QA/QC Tests on Drilled Shafts and CFA Piles

Wednesday October 19th 9:10 – 10:00 am

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Cleveland, OH
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QA/QC Tests on Drilled Shafts and CFA Piles

Structural Integrity

- Low Strain Integrity Tests
- Crosshole Sonic Logging
- Thermal Integrity Profiling

Base Cleanliness

- SID
- SQUID

Nominal Resistance

- High Strain Dynamic Testing
- Rapid Load Testing

Low Strain Integrity Tests

Low Strain - Pulse Echo

Overview

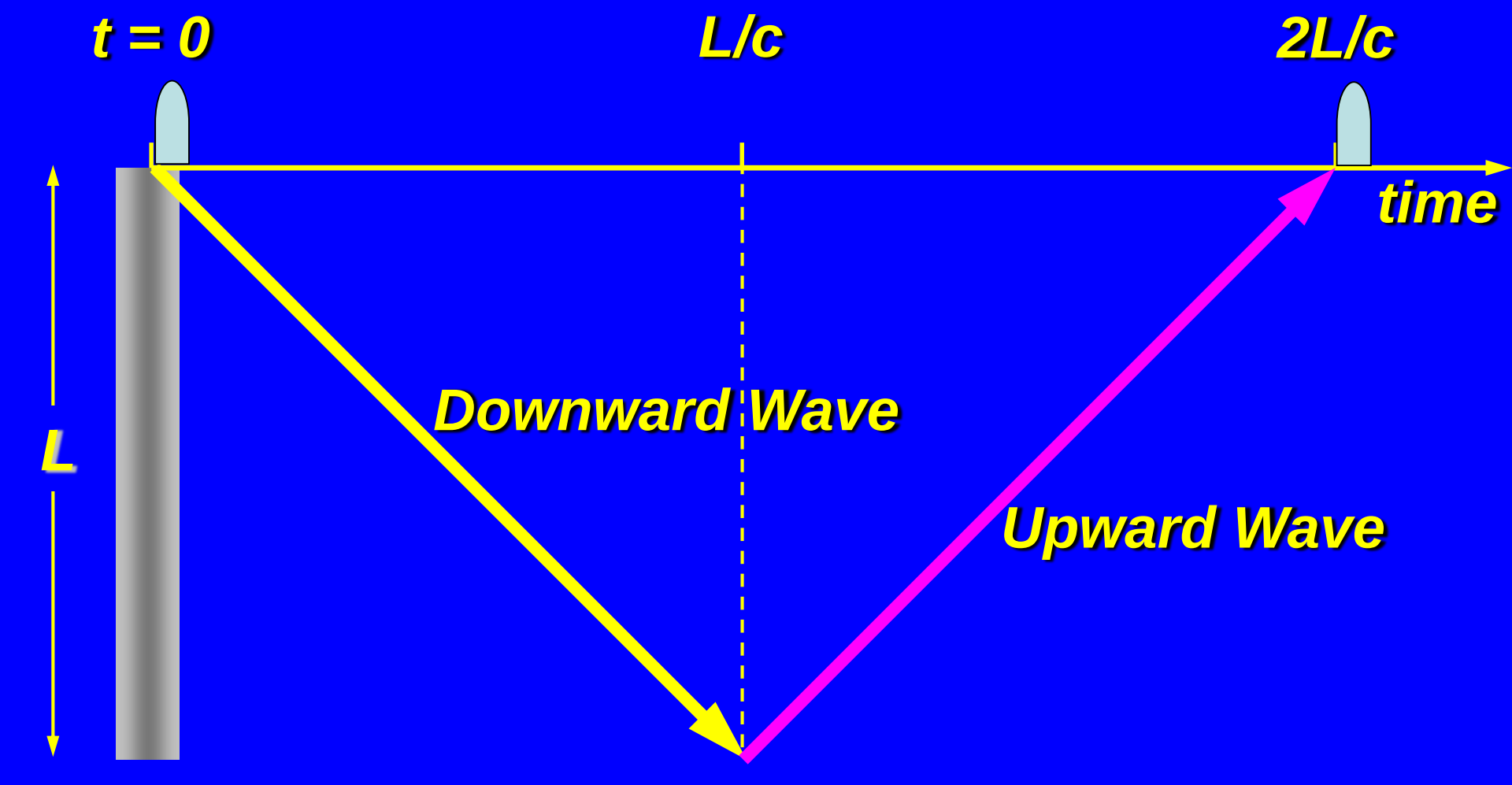
- Small hammer used to apply low strain compression wave in shaft. Resulting shaft top motion monitored by accelerometer.
- Technical competence required: - Moderate.
- Relative cost: Testing - Low.
  Overall - Low
- ASTM D 5882

Low Strain - Pulse Echo

Test Preparation Required
Shaft top surface smoothly ground at selected spots.
04/13/2005

- A stress wave propagates along a uniform elastic rod unchanged at wave speed c.

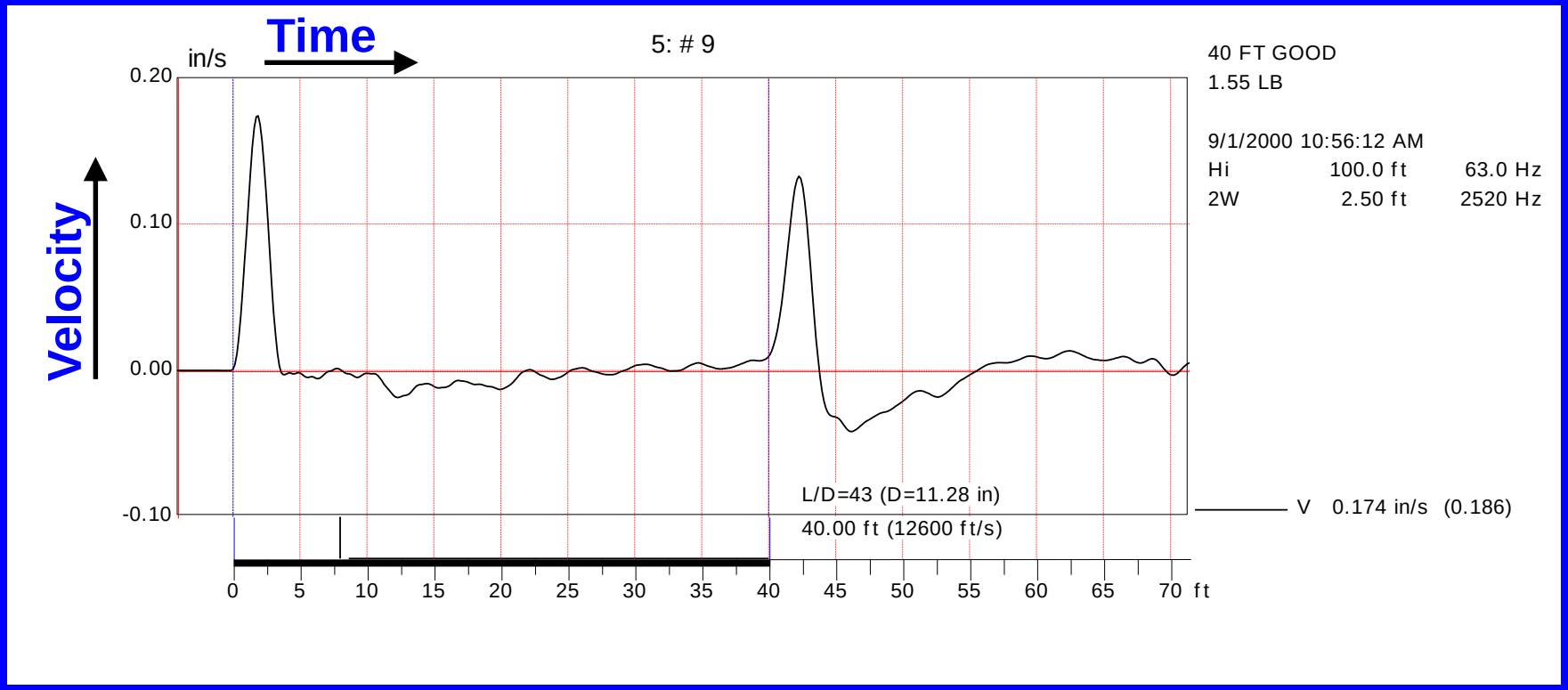
- Reflection occurs where pile impedance changes.



Pulse Echo Method Results

Output

- Plot of filtered, un-amplified shaft top velocity versus time.



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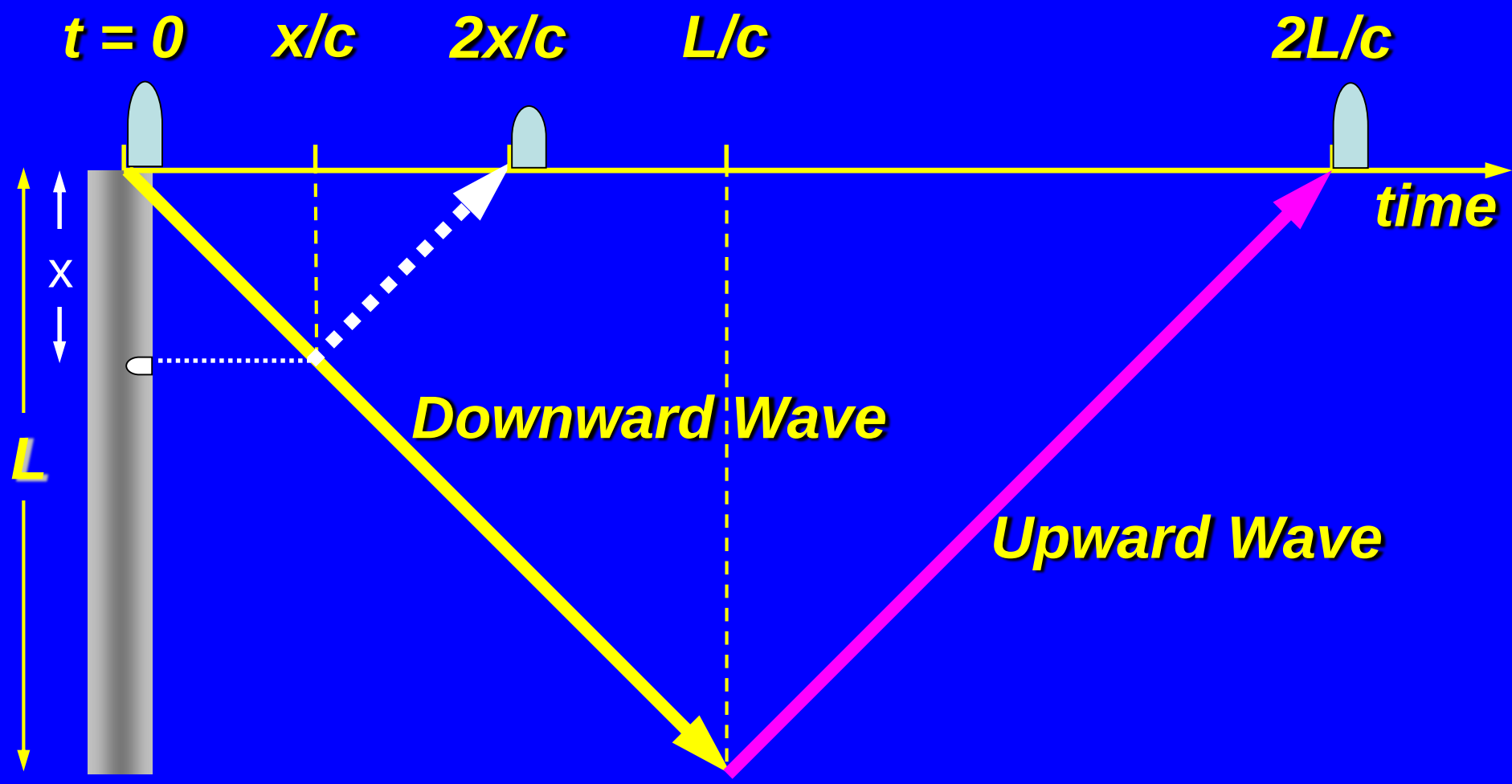
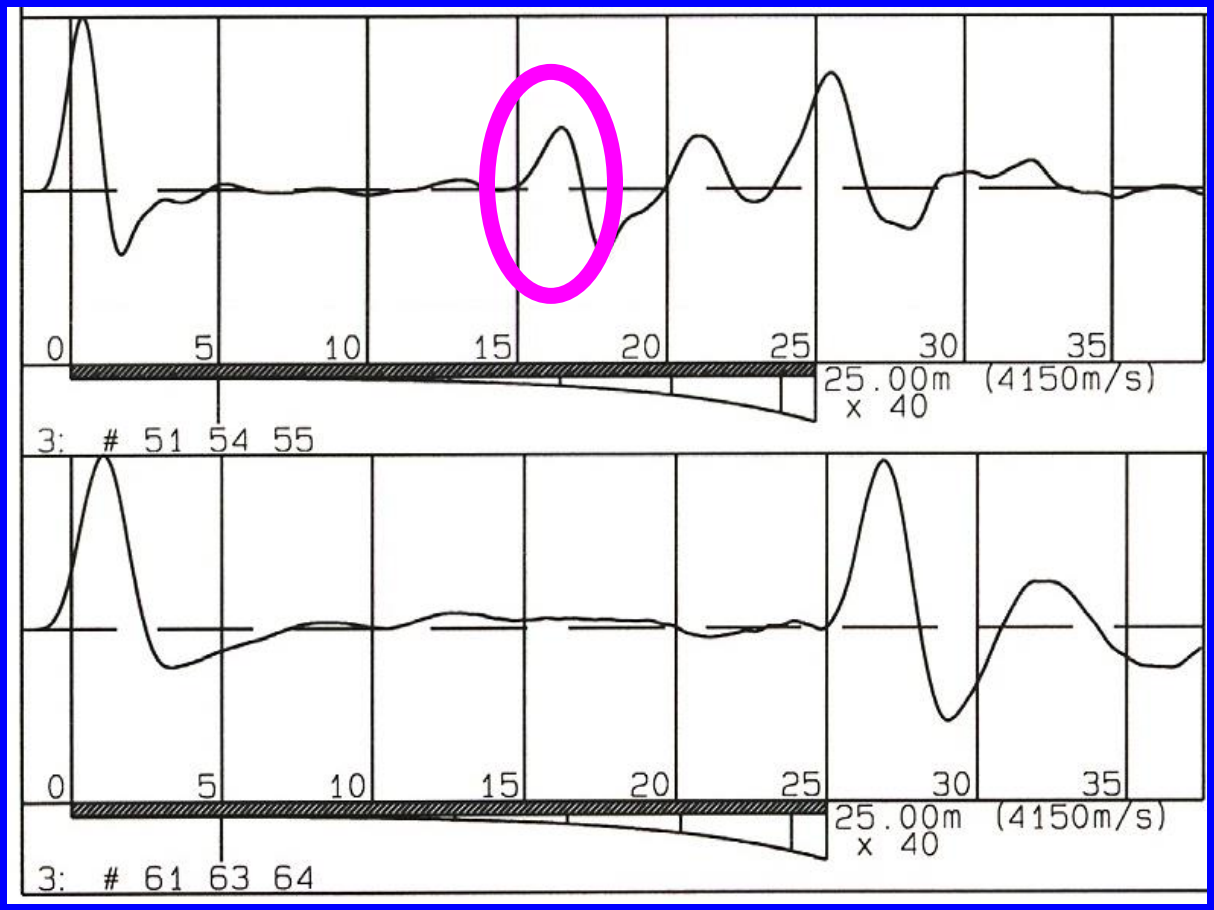


Pulse Echo Method Results

L = 25 m, D = 800 mm (L/D = 31)
L = 82 ft, D = 2.62 ft (L/D = 31)



P98

Defective

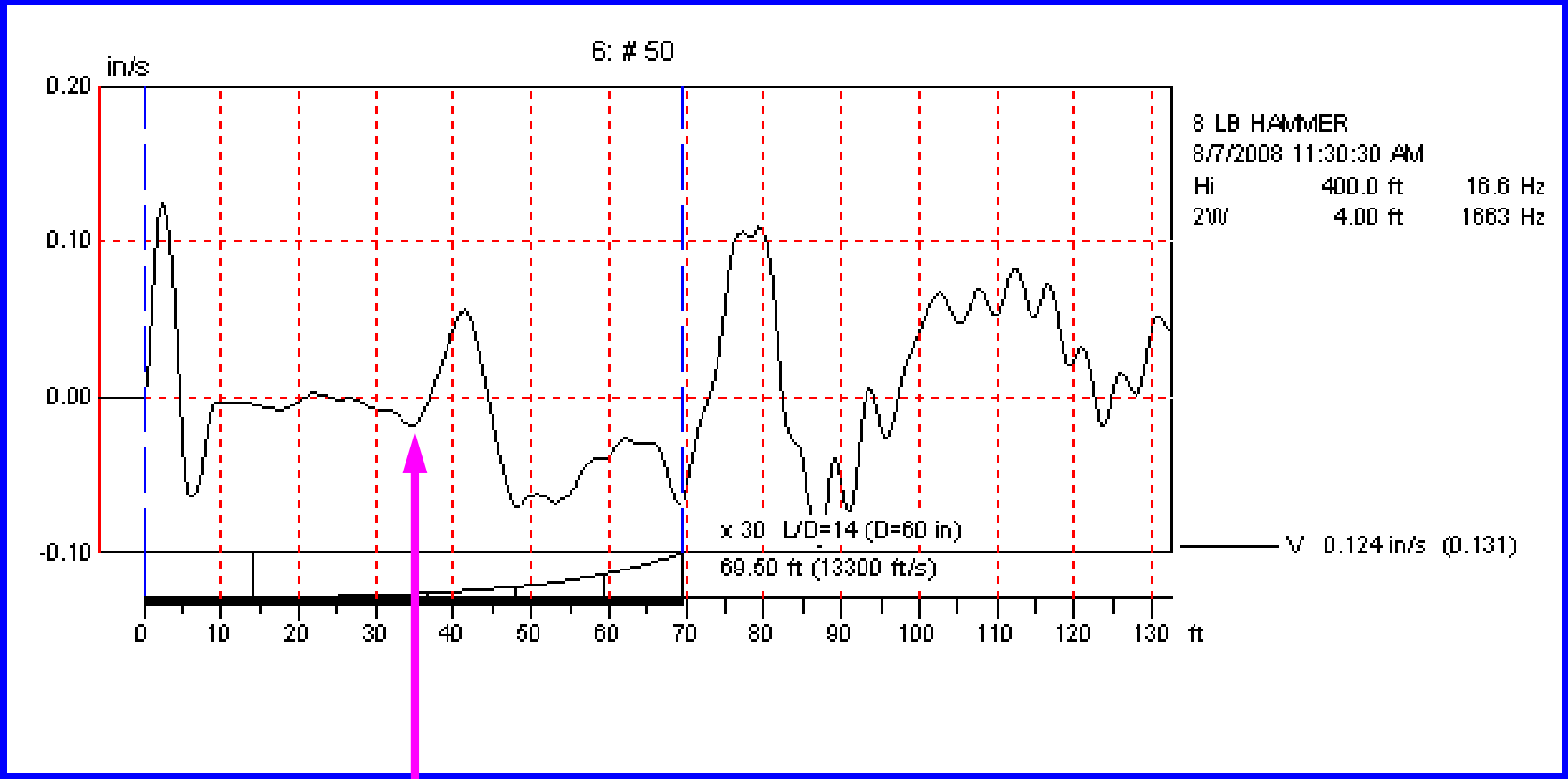
P125

Good Shaft

Top **Bottom**

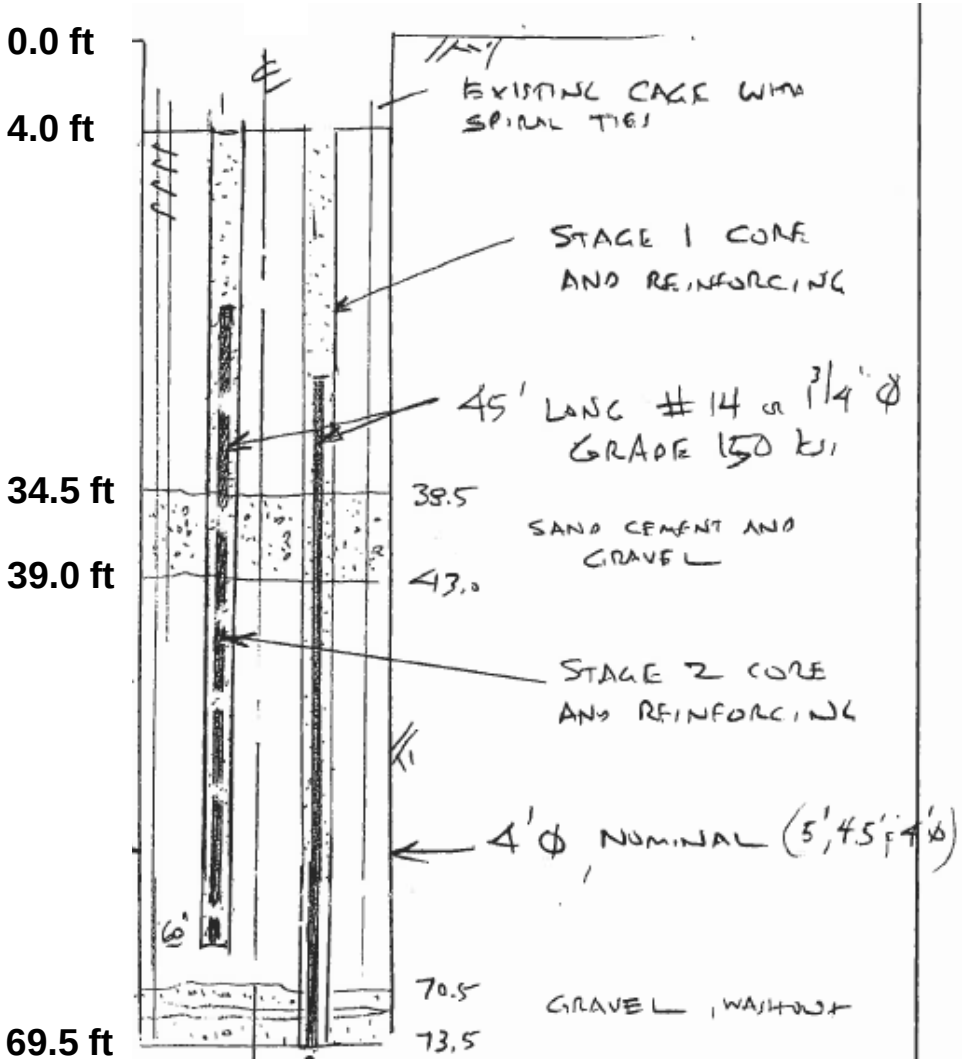
Pulse Echo Method Results

Low strain tests specified for routine drilled shaft quality assurance



Major Defect at 35 Ft

Coring Results on Shaft

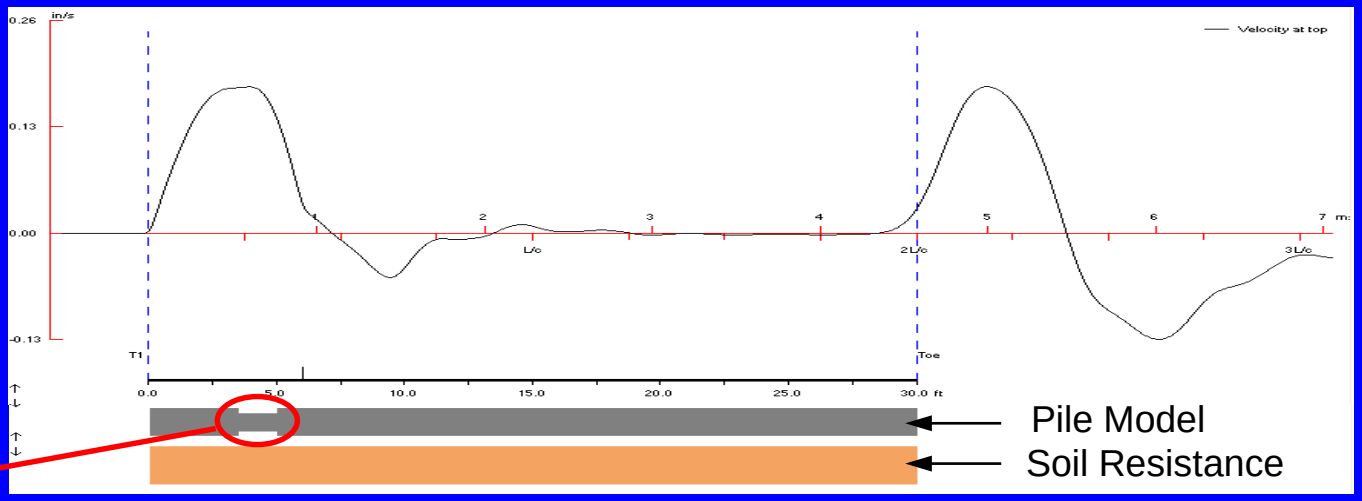


04/13/2005

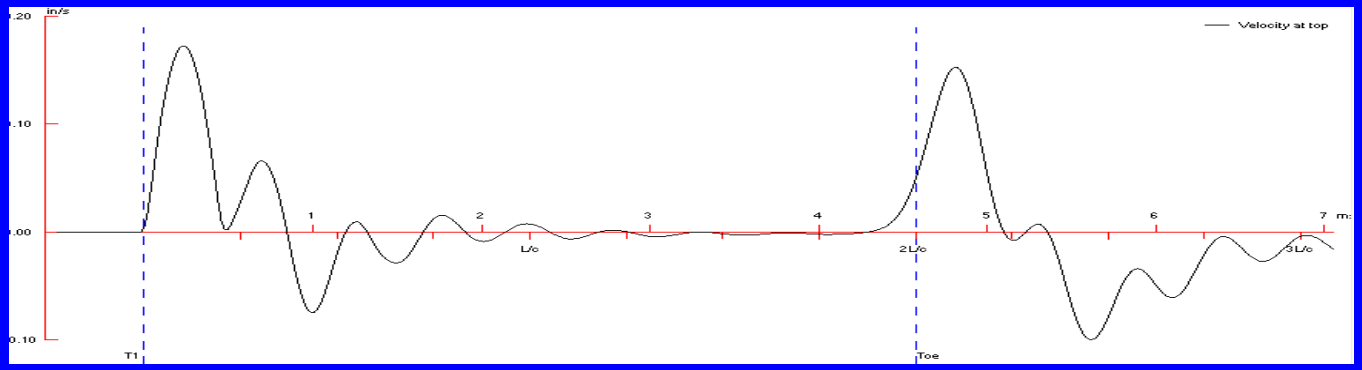
INFLUENCE OF PULSE WIDTH ON DEFECT DETECTION

6 ft Pulse Width

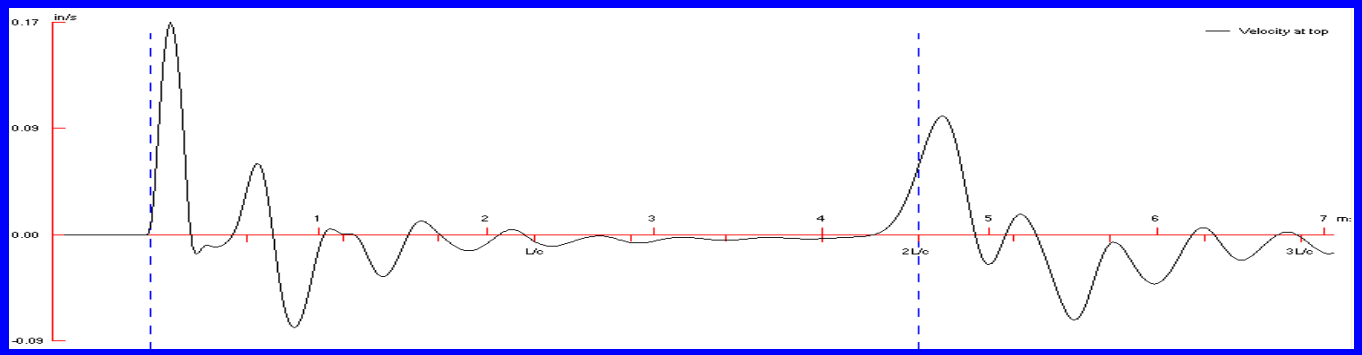
37% reduction
2 ft long



3 ft Pulse Width



1 ft Pulse Width



Low Strain - Pulse Echo

Advantages

- Provides information about relative depth and severity of major defects.
- Does not require pre-selection of shafts to be tested.
- Minimal preparation of shaft required for testing.
- Typically fast and economical (30 to 40 per day).

Low Strain - Pulse Echo

Limitations

- Typical length limitation of about 30 to 40 diameters.
  - *can be less than 30 L/D if high soil resistance and non-uniform shafts.*
  - *can be up to 60 L/D if low soil resistance and uniform shaft.*
- Multiple defects or defect below length limitation noted above not detectable.
- Unable to determine thickness or lateral extent of defects.
- Small defects not detectable.
- Defect depth based on assumed wave speed (+/- 10%).
- Data requires experience to interpret.

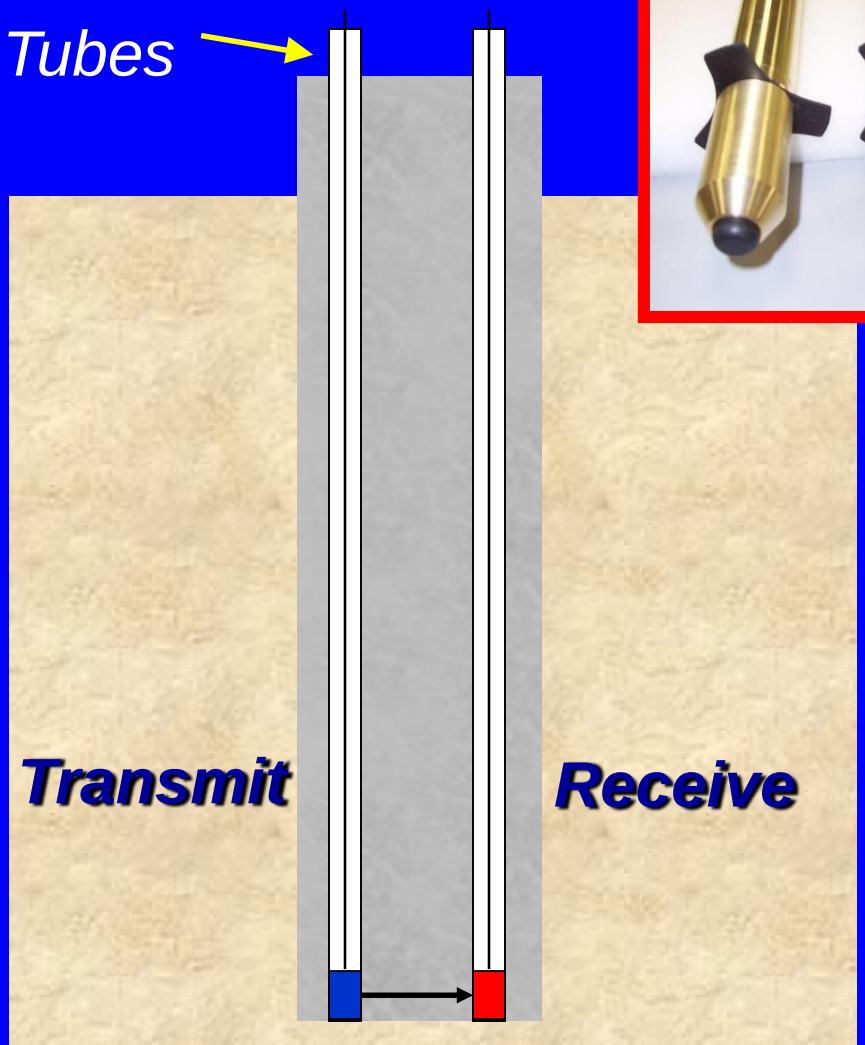
Crosshole Sonic Logging

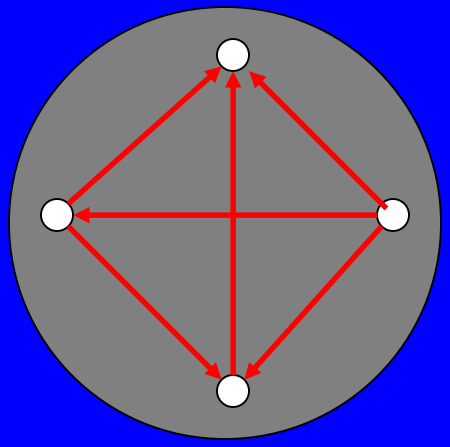
Crosshole Sonic Logging (CSL)

Overview

- Measures travel time of ultrasonic pulse between pre-placed access tubes or core holes in shaft concrete.
- Technical competence required: - Moderate.
- Relative costs: Testing - Moderate
  Overall - High
- ASTM D 6790

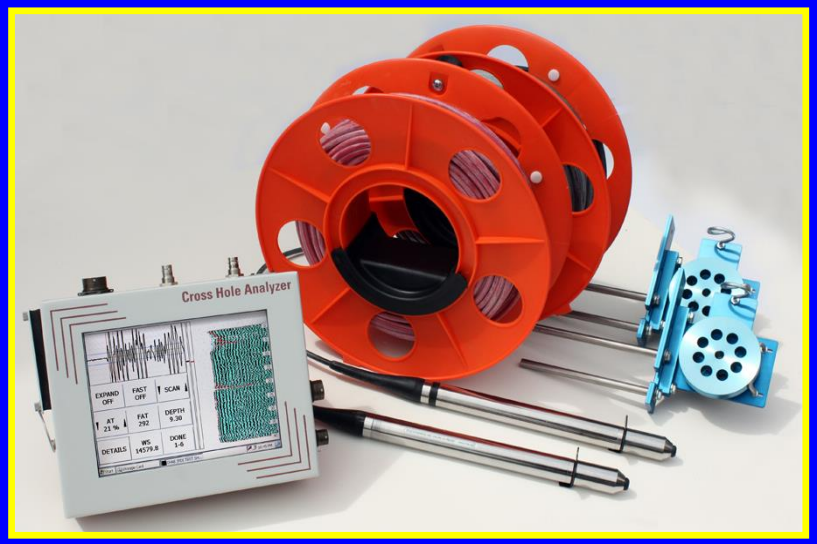
Cross Hole Sonic Logging



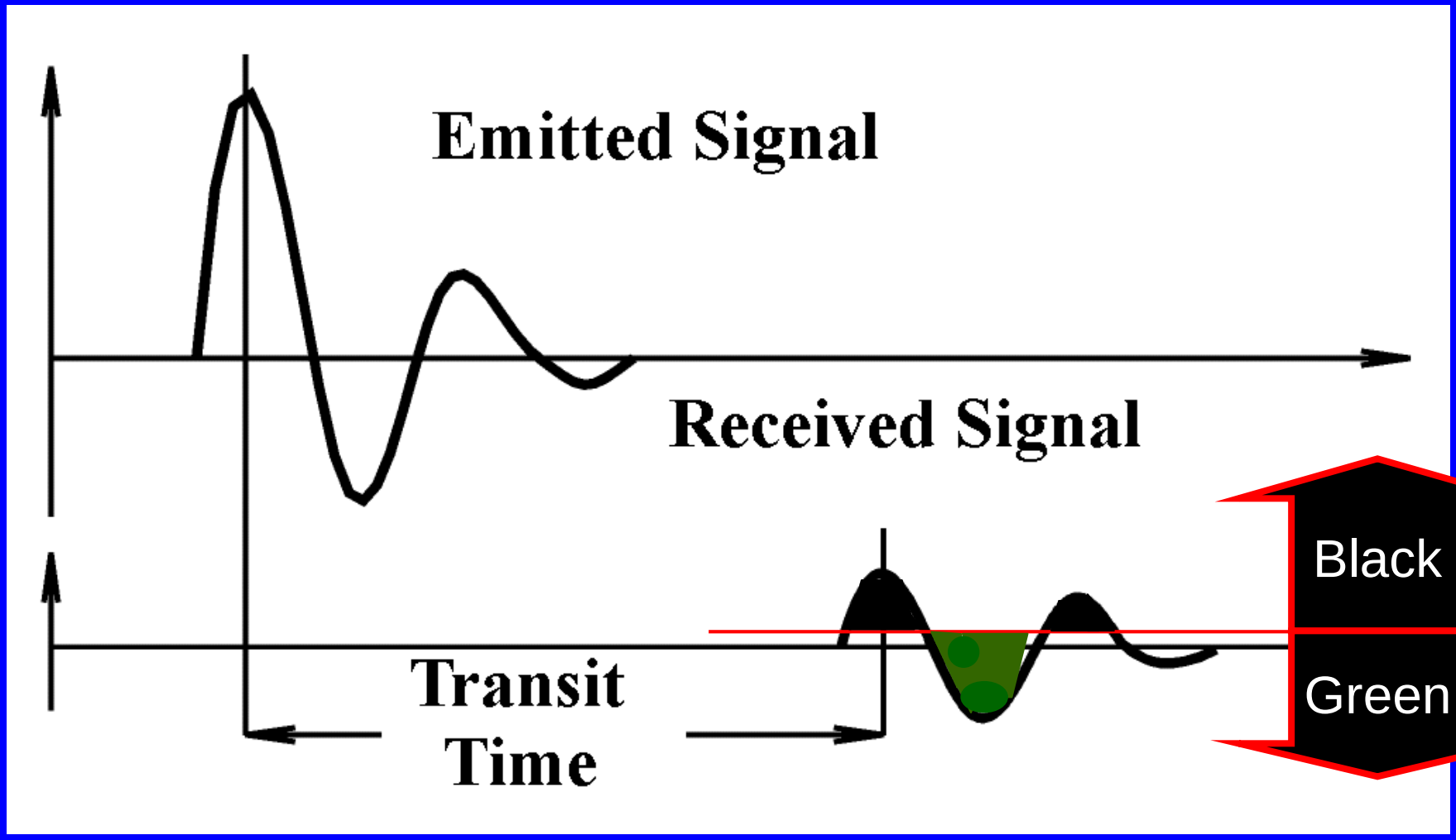


Stress Waves, emitted in one tube are received in another one if concrete quality is satisfactory

Cross Hole Sonic Logging



Cross Hole Sonic Logging

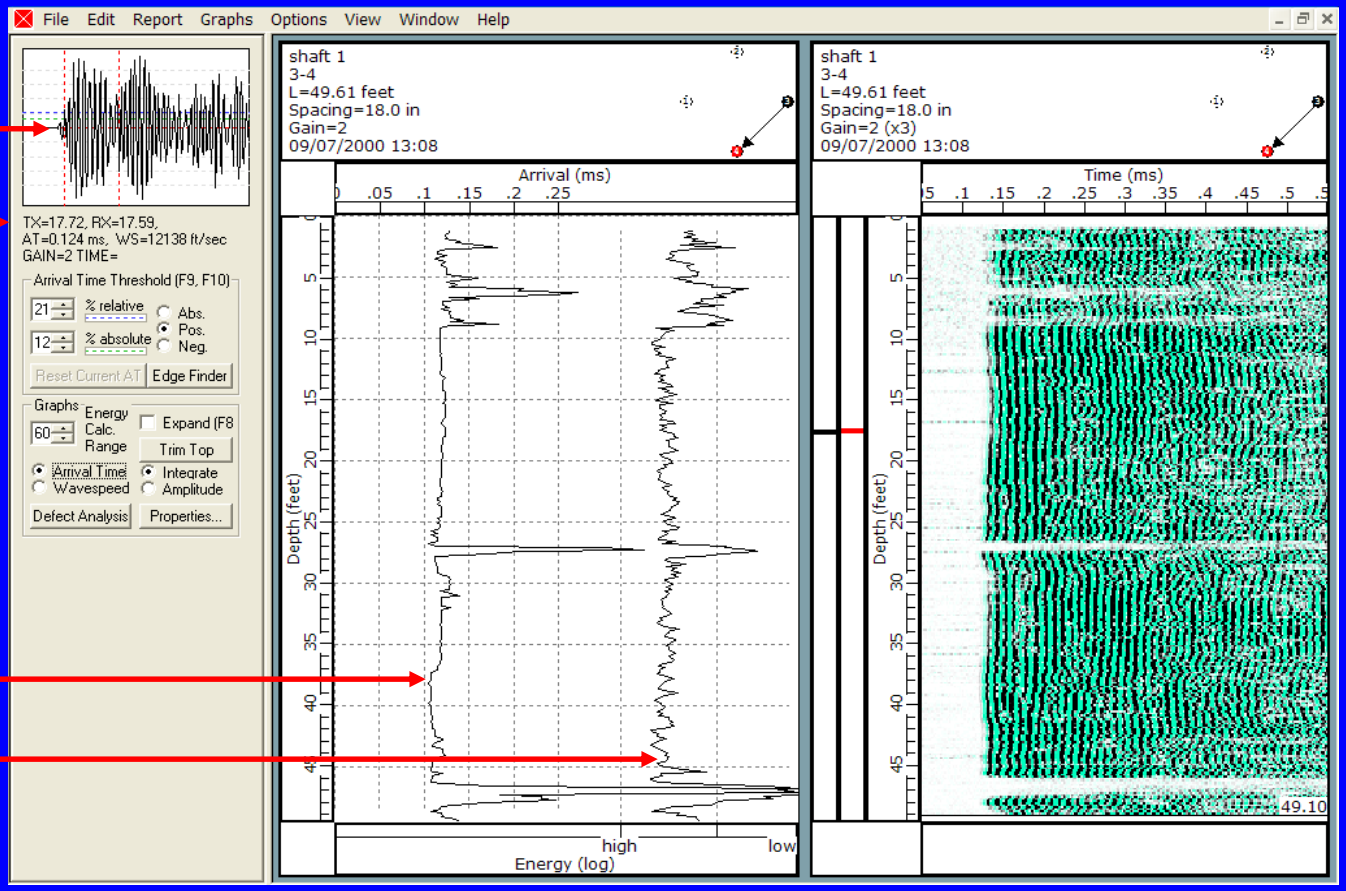


Traditional analysis

Crosshole Sonic Logging

Output

- Waterfall plot of arrival time and processed plots of arrival time (or wave speed) and energy.



Raw Signal

Depth

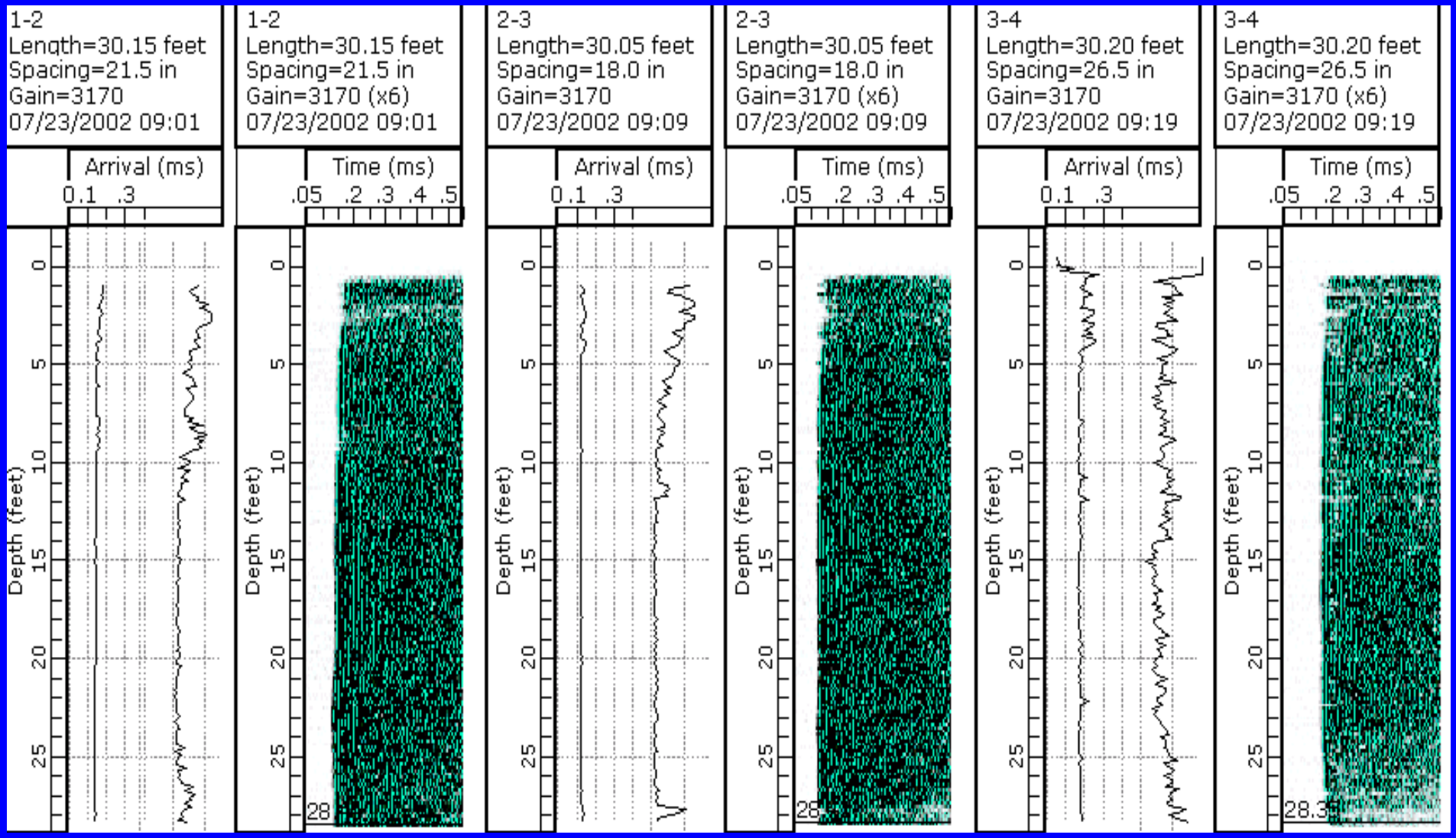
FAT

Energy

Processed Plots

Waterfall Plot (raw signal)

Crosshole Sonic Logging



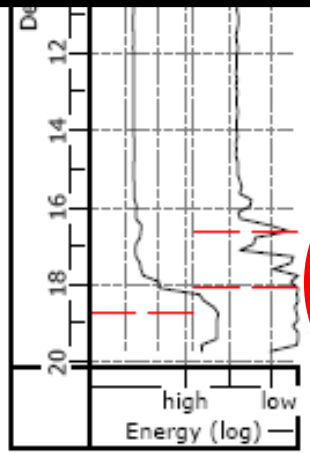
Good: FAT <10% and Energy Reduction < 6db

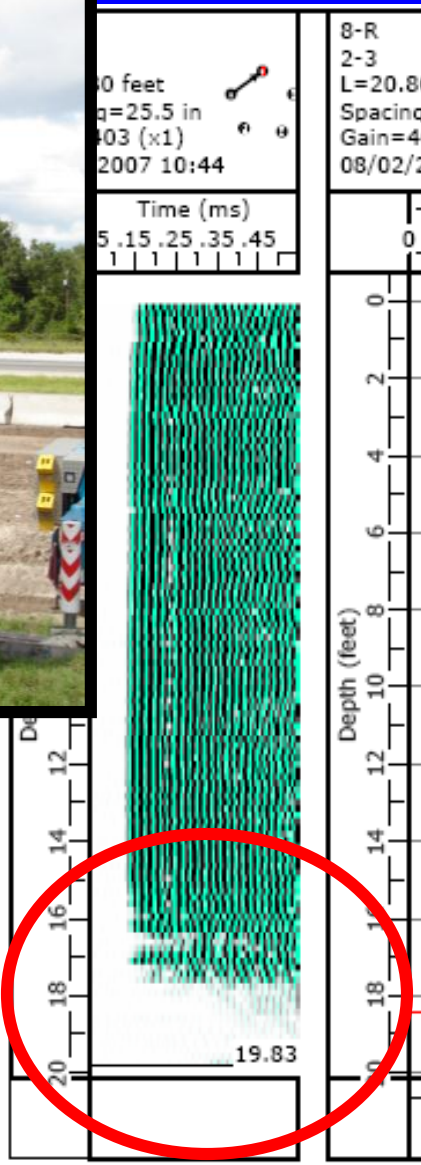
Flaw: FAT 21 to 30% or Energy Reduction 9 to 12 db

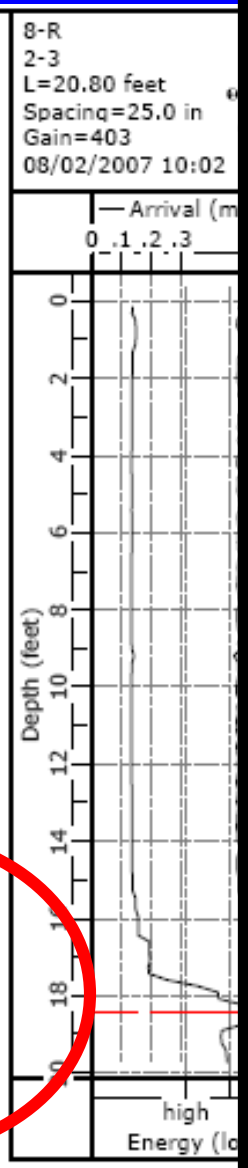
Anomaly: FAT 11 to 20% and Energy Reduction < 9db

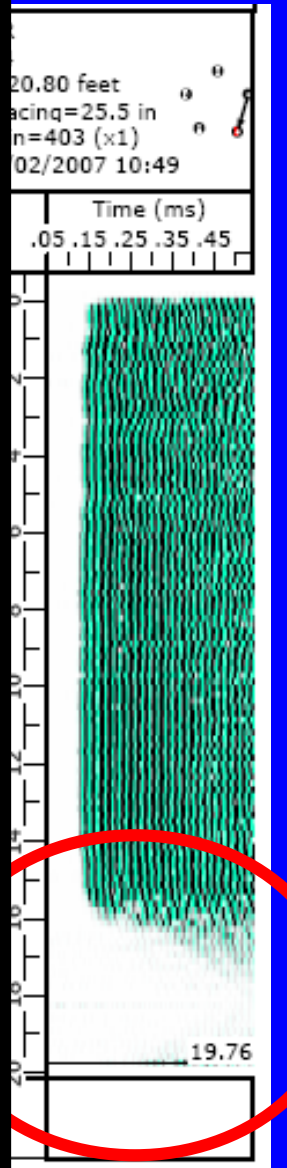
Defect: FAT > 31% or Energy Reduction > 12 db

Defective Shaft





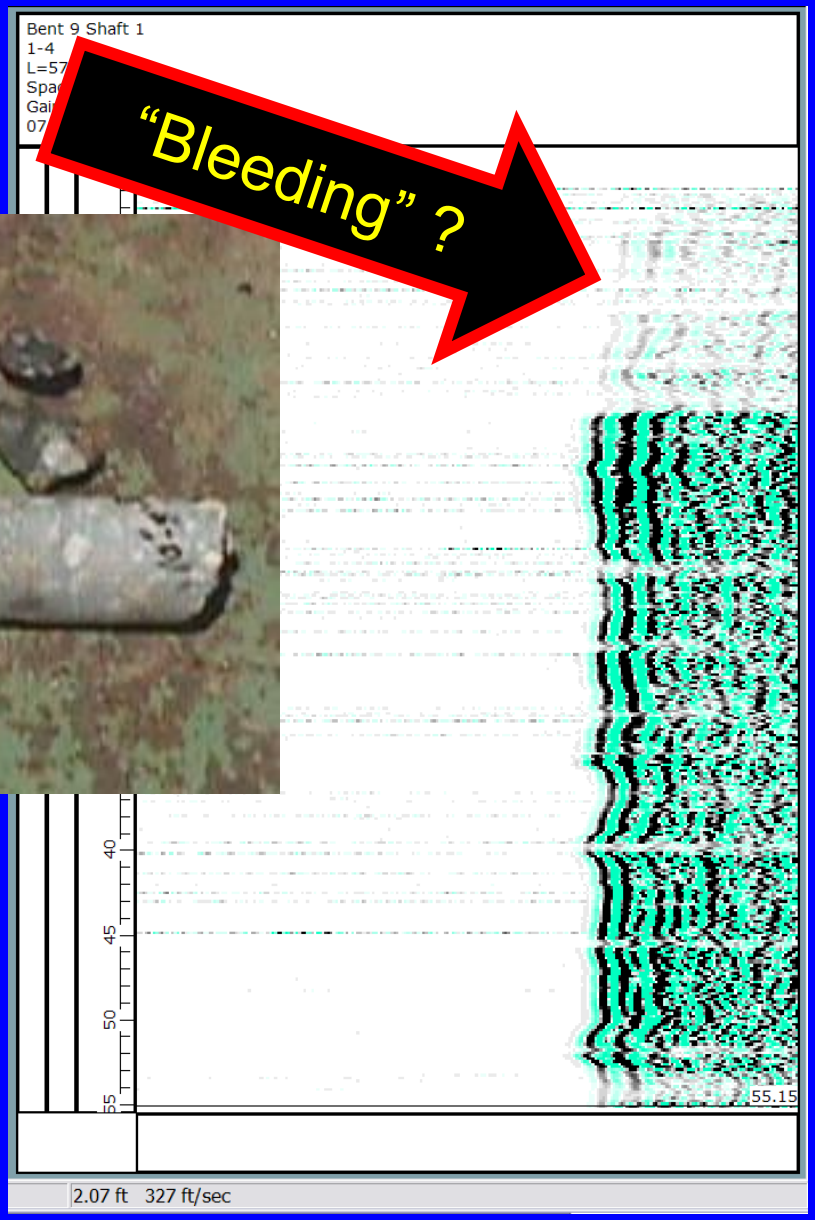




Pile Dynamics, Inc.
Cross-Hole Analyzer

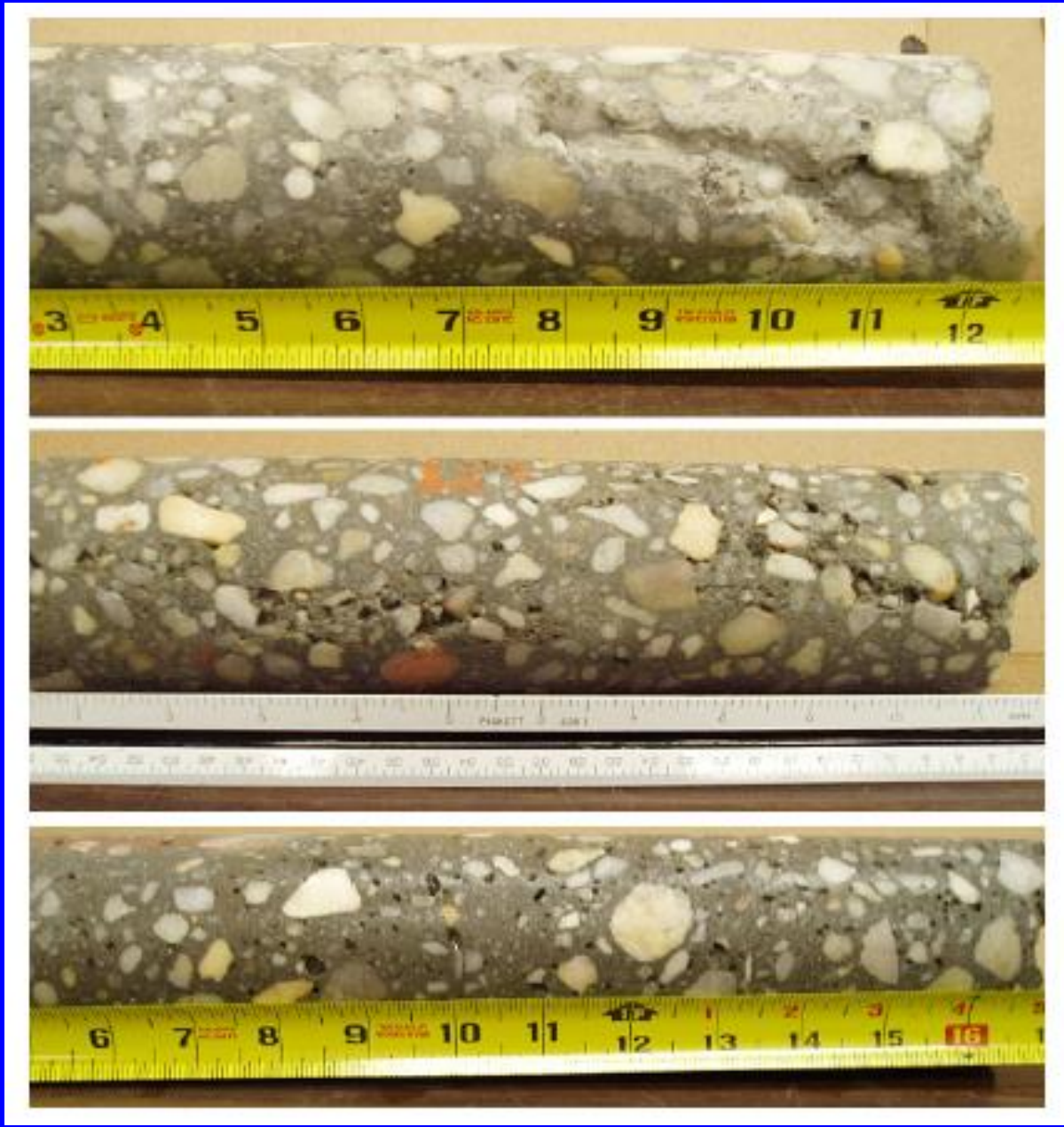
Construction Details Important

Bleed water effect

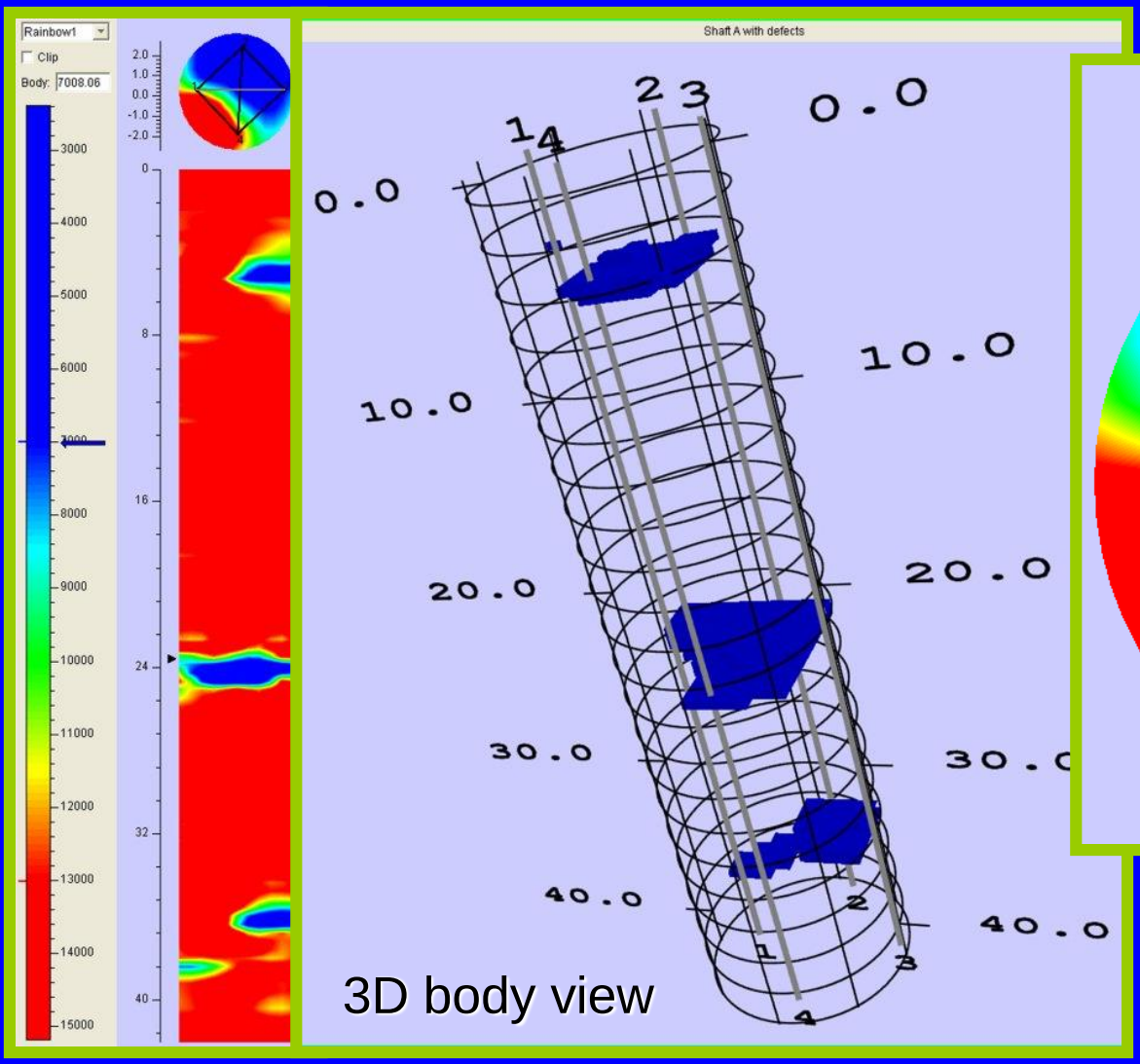


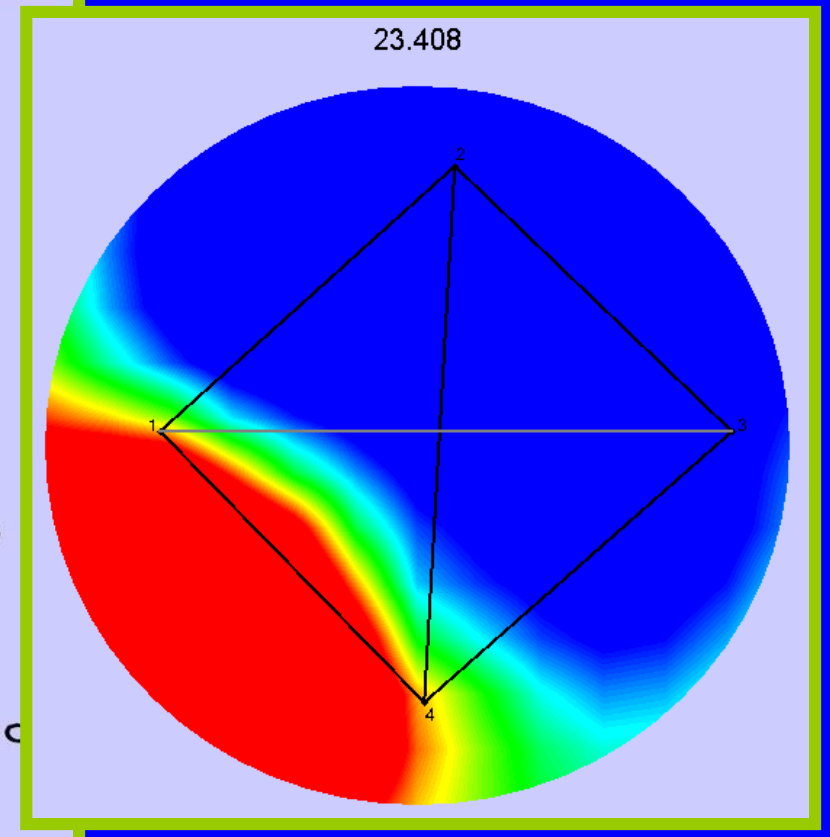
"Anomaly" not always a defect

Bleed Water Channel Effect



Tomography Analysis of CSL Data





2D horizontal slice view of a defect

Crosshole Sonic Logging

Advantages

- Test has no shaft length limitations.
- Multiple anomalies can be detected, if present.
- Checks concrete quality inside cage by depth and quadrant.
- Vertical and lateral resolution of defects possible.
- Can typically test 6 to 8 shafts per day.
  (lower number if long shafts with multiple tubes)
- Data is somewhat easier to interpret compared to other NDE methods.

Crosshole Sonic Logging

Limitations

- Requires access tubes or core holes for test.
- Shafts must be preselected for testing or access tube must be placed in all shafts.
- Sensitive to quality of bond between access tubes and concrete. *(bleed water, wet sticking of column steel, thermal shock)*
- Wait of 3 to 7 day after concrete placement required prior to testing depending on shaft size and admixtures.
- Defects outside cage or fine horizontal cracks not detectable.
- Access tube location can obstruct concrete flow.

Thermal Integrity Profiling

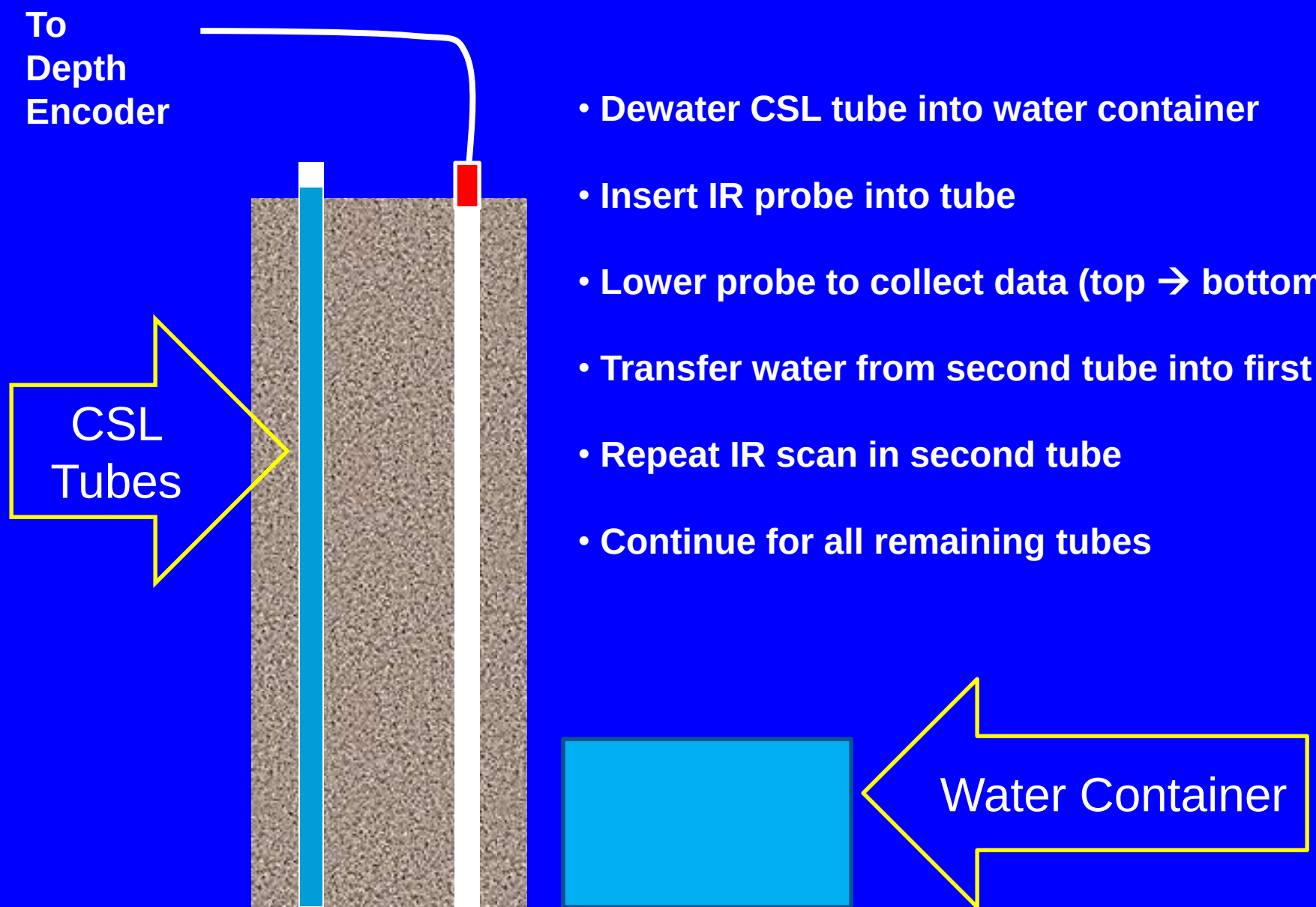
Thermal Integrity Profiling

Overview

- Measures temperature of curing concrete using a thermal wires cast into concrete or thermal probe lowered into access tubes.
- Technical competence required: - Moderate.
- Relative costs: Testing - Moderate
  Overall - Moderate to High
- ASTM D 7949

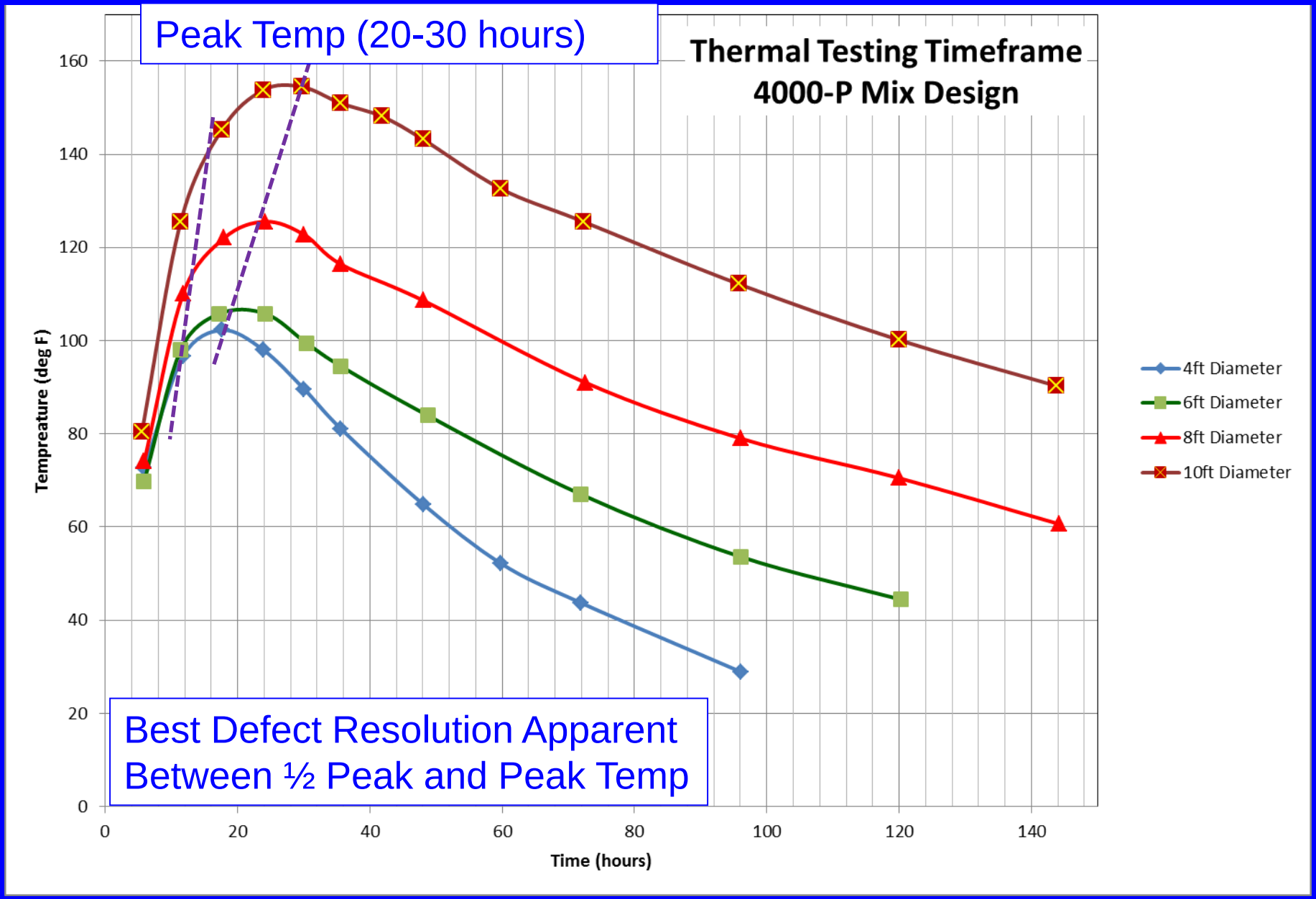
Thermal Integrity Profiling - Probe

Thermal Probes - Test Procedure

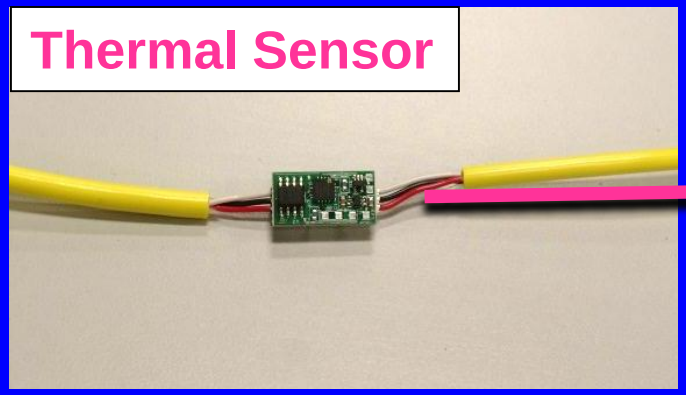


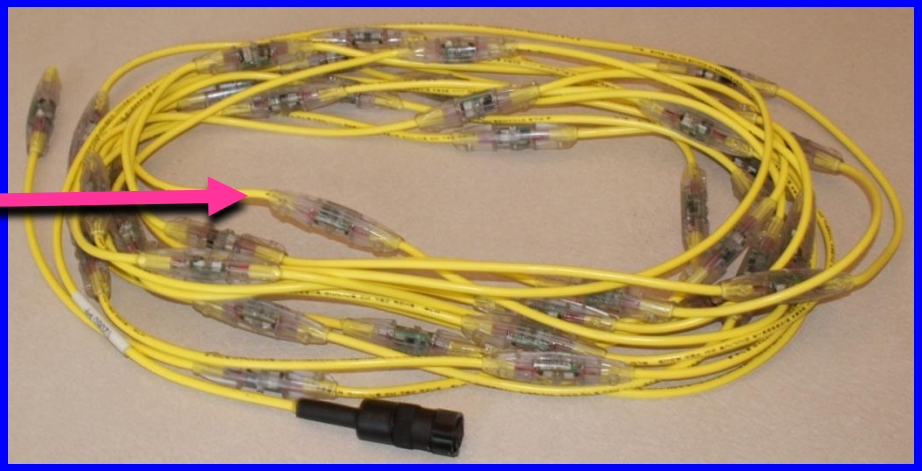
- Dewater CSL tube into water container
- Insert IR probe into tube
- Lower probe to collect data (top → bottom)
- Transfer water from second tube into first
- Repeat IR scan in second tube
- Continue for all remaining tubes

Test Window with TIP



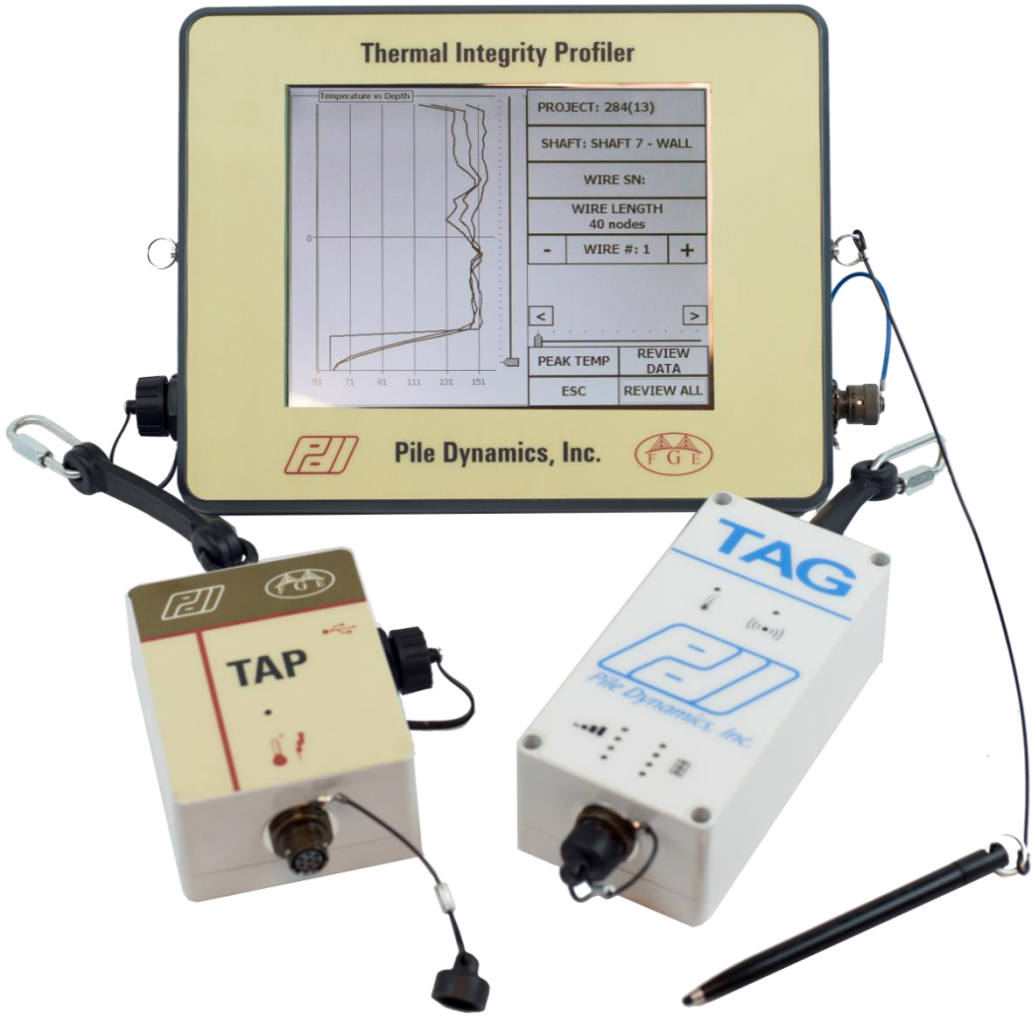
Thermal Integrity Profiling - Wire



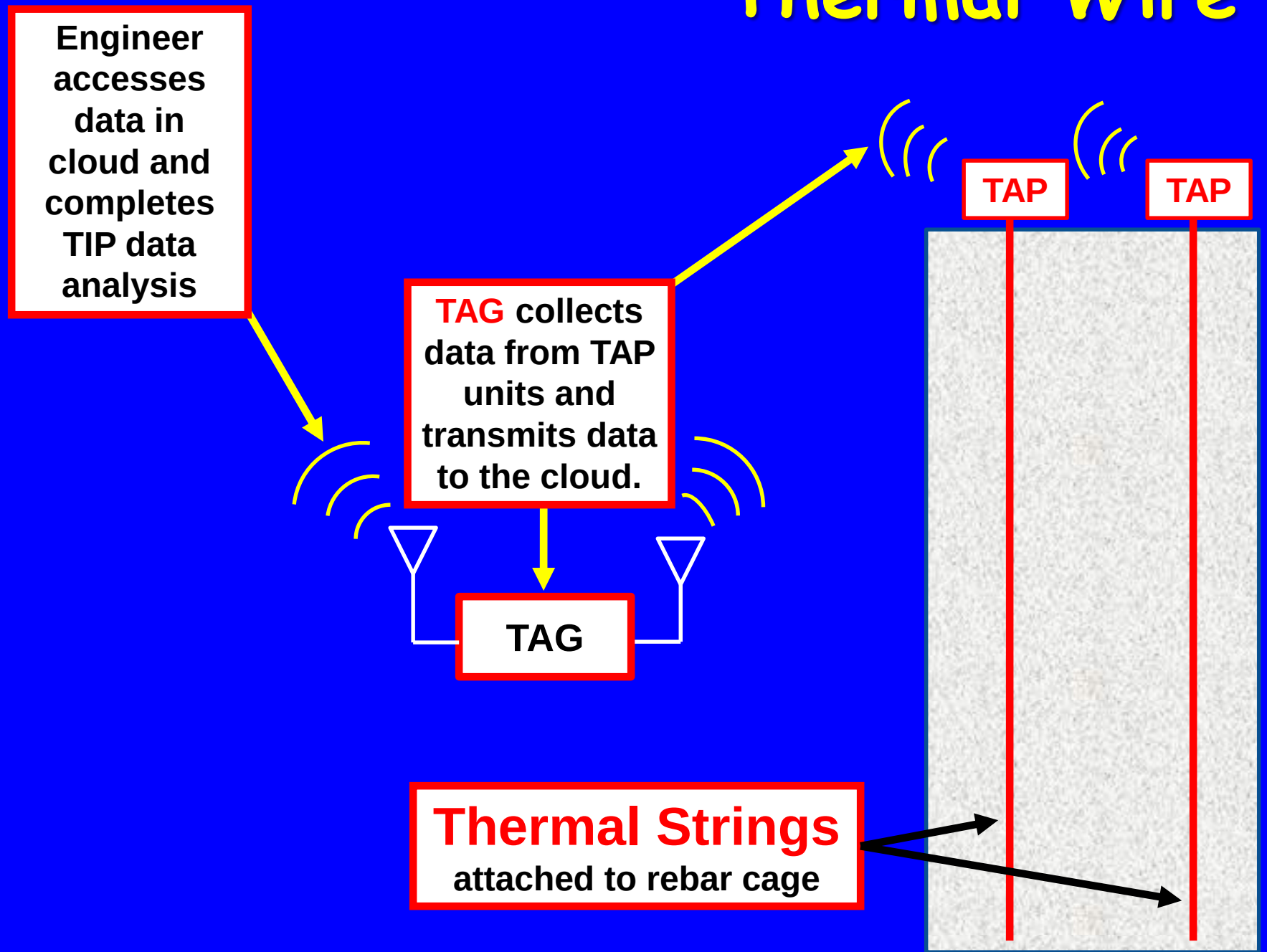


Each Thermal Wire is connected to a TAP box

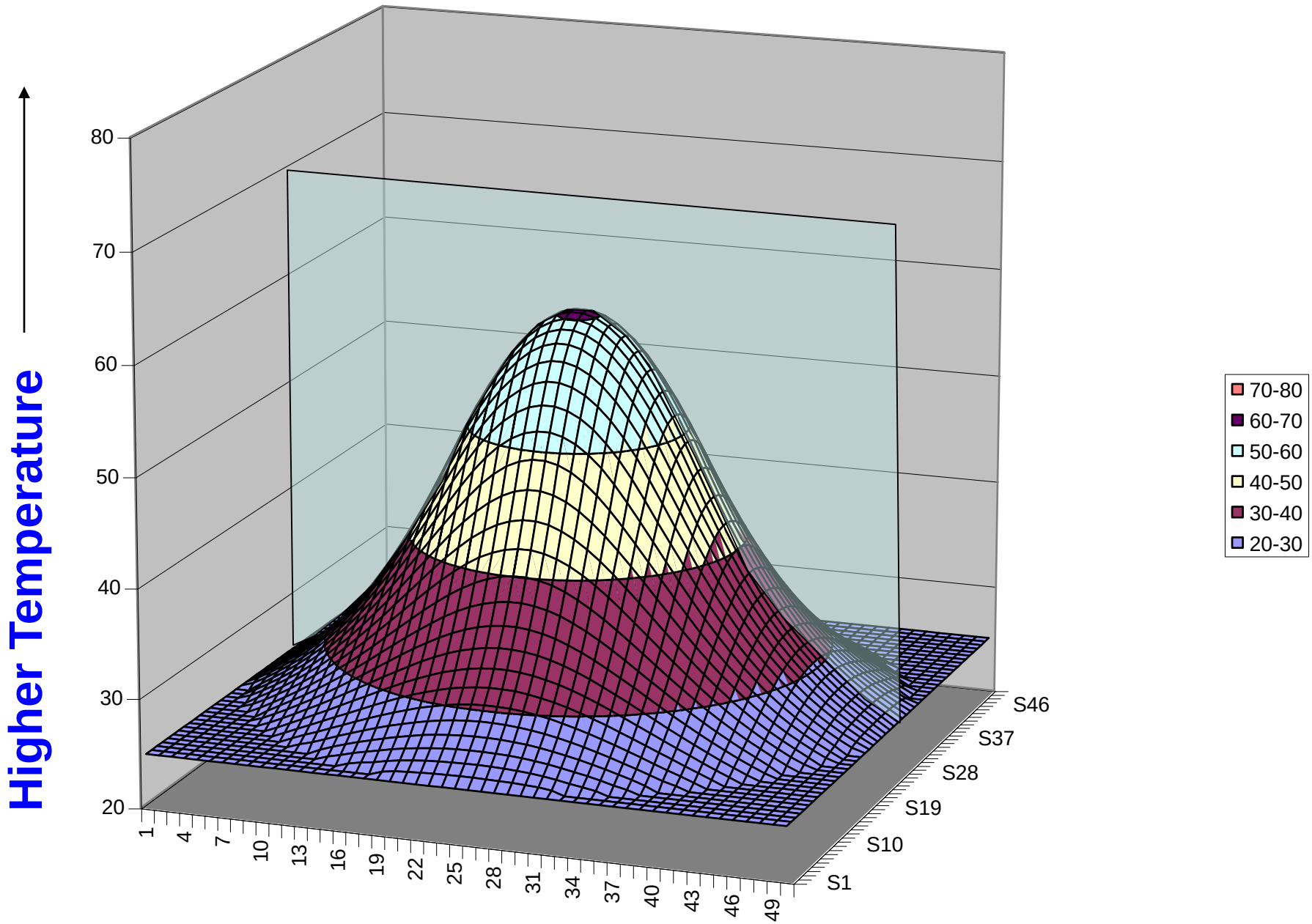
Thermal Wire Data Acquisition System

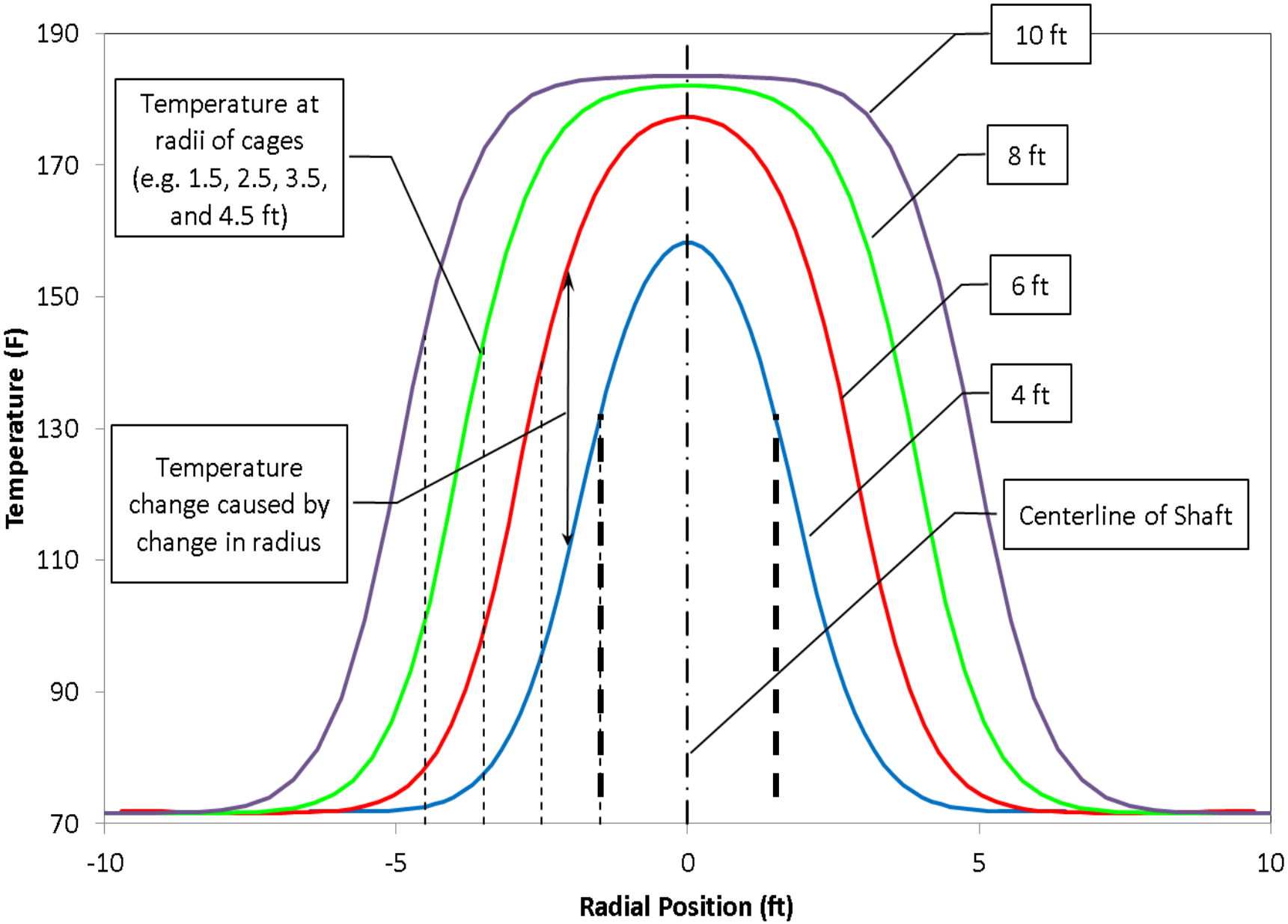


Thermal Wire

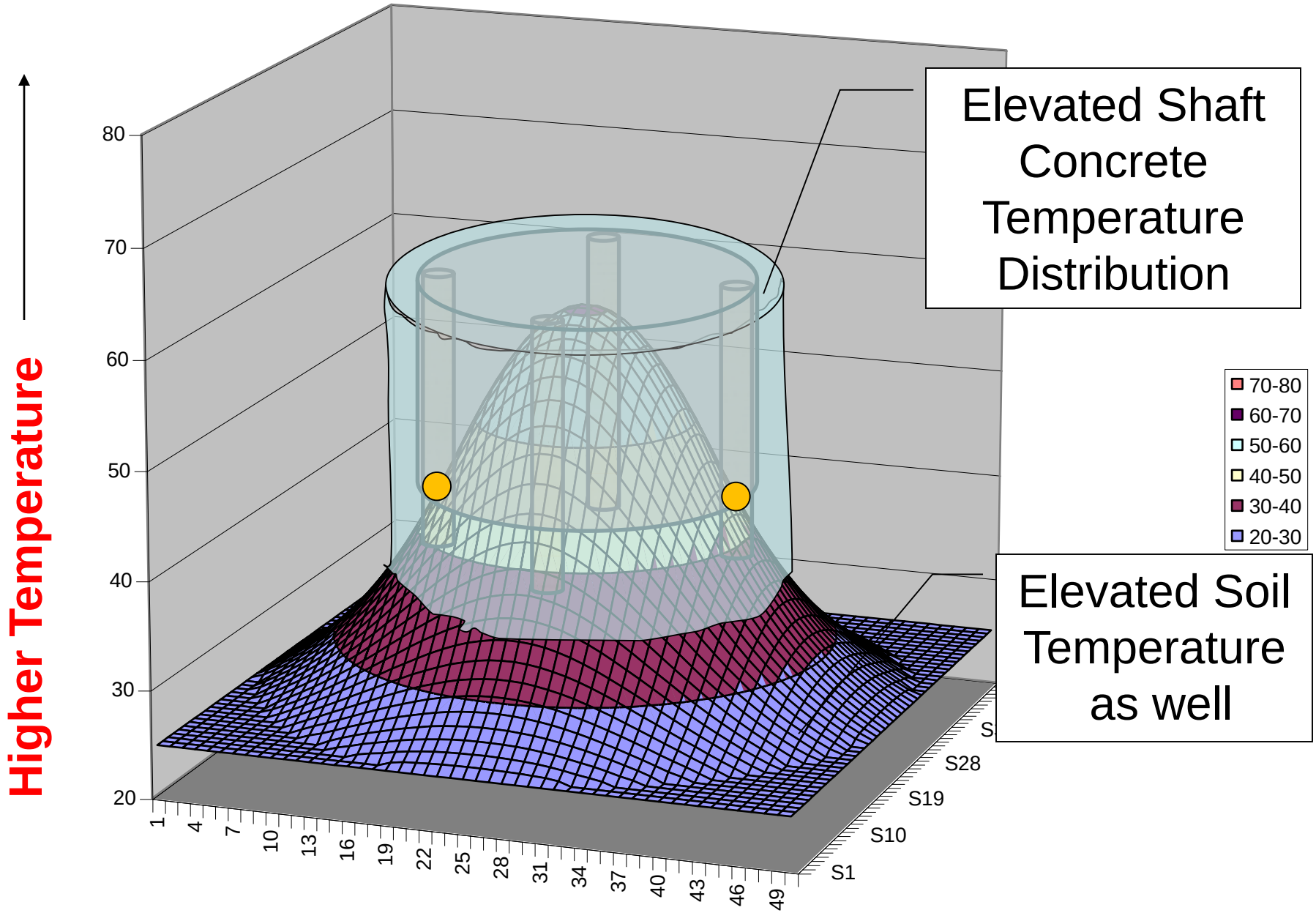


Single Shaft Heat Signature

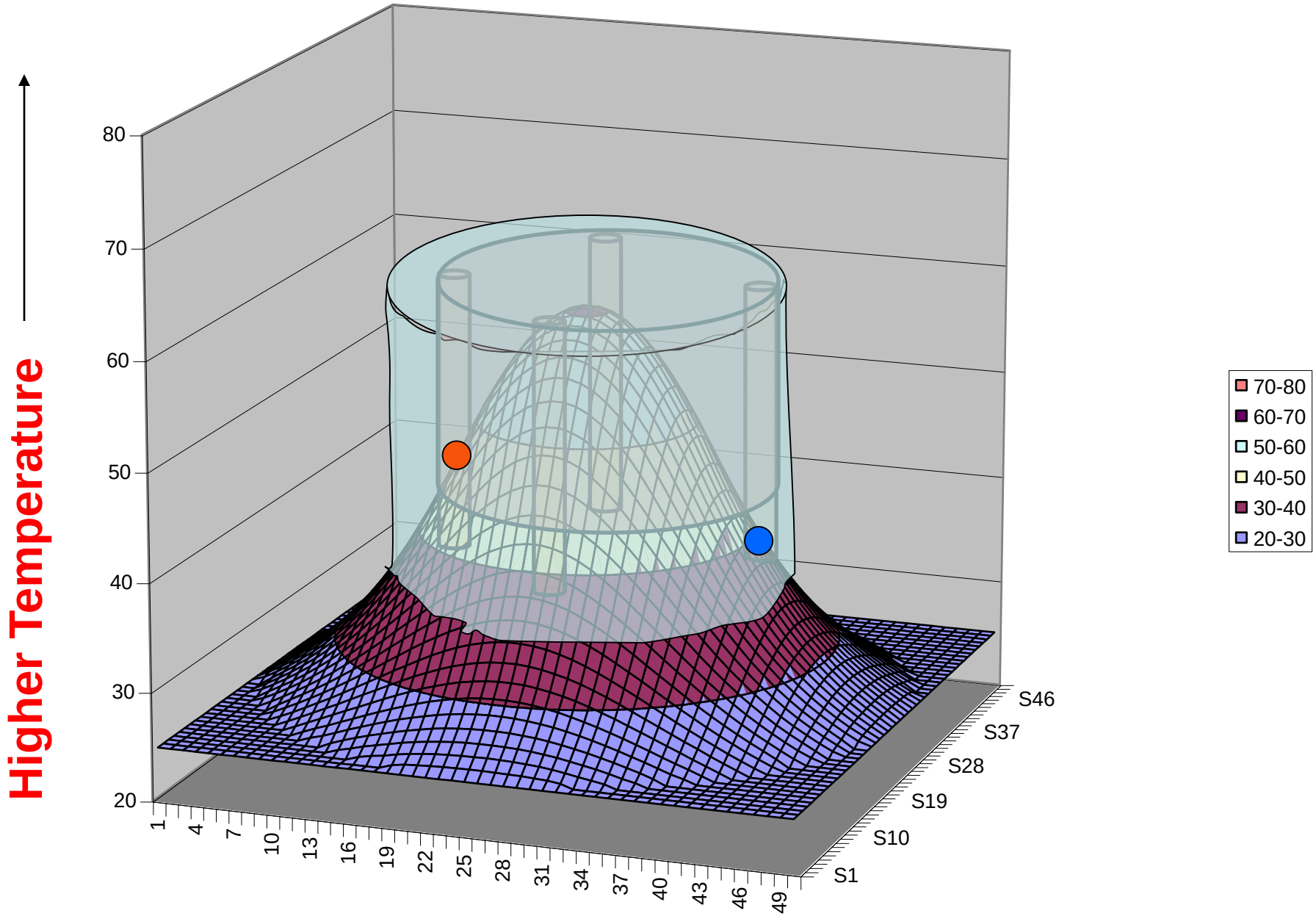


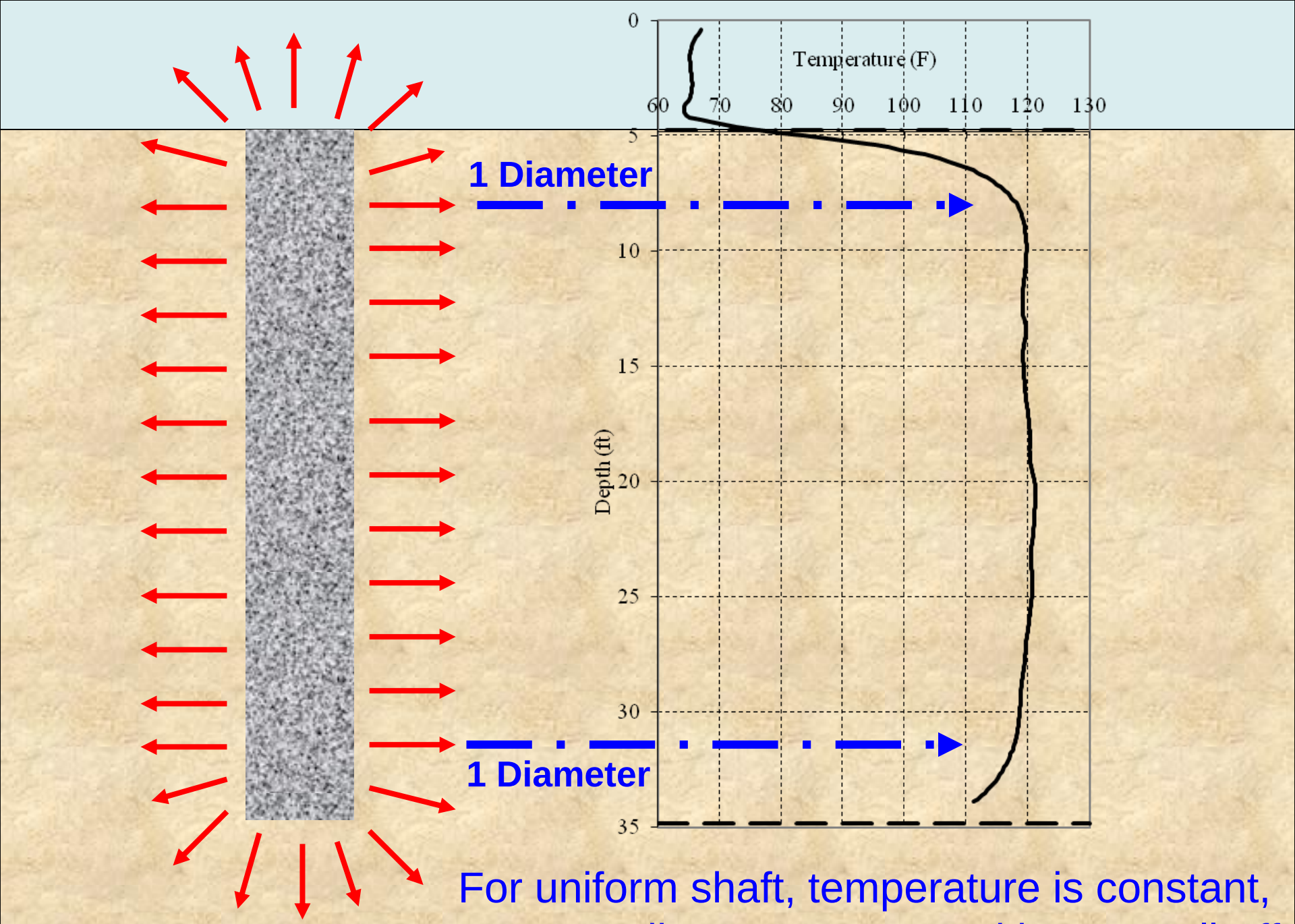

190
170
150
130
110
90
70
Temperature (F)
-10
-5
0
5
10
Radial Position (ft)
10 ft
8 ft
6 ft
4 ft
Centerline of Shaft
Temperature at radii of cages (e.g. 1.5, 2.5, 3.5, and 4.5 ft)
Temperature change caused by change in radius

Single Shaft Heat Signature



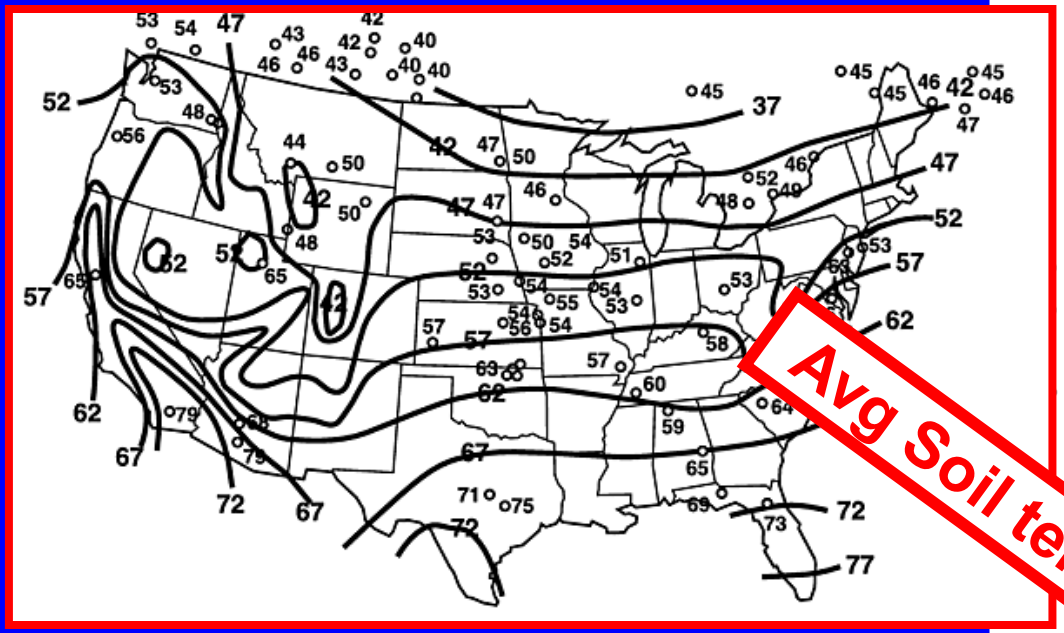
Single Shaft Heat Signature

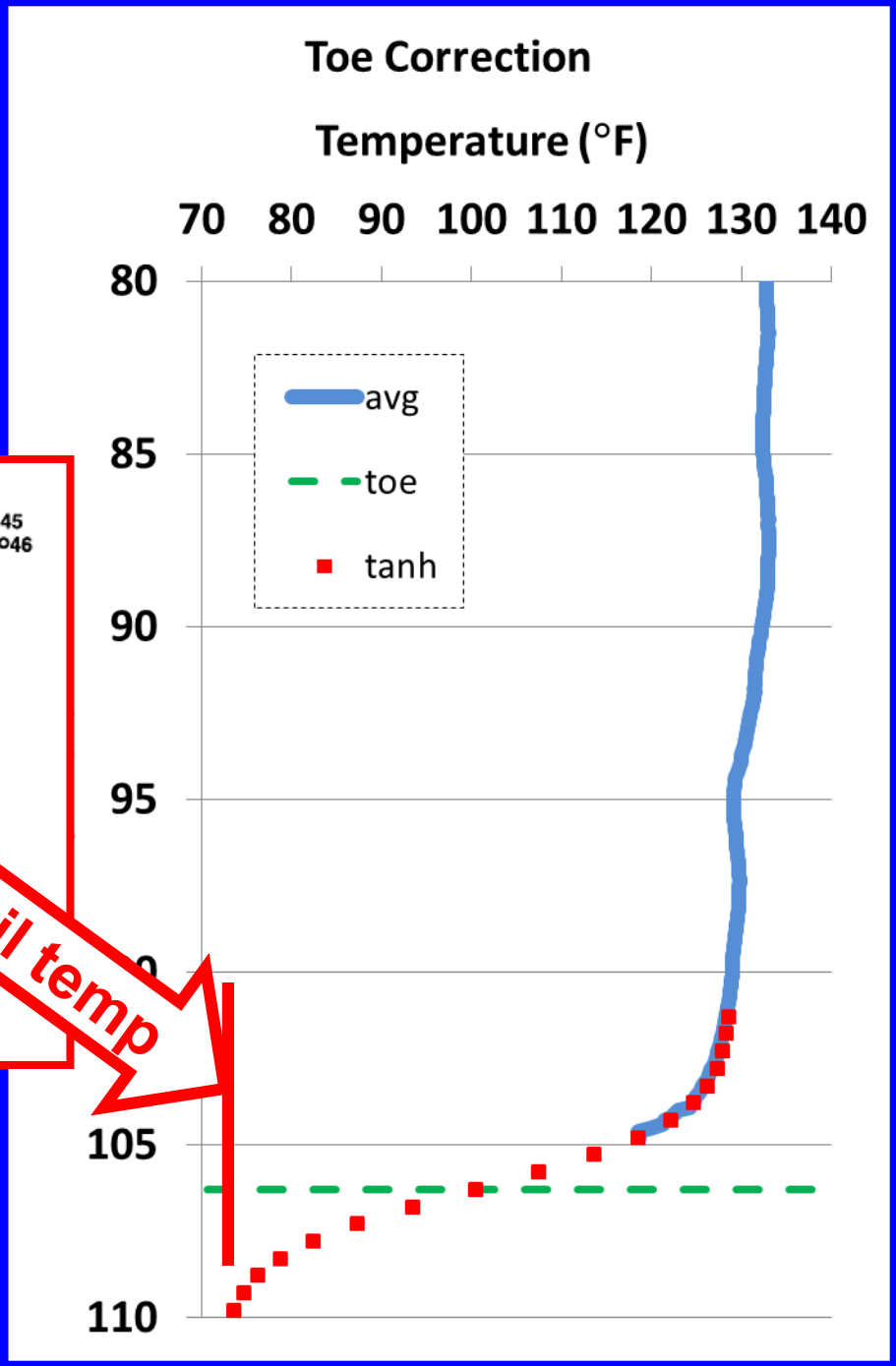




For uniform shaft, temperature is constant, except 1 diameter at top and bottom roll-off

Correcting for End Effects





End Correction Example

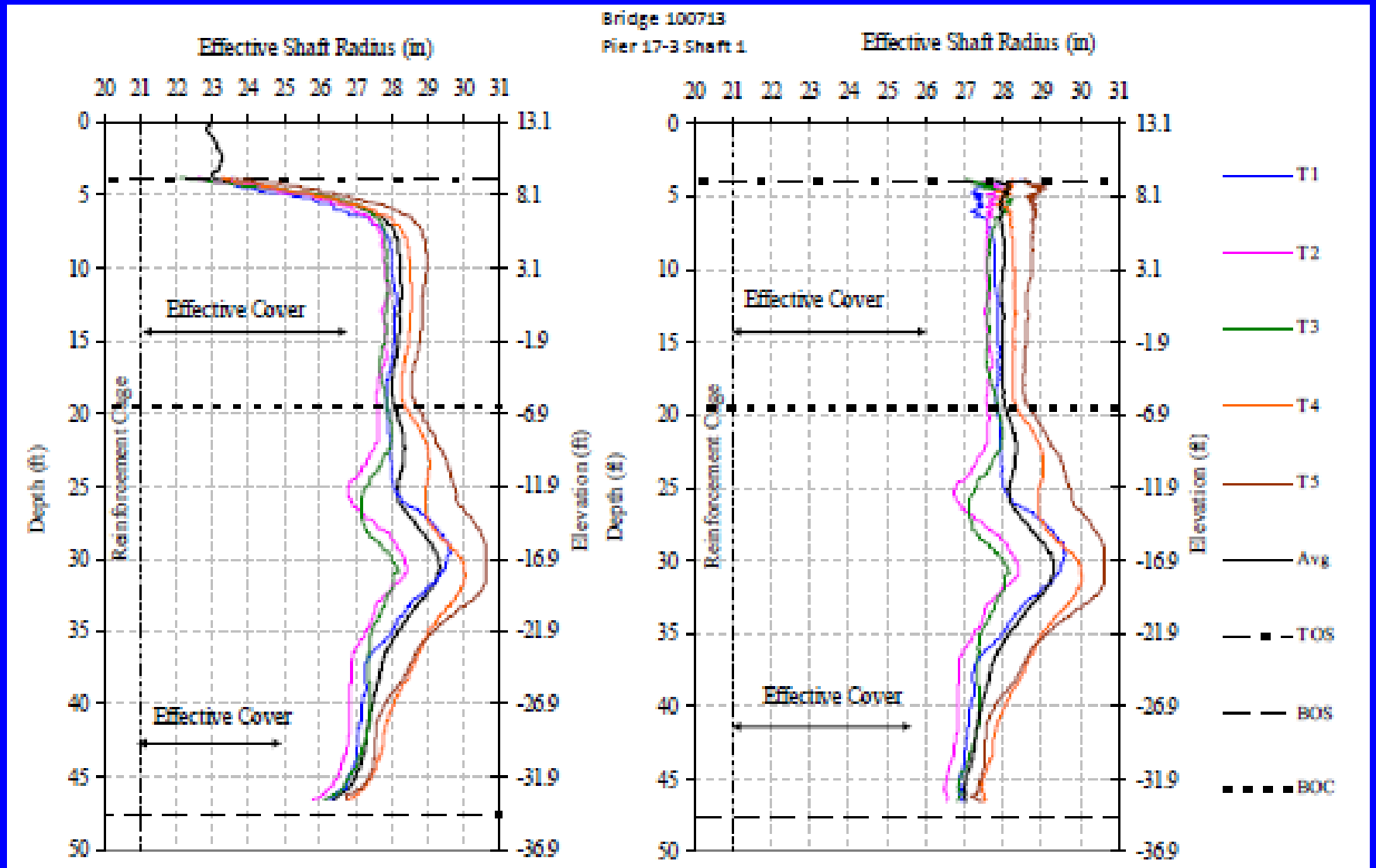
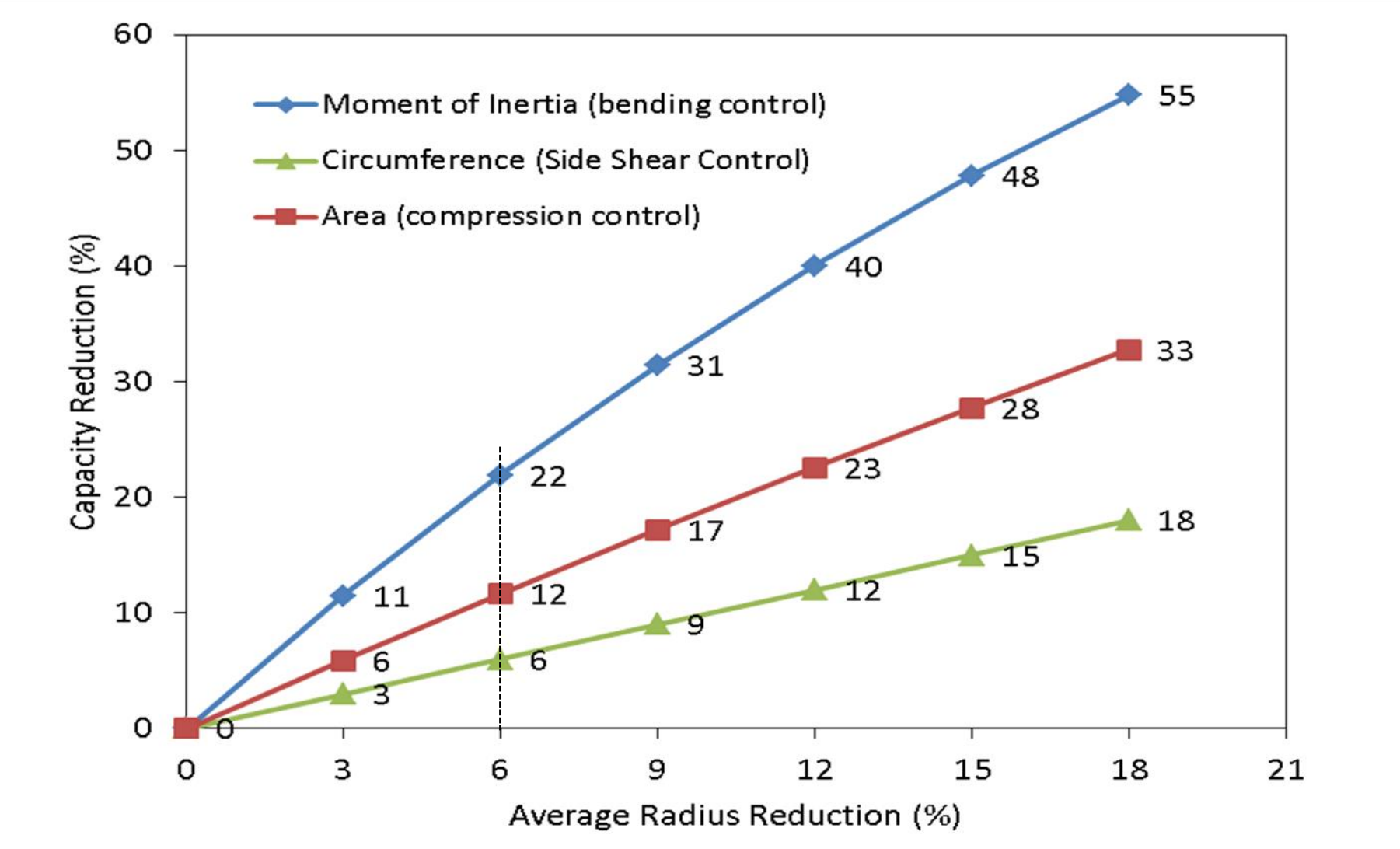


Figure 5. Effective shaft radius showing cage alignment, effective cover, and model correction for end effects.

Basis of Recommended TIP Criteria



Recommended TIP Criteria

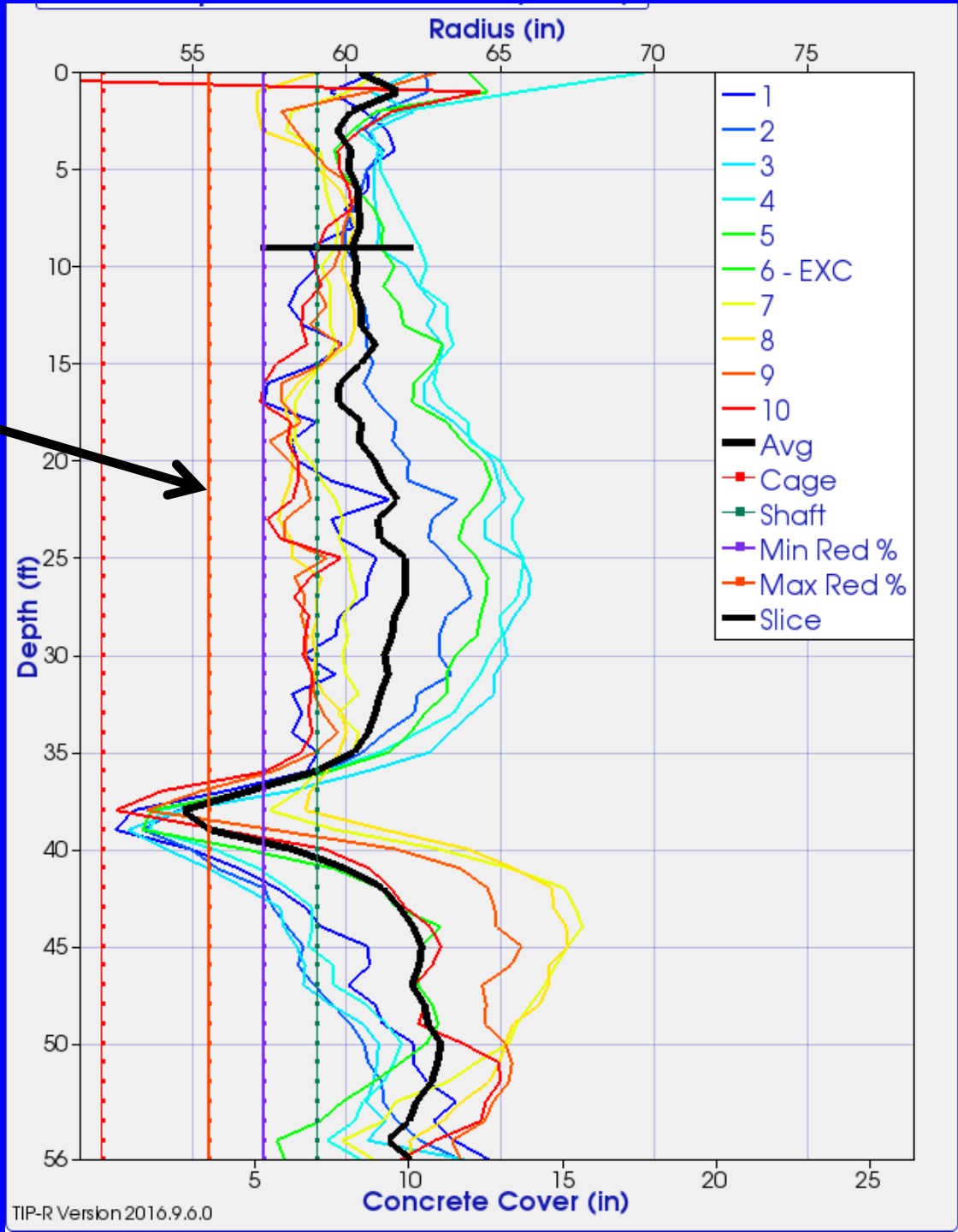
- Satisfactory
  - < 6% Radius Reduction and Cover Criteria Met
- Anomaly requiring further Evaluation
  - Radius Reduction > 6% or Cover Criteria Not Met
- A 6% reduced radius is a 12% area reduction.

Ref: "Drilled Shaft Acceptance Criteria Based upon Thermal Integrity Profiling", Piscsalko et al., DFI Annual Conference 2016.

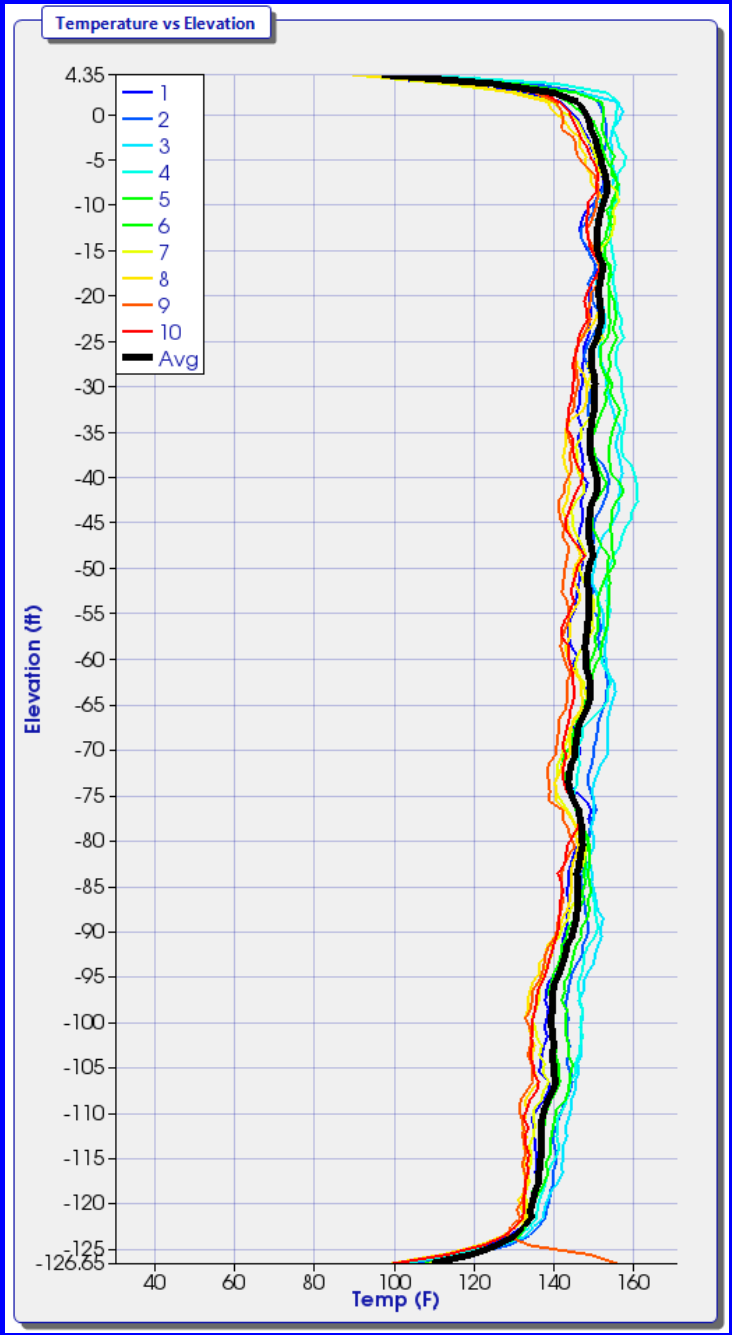
www.pile.com

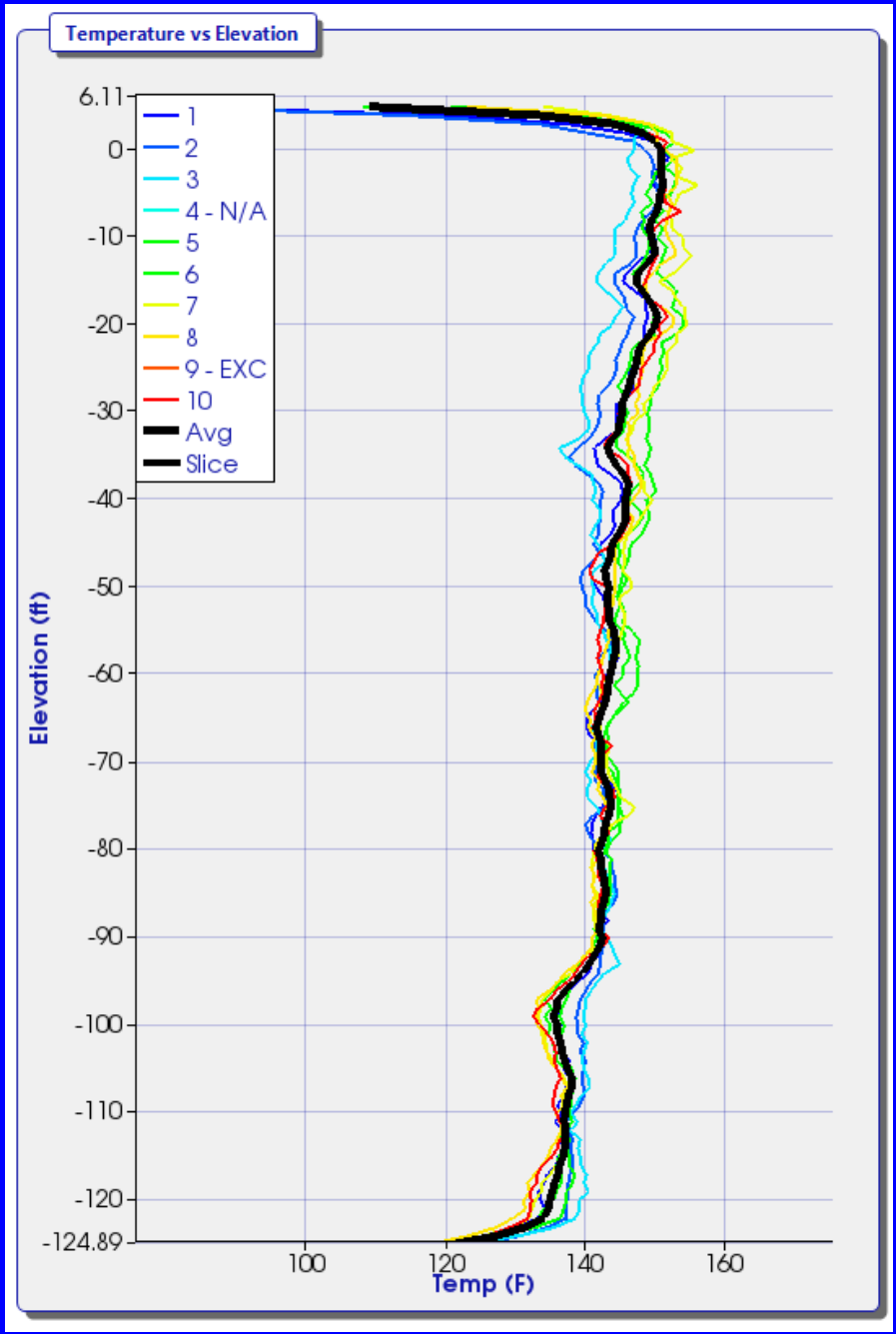
TIP Criteria Example

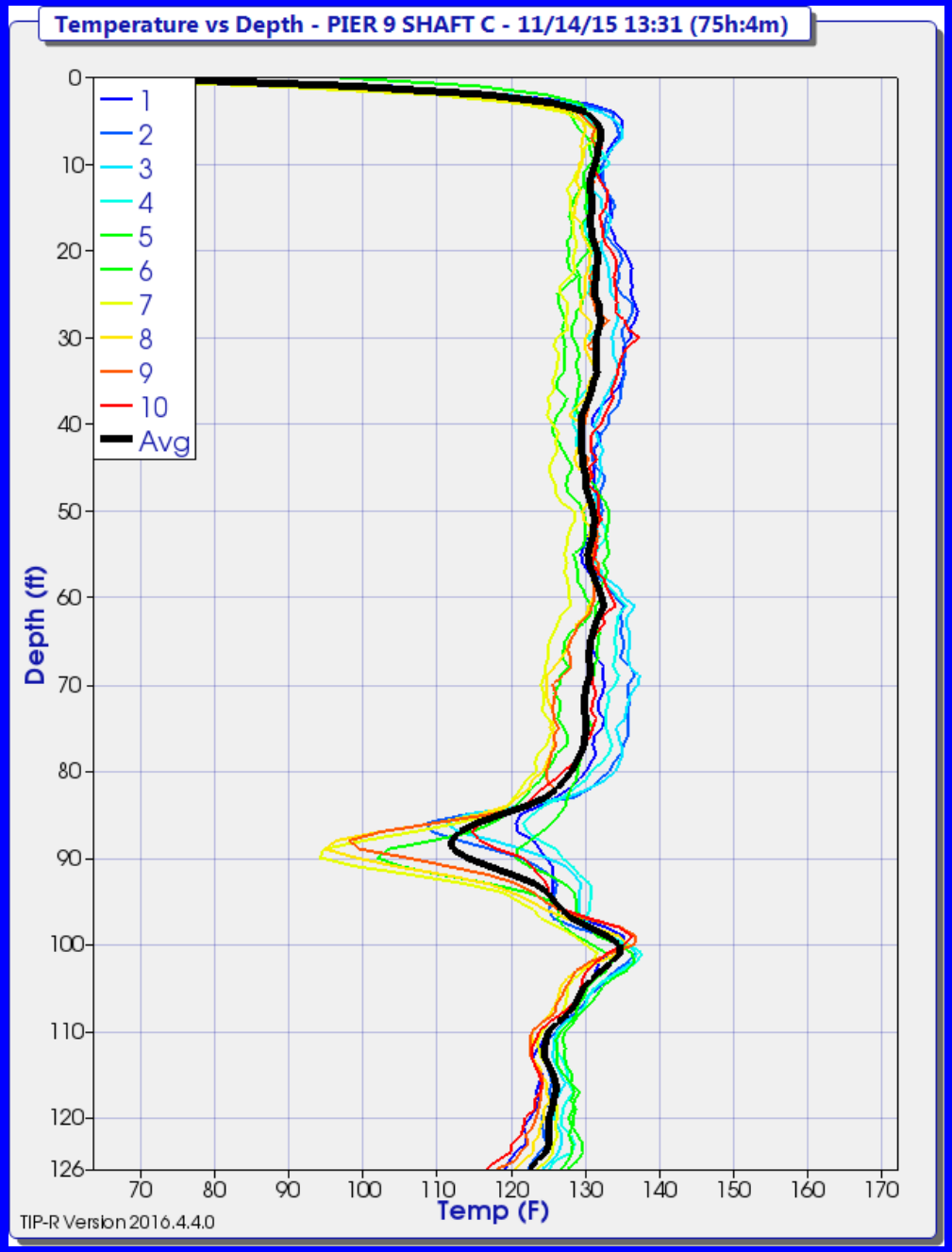
- Orange vertical line is a 6% radius reduction.
- This 6% reduction would trigger further evaluation per TIP Criteria.
- Note the accuracy of the shaft volume is important to radius calculation.

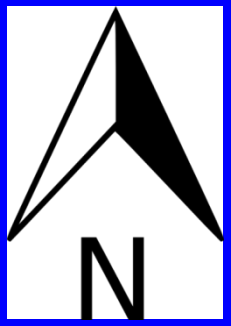


I-5 Bridge over Puyallup River Tacoma, Washington


Temperature vs Elevation
1
2
3
4
5
6
7
8
9
10
Avg
Elevation (ft)
4.35
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100
-105
-110
-115
-120
-125
-126.65
40
60
80
100
120
140
160
Temp (F)


Temperature vs Elevation
1
2
3
4 - N/A
5
6
7
8
9 - EXC
10
Avg
Slice
Elevation (ft)
6.11
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-124.89
100
120
140
160
Temp (F)


Temperature vs Depth - PIER 9 SHAFT C - 11/14/15 13:31 (75h:4m)
1
2
3
4
5
6
7
8
9
10
Avg
Depth (ft)
0
10
20
30
40
50
60
70
80
90
100
110
120
126
70
80
90
100
110
120
130
140
150
160
170
Temp (F)
TIP-R Version 2016.4.4.0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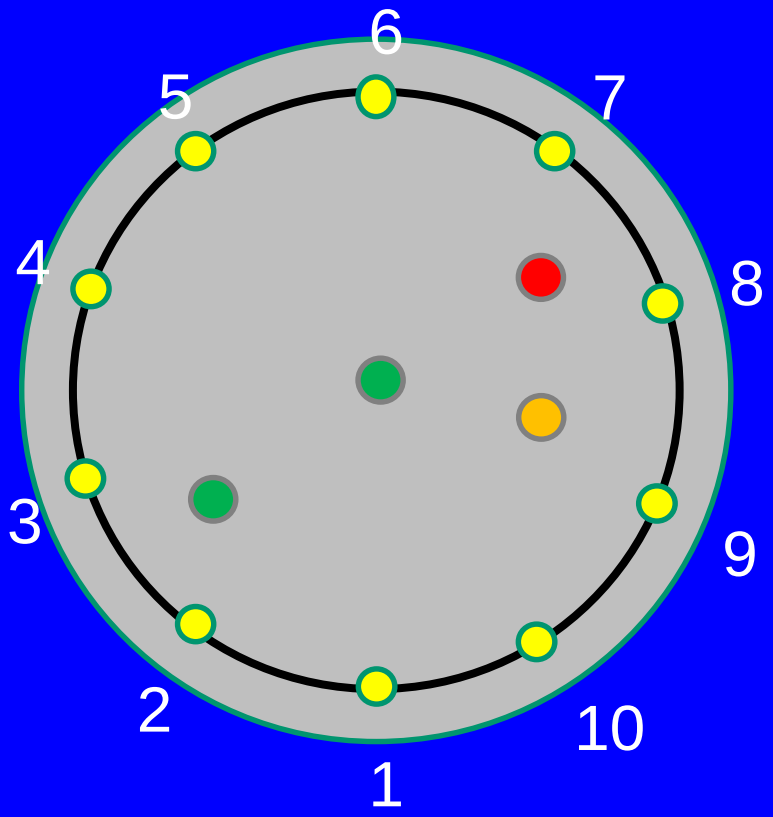
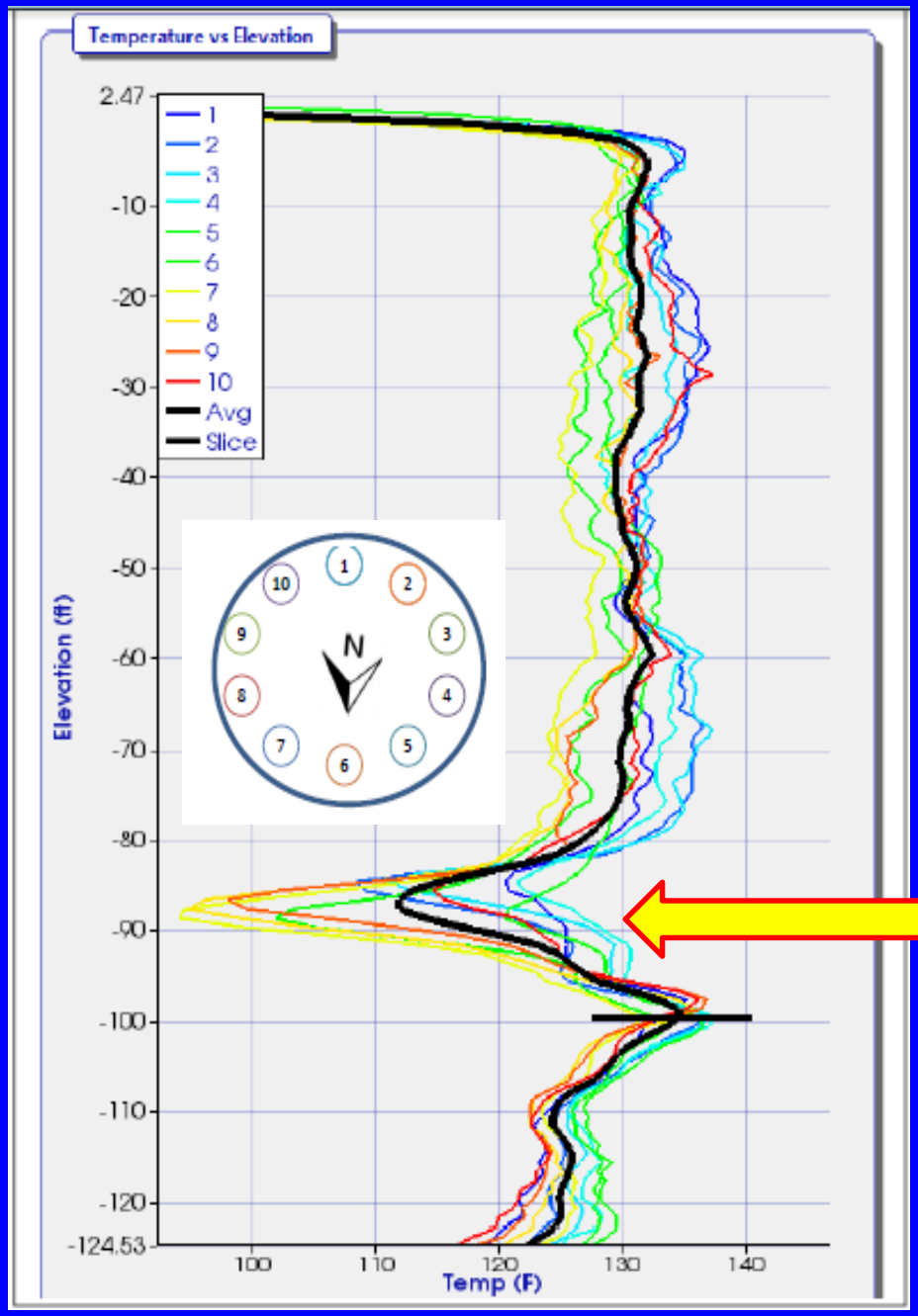

6
5
7
4
8
3
9
2
10
1



November 2015
10 ft. diameter shaft
8.5 ft. diameter cage

Core near wires 7 and 8

Thermal Integrity Profiling

Advantages

- Test has no shaft length limitations.
- Method capable of detecting cage shift / alignment.
- Multiple anomalies inside or outside the cage detectable.
- Vertical and lateral resolution of defects possible.
- Shaft integrity can be evaluated and reported earlier than with crosshole sonic logging or low strain integrity test.
- Shafts can be wired and data collected by inspection or contractor personnel and sent to engineer for analysis.
- Data interpretation easier compared to surface NDT methods.

Thermal Integrity Profiling

Disadvantages – Wire Method

- Wires must be attached to cage before cage placement.
- Shafts must be preselected for testing or wires must be attached to all shafts.
- Wires can be damaged by construction activities.
- Fine horizontal cracks or thin defects not detectable.

Thermal Integrity Profiling

Disadvantages – Probe Method

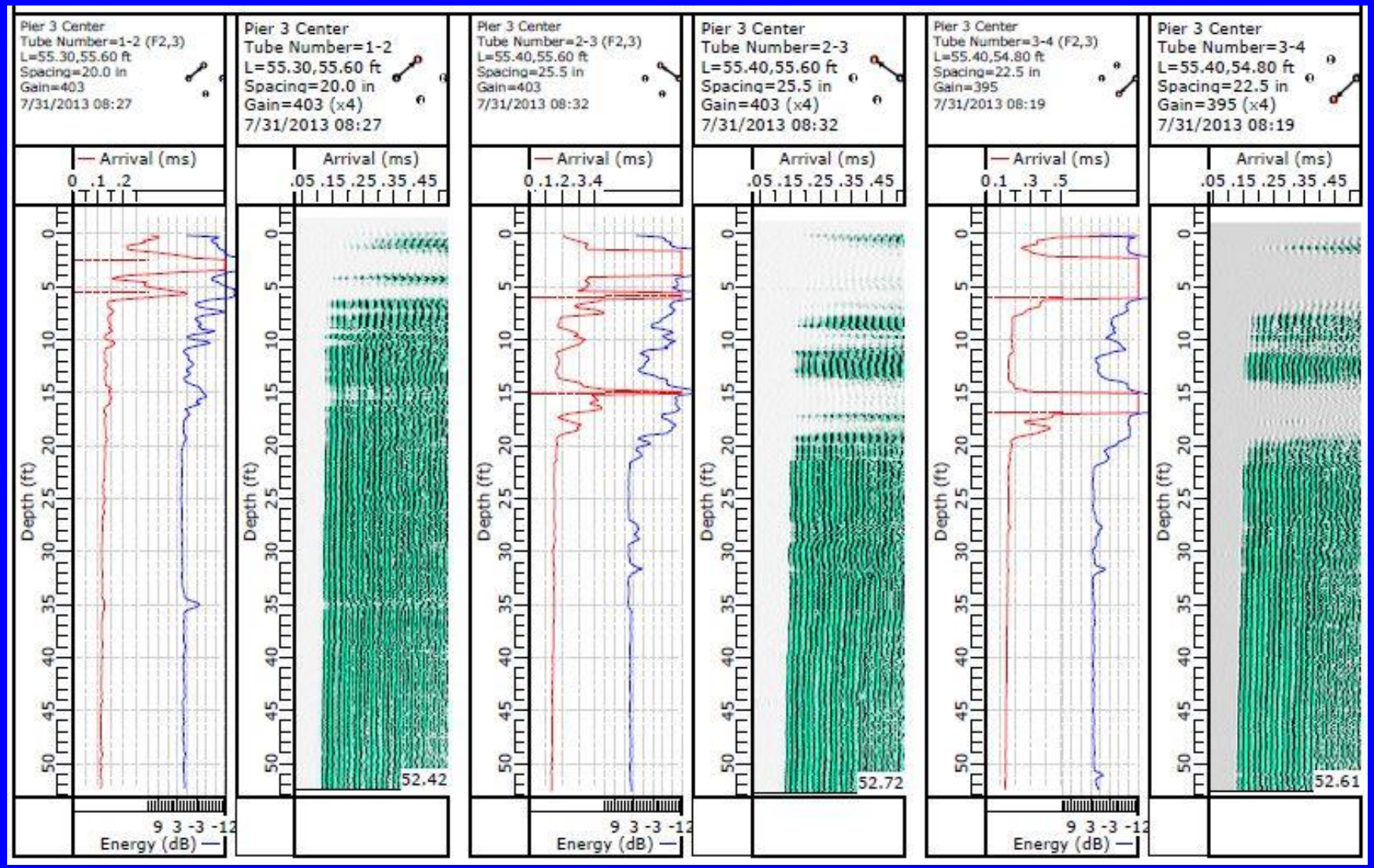
- Requires dry access tubes for test.
- Shafts must be preselected for testing or access tube must be placed in all shafts.
- Tests must be conducted within time window of peak temperature relative to shaft diameter and concrete mix.
- Fine horizontal cracks or thin defects not detectable
- Access tube locations can obstruct concrete flow.

Quick Comparison of Integrity Test Results on Same Shaft:

- Crosshole Sonic Logging
- Low Strain Integrity
- Thermal Integrity Profiling

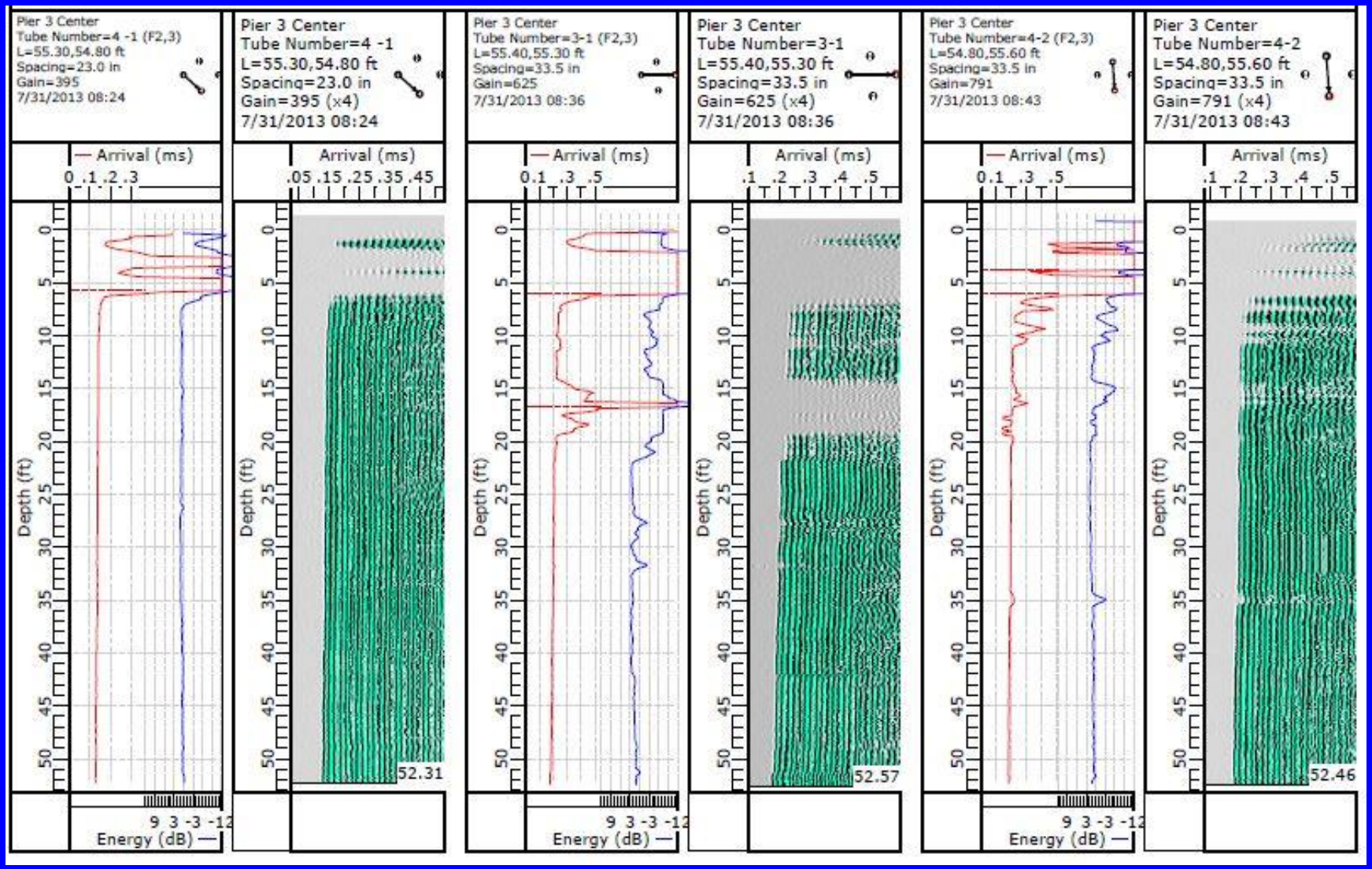
Crosshole Sonic Logging Results

Potential Issues Upper 7 Ft and from 15 to 20 Ft



Crosshole Sonic Logging Results

Potential Issues Upper 7 Ft and from 15 to 20 Ft



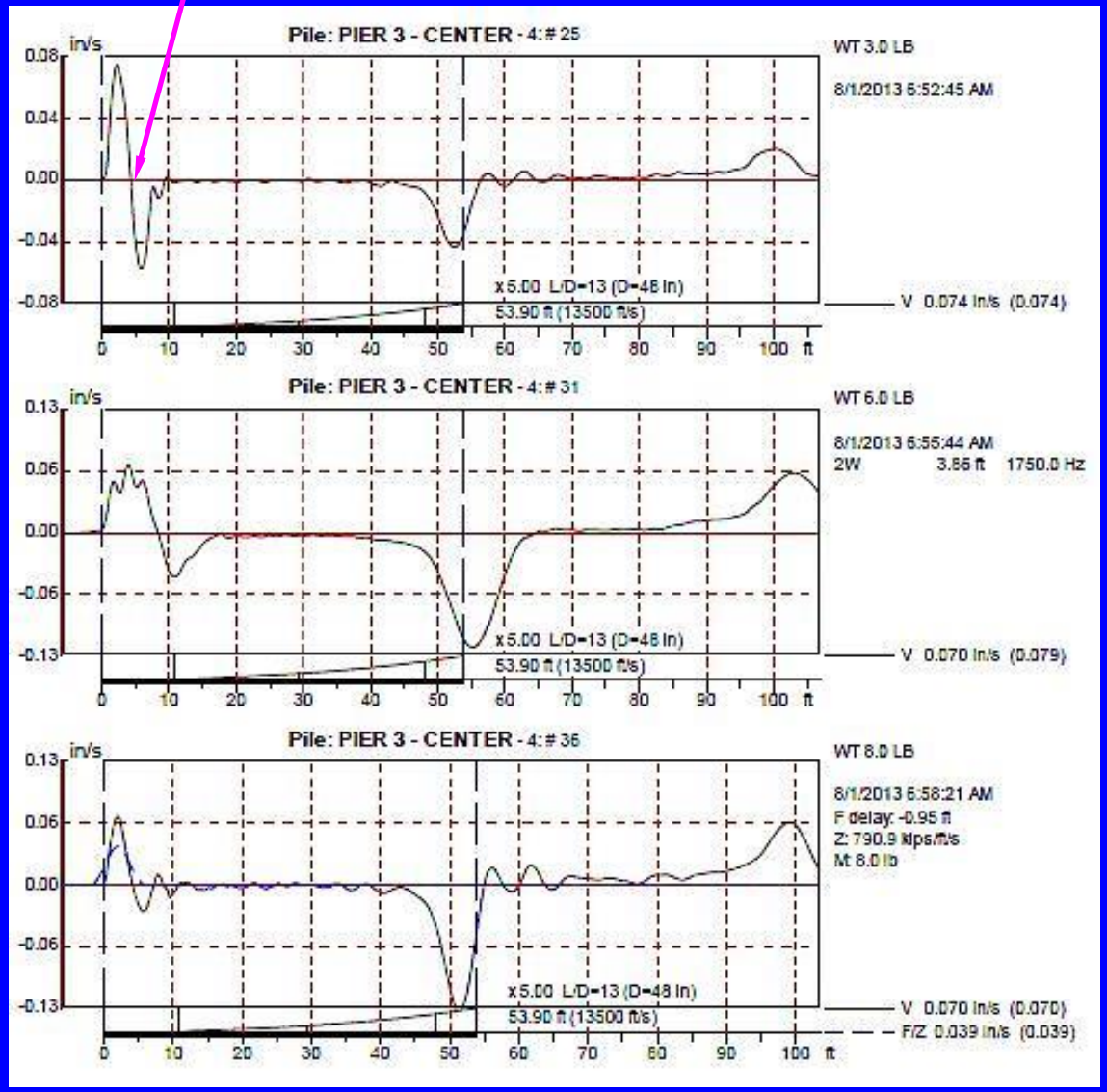
Low Strain Test Results

5 Ft Pulse Width

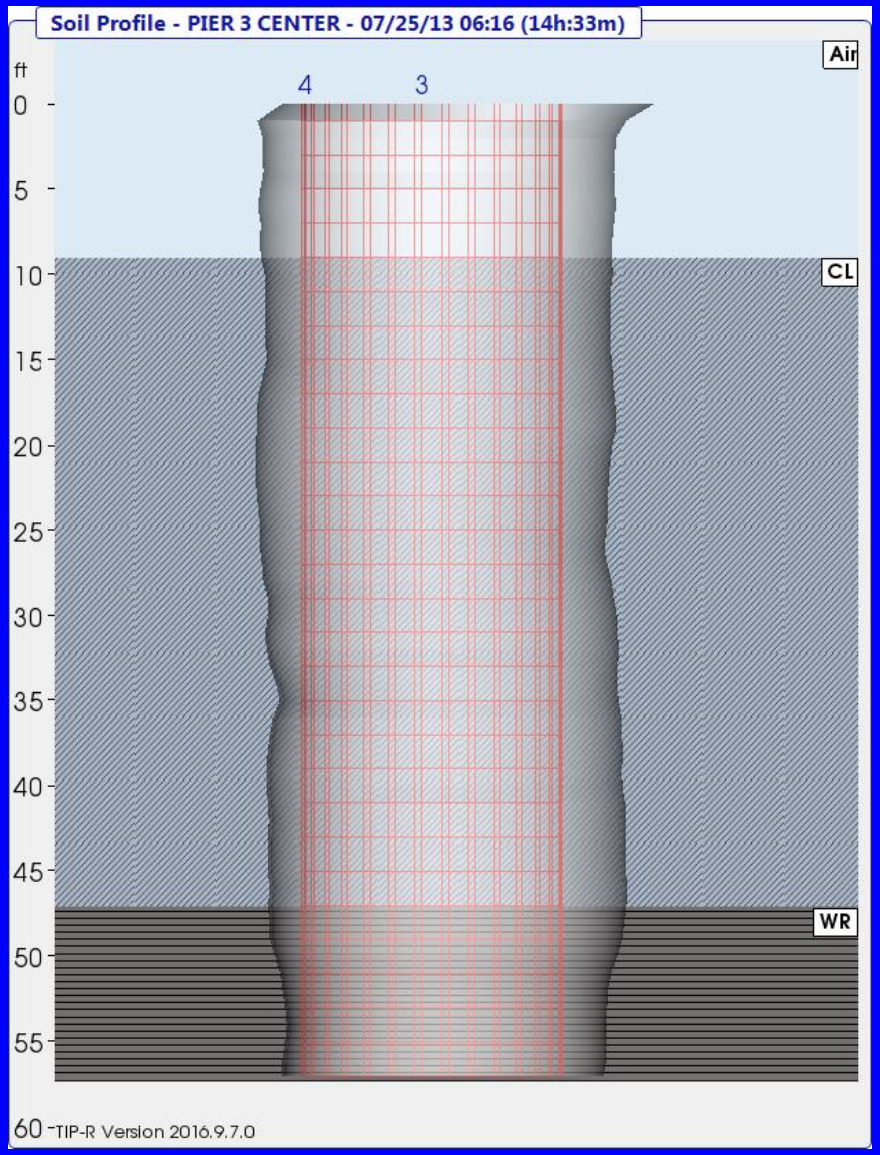
3 lb Hammer

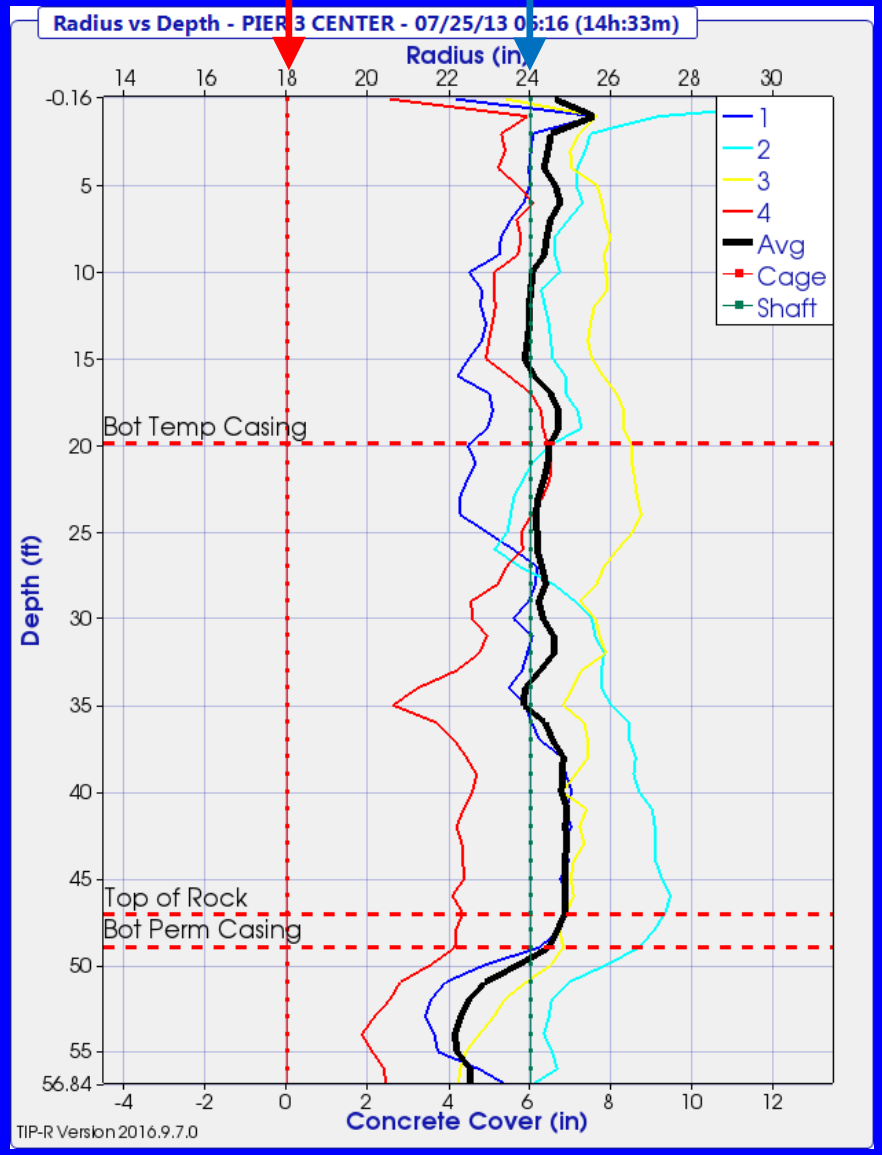
6 lb Hammer

8 lb Instrumented Hammer



Thermal Integrity Test Results





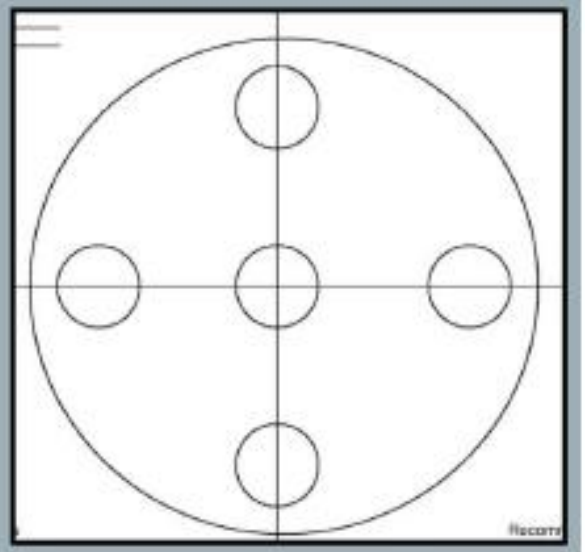
Base Cleanliness

Base Cleanliness

Illinois Department of Transportation

Shaft Excavation – Acceptance

- Is the bottom clean?
  - A weighted tape can also be used to check the bottom
  - Check at 5 points on the bottom
  - Section 516.08 of the Specifications
  - Max debris thickness is 1.5 inches
  - 50% of the bottom should have less than ½ inch



Source: Illinois DOT Drilled Shaft Foundation Construction Inspection Class Reference Guide (2015)

Base Cleanliness Specs

State	Spec	Max Debris Thickness	Debris Area	Date
IADOT	2433.03.F.2	1.0 inch	Min. of 50% of base area will have < ½ inch	2016
IDOT	516.08	1.5 inches	50% of bottom area with < ½ inch	2015
INDOT	728.12	1.5 inches	50% of bottom area with < ½ inch	2015
KDOT[1]	703.3e	Not stated	Min. of 75% of base area will have < ½ inch	2015
MDOT	718.03.F.1	1.5 inches	50% of bottom area with < ½ inch	2012
MODOT[2]	701.4.10.2	1.5 inches	50% of bottom area with < ½ inch	2016
ODOT	524.08	As clean as practical	As clean as practical	2016

1) Inspection performed visually, or using a weighted tape on 12 inch grid, or by camera.
2) Camera required for primary inspection.

Shaft Inspection Device (SID)

Device lowered to shaft bottom.

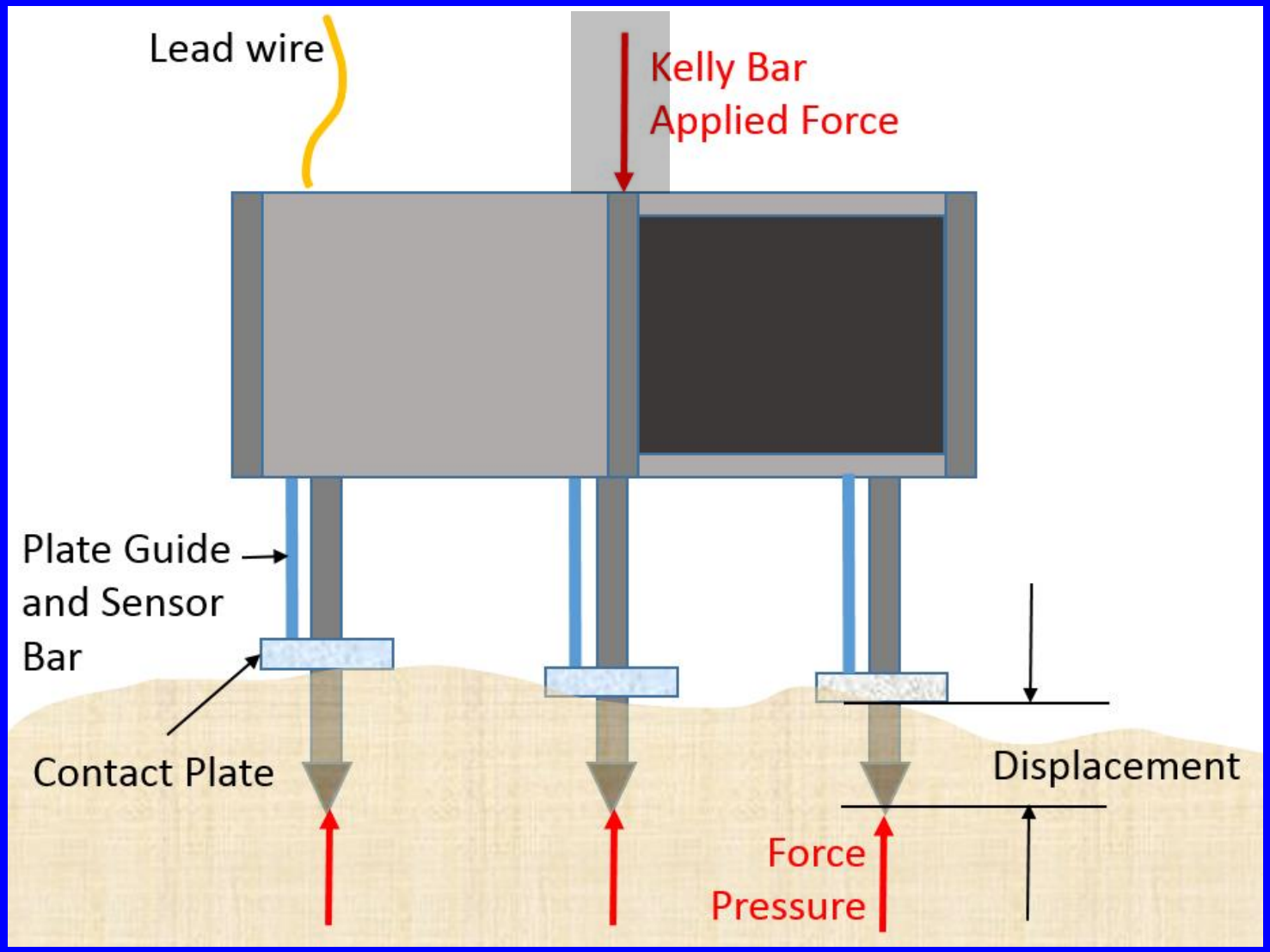
Compressed gas used to displace water or slurry inside the bell.

Bottom cleanliness inspection performed by video camera and depth gages.

Inspection typically performed at shaft center and four quadrants.

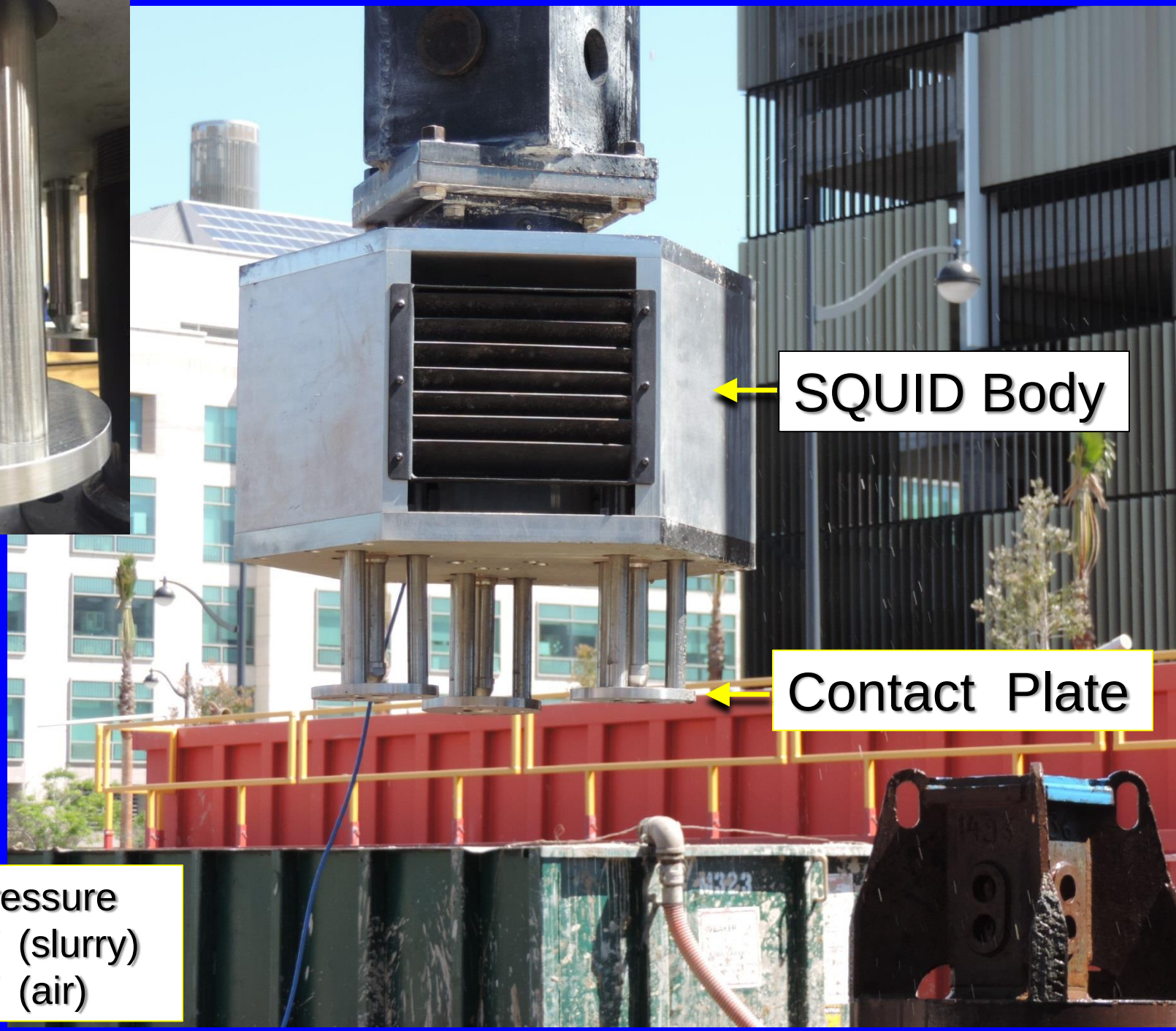
Photo Source: FHWA NHI-10-016, Drilled Shafts: Construction Procedures and LRFD Design Methods, GEC-10 (2010)

Shaft Quantitative Inspection Device (SQUID)



Shaft Quantitative Inspection Device (SQUID)

Shaft Quantitative Inspection Device (SQUID)



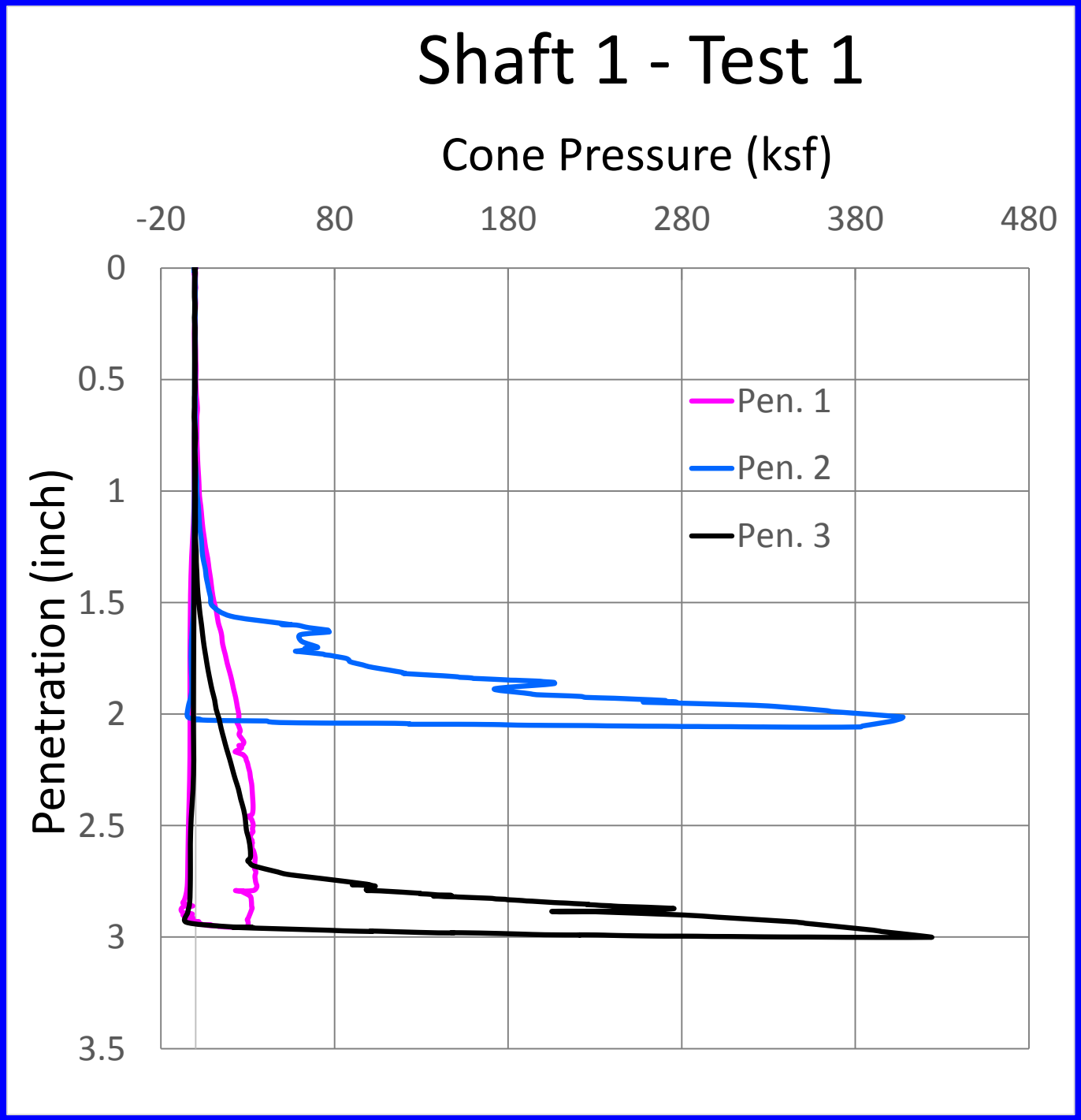
Cone

Contact Pressure
= 0.072 ksf (slurry)
= 0.083 ksf (air)

SQUID Lowered Into Shaft

Shaft Quantitative Inspection Device (SQUID)

SQUID Test Results

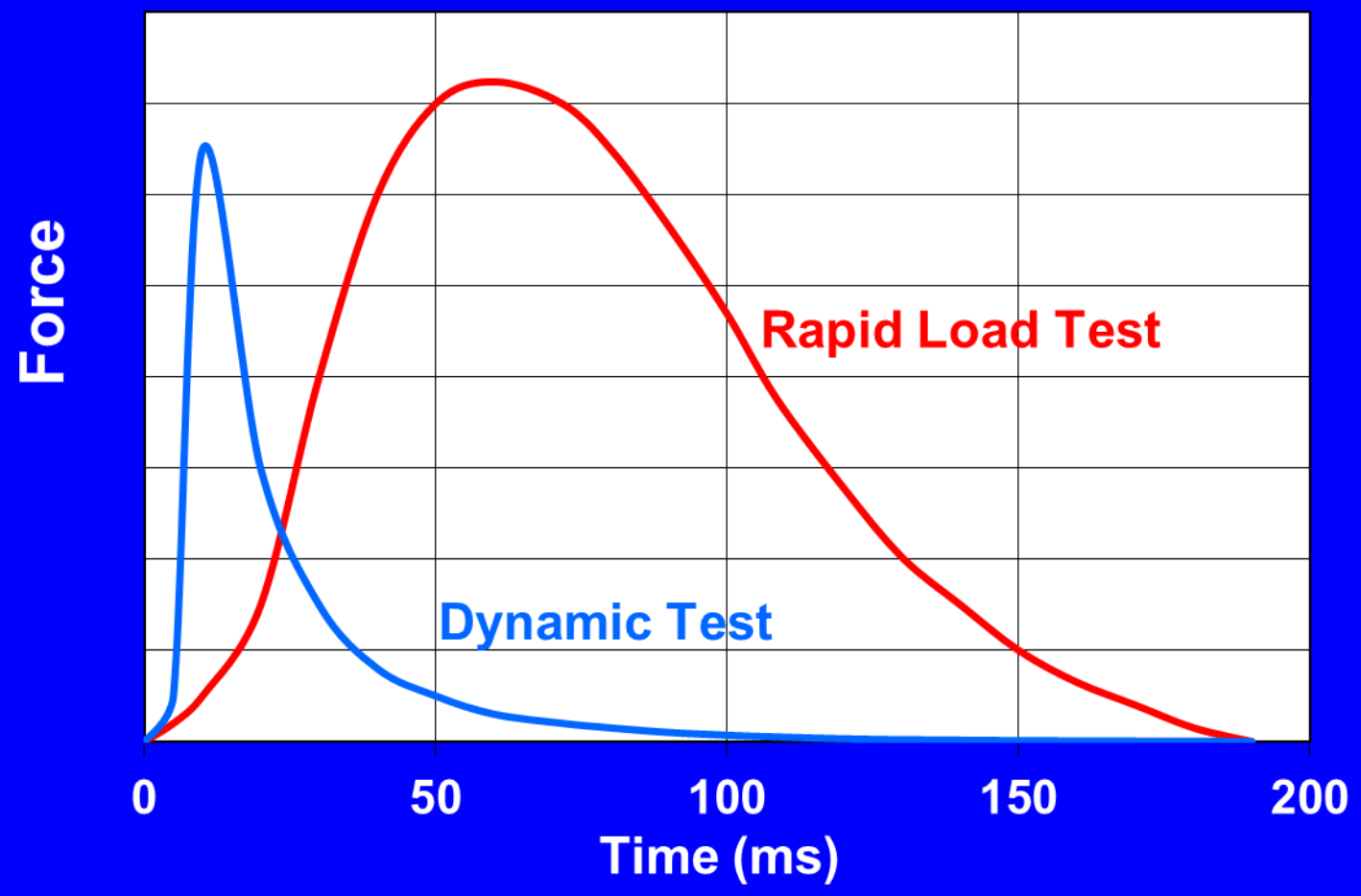


High Strain Dynamic

And

Rapid Load Tests

Comparison of Force Pulse in DLT and RLT

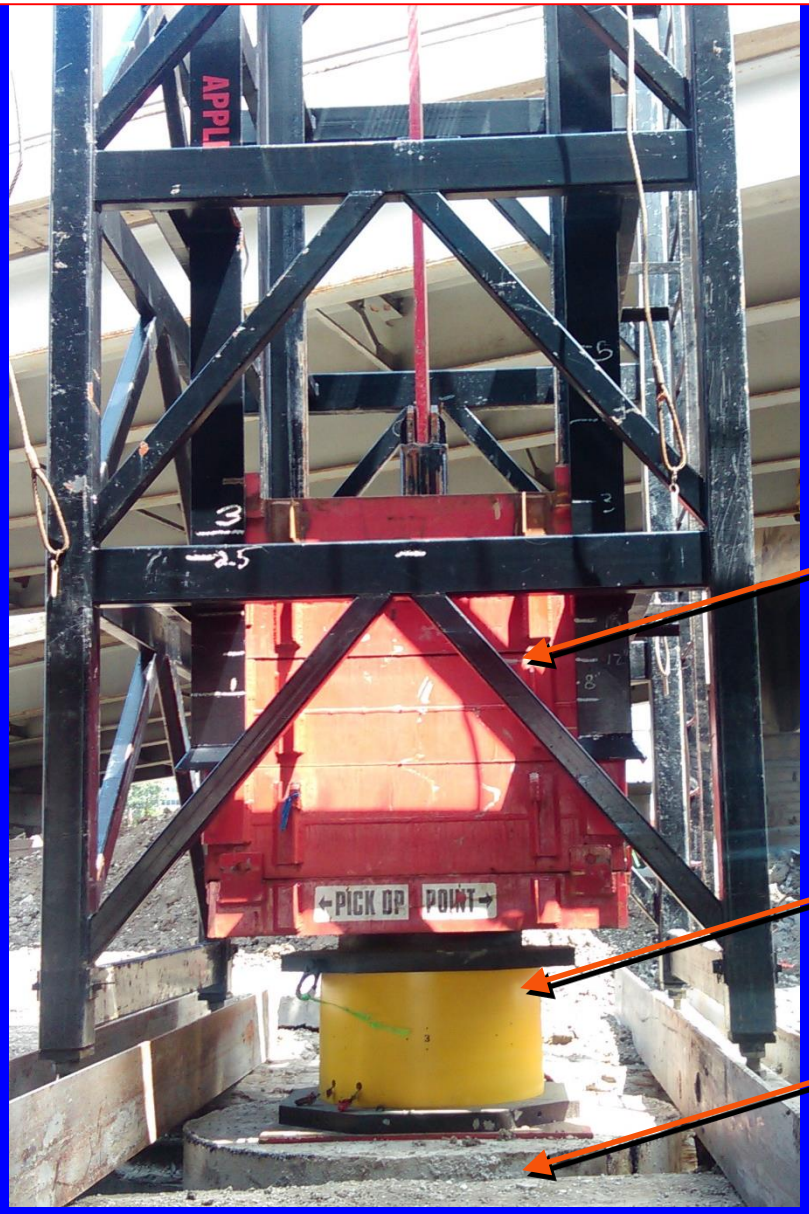


High Strain Dynamic Load Test

Overview

- Measure strain on shaft top load cell and acceleration from accelerometers on shaft perimeter to obtain force and velocity records vs time.
- Technical competence required: - High
- Relative costs: Testing - High
  Overall - High
- ASTM D 4945

High Strain Dynamic Test on Drilled Shaft with Questionable Toe



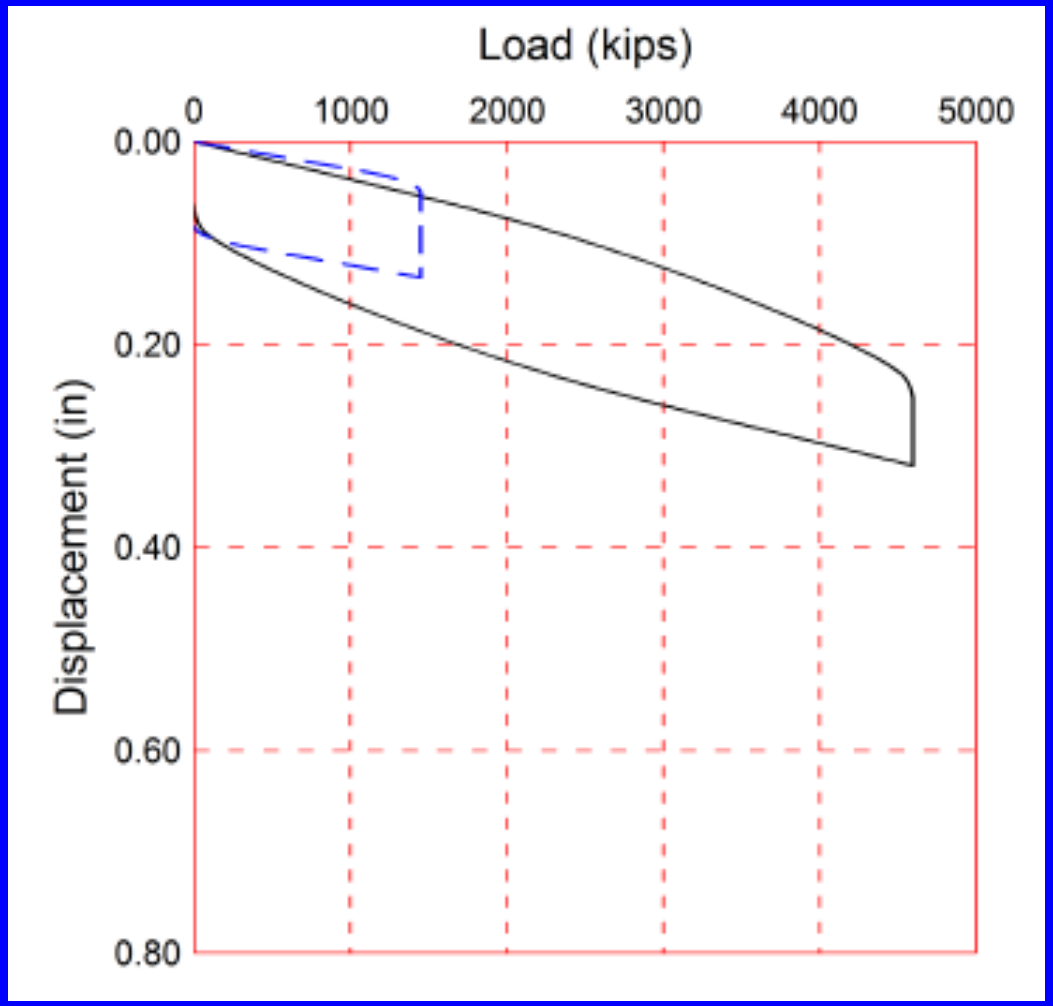
Required Nominal Resistance = 2853 kips

32 ton ram

36 inch diameter shaft top transducer F_{max} = 7100 tons

72 inch diameter drilled shaft with 66 inch rock socket

High Strain Dynamