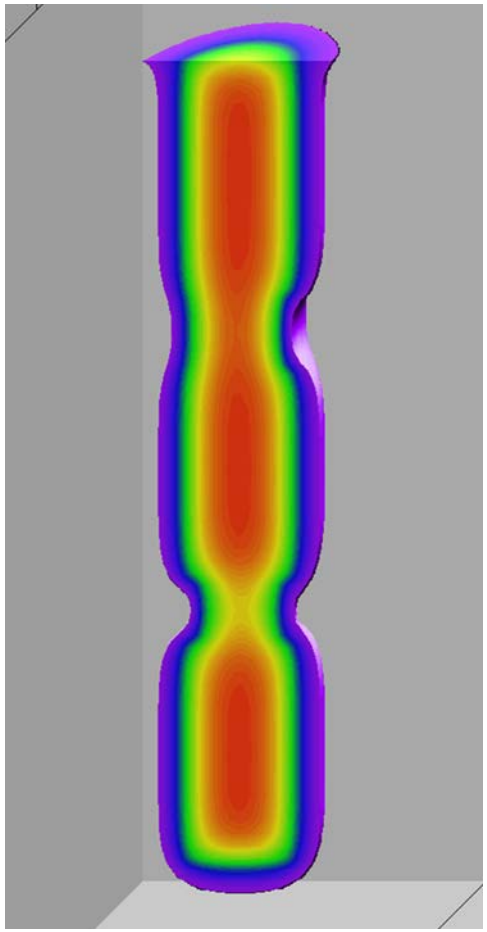
Optimizing the Use of Thermal Integrity System for Evaluating Auger-Cast Piles



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Civil & Environmental Engineering

Problem Statement

- Thermal Integrity Profiling (TIP) has proven to be an effective method for evaluating the as-built integrity of drilled shafts.
- However, TIP is rarely used for evaluating auger-cast-in-place (ACIP) piles, as current practices do not require installation of standard integrity access tubes.
- Current integrity methods for ACIP piles is limited, thus their FDOT use has been limited to foundations for sound walls.
- GOAL: **Translate the use of thermal integrity technology to an effective method for evaluating ACIP piles**.

Research Approach

- Task 1 Literature Review
- Task 2 Numerical Modeling
- Task 3 Feasibility Study of Probe-based Inclination Measurements
- Task 4 Field Testing
- Task 5 Reporting

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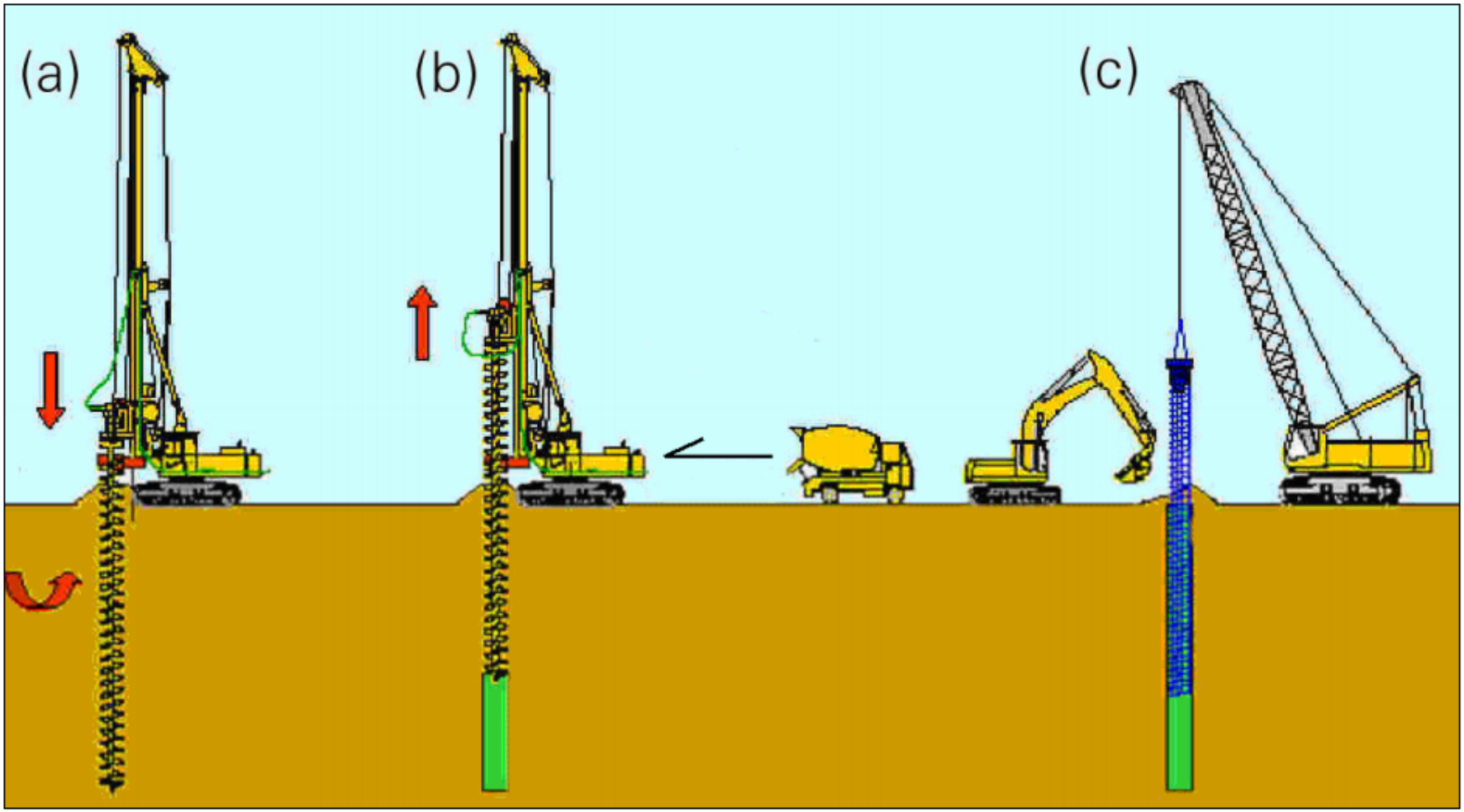
ACIP Piles
Construction



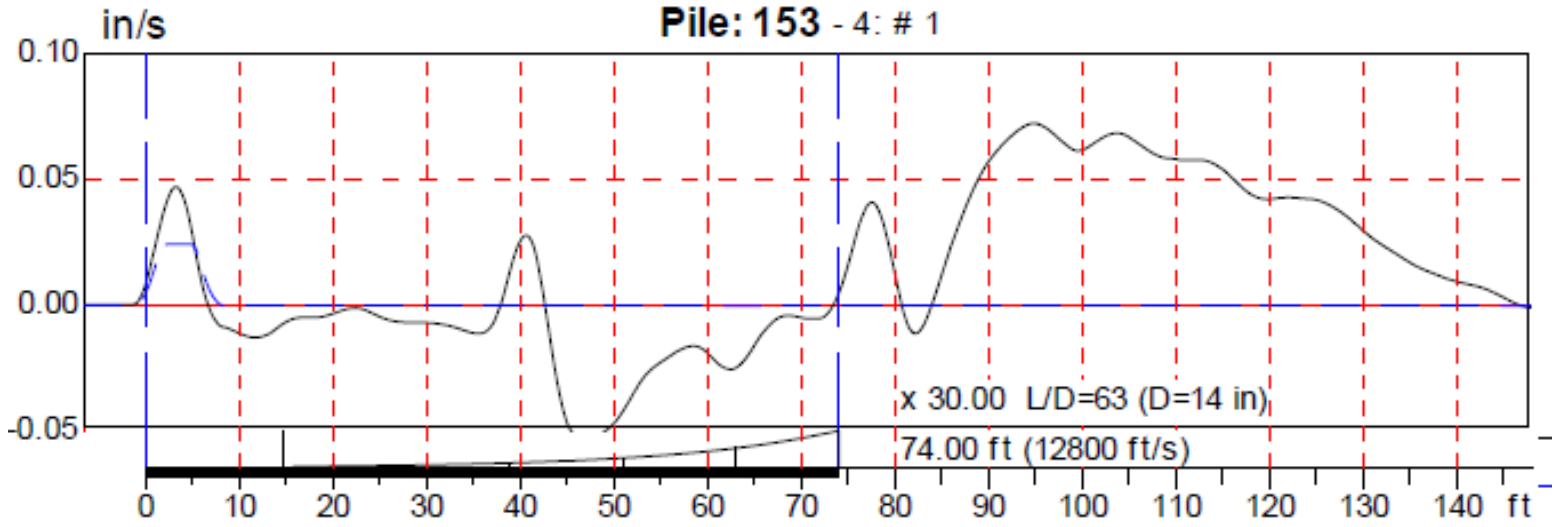
Source: Dan Brown et al., FHWA-HIF-07-03

ACIP Piles
Construction

ACIP Piles
Quality Control

ACIP Piles
Quality Assurance

Surface methods involving stress wave propagation analysis are the most common form of integrity testing for ACIP piles.

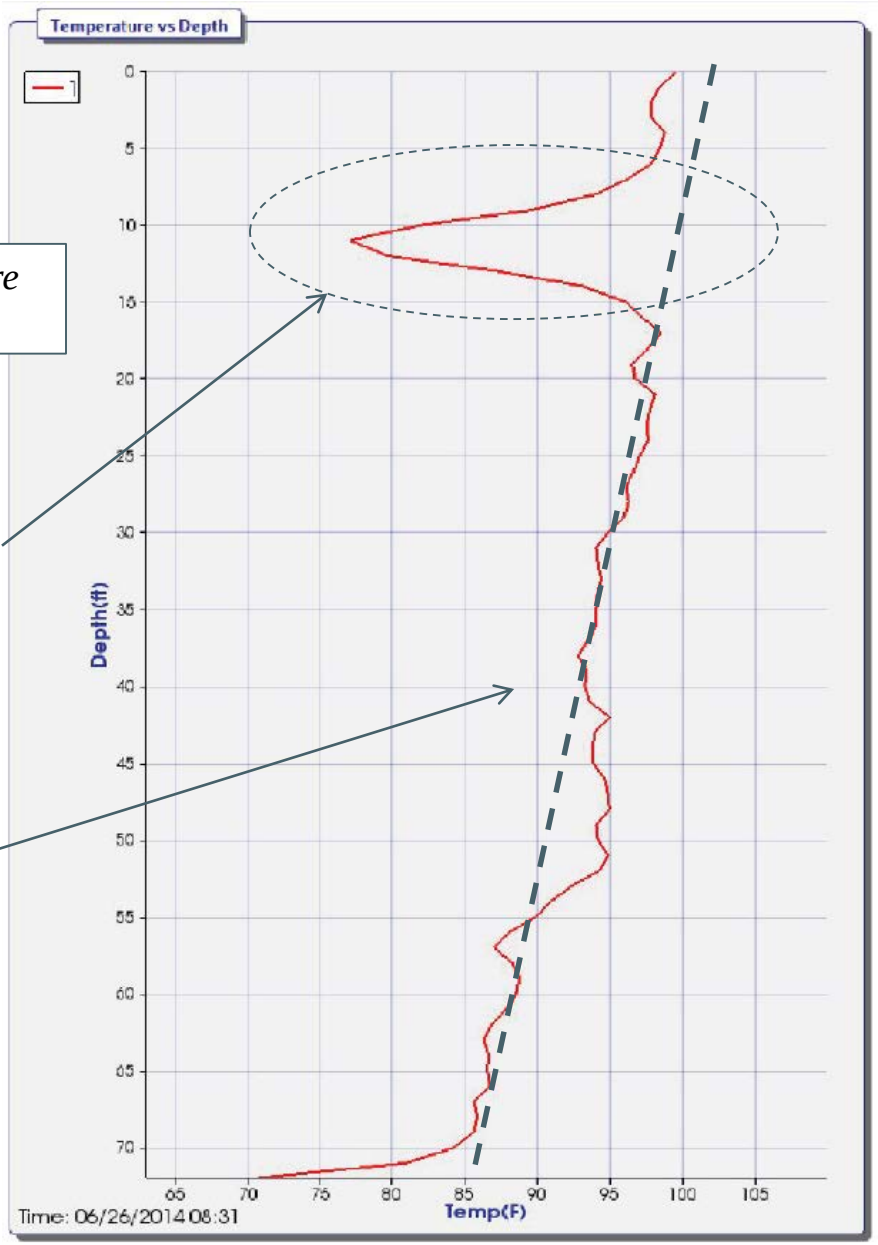


ACIP Piles
Quality Assurance

Single thermal wire tied to center bar

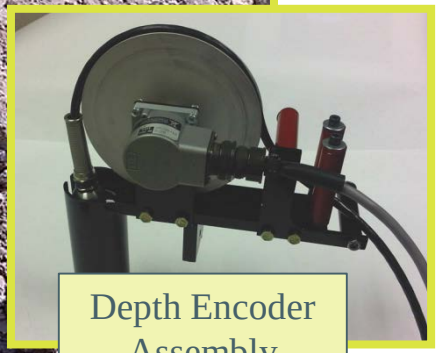
Single Center Wire Detects Anomaly

Inclination / alignment not quantifiable

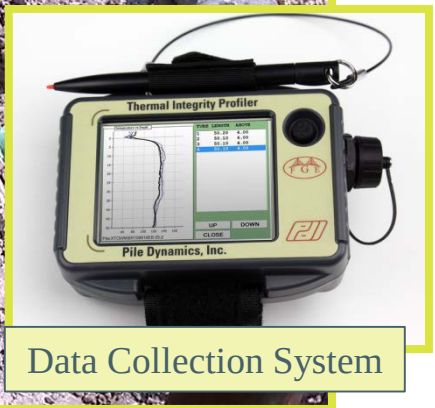


TIP Methods
Infrared Probe

Thermal Probe w/ Infrared Sensors



Depth Encoder Assembly



Data Collection System

TIP Methods
Thermal Wire

New Thermal Wire

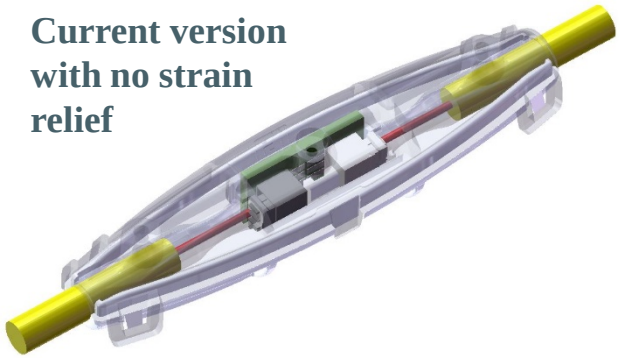
Thermal Wire:

- New version of Thermal Wire in production now is much stronger and requires far less cable ties, greatly reducing potential data loss and speeding installation.

*The new version of the wire has been deployed on numerous shafts with excellent results

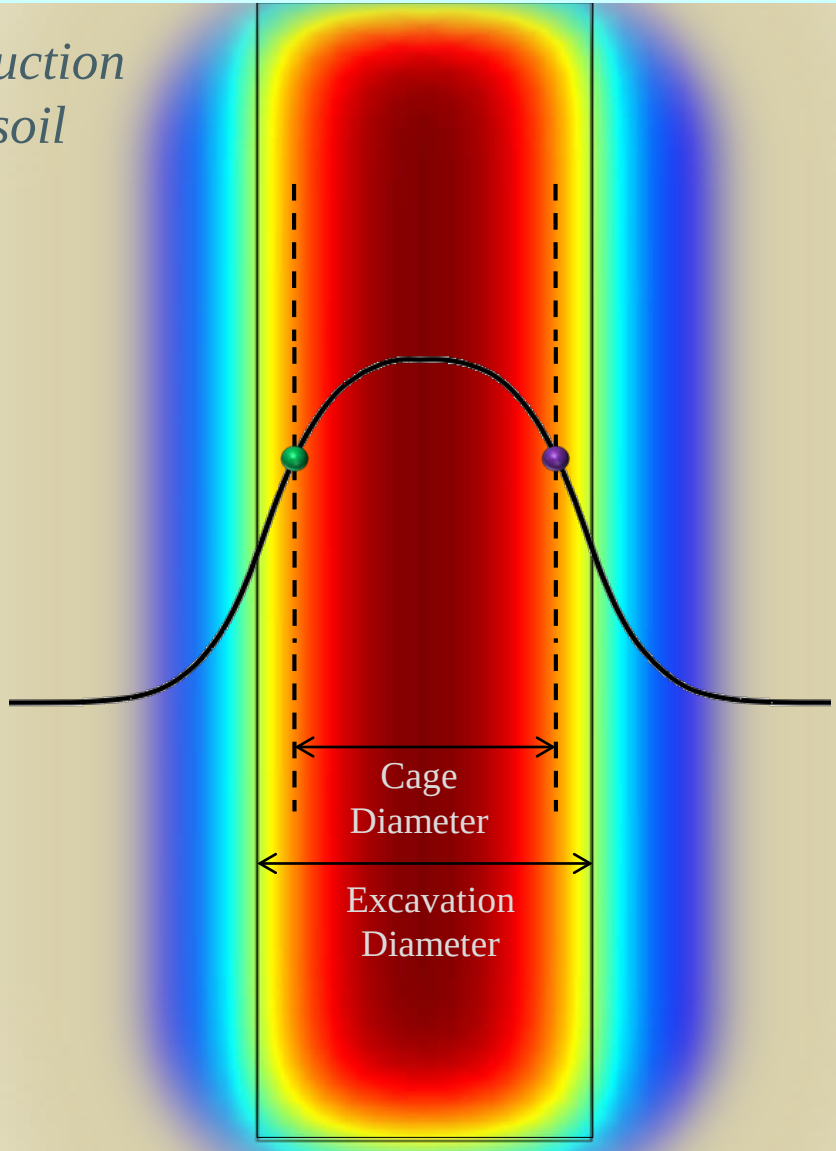
New version with internal strain relief

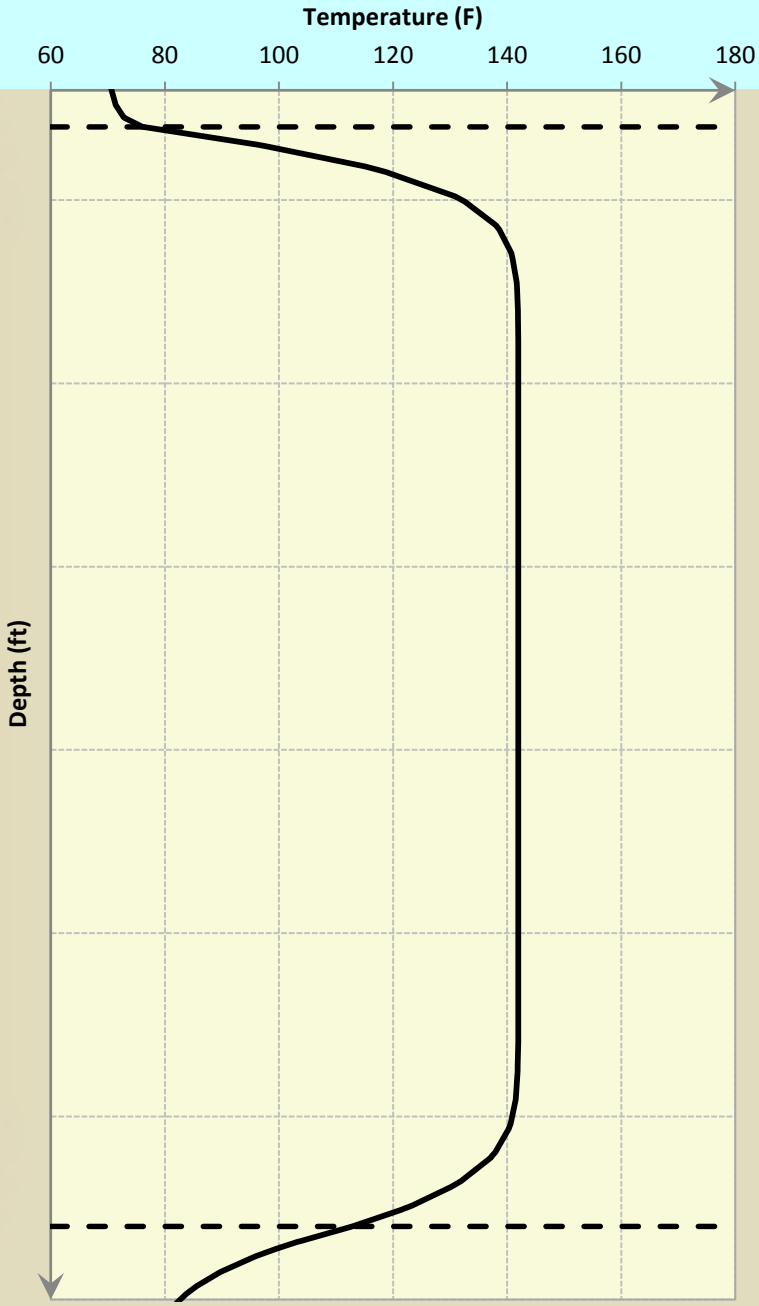
Current version with no strain relief



Convection to air

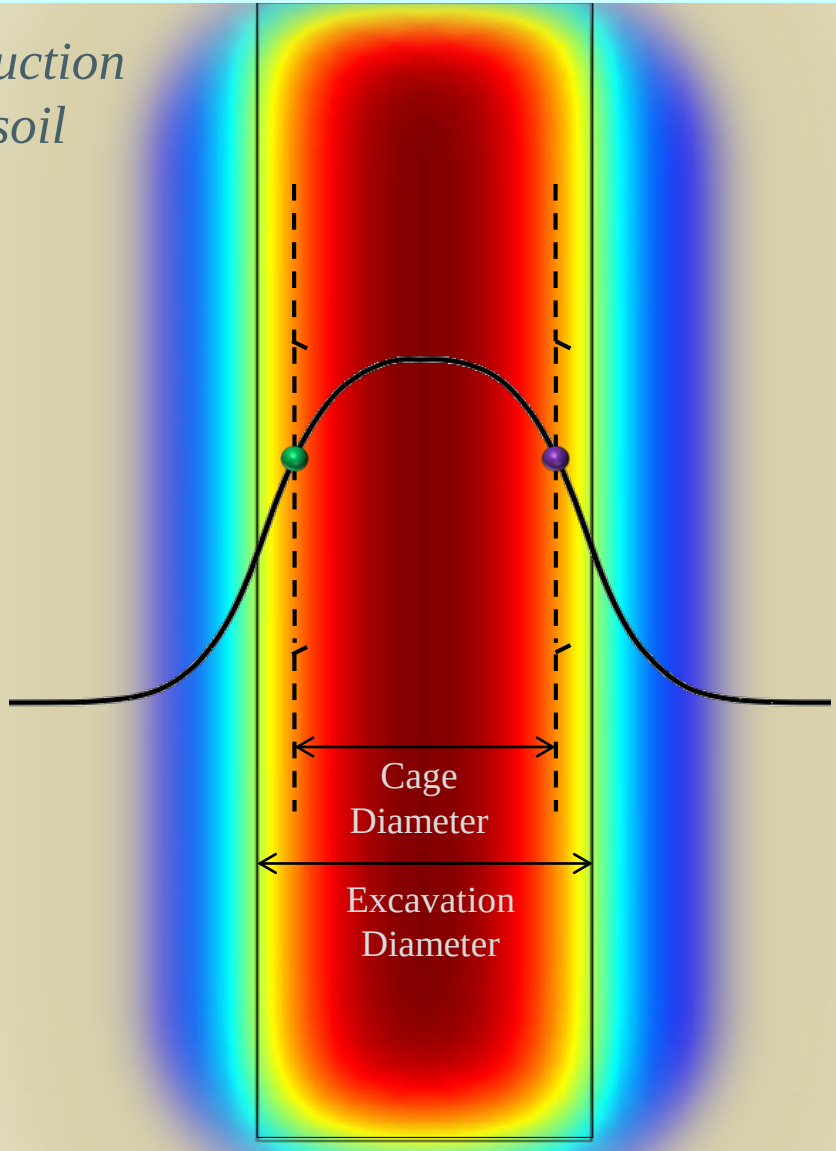
Conduction to soil

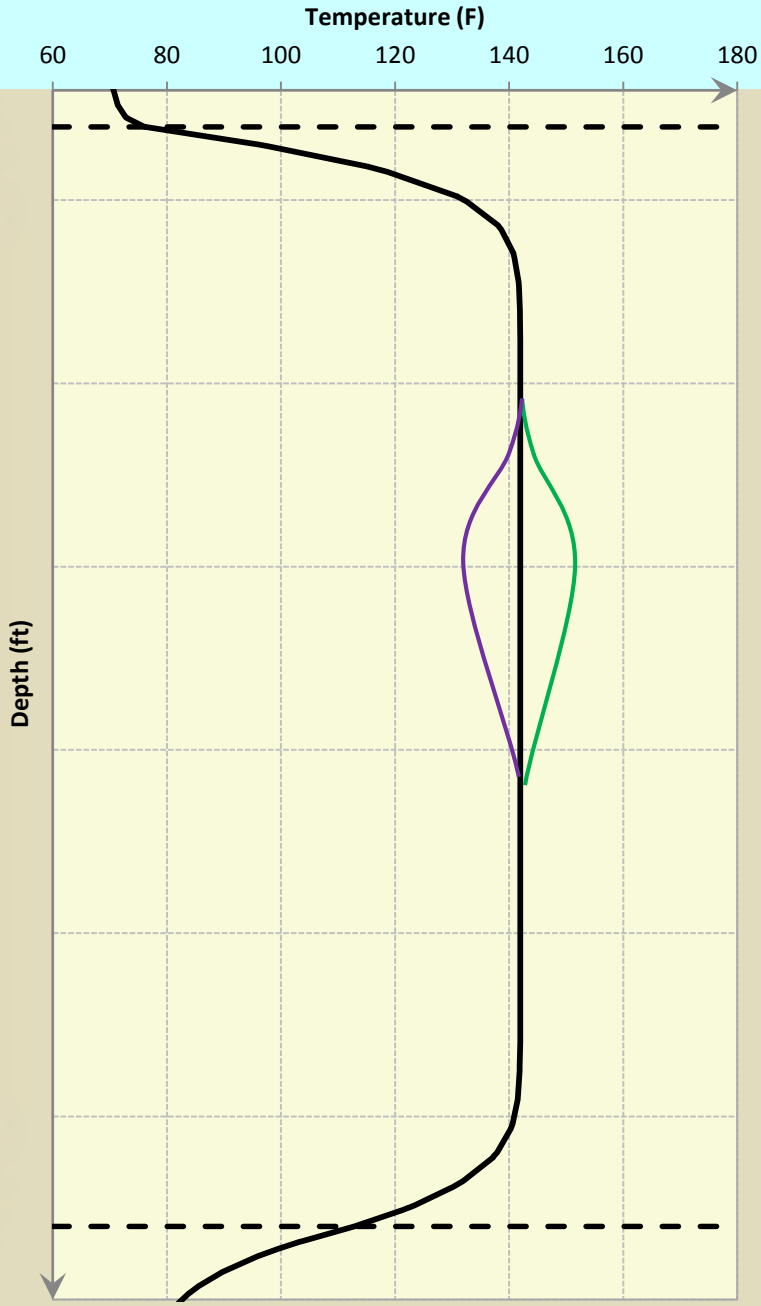


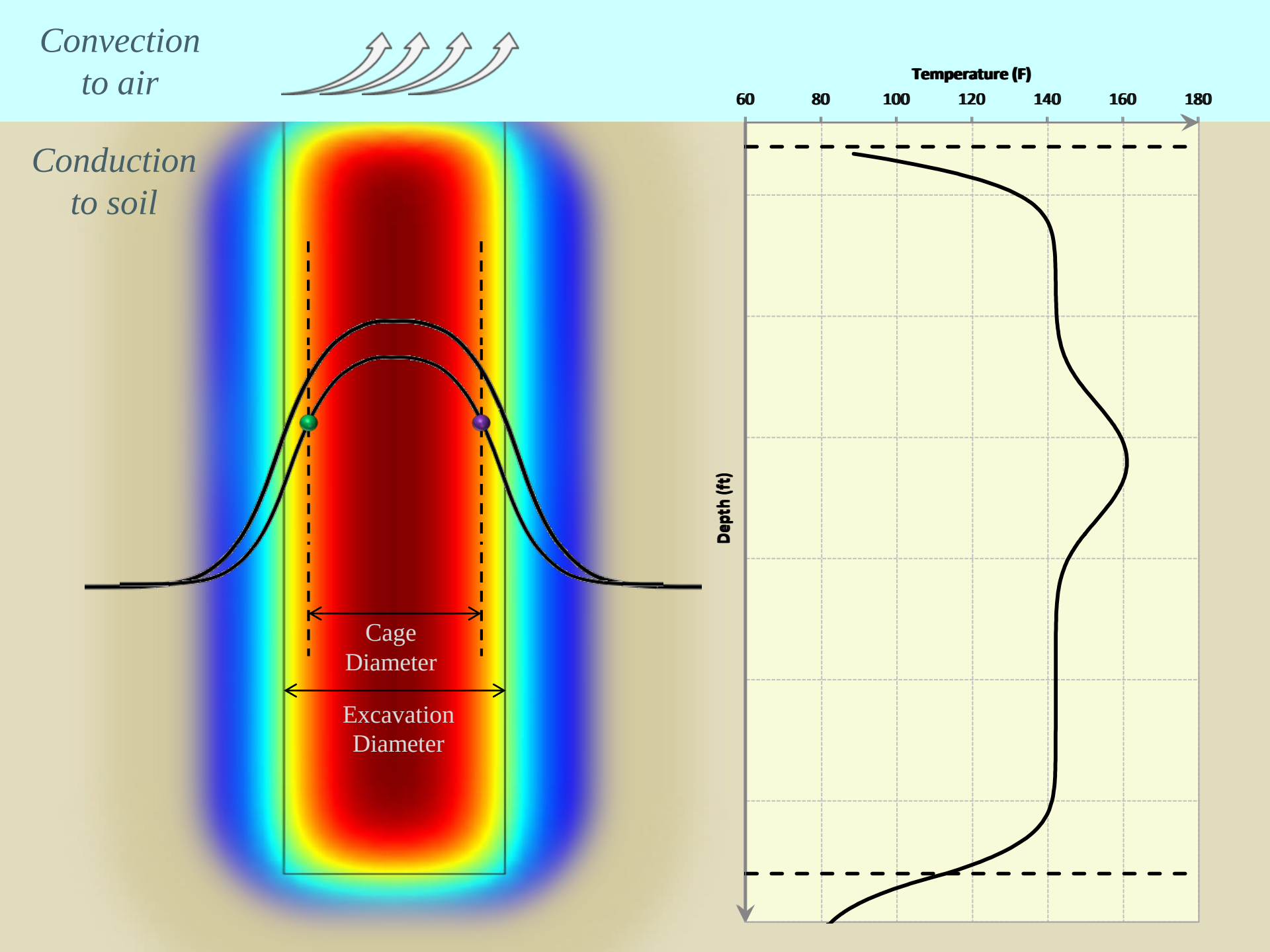


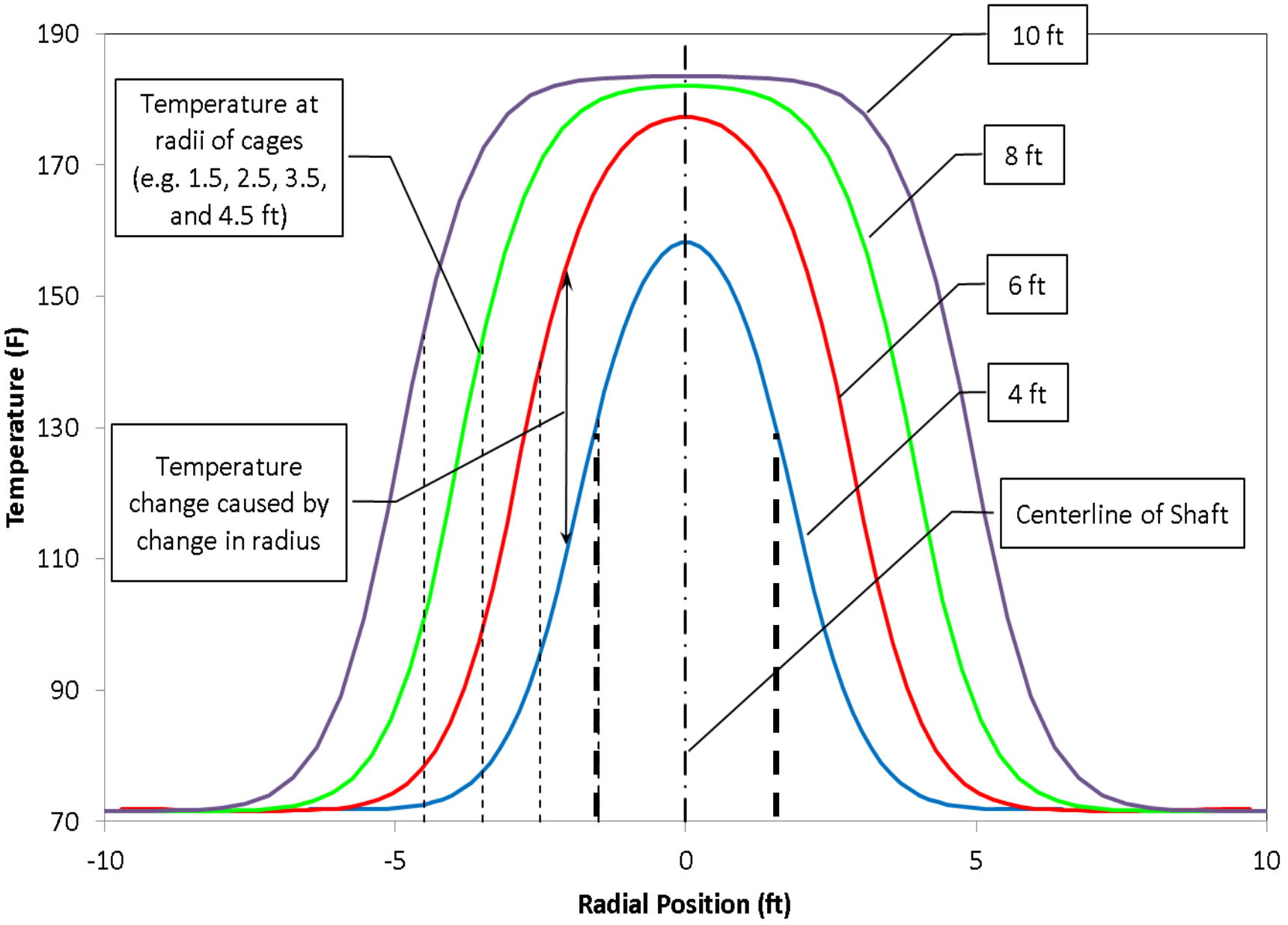
Convection to air

Conduction to soil

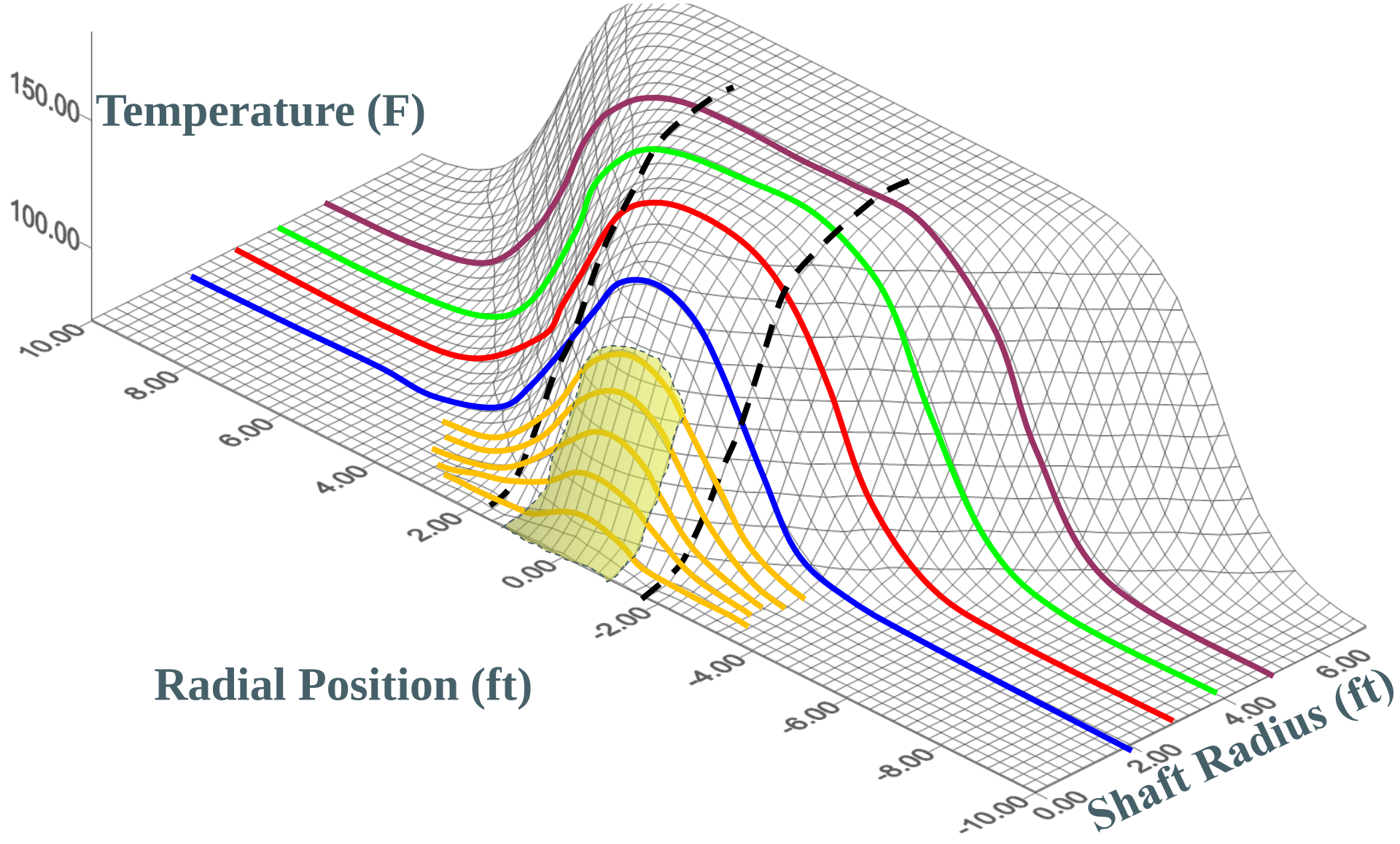





Convection
to air
Conduction
to soil
Cage
Diameter
Excavation
Diameter
Temperature (F)
60
80
100
120
140
160
180
Depth (ft)


190
170
150
130
110
90
70
Temperature (F)
-10
-5
0
5
10
Radial Position (ft)
10 ft
8 ft
6 ft
4 ft
Centerline of Shaft
Temperature at radii of cages (e.g. 1.5, 2.5, 3.5, and 4.5 ft)
Temperature change caused by change in radius

Effects of Alignment and Shaft Radius



TIP Analysis – Concepts

- Integrity of a shaft can be affected by
  - reduced cross section,
  - cage offset resulting in decreased cover, and
  - inclusions of compromised or poor quality concrete,
  - all affect the heat production and temp of the shaft.

- Effective Radius – *the radius of intact, uniform quality concrete that would produce the measured temperature.*

- $Temperature \propto Effective\ Radius$

TIP Analysis

Suggested Methods & Levels of Analyzing TIP Data

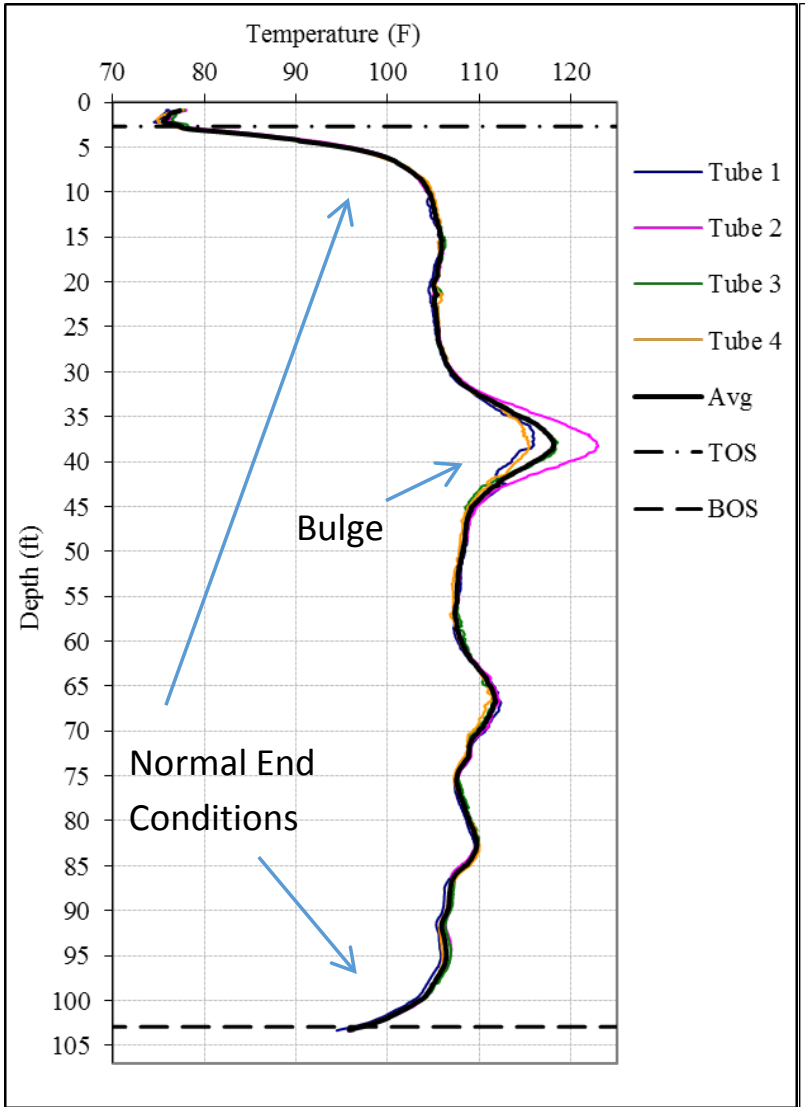
Level 1: Direct observation of the temperature profiles.

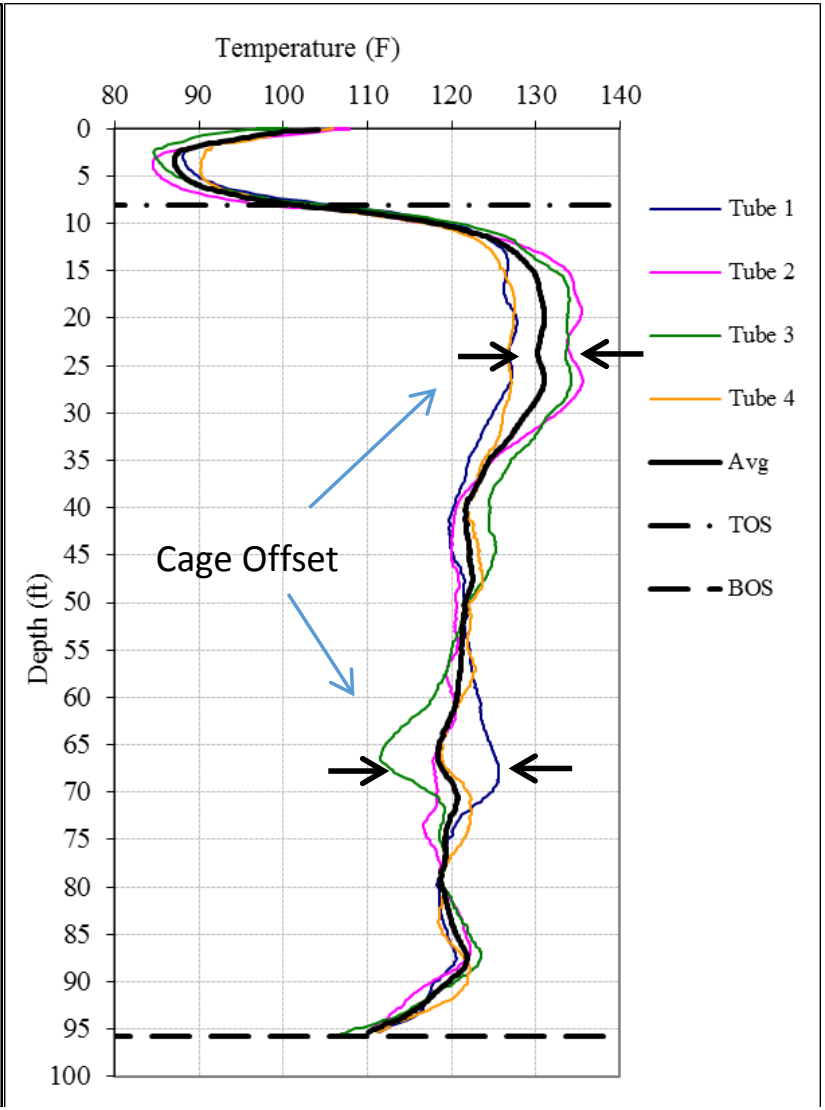
Level 2: Superimposed construction logs and concrete yield data. MOST COMMON

Level 3: Three dimensional thermal modeling.

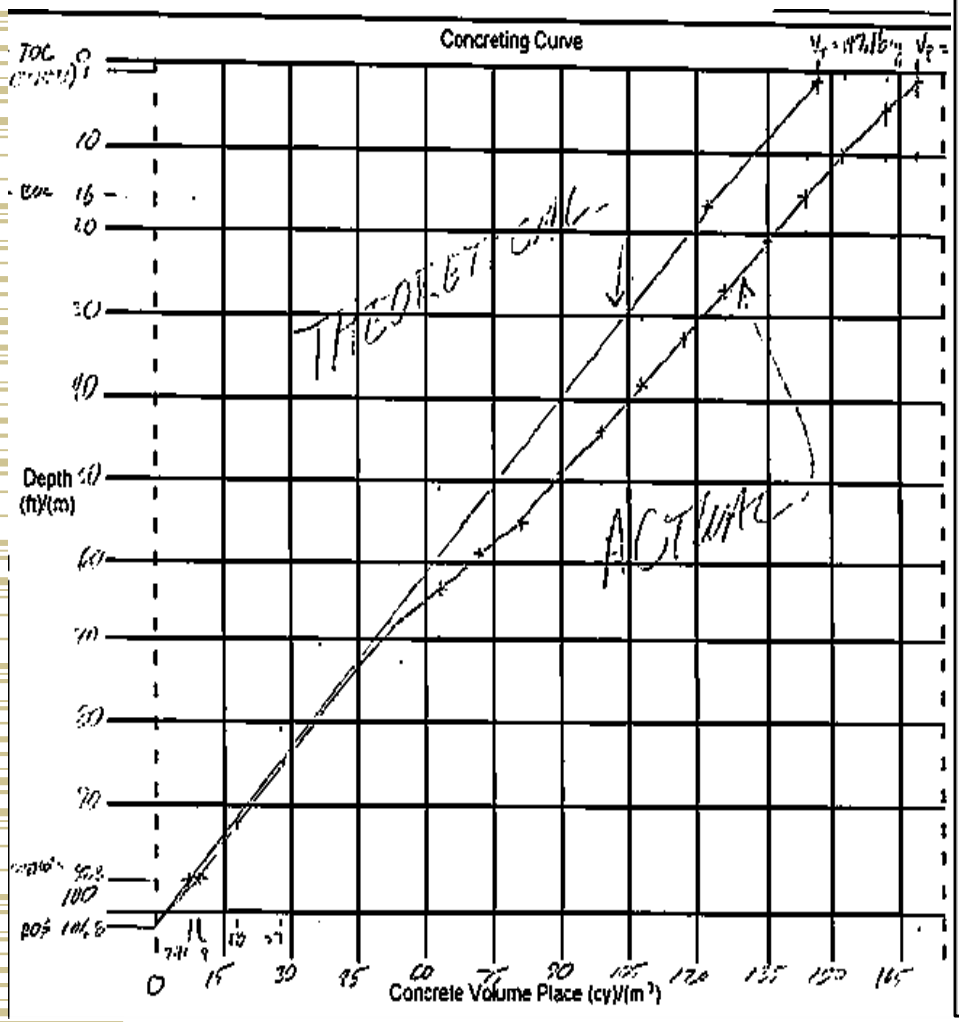
Level 4: Signal matching numerical models to field data.

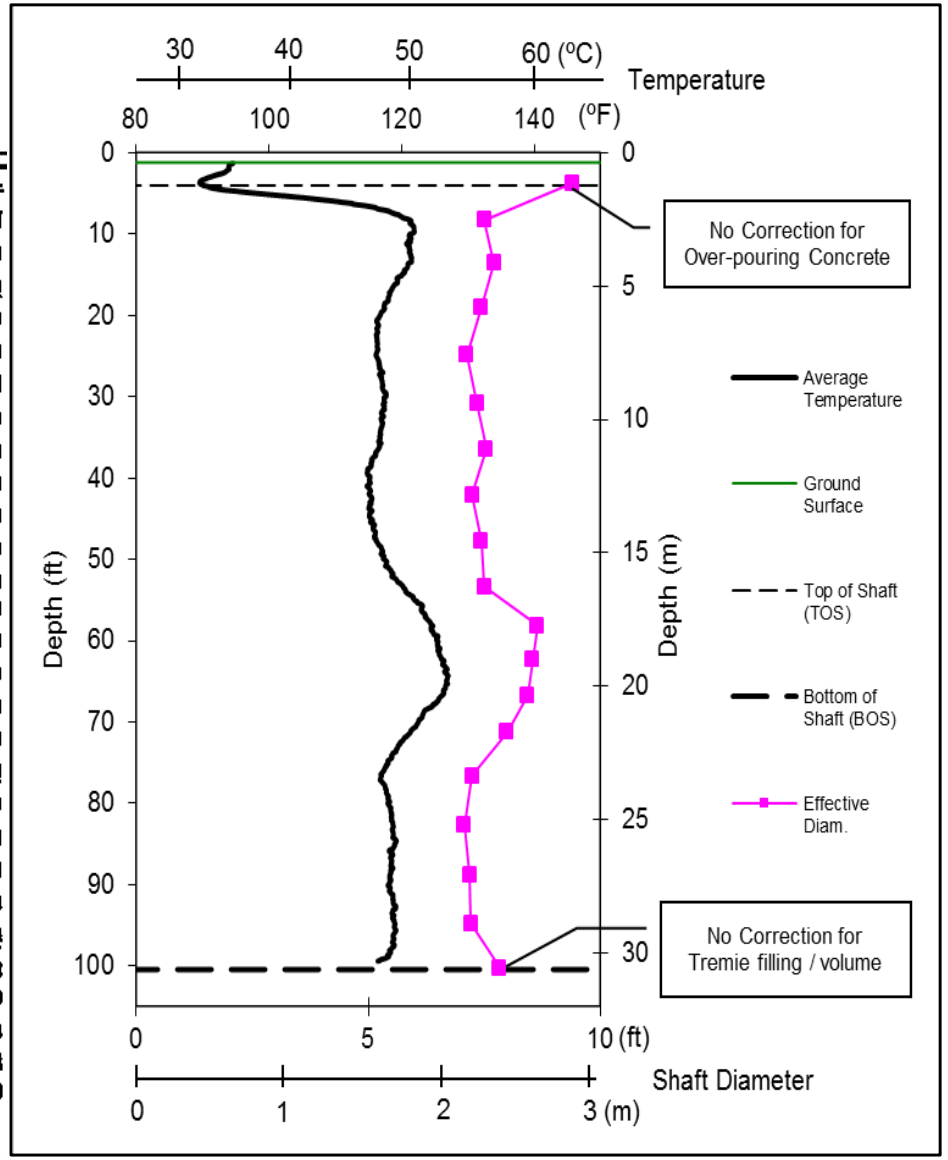
TIP Analysis - Direct Observation





TIP Analysis - Superimposed Construction Logs & Concrete Yield Data





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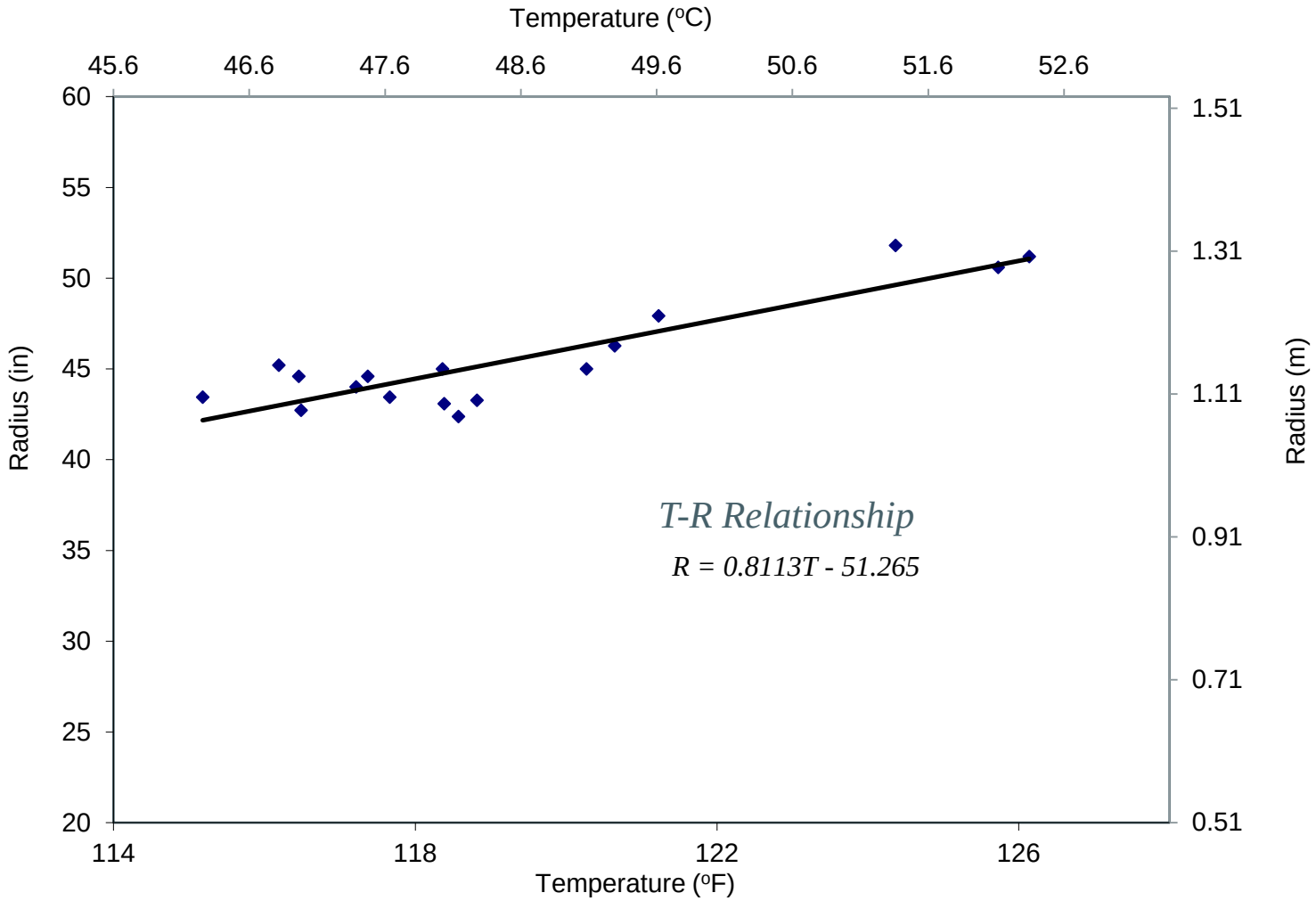
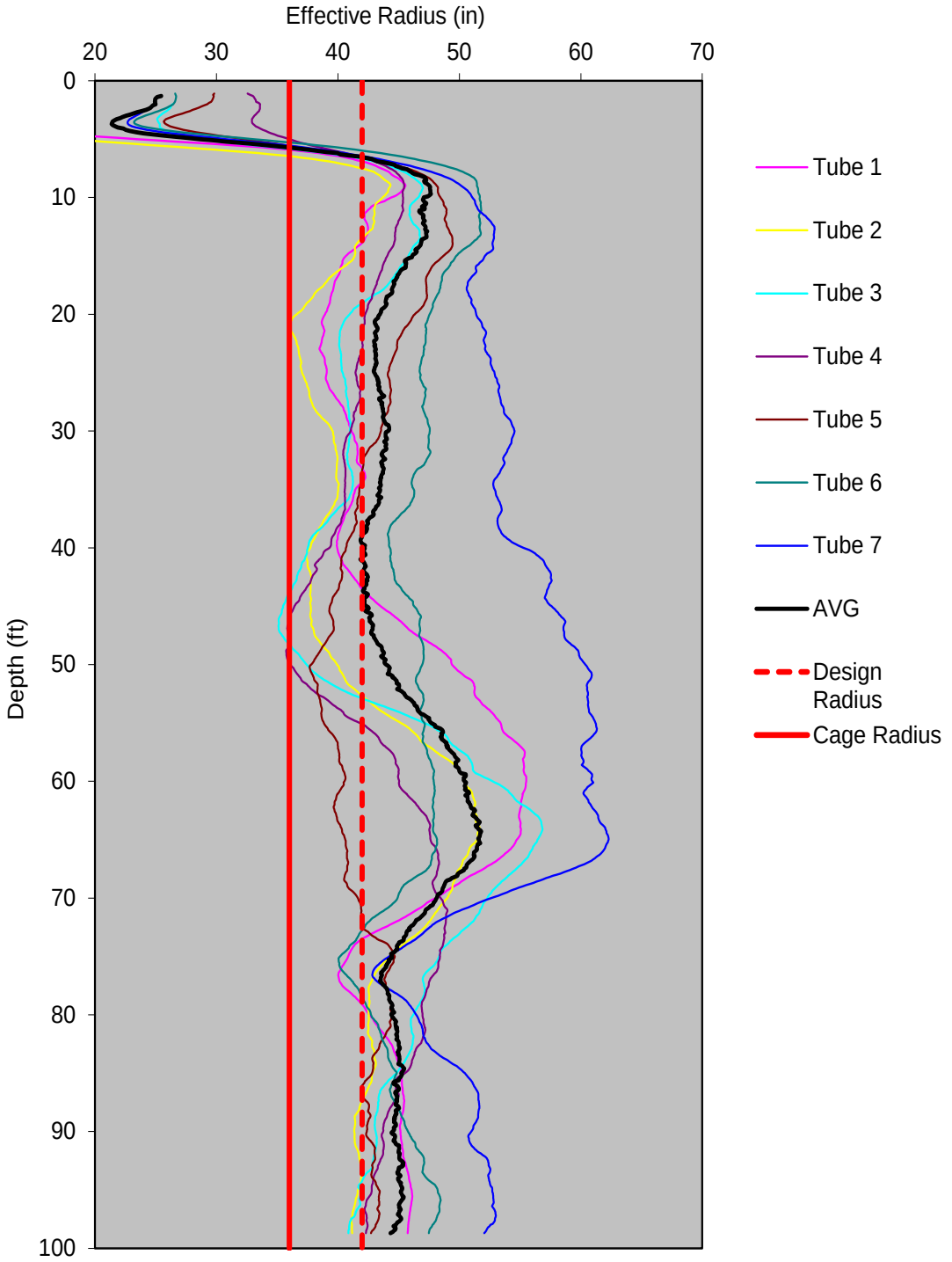


TIP Analysis – Convert Temp to Radius

Average Looks Good (black)

Individual tubes show cage is touching side wall.



Corrections for End Effects

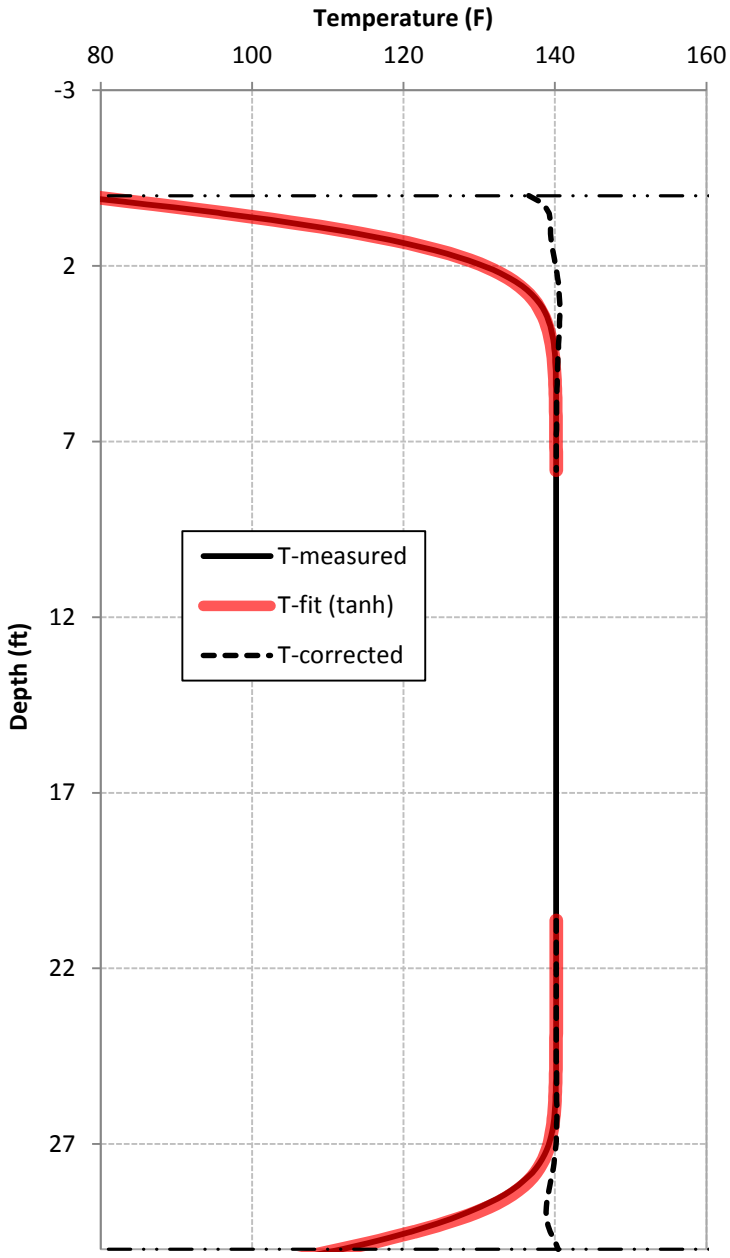
Inverse Hyperbolic Tangent

$$T_{fit} = \pm\left(\frac{T_{max} - T_{min}}{2}\right)\tanh\left(\frac{z - z_0}{\alpha}\right) + T_0$$

$T_{max} = Maximum\ asymptotic\ temperature$
$T_{min} = Minimum\ asymptotic\ temperature$
$T_0 = Inflection\ point\ temperature\ = (T_{max} + T_{min})/2$
$z_0 = Inflection\ point\ depth$
$\alpha = Time\ diffusion\ factor$

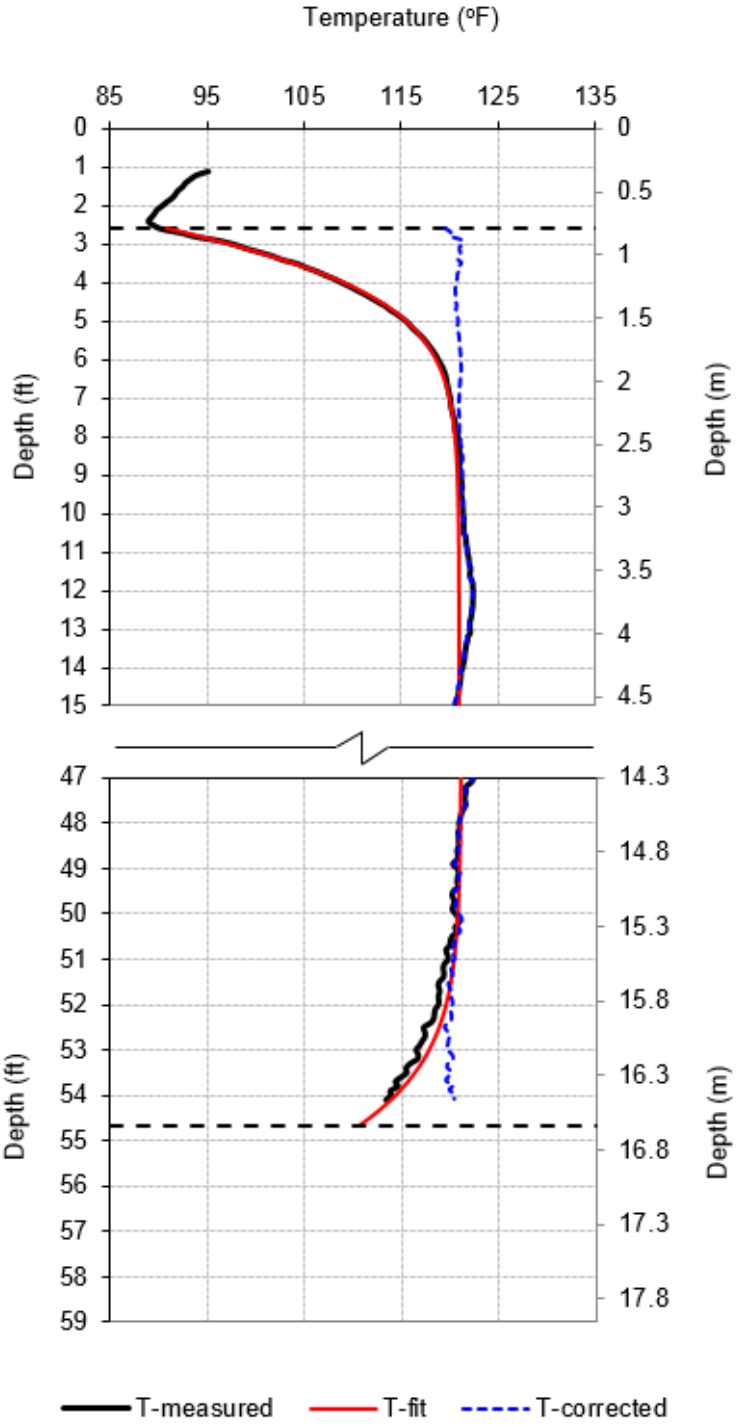
$$T_{cor} = \left(T_{meas} - T_{fit}\right)\left(\frac{T_{norm}}{T_{fit}}\right) + T_{norm}$$

$T_{meas} = Measured\ temperature$
$T_{norm} = Normalized\ temperature$



	T.O.S.
Depth:	0.59 m (1.95 ft)
Alpha	2.30
T min:	3.89°C (39°F)
T max:	49.4°C (121°F)

	B.O.S.
Depth:	17.15 m (56.28 ft)
Alpha	2.50
T min:	22.8°C (73°F)
T max:	49.4°C (121°F)



Research Approach

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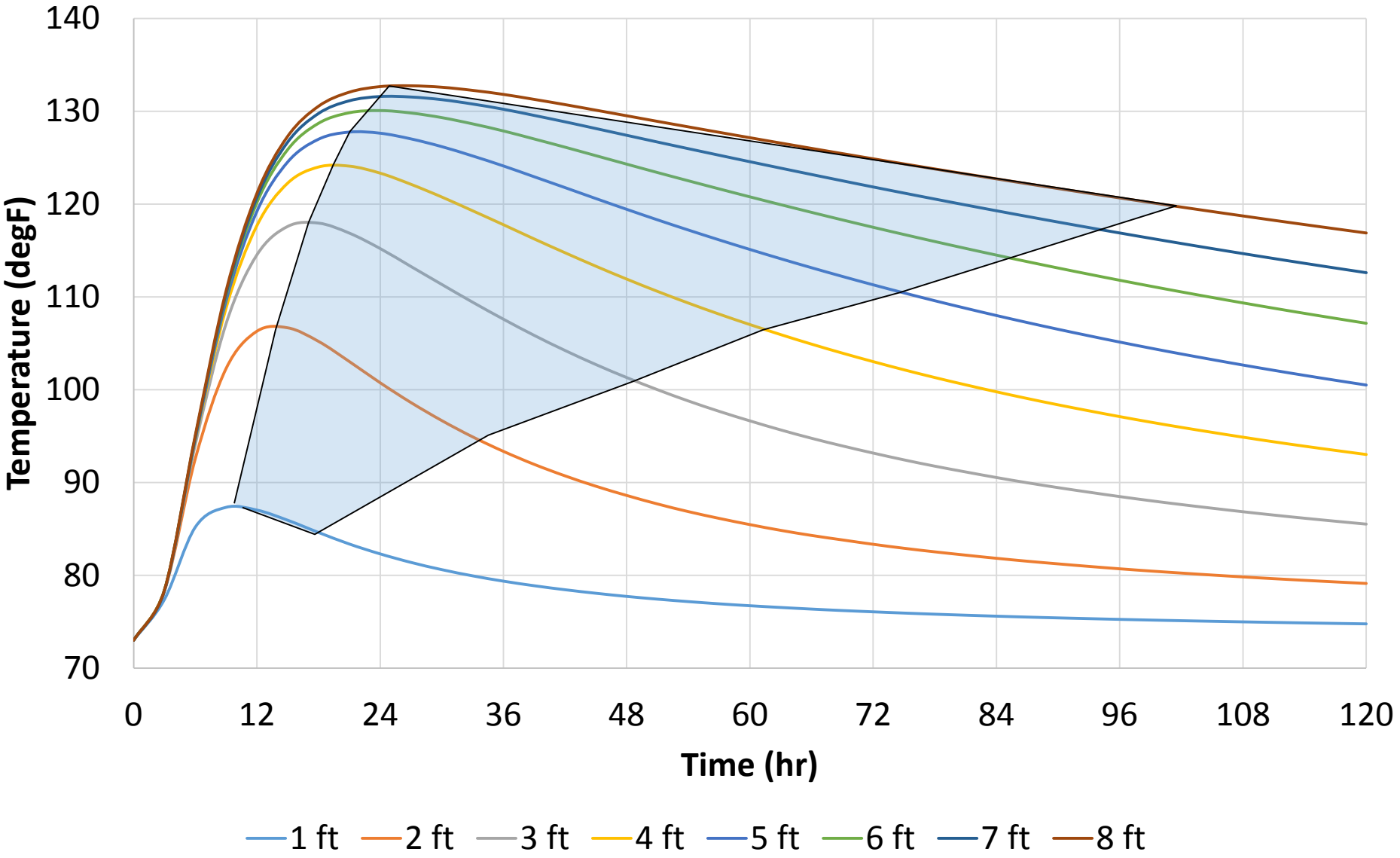
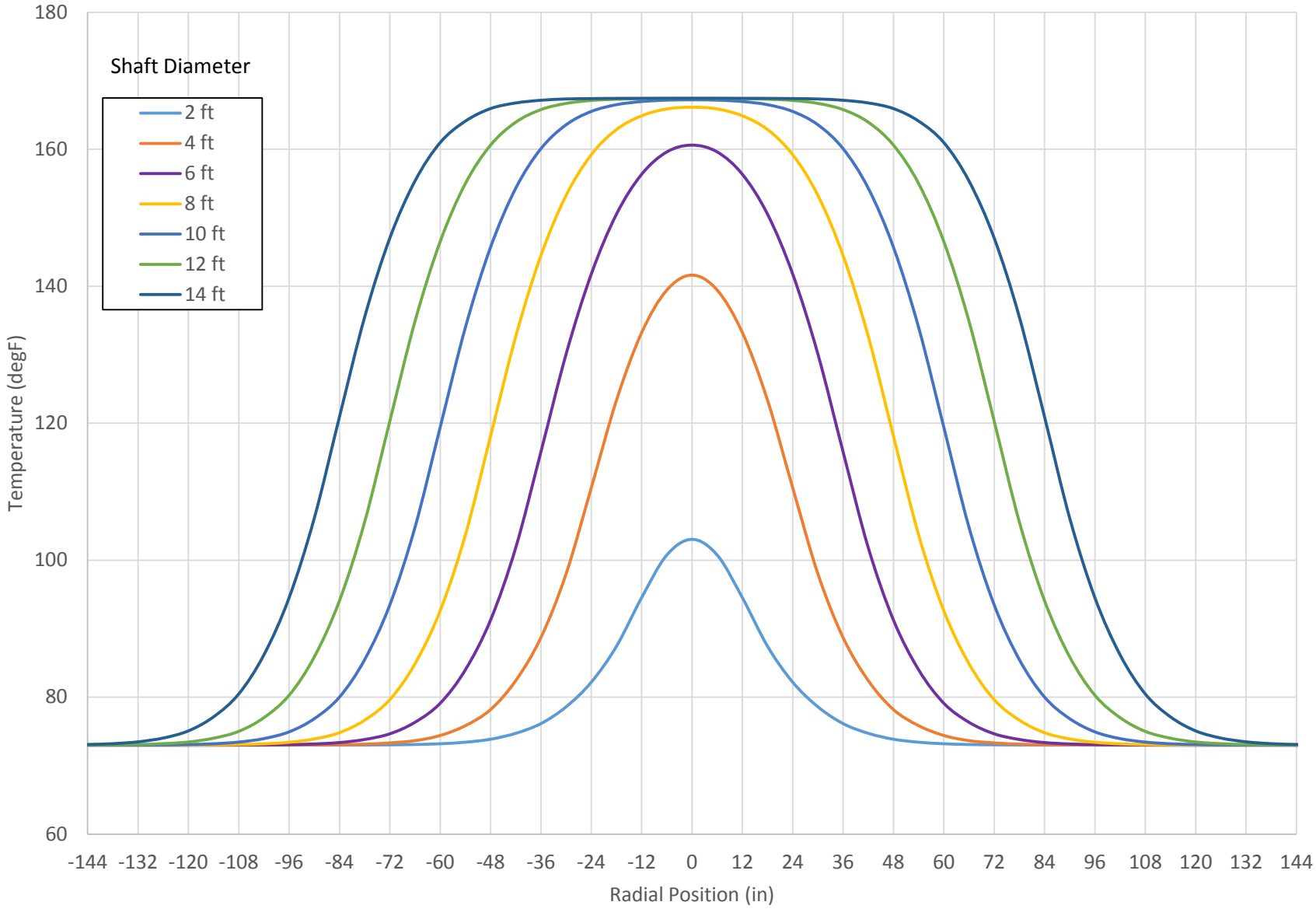
What we learn from models

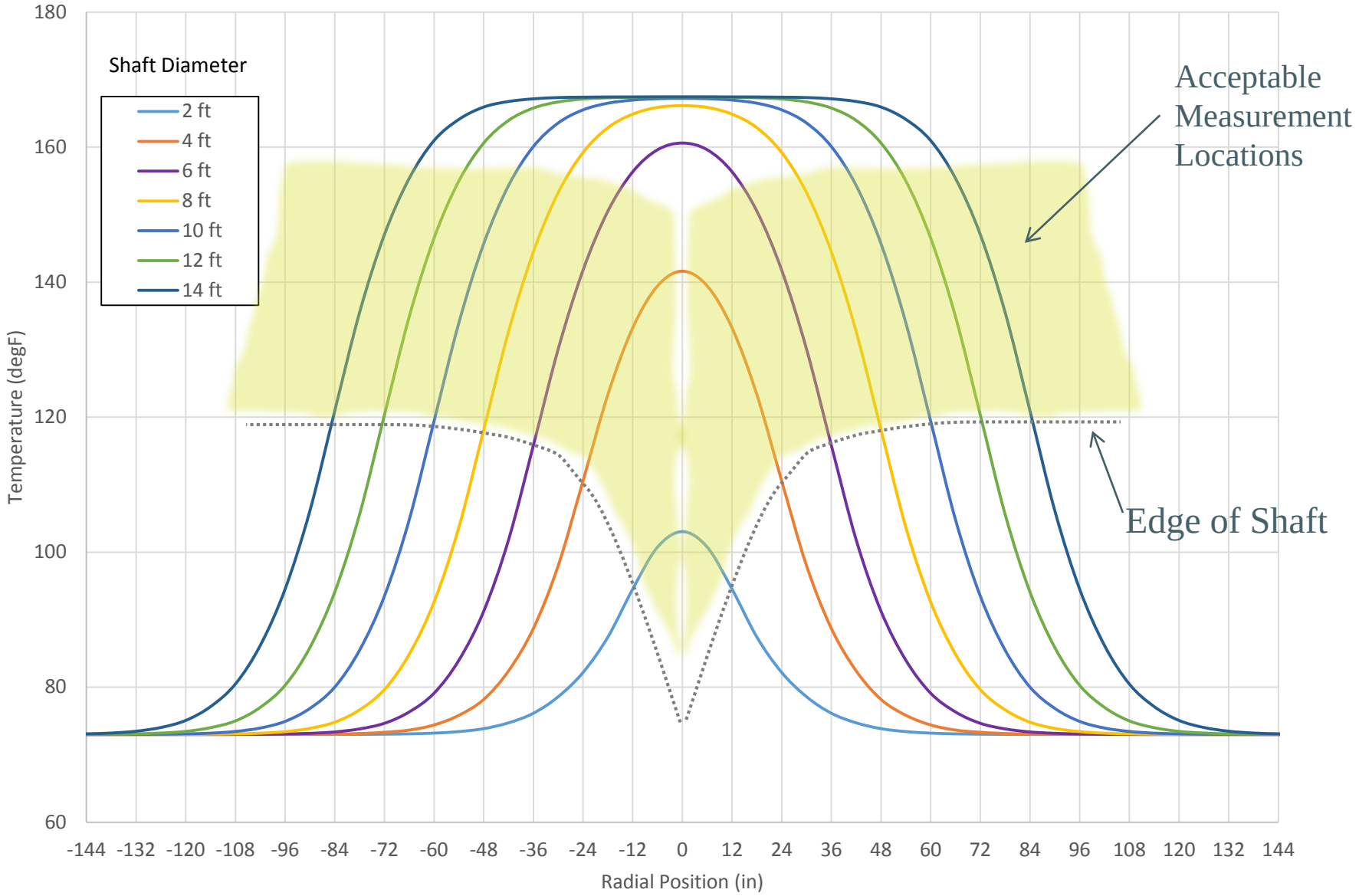
- Range of times for analysis/testing
- Best locations for placing sensors/tubes
- Minimum number of tubes/wire
- Size of anomaly that is detected with minimal sensors/tubes
- Effects of drastic changes in external environment (above ground in water or air)

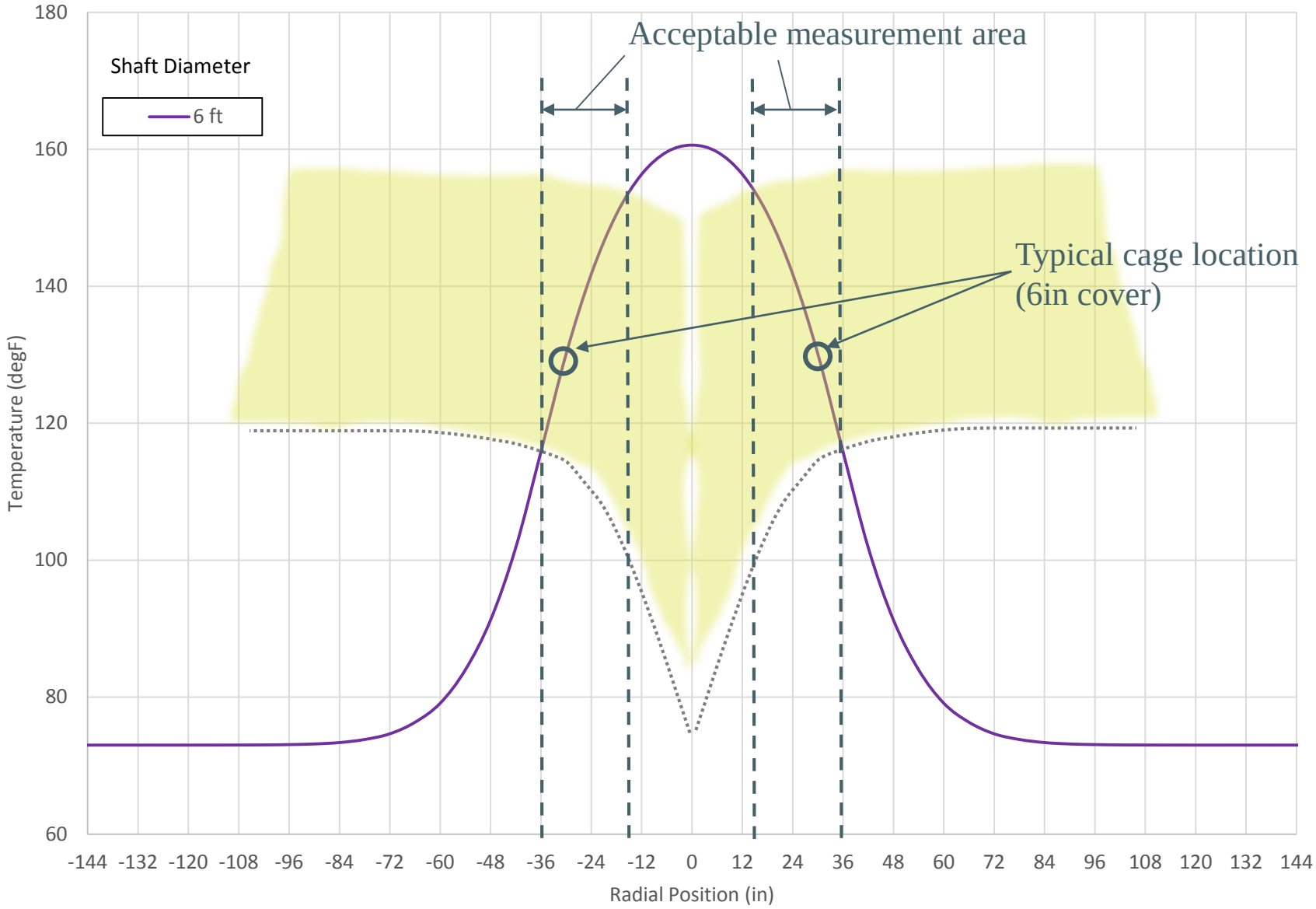
Best Times to Test/Analyze (small window for ACIP)

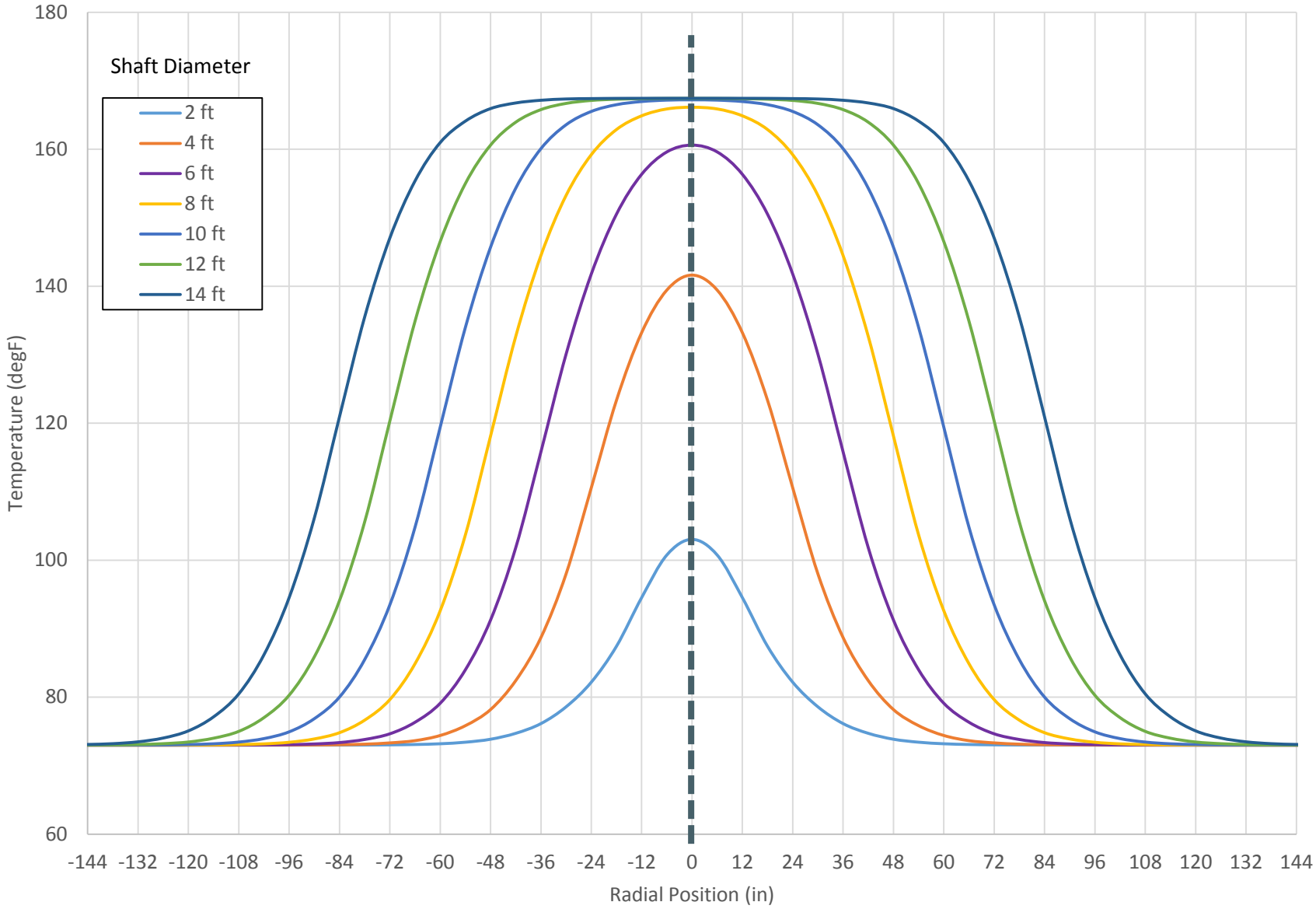


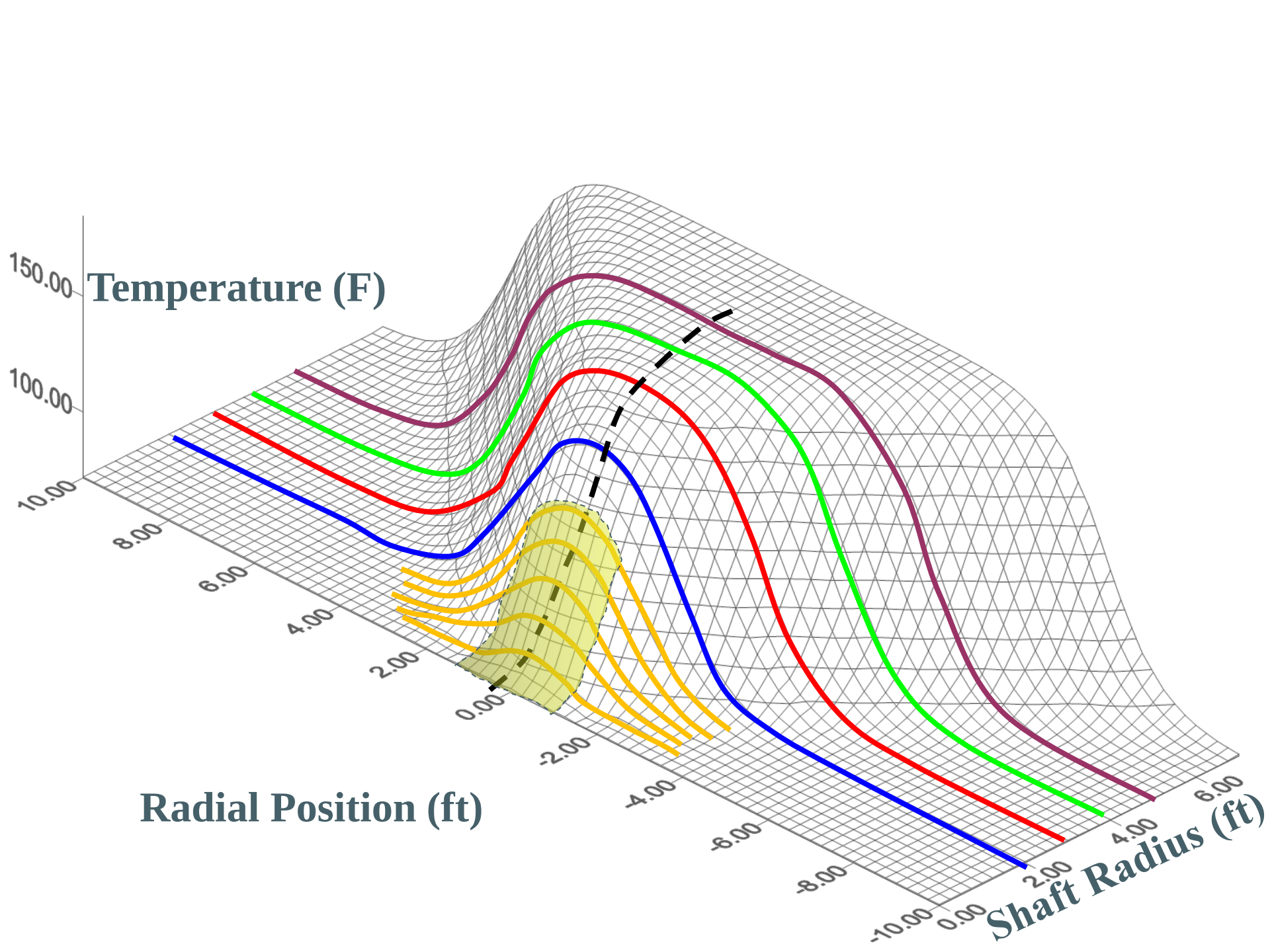
Best places to take measurements



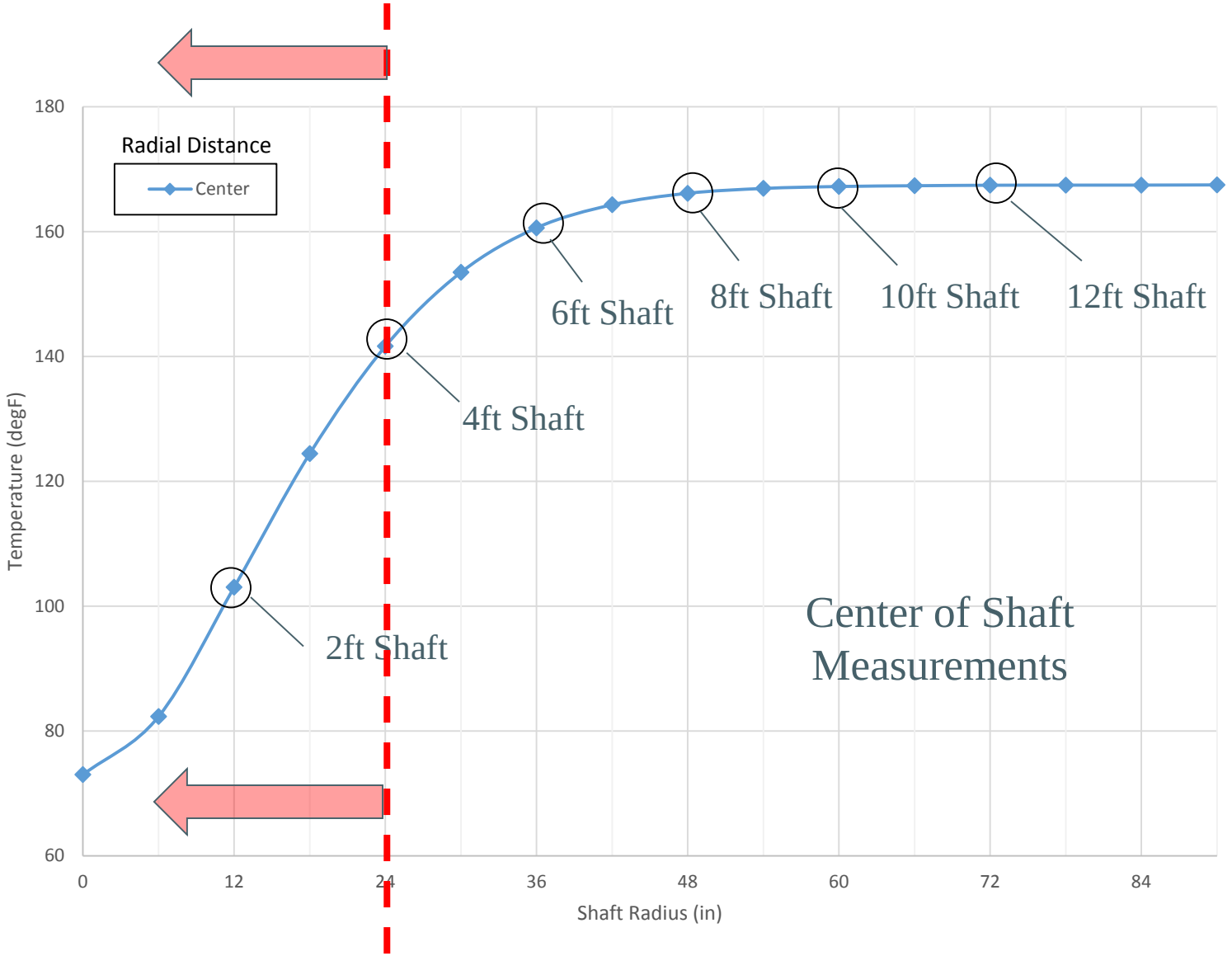

Shaft Diameter
2 ft
4 ft
6 ft
8 ft
10 ft
12 ft
14 ft
Acceptable Measurement Locations
Edge of Shaft
Temperature (degF)
180
160
140
120
100
80
60
-144 -132 -120 -108 -96 -84 -72 -60 -48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108 120 132 144
Radial Position (in)


Acceptable measurement area
Typical cage location
(6in cover)
Shaft Diameter
6 ft
Temperature (degF)
180
160
140
120
100
80
60
-144 -132 -120 -108 -96 -84 -72 -60 -48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108 120 132 144
Radial Position (in)

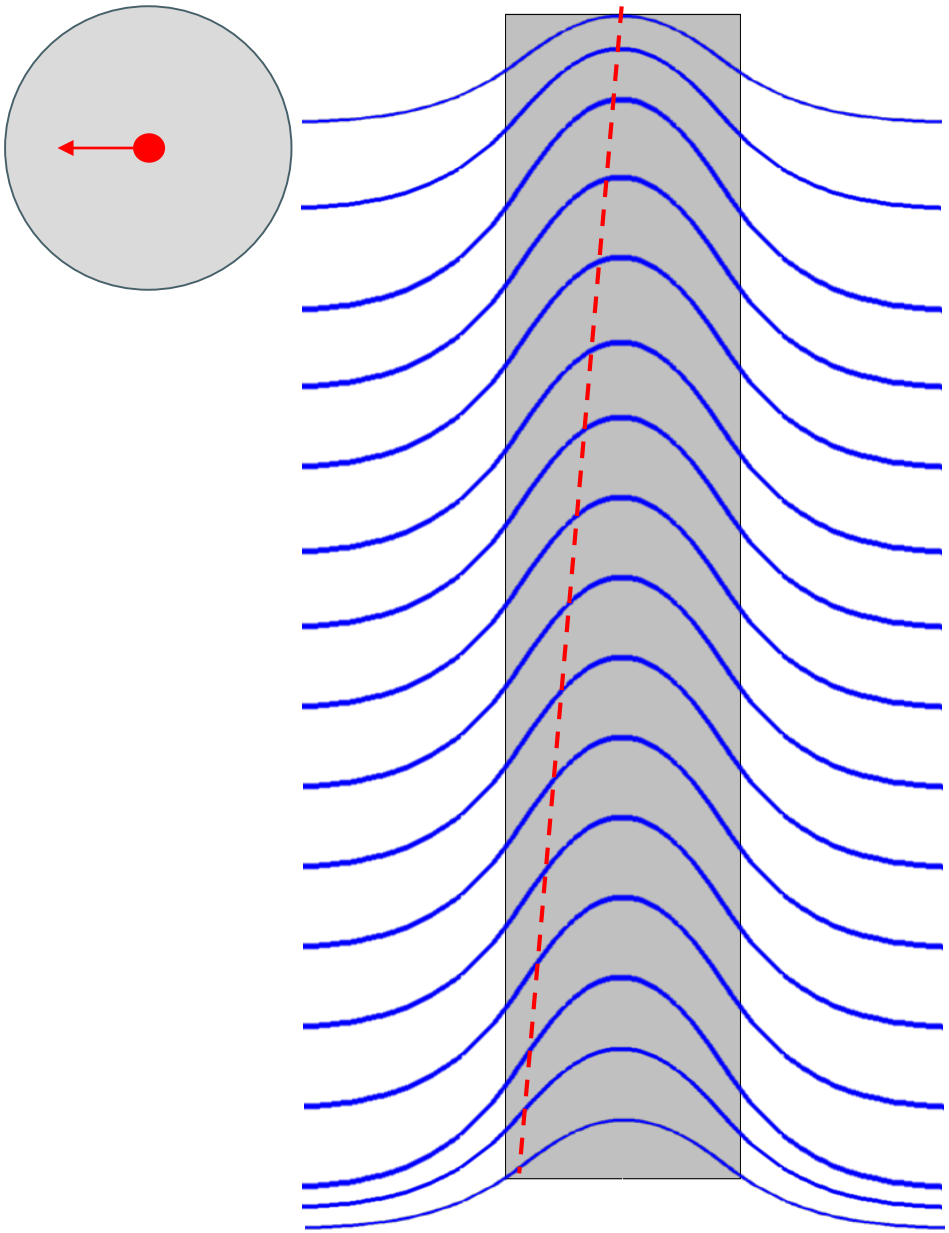

Shaft Diameter
2 ft
4 ft
6 ft
8 ft
10 ft
12 ft
14 ft
Temperature (degF)
180
160
140
120
100
80
60
-144 -132 -120 -108 -96 -84 -72 -60 -48 -36 -24 -12 0 12 24 36 48 60 72 84 96 108 120 132 144
Radial Position (in)

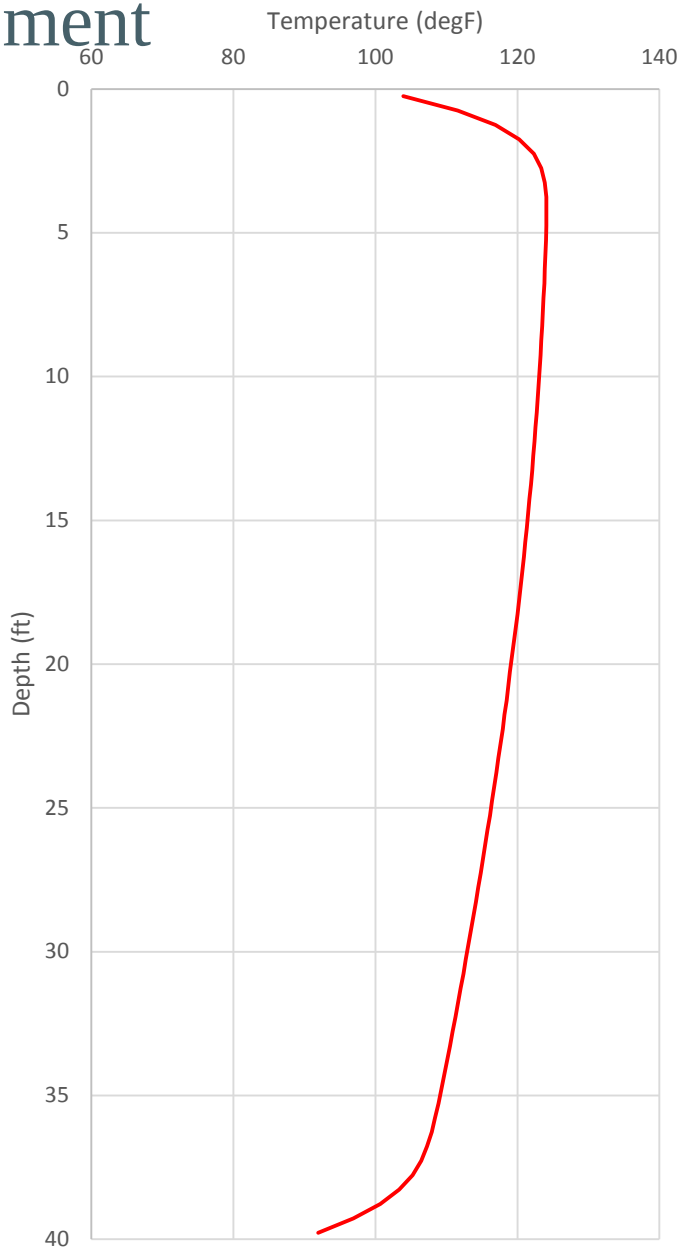

Temperature (F)
150.00
100.00
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
-4.00
-6.00
-8.00
-10.00
Radial Position (ft)
0.00
2.00
4.00
6.00
Shaft Radius (ft)

What's the best location for thermal measurements?

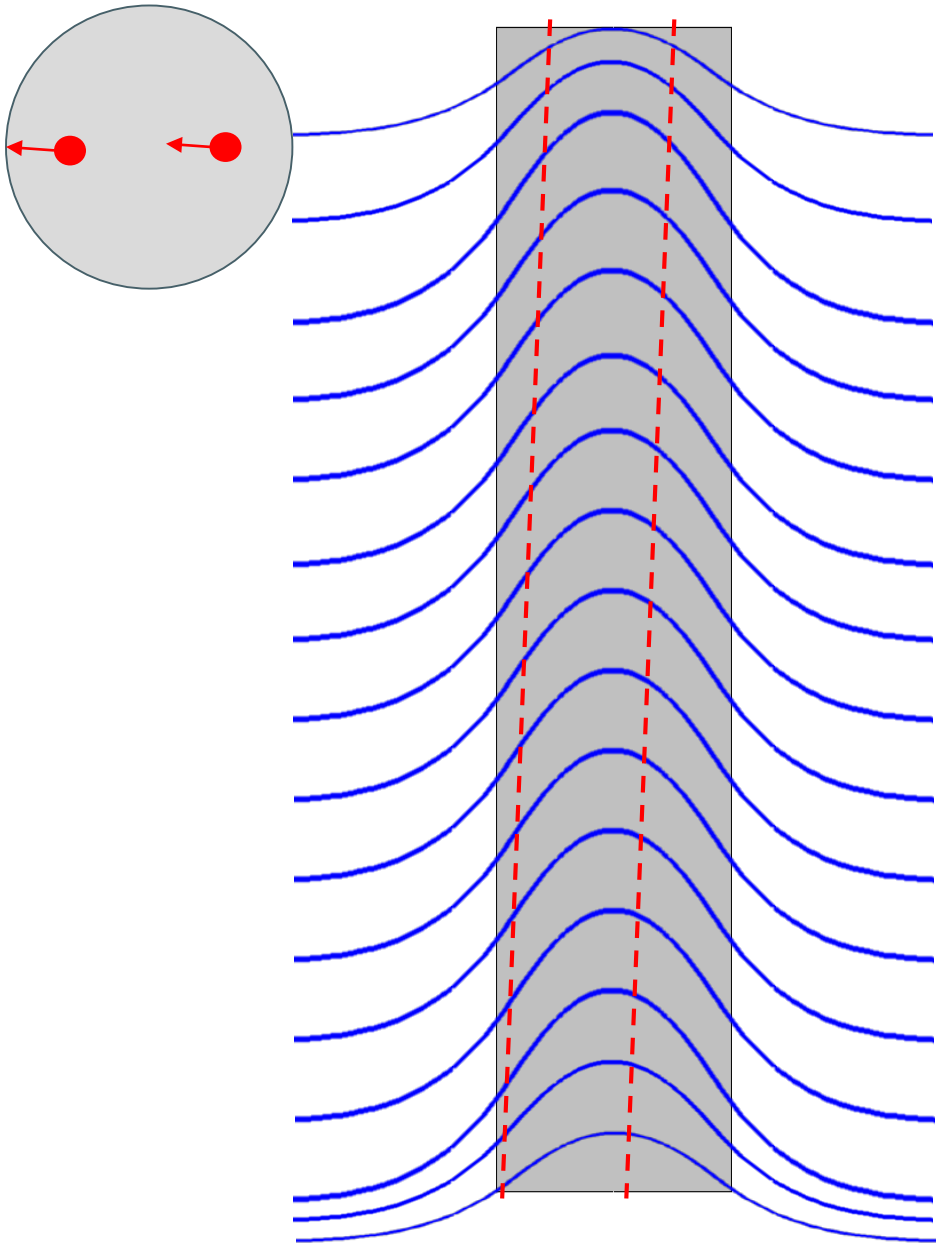


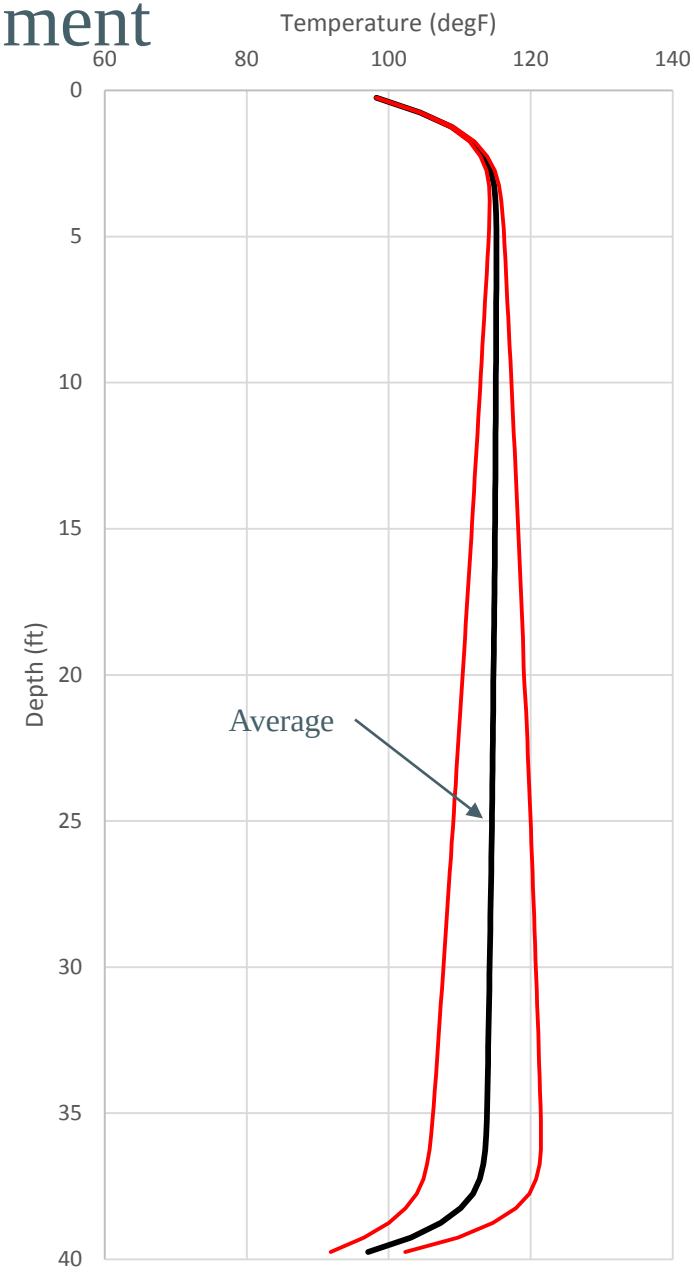
Number of Sensors
Effects of cage movement



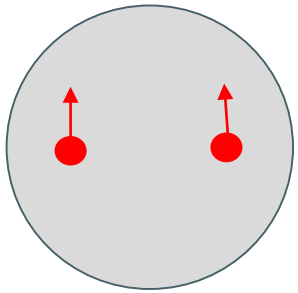


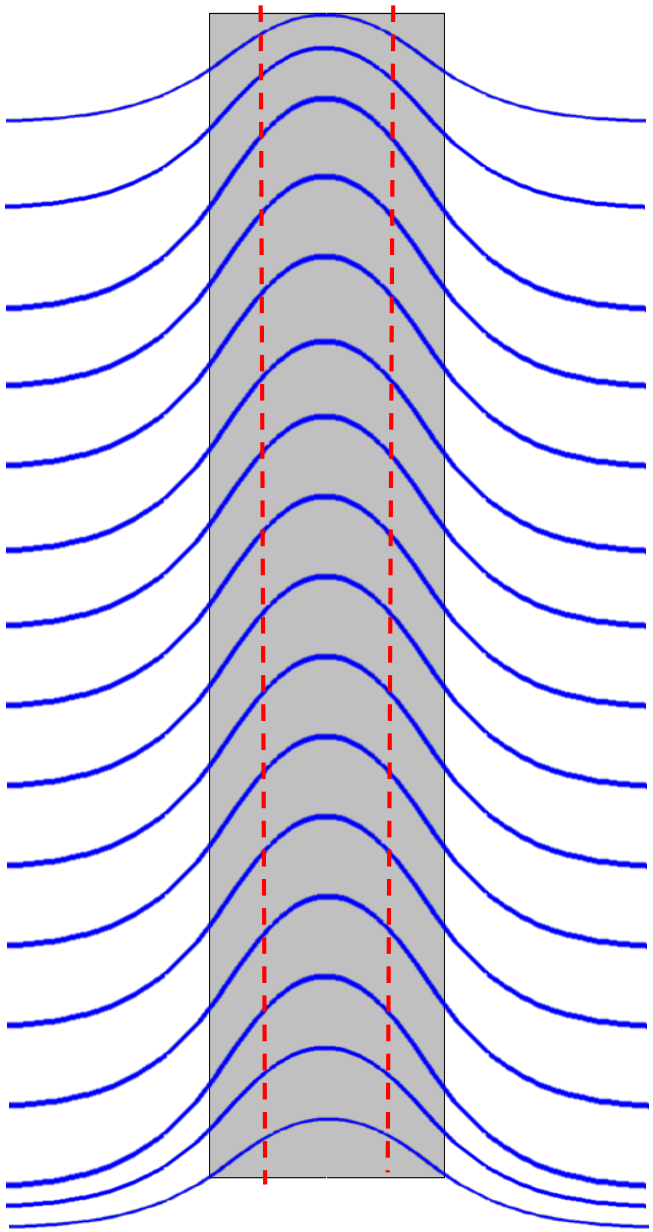
Number of Sensors
Effects of cage movement

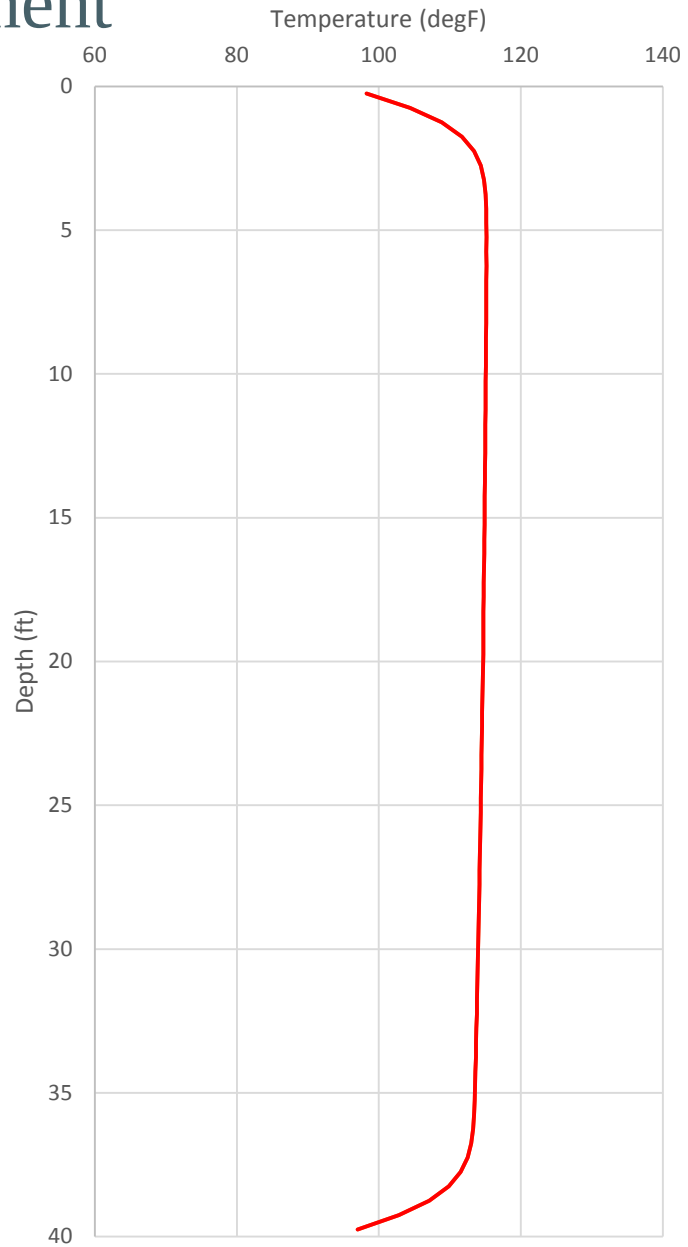




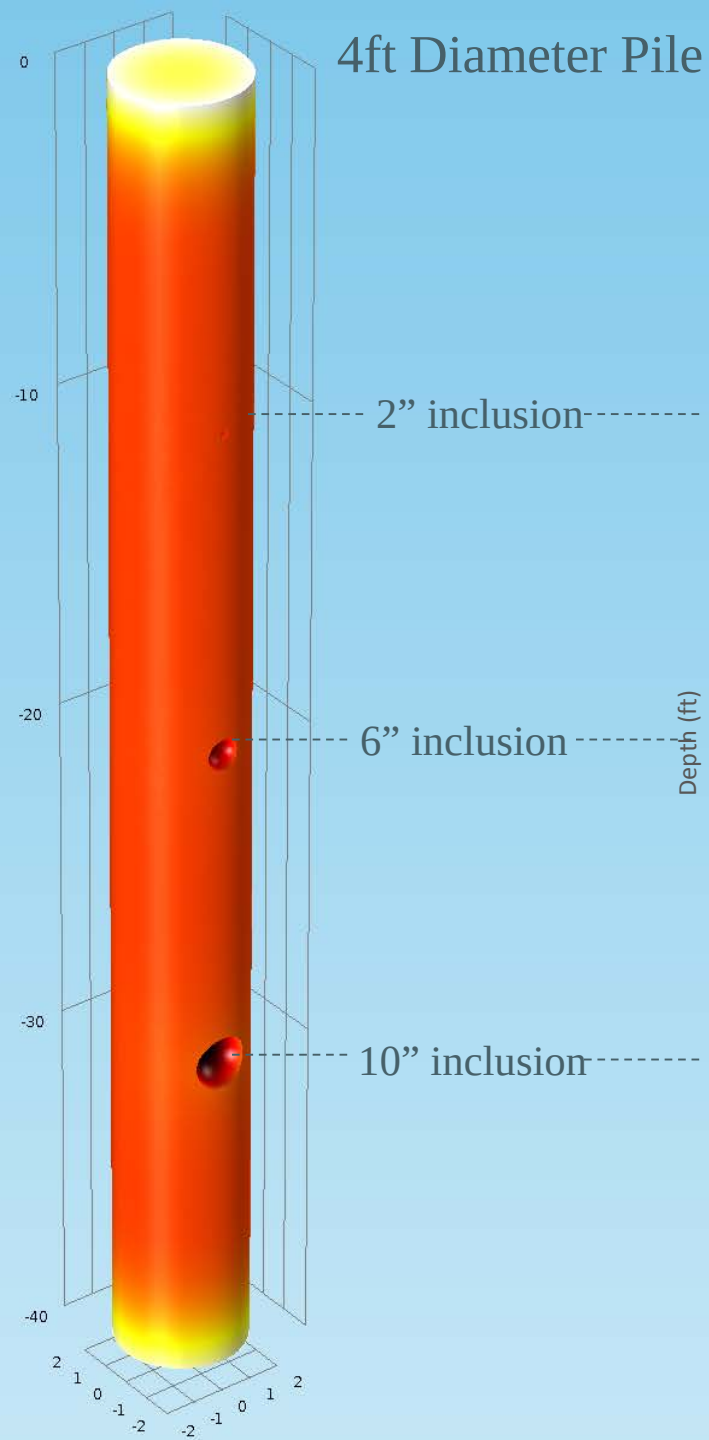
Number of Sensors
Effects of cage movement

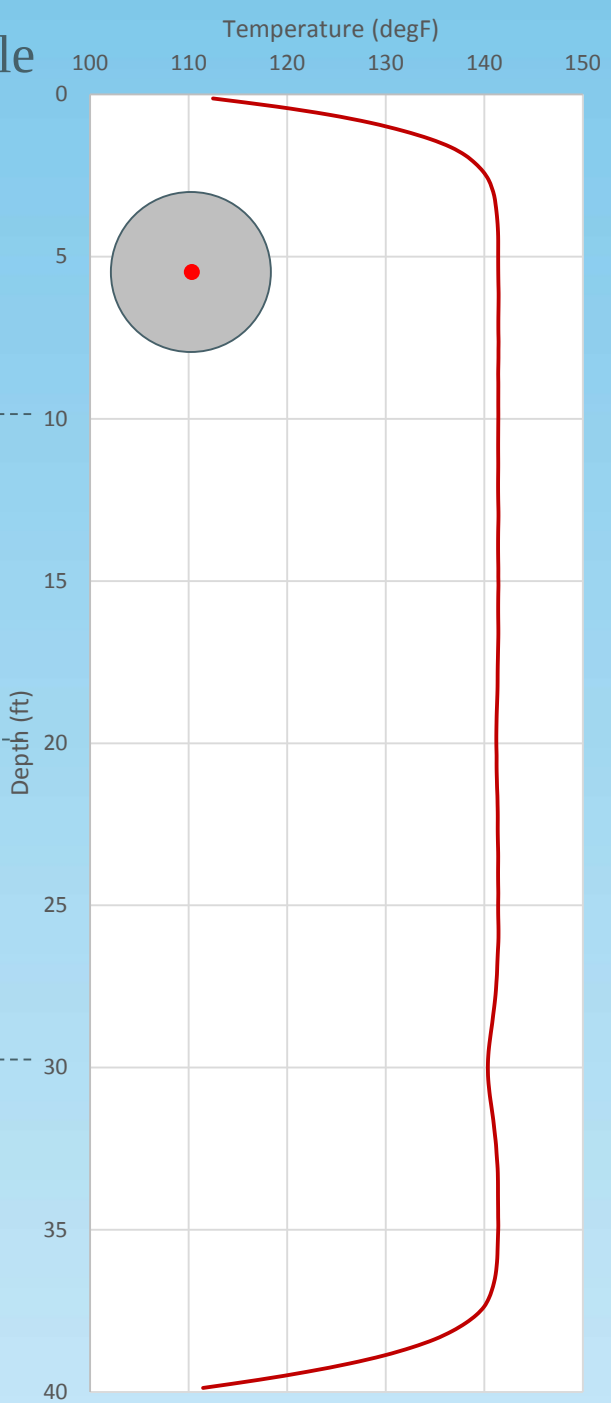


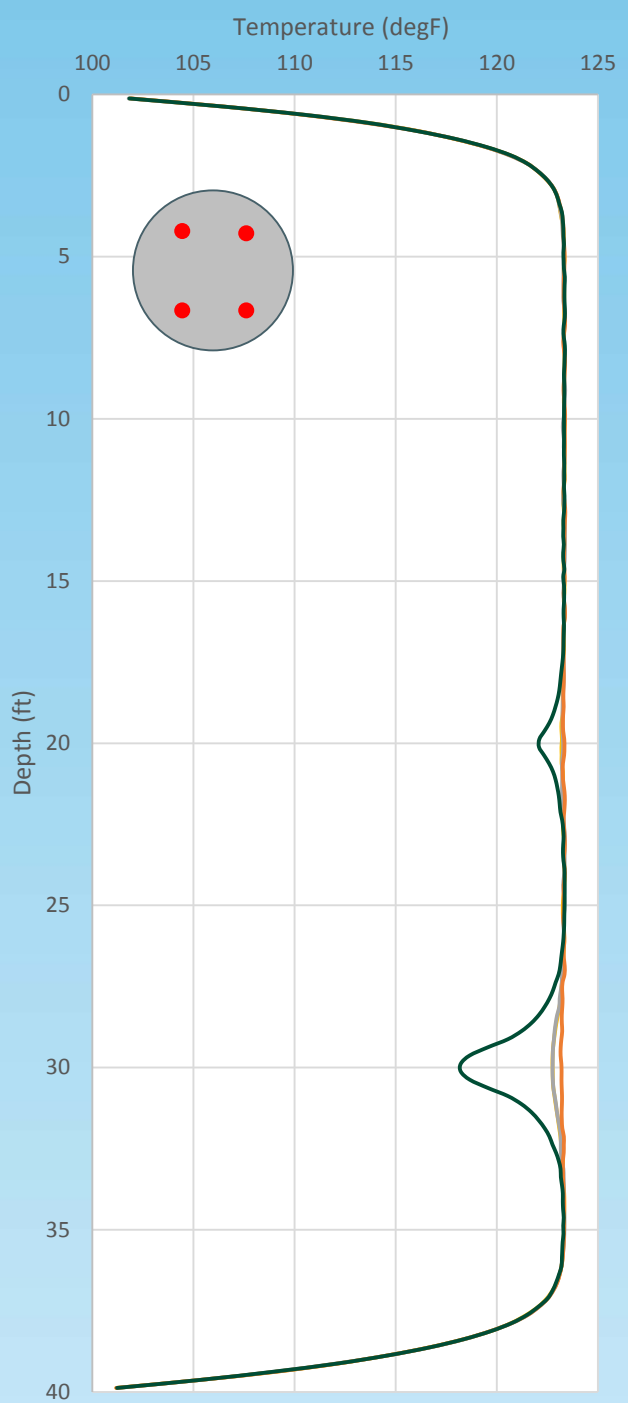




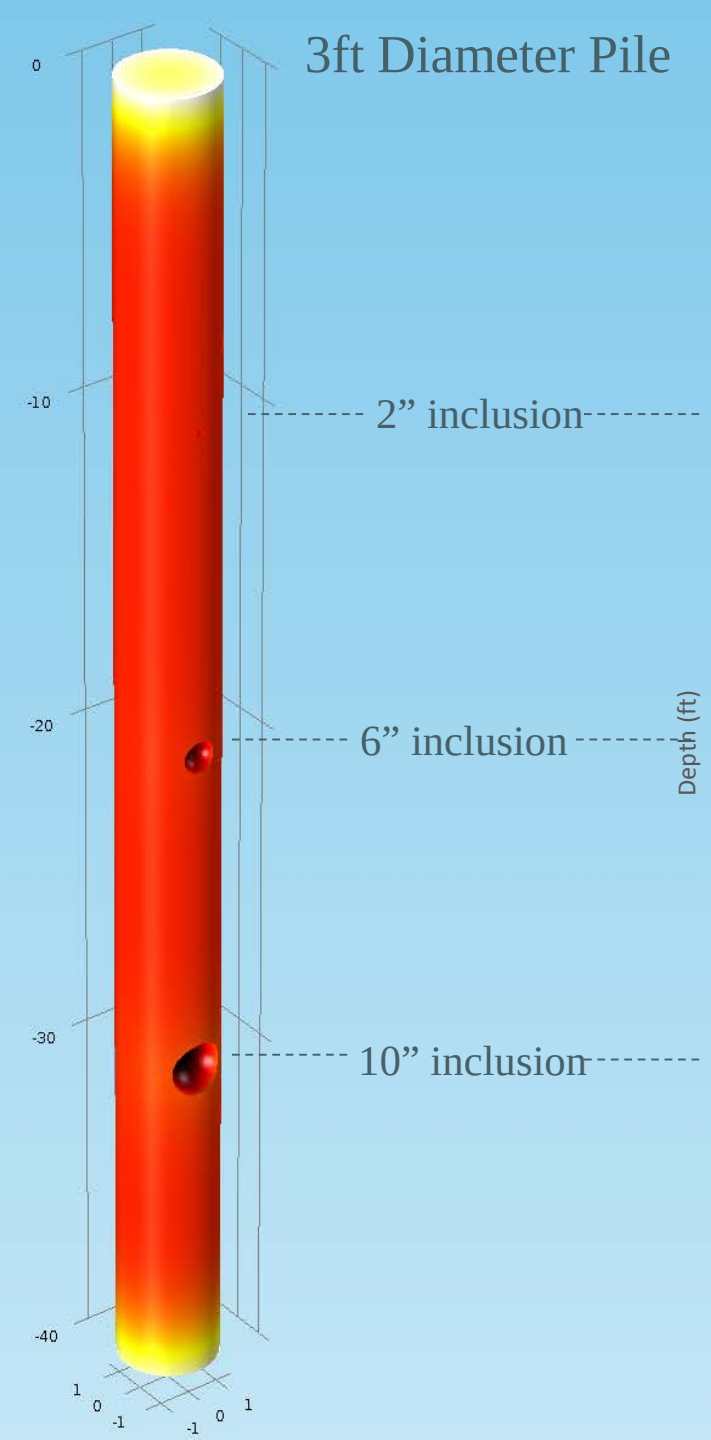
4ft Diameter Pile

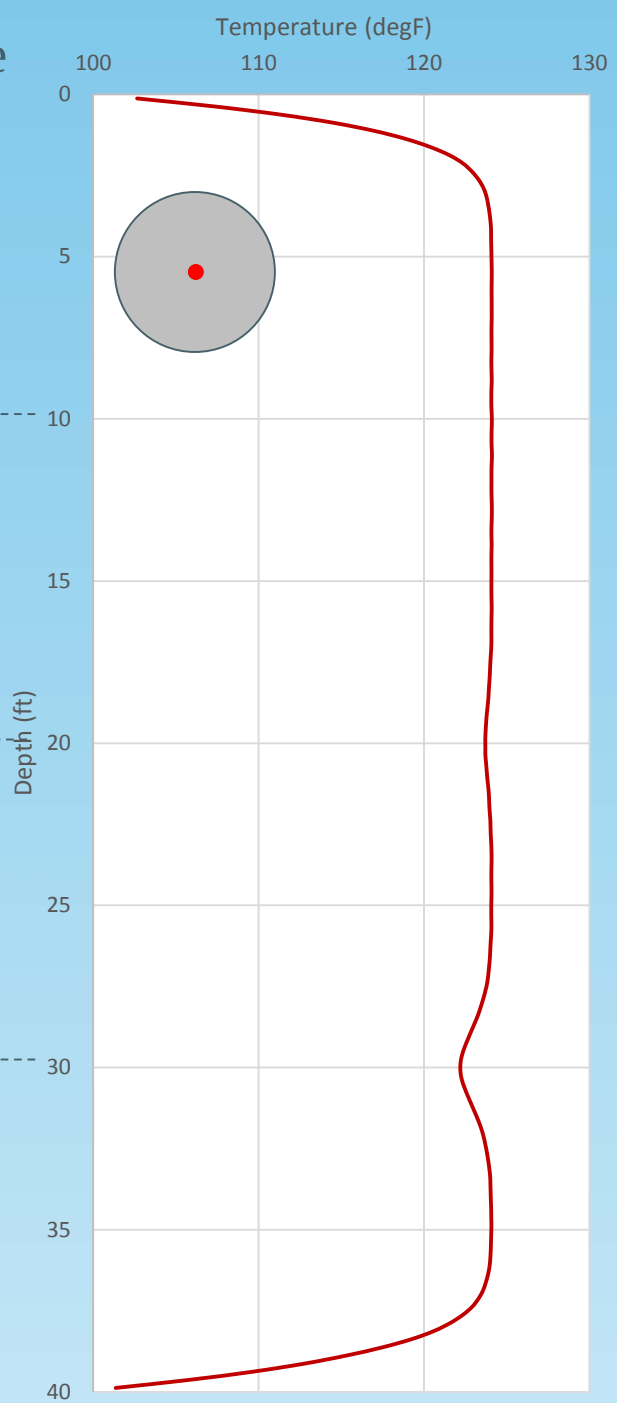


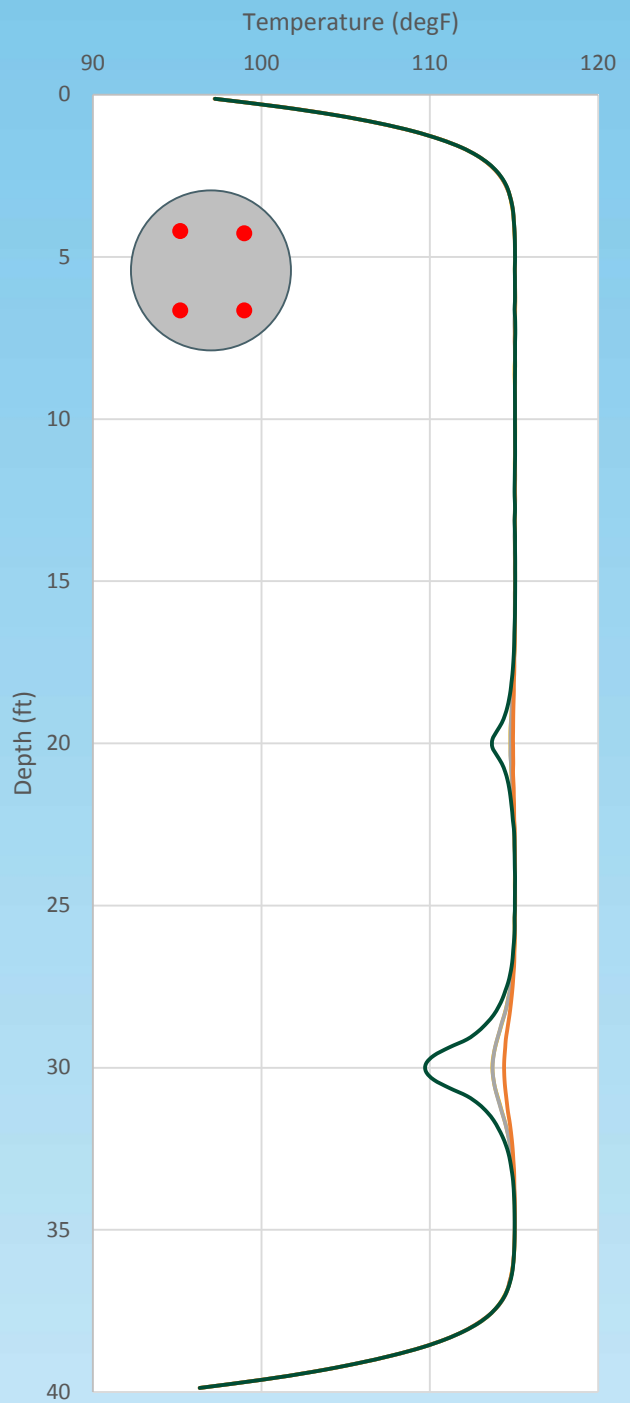




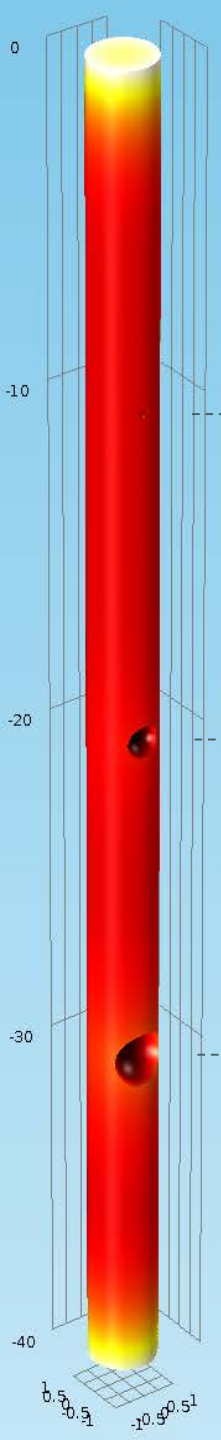
3ft Diameter Pile







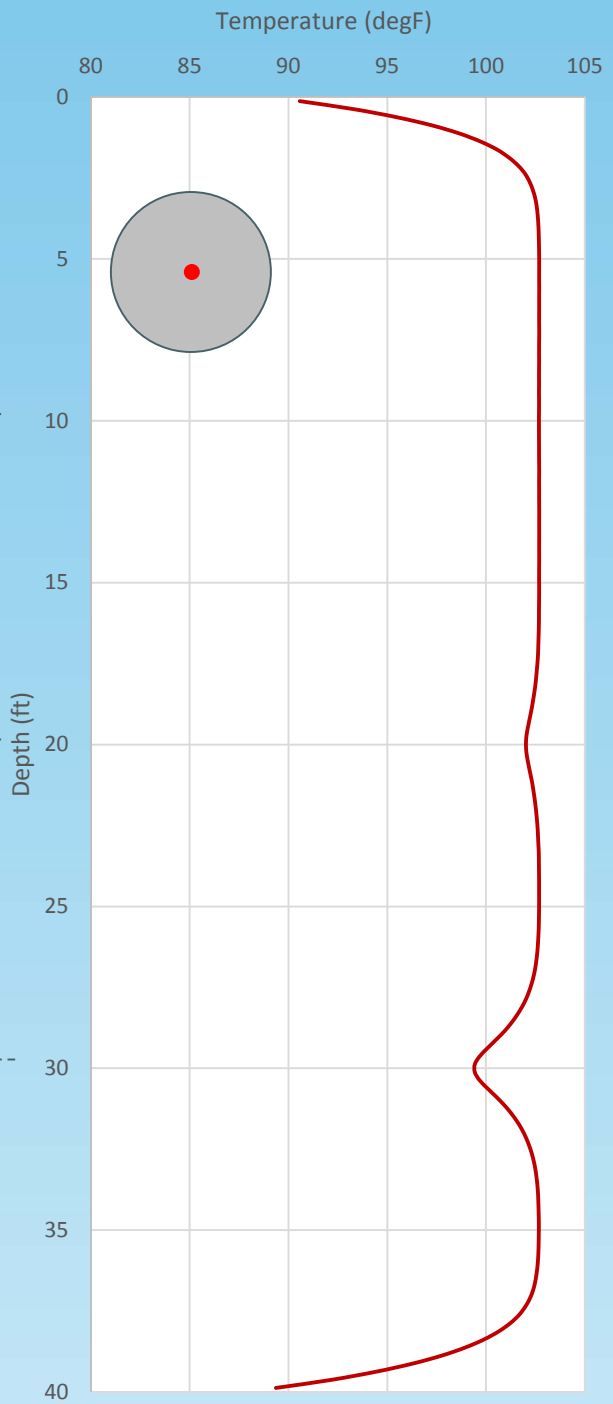
2ft Diameter Pile

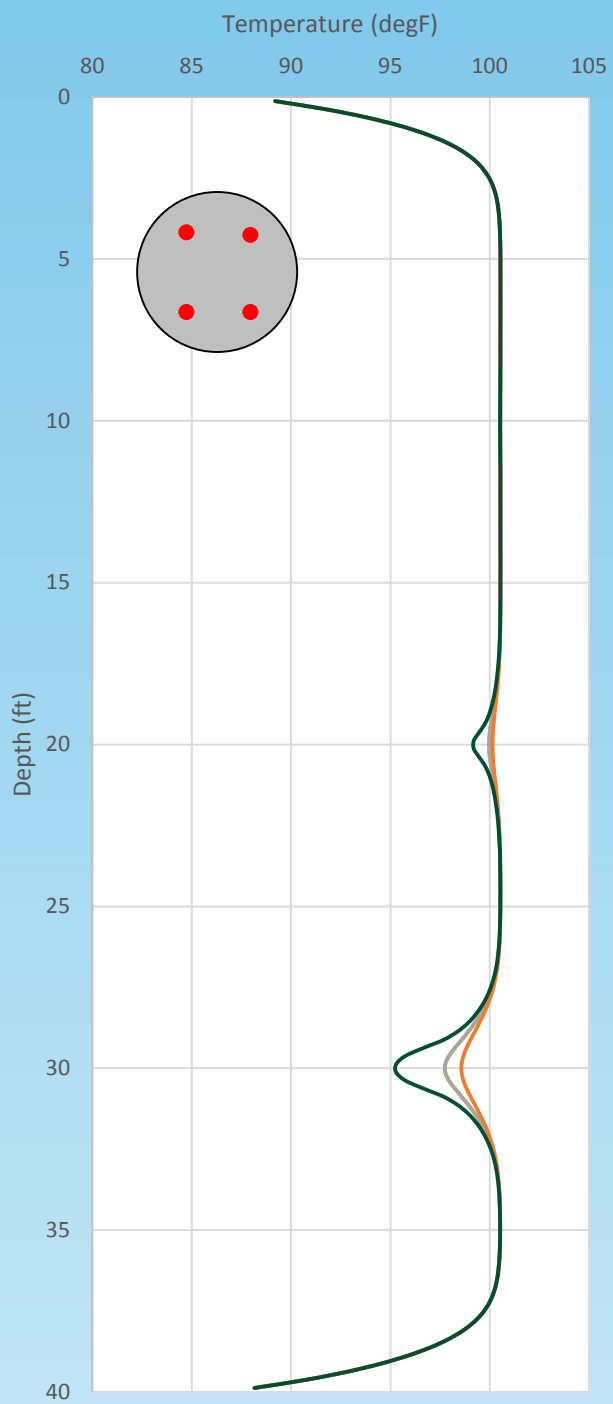


2” inclusion

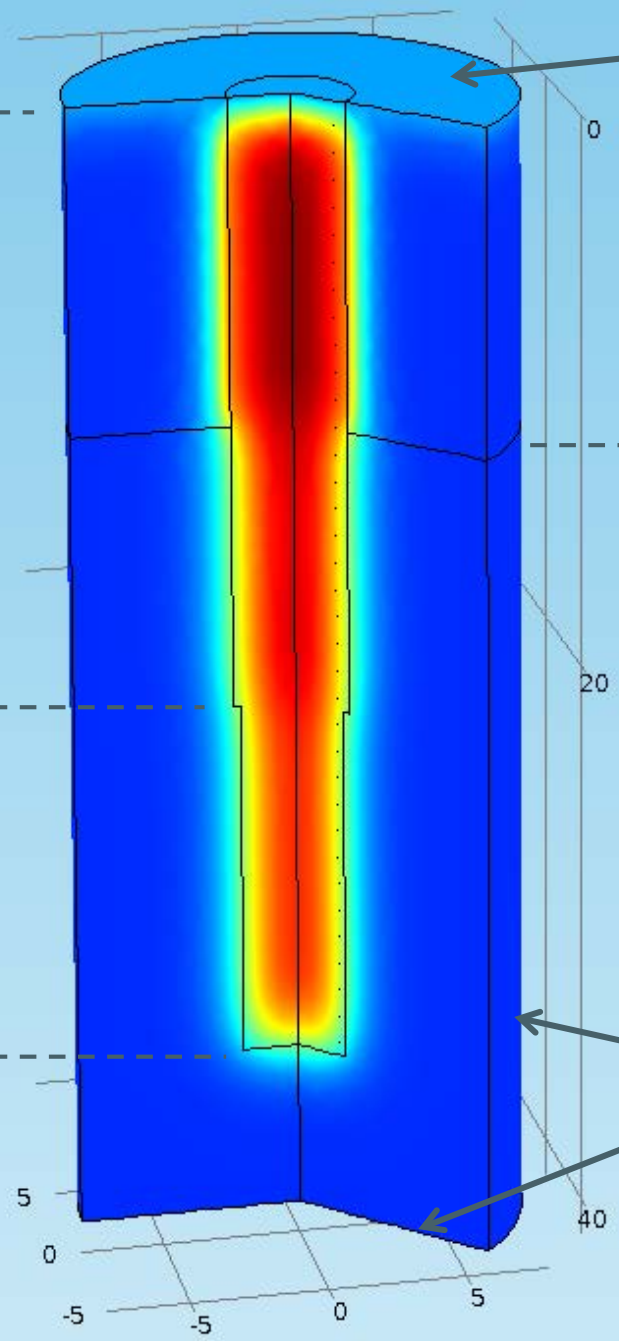
6” inclusion

10” inclusion





Case Study



TOS = GSE = 0ft

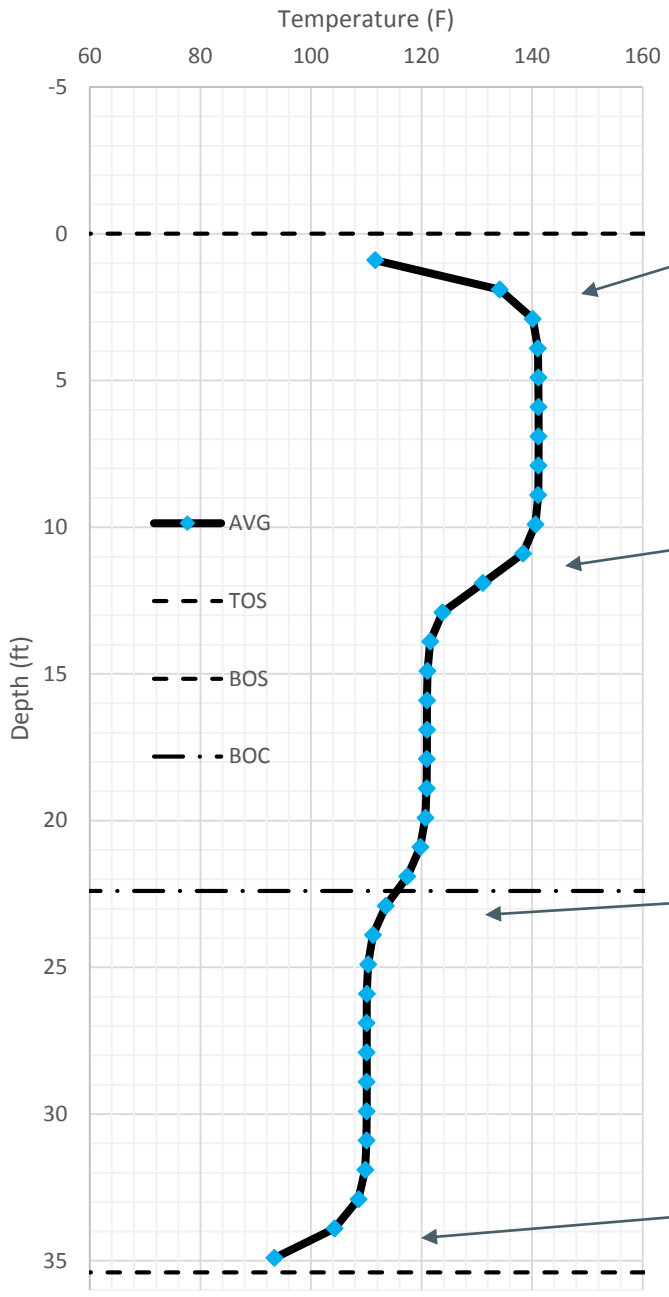
Convective air cooling w/ diurnal temperatures 66-83 F

Dry clay (with annular air gap) overlying saturated sand at 12ft

BOC (i.e. diameter change from 54” to 48”) at 22.4ft

BOS = 35.4ft

Ambient soil temperature = 60 F

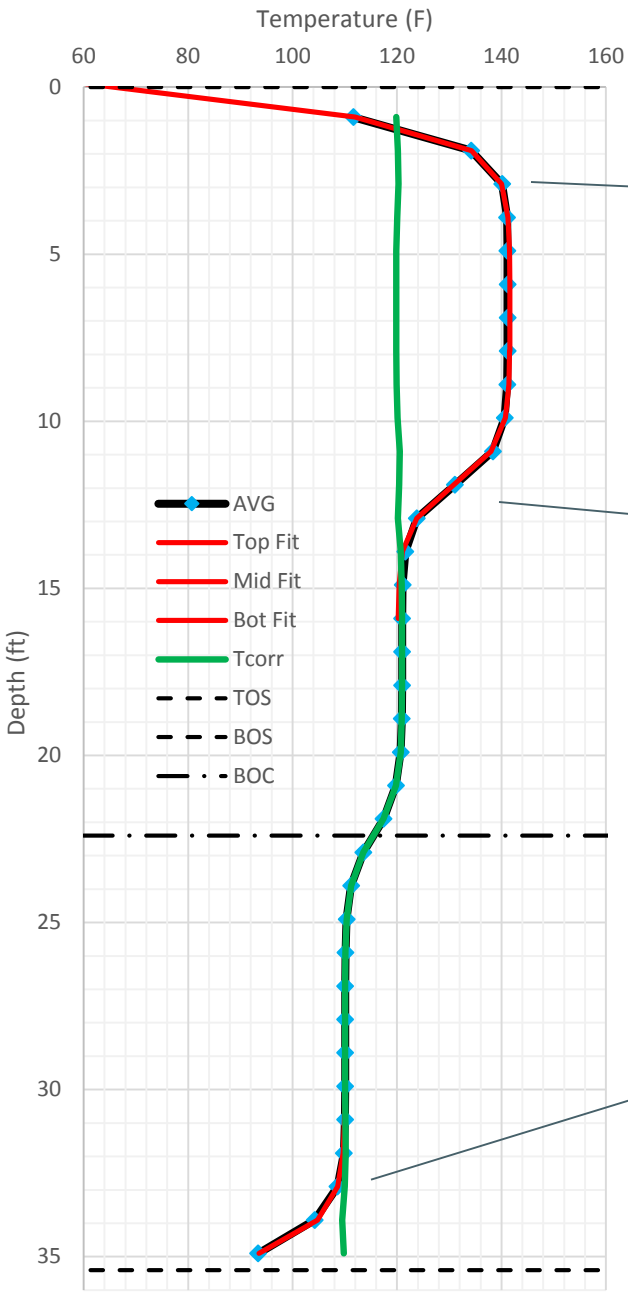


Top Roll-off – *needs correction*

Transition due to boundary change (sand overlying clay) – *needs correction*

Transition due to change in shaft diameter (e.g. bottom of casing) – *do not correct!*

Bottom Roll-off – *needs correction*



<u>Top Roll-off</u>

z_0 = 0 ft

T_{max} = 141.6 ^oF

T_0 = 66.3 ^oF

$\alpha = 1.28$

<u>Soil Transition</u>

z_0 = 11.9 ft

T_{max} = 141.6 ^oF

T_{min} = 120.2 ^oF

$\alpha = 1.25$

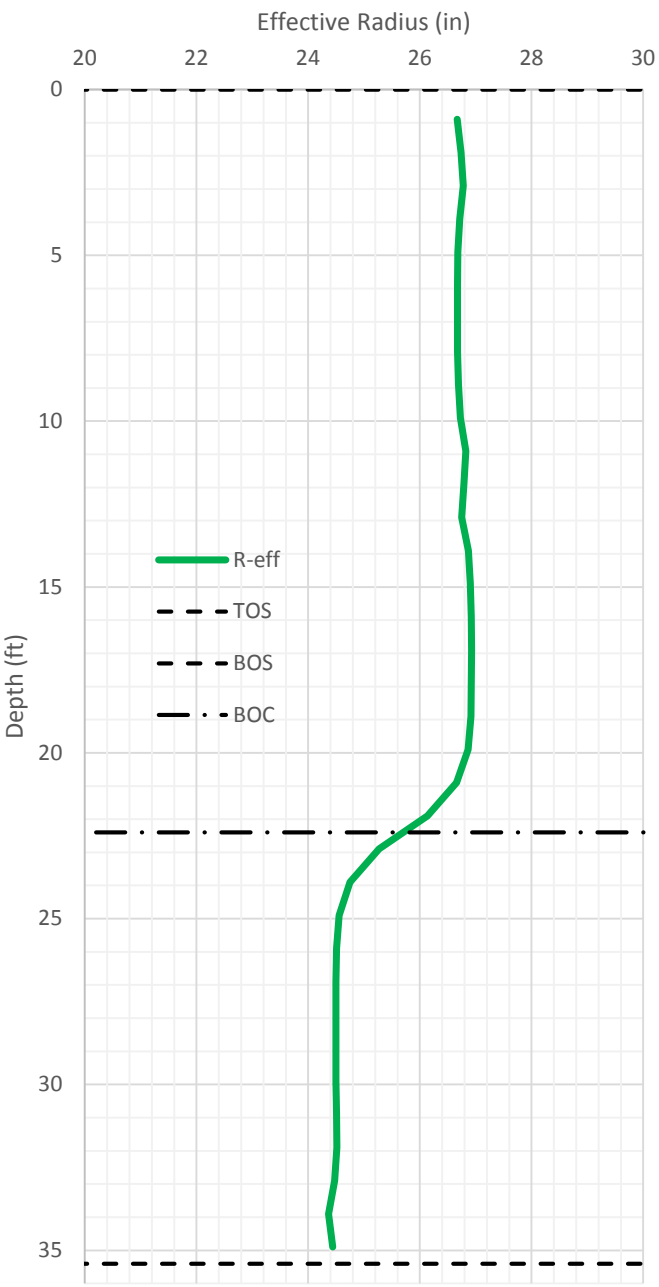
<u>Bottom Roll-off</u>

z_0 = 35.4 ft

T_{max} = 110 ^oF

T_{min} = 60 ^oF

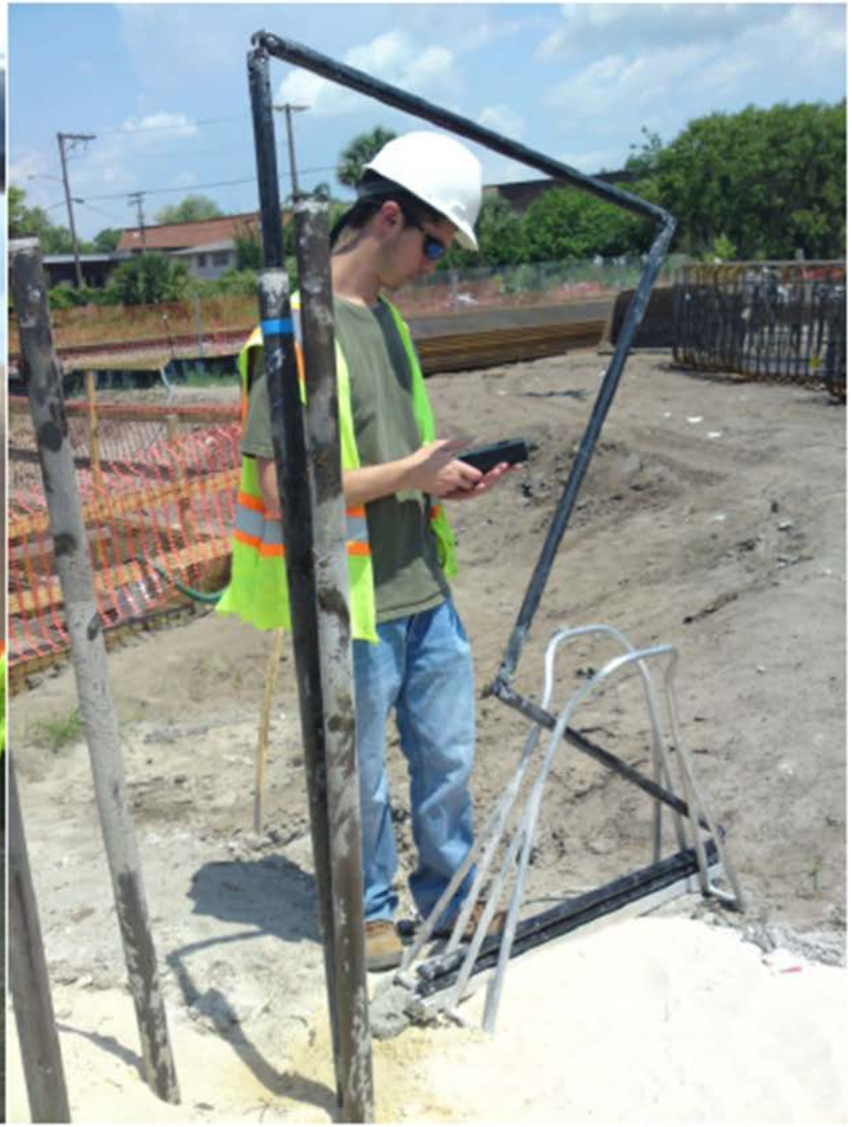
$\alpha = 1.4$

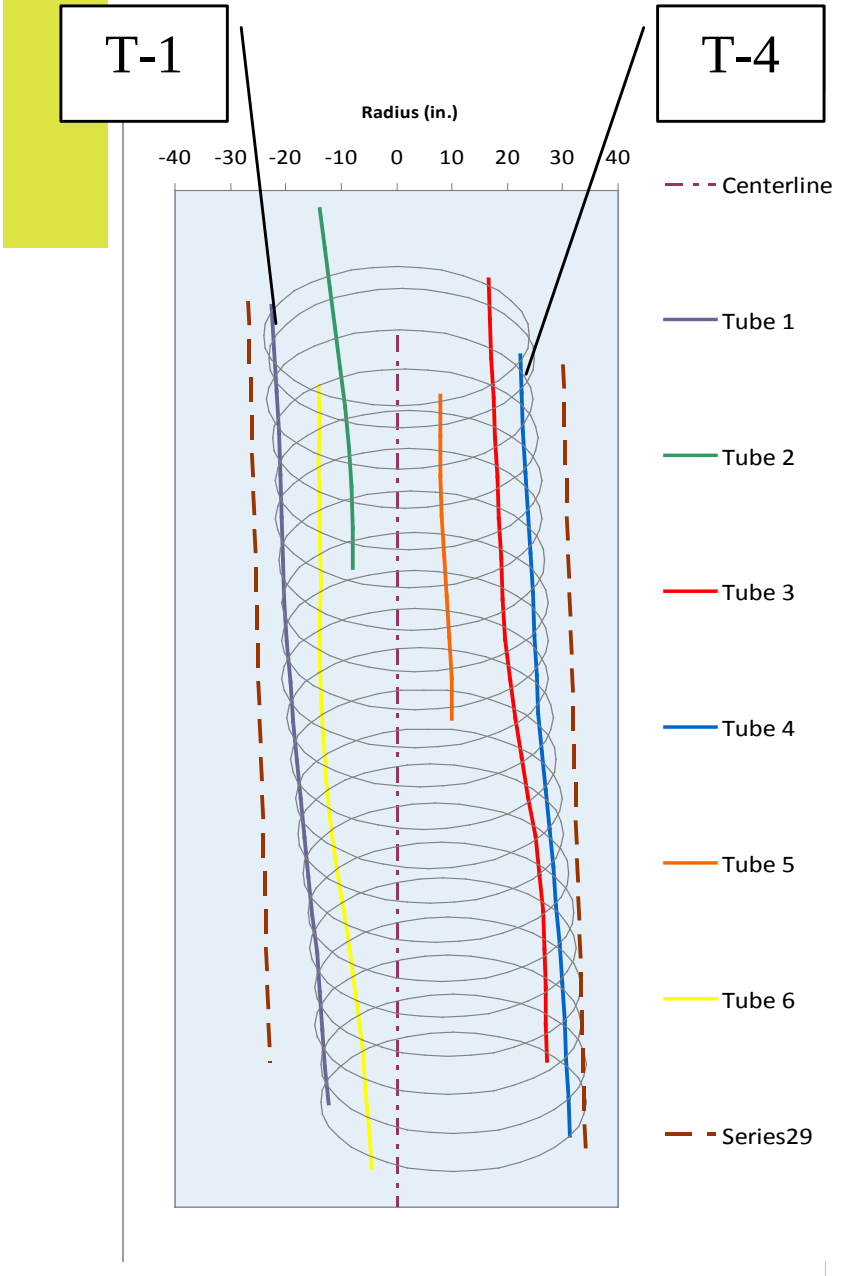


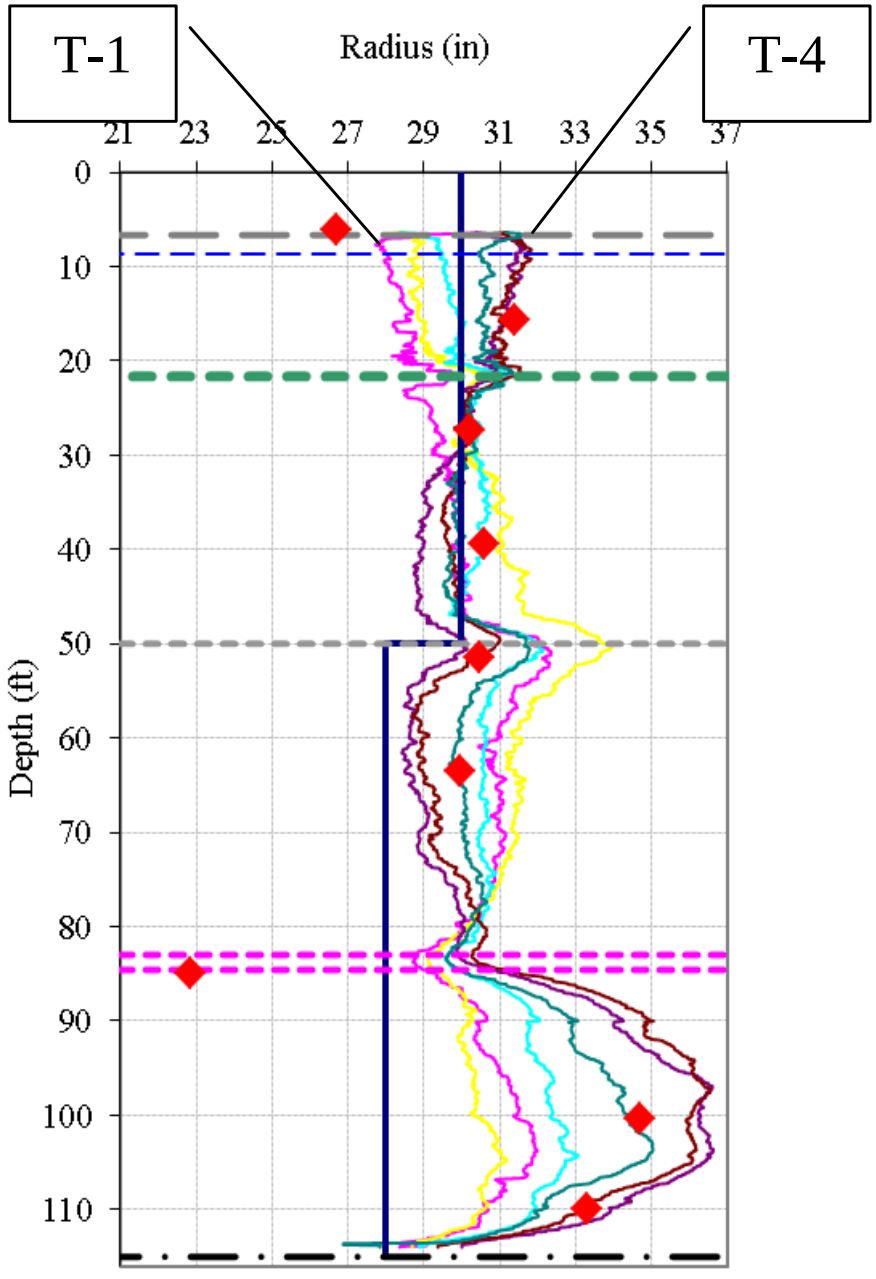
Research Approach

- Task 1 Literature Review
- Task 2 Numerical Modeling
- Task 3 Feasibility Study of Probe-based Inclination Measurements
- Task 4 Field Testing
- Task 5 Reporting

Inclination Measurements




T-1
T-4
Radius (in.)
-40 -30 -20 -10 0 10 20 30 40
Centerline
Tube 1
Tube 2
Tube 3
Tube 4
Tube 5
Tube 6
Series29

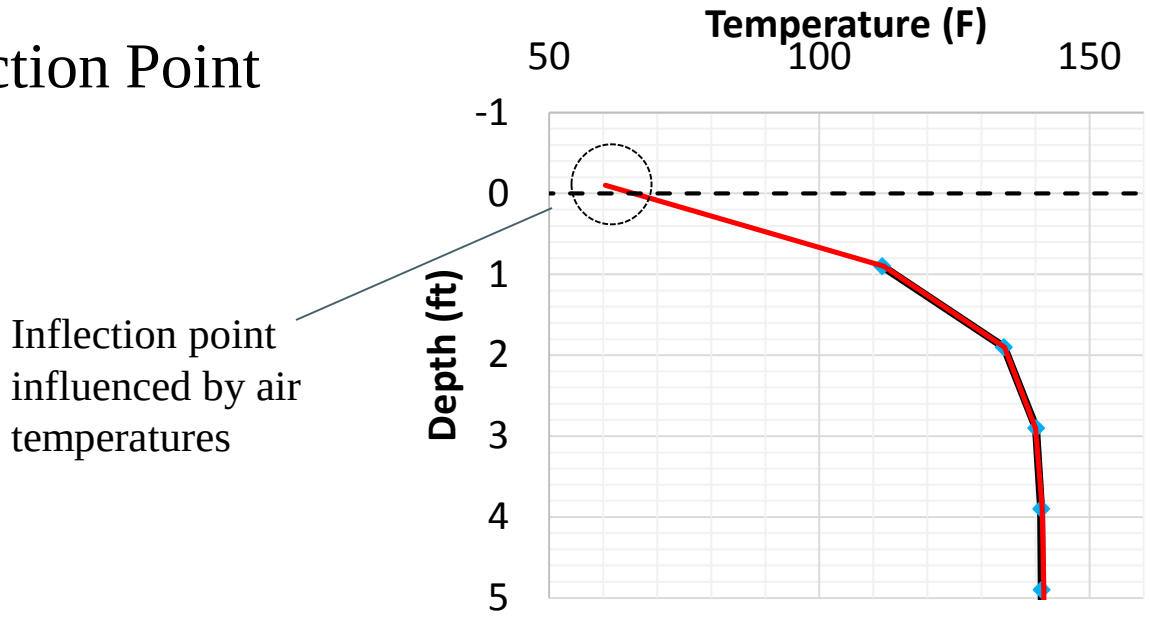

T-1
T-4
Radius (in)
21 23 25 27 29 31 33 35 37
Depth (ft)
0 10 20 30 40 50 60 70 80 90 100 110

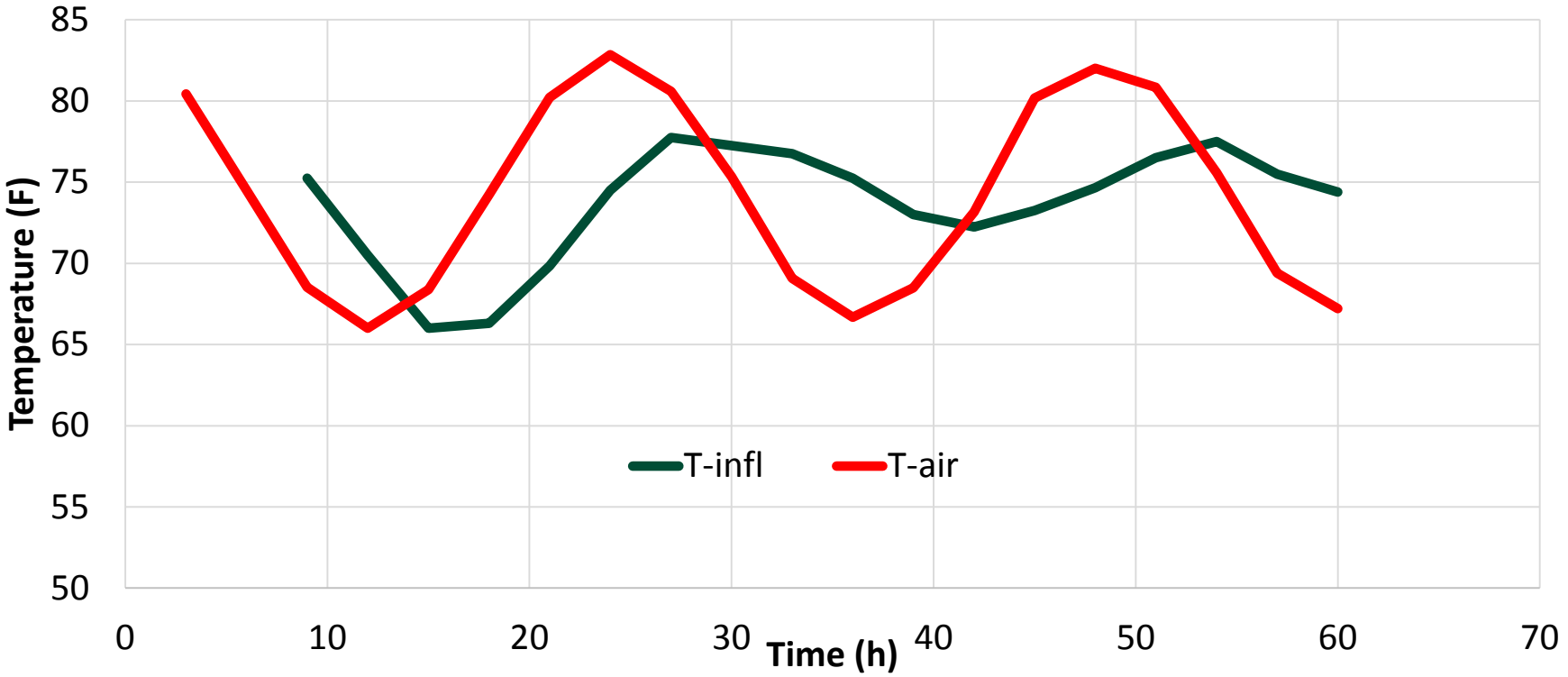
Questions?


TAPP

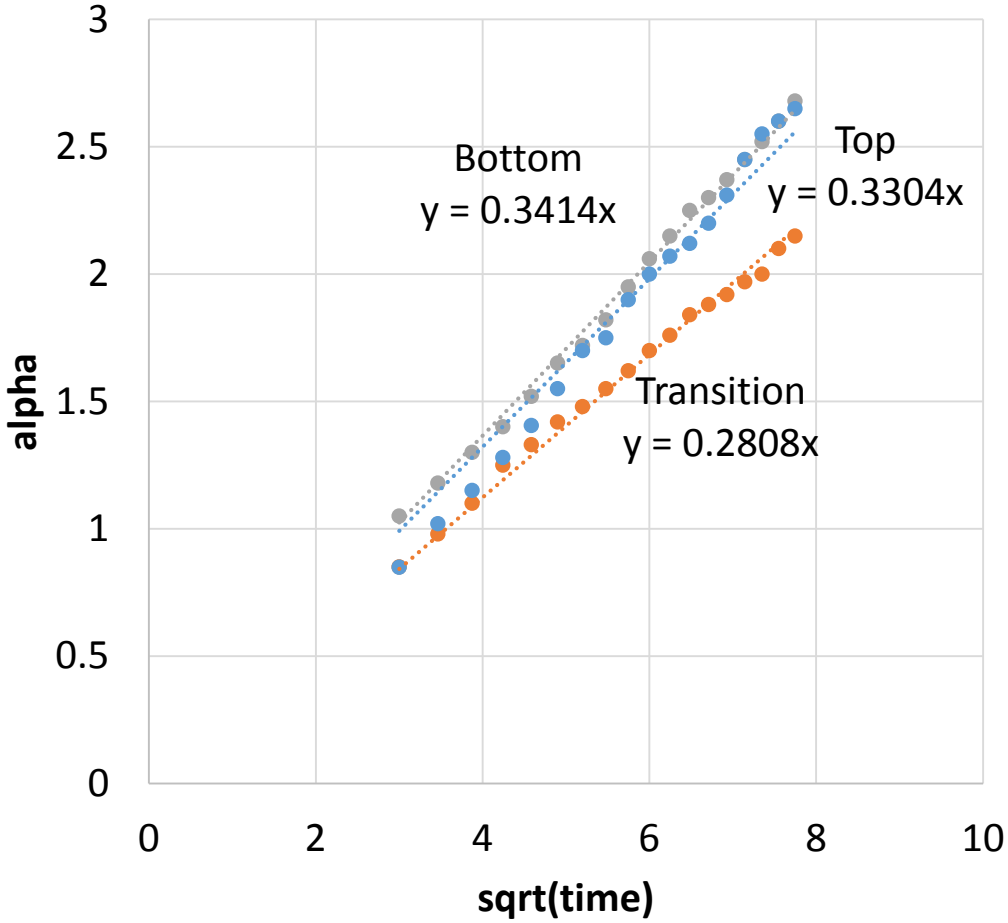
Thermal Integrity Profiler
UP
DOWN
CLOSE
Pile Dynamics, Inc.

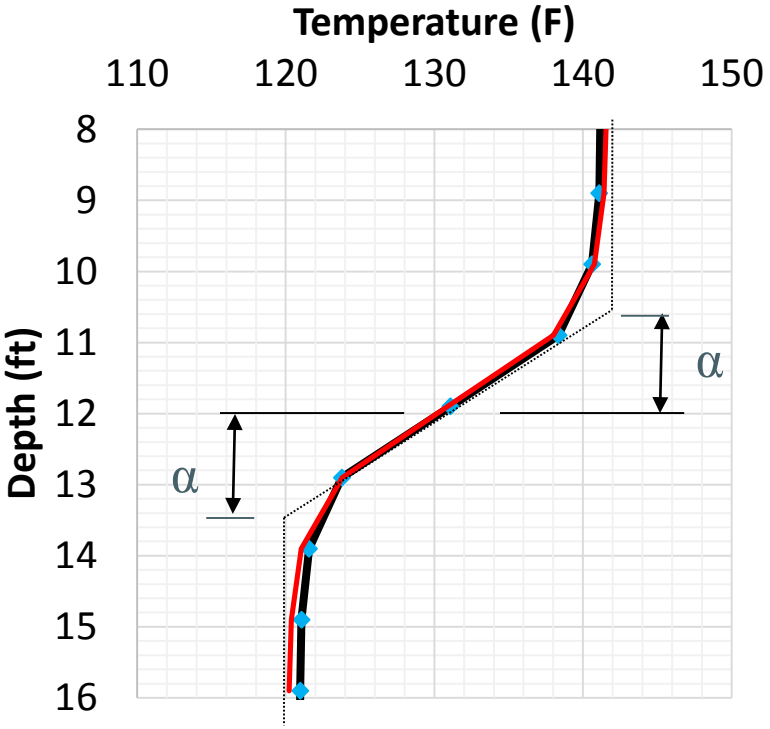
Selection of TOS Inflection Point





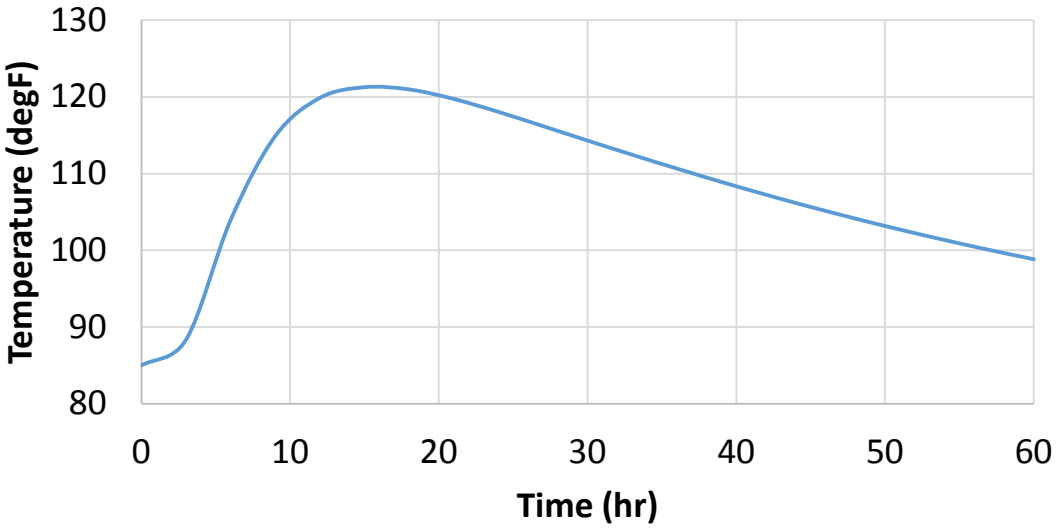
Selection of Inverse Hyperbolic Scaling Factor

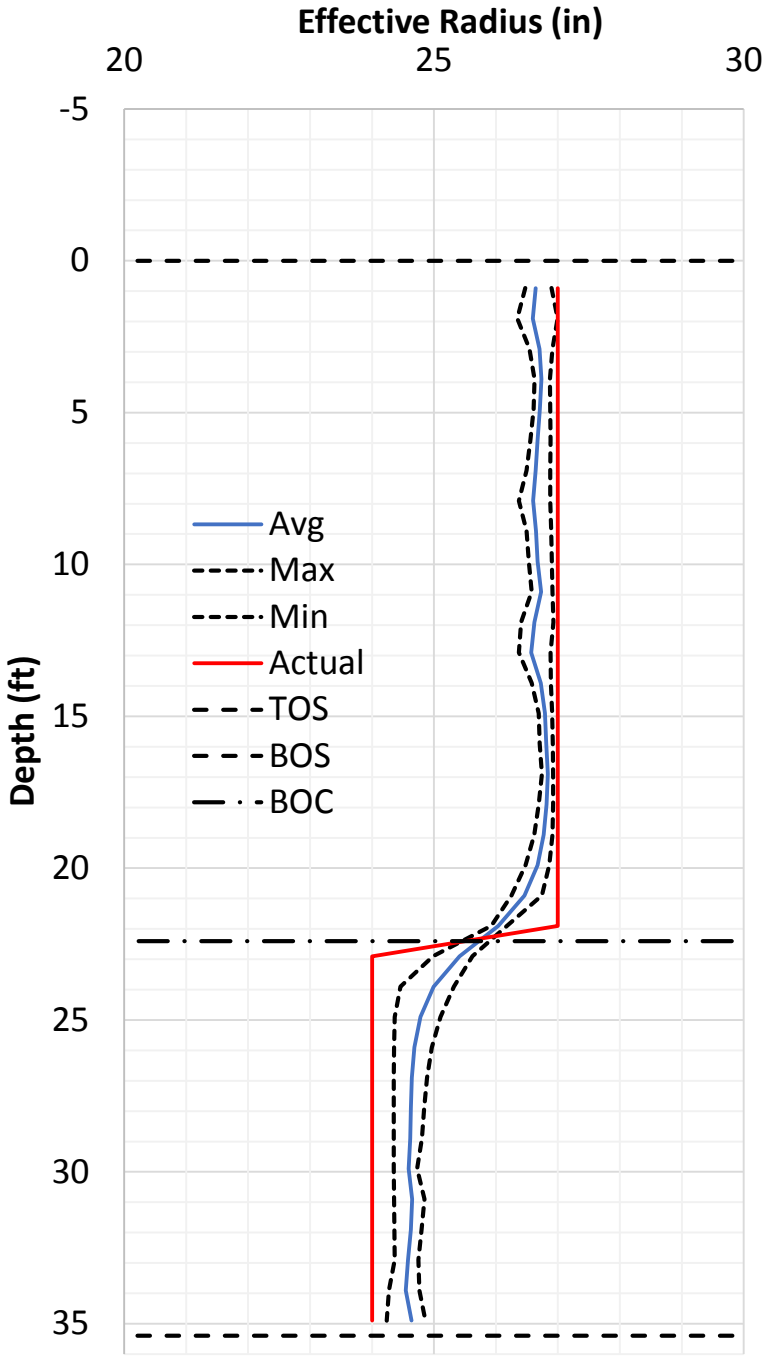


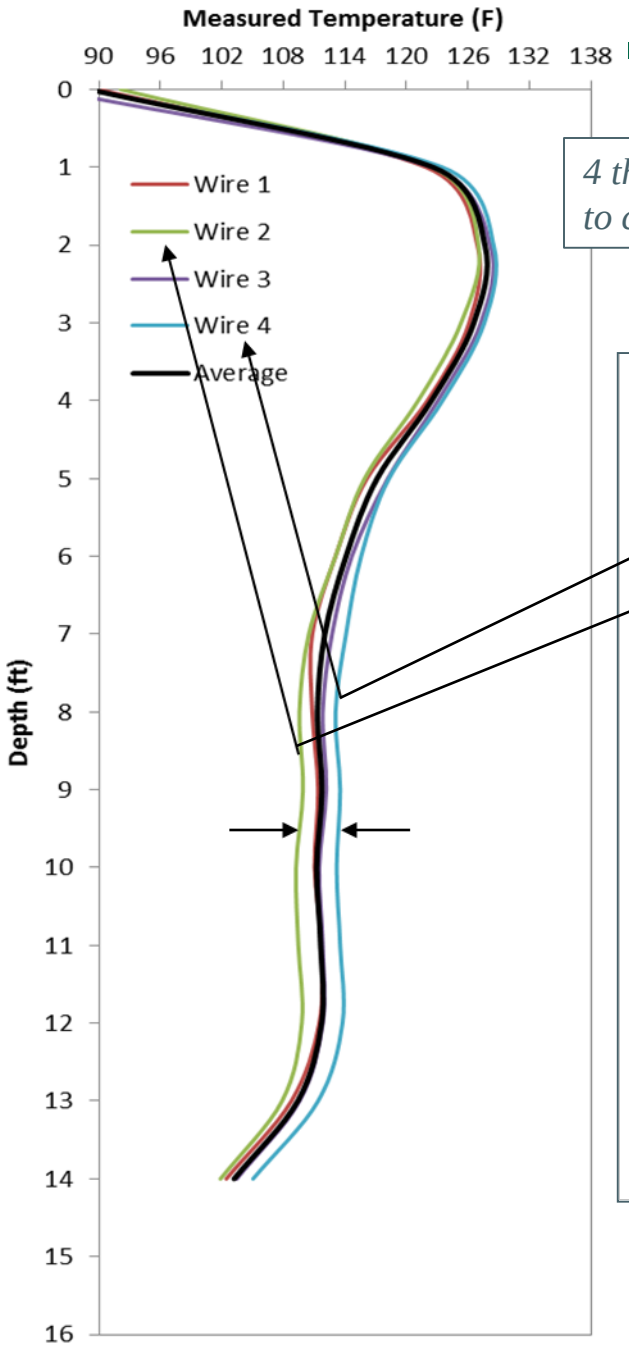


$$\propto = \sqrt{0.3t}$$

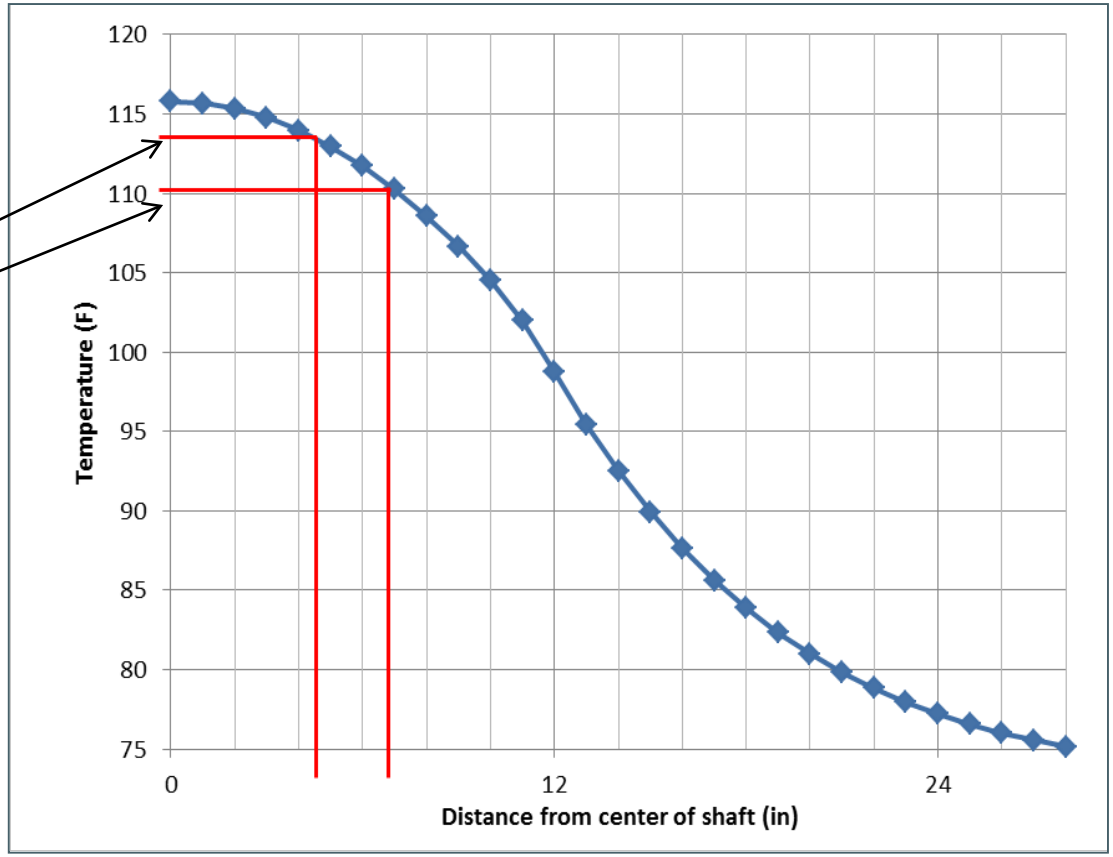
Range of Predicted Radii for all times (0 to 60hrs)

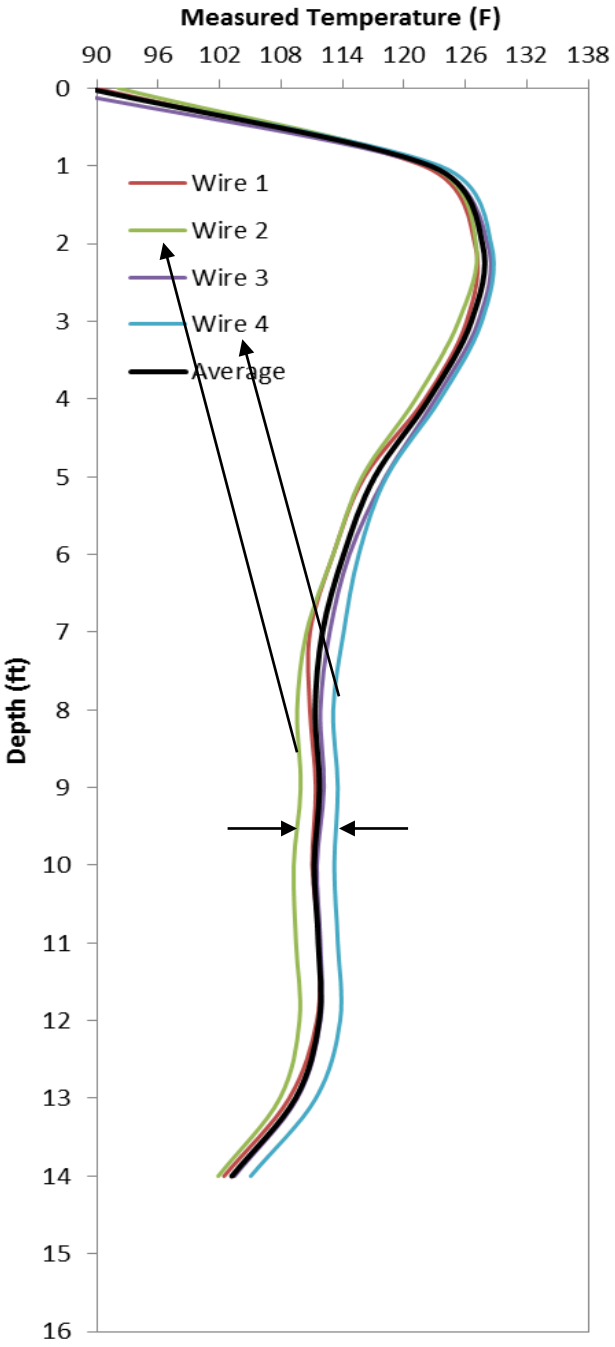


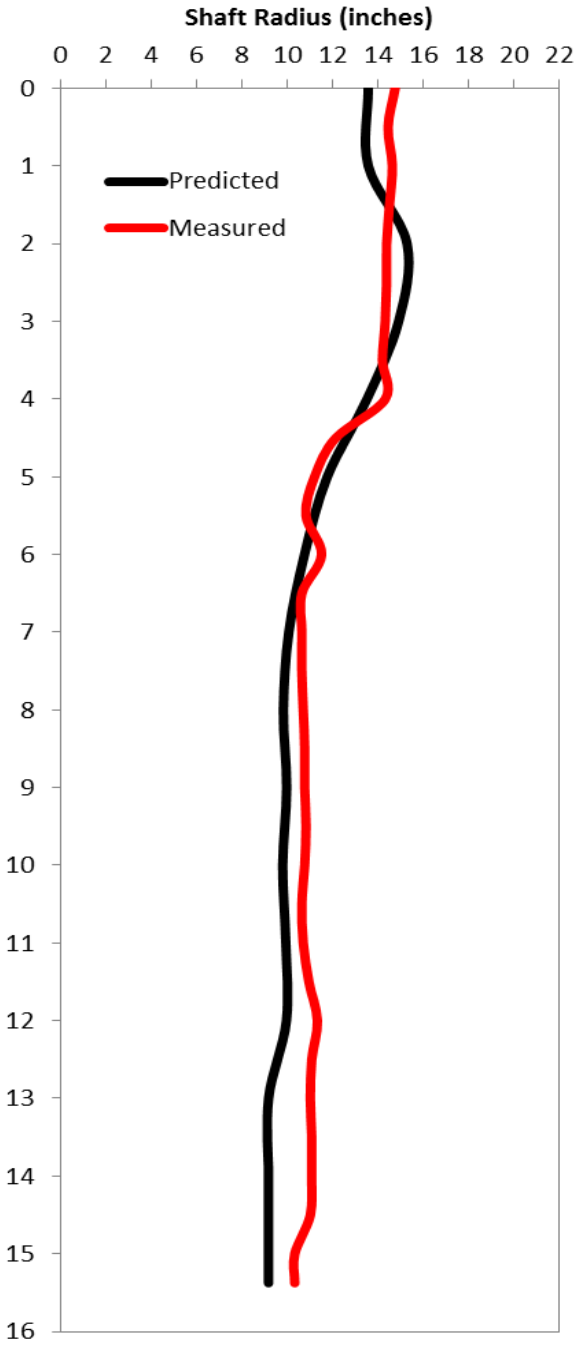




4 thermal wires tied to center bar







Signal matching approach yields good results but can be time consuming for everyday practice.