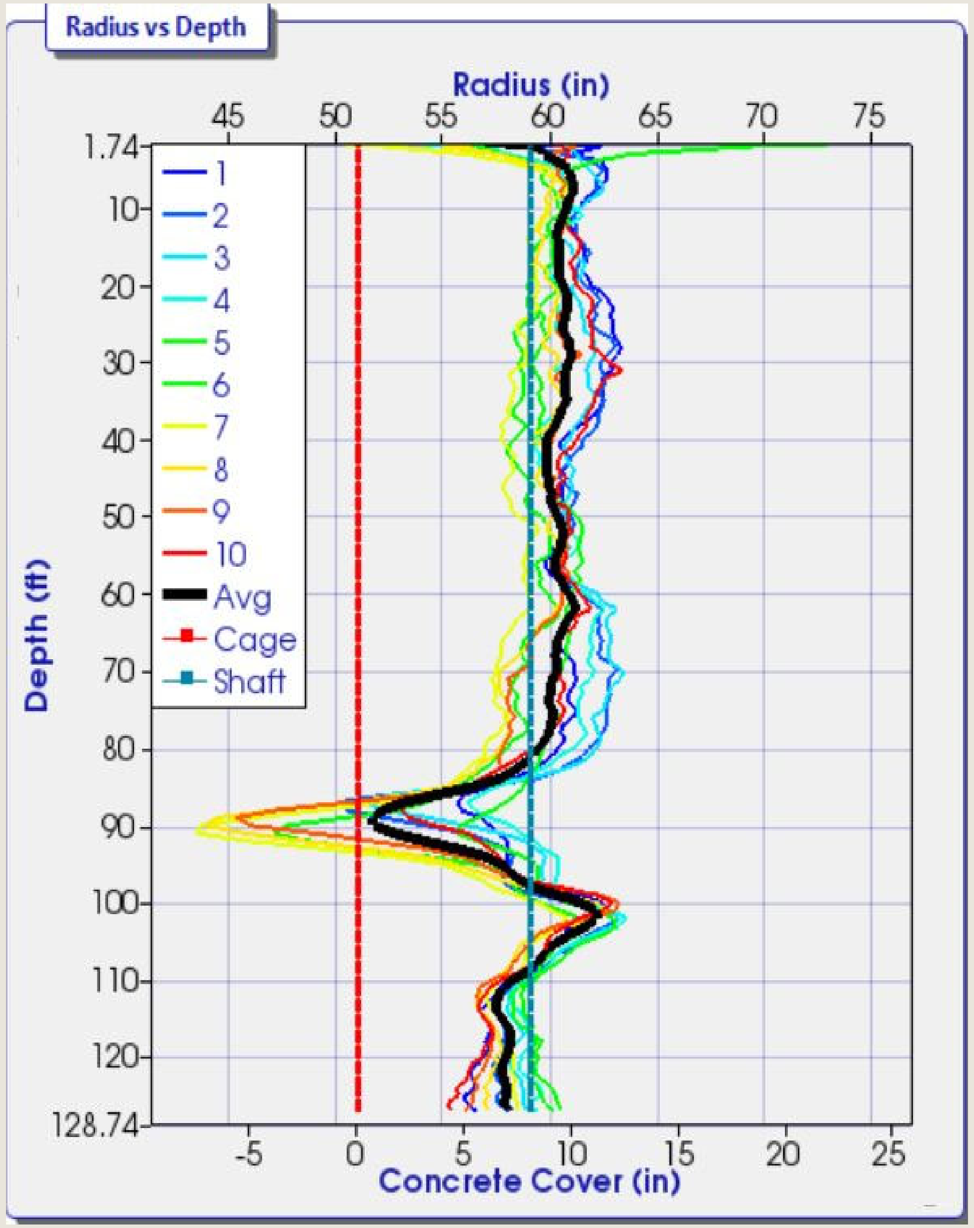
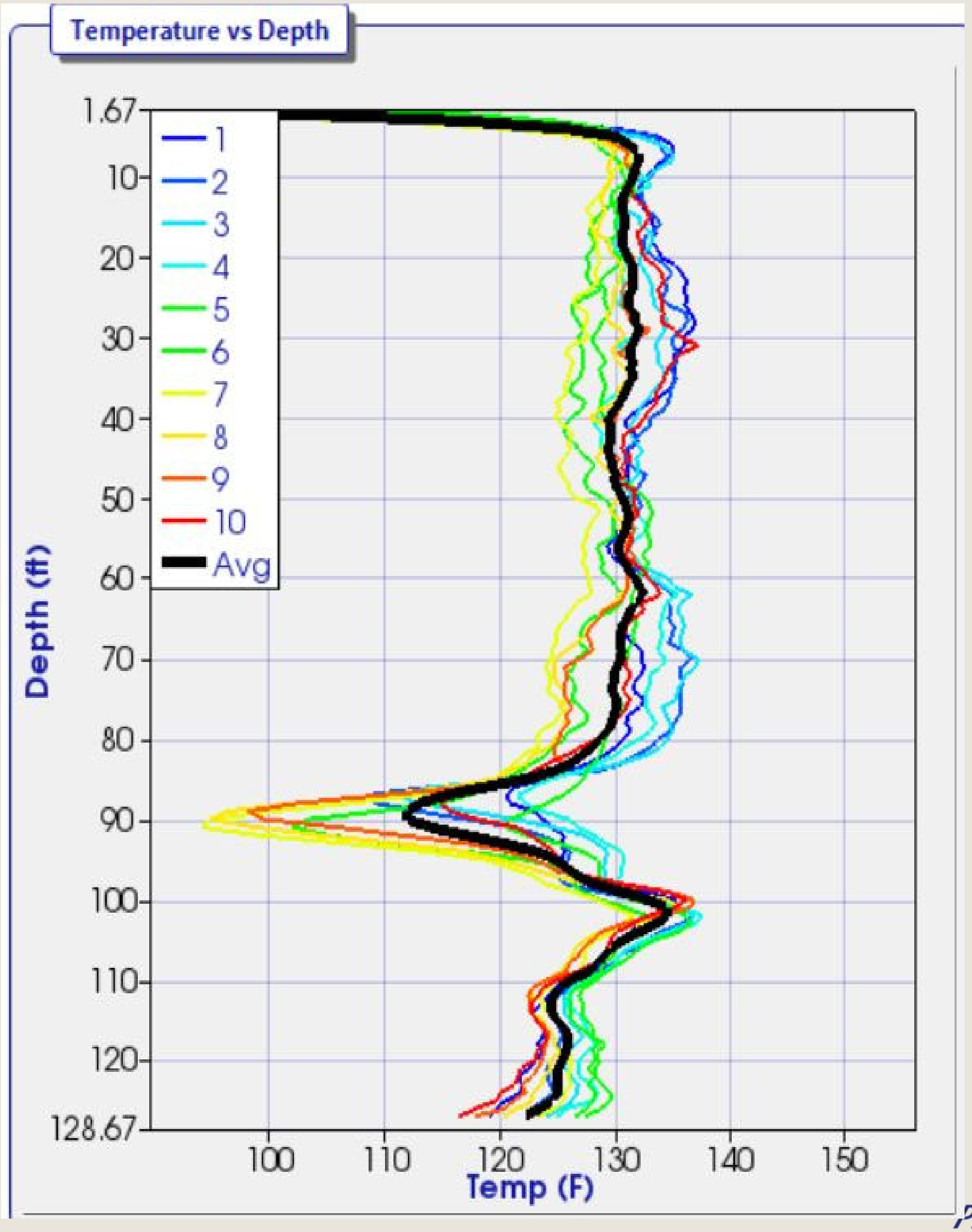
TIP DATA AT PEAK TEMPERATURE





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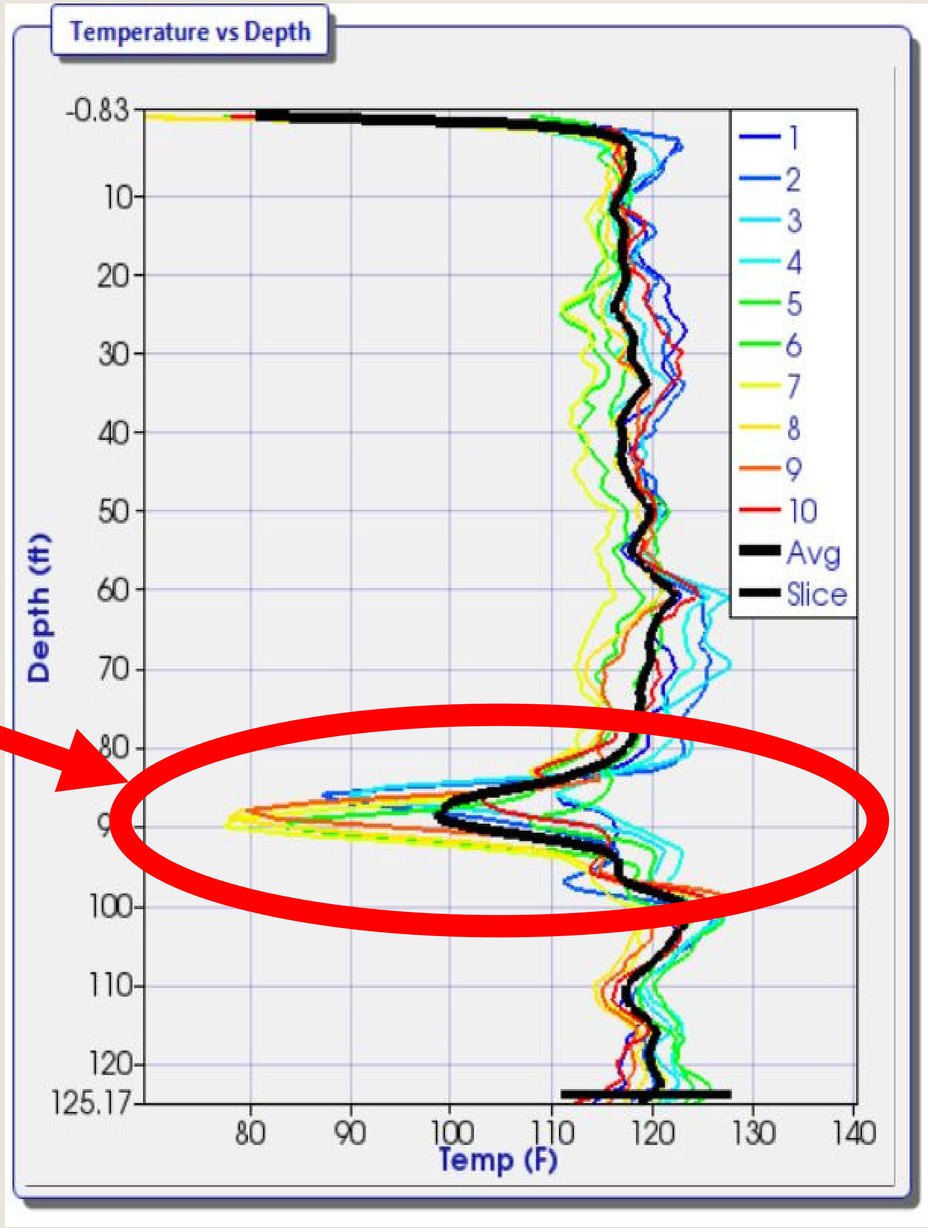
TIP DATA AT TIME OF ONE HALF PEAK TEMPERATURE

Temperature drop is approximately 42 °F between average shaft temperature and local temperature near wires 7, 8, and 9



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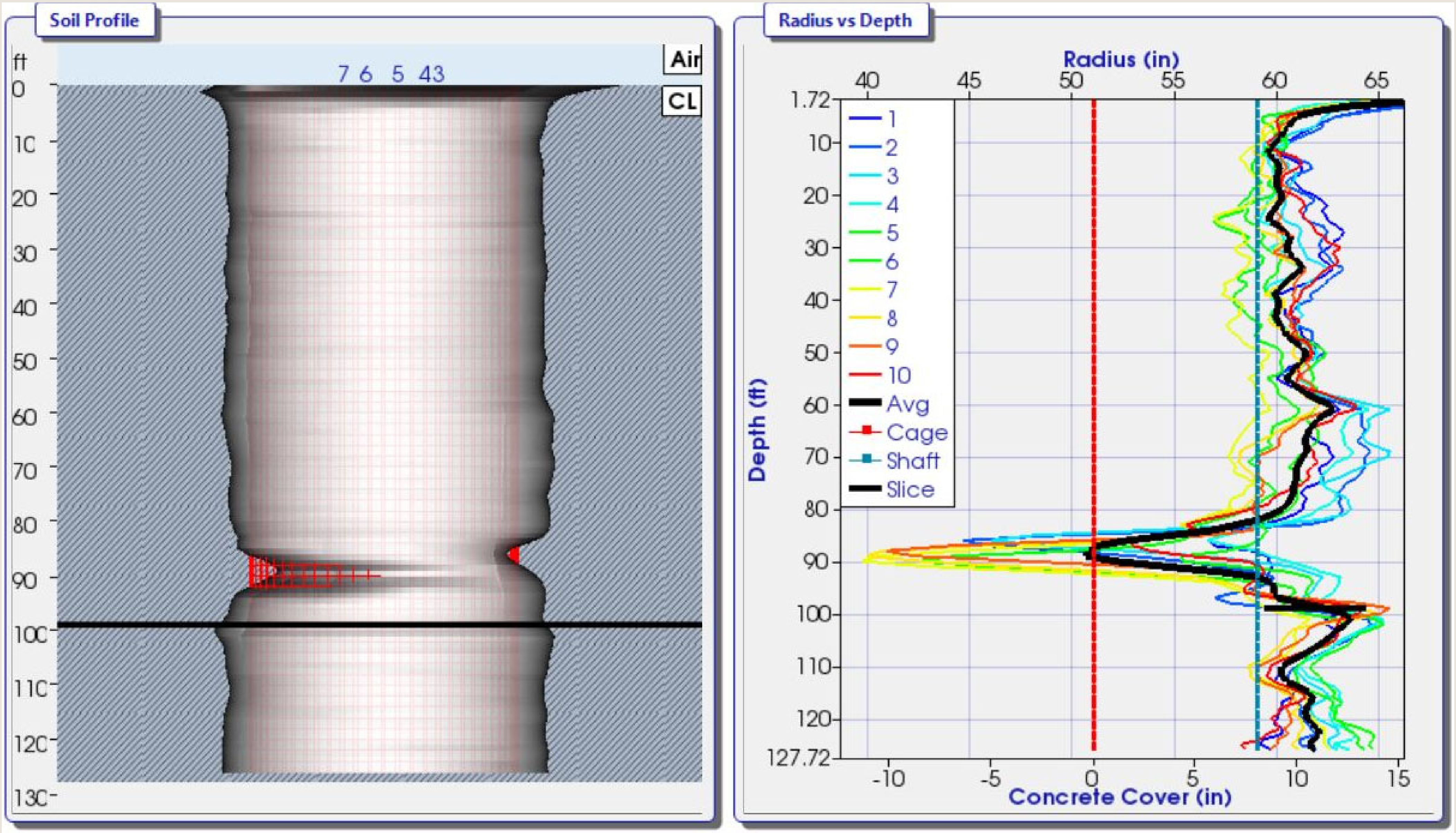
TIP DATA AT ONE HALF PEAK TEMPERATURE



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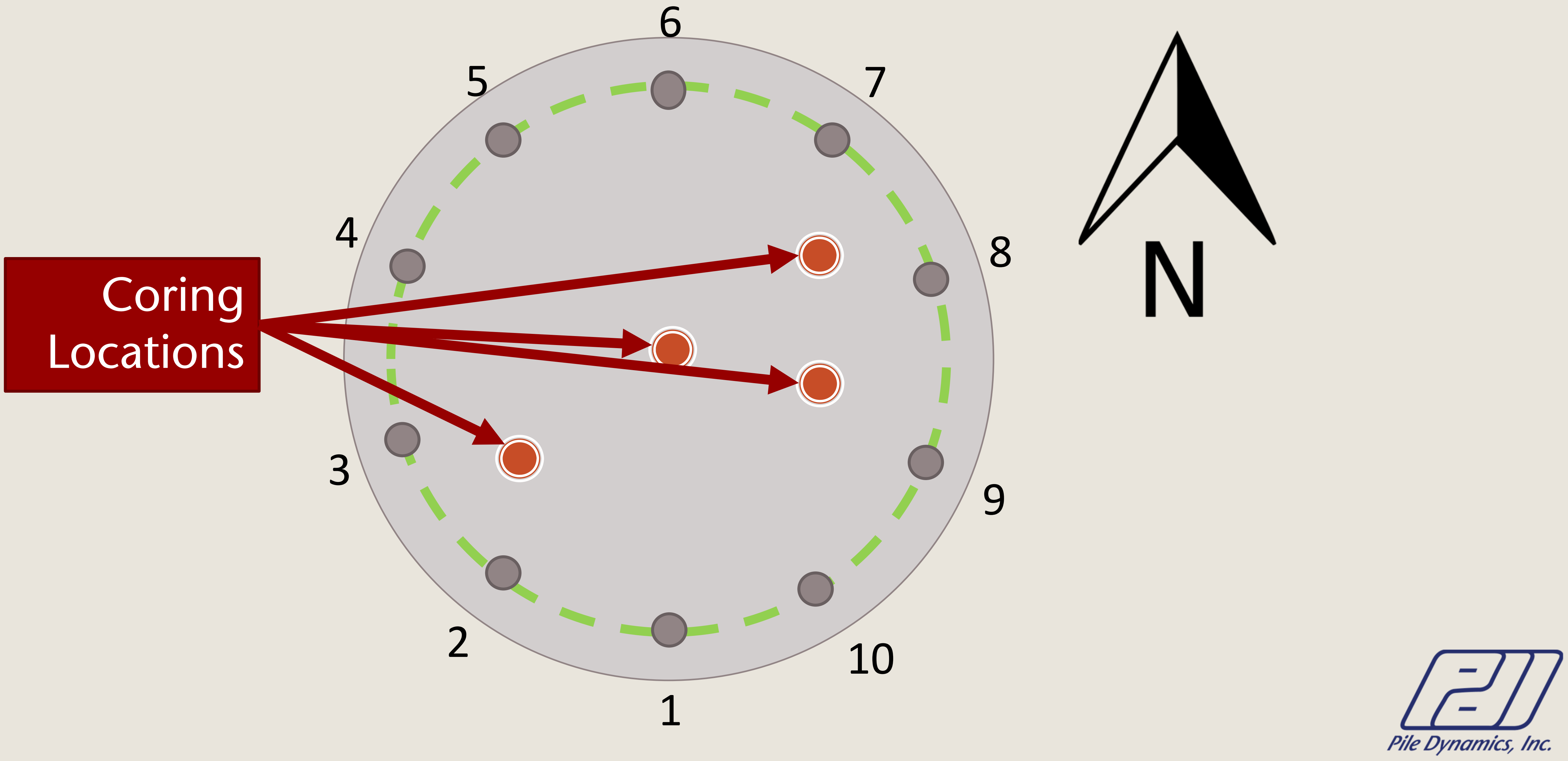
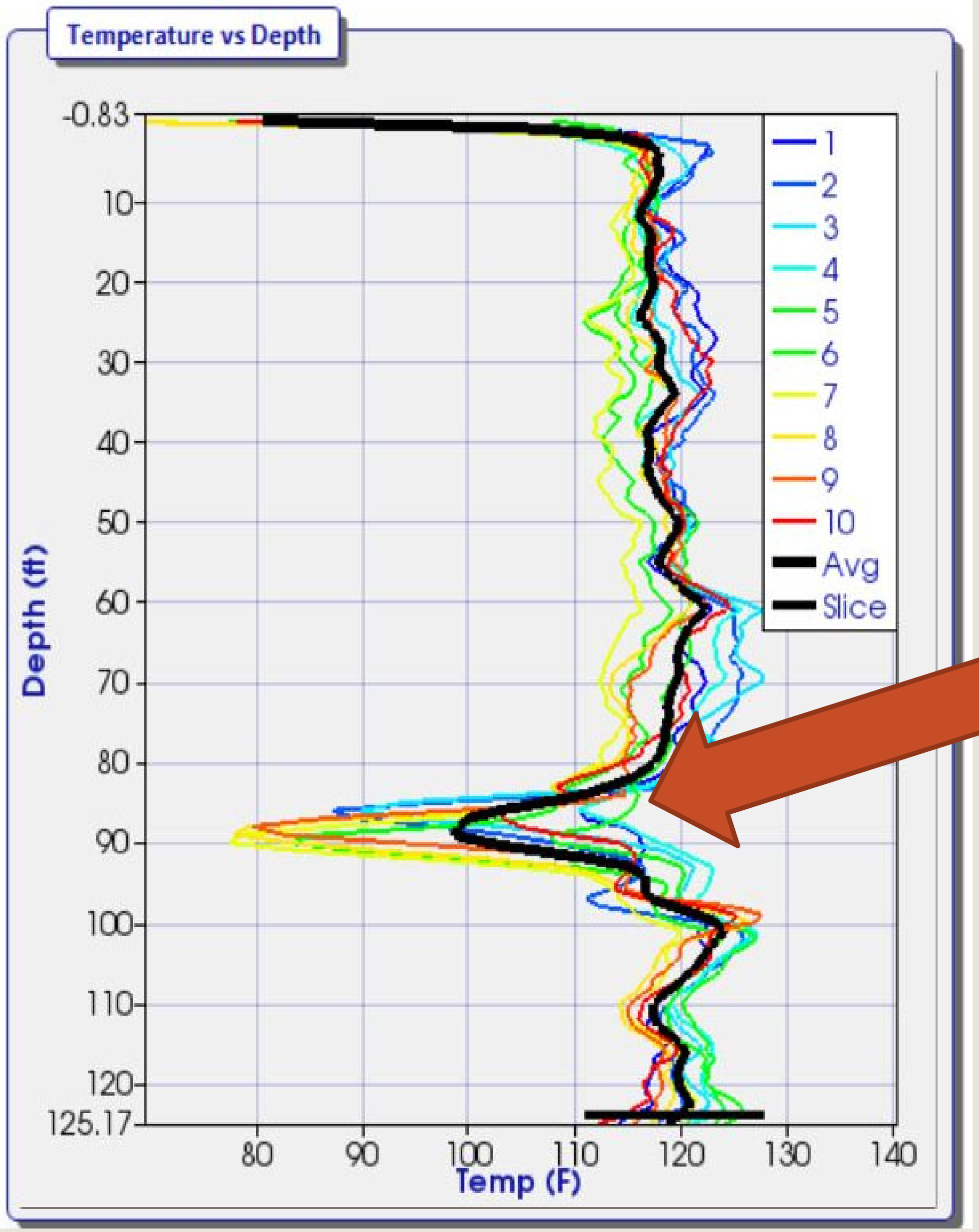
WHERE TO CORE?



CORING RESULTS AT APPROXIMATELY 90' DEPTH



- Coring result close to wires 7 and 8, where largest reduction occurred
- Coring confirms TIP test results
- Zone was hydro-blasted and pressure grouting was performed

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EXAMPLE 2 SUMMARY

- Shaft shows a local reduction near wires 6 through 9
  - Design radius = 59 inches
  - Local effective radius at wires 7 & 8 = 40 inches
  - Reduction in Local Radius = 32.2%
  - Cover is also reduced to zero in these regions
    - Anomaly extends inside the reinforcing cage
  - Coring is done in several locations in the shaft

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EXAMPLE 3: TOE DEFECT

- Illinois Department of Transportation
  - I-57 over NS Railway
- 48” nominal diameter
- Four thermal wires per shaft
- Temporary casing (54 inches) was installed extending approximately 16 ft.
- The lower 10 feet of the shafts consisted of a rock socket with a diameter of 48 inches.
- Overall length of the tested shafts are 26 feet

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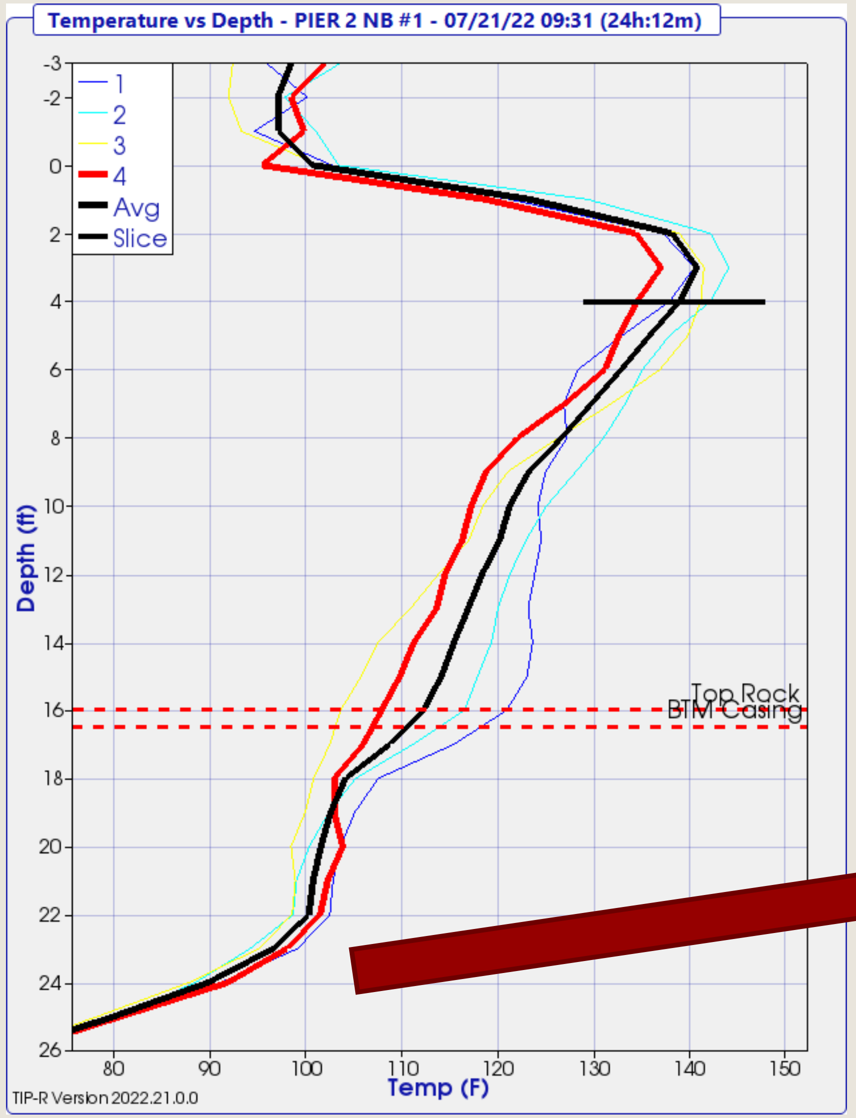
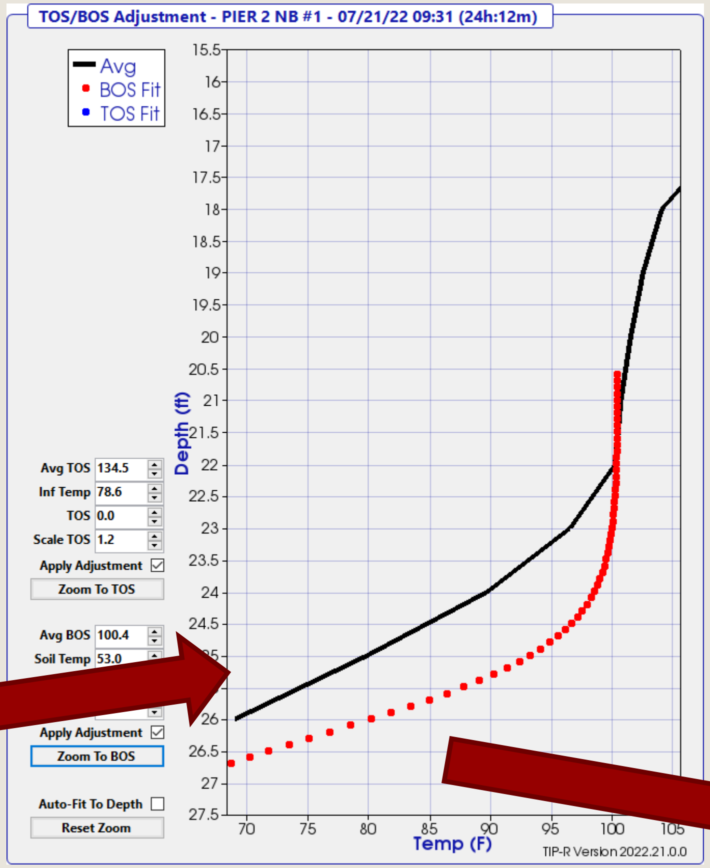
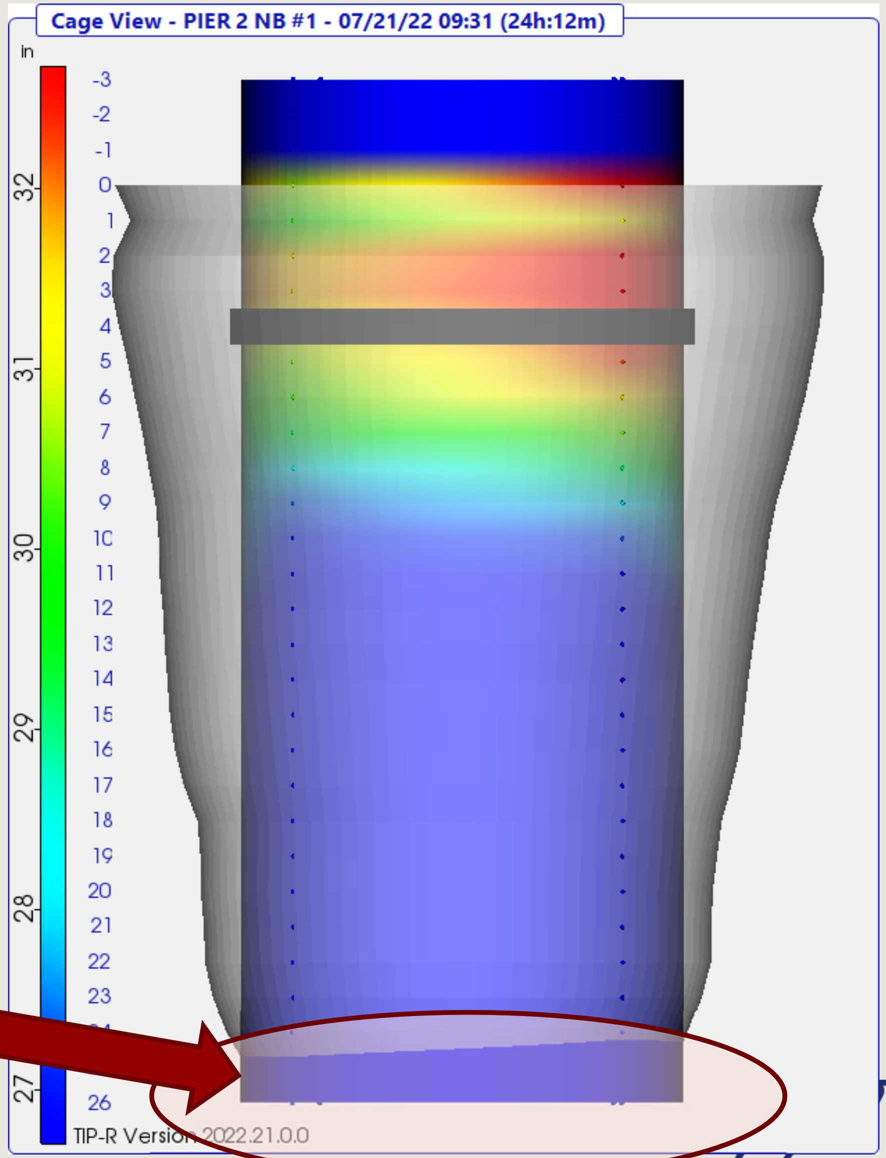
EXAMPLE 3: TOE DEFECT







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EXAMPLE 3: TOE DEFECT

- Thermal results identify toe defect
- Results prompted coring
- Coring confirms degraded concrete and gravel

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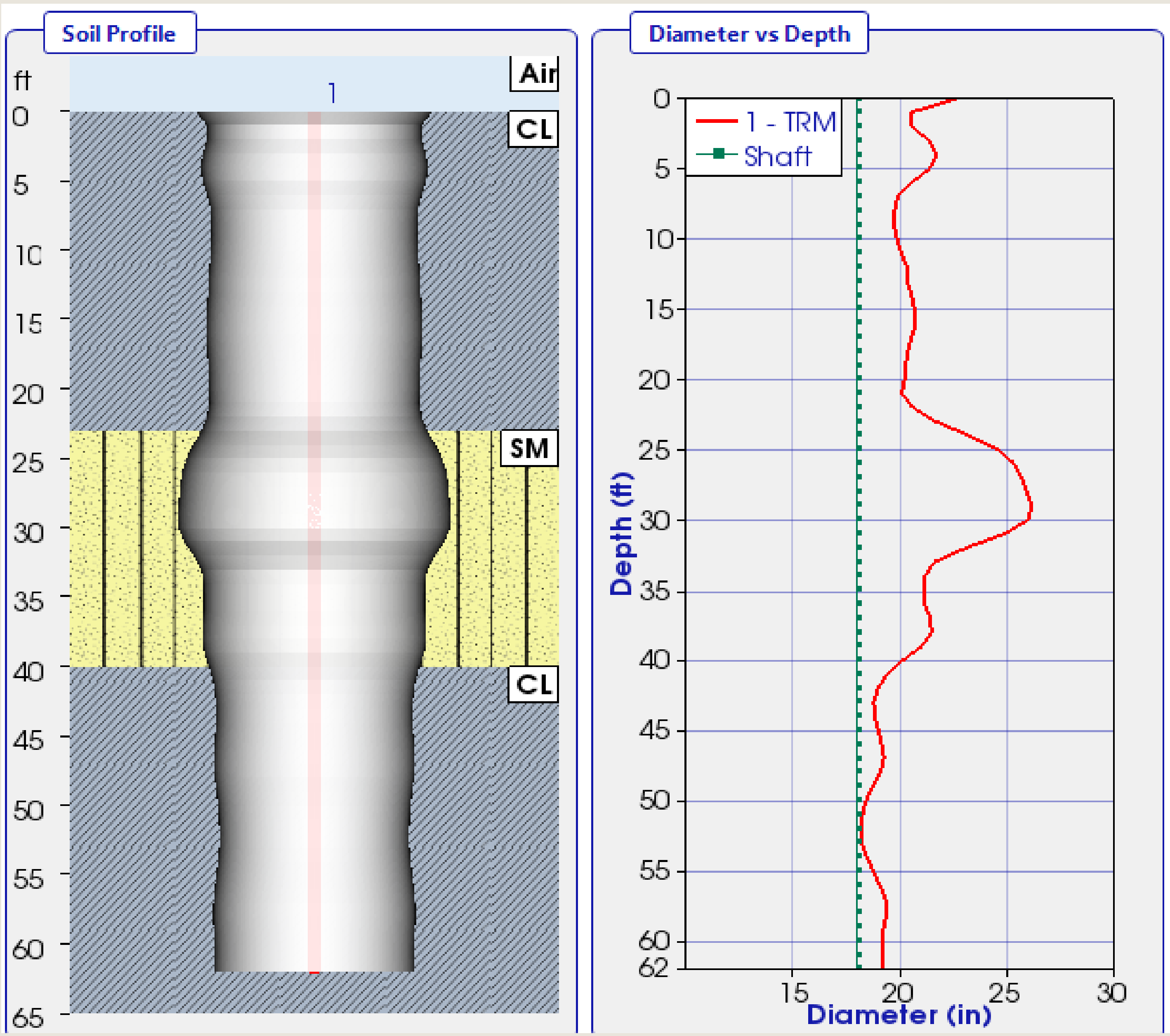

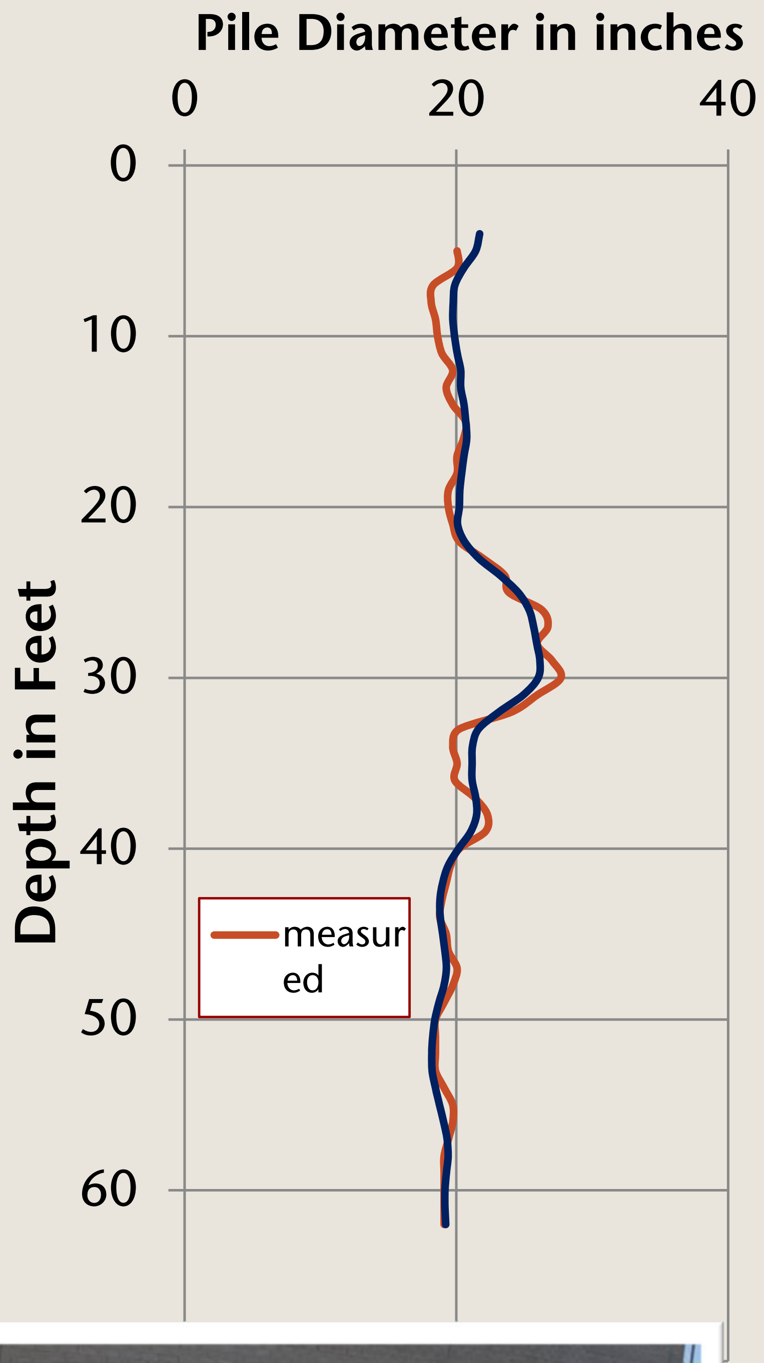

TIP provided area versus depth to properly convert embedded strain sensor data to force for a static load test

USE ON AUGERCAST LOS ANGELES 2017

18 inch augercast pile

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THERMAL INTEGRITY PROFILING

- **Advantages**
  - Uses temperature vs. depth vs. quadrant
  - Test early after casting (speeds construction)
  - 6 to 48 hours (depends on diameter)
  - Evaluates concrete quality, cover & alignment
  - Evaluates shape (look at peak temperature time)
  - Finds significant defects (look at "half peak time")
  - Inspires quality construction
  - Avoids CSL issues of debonding, bleeding

- **Limitations / Disadvantages**
  - Use: Drilled/auger-cast shafts, barrettes, micropiles…
  - Preplan thermal wire cables
  - Can test only during early curing

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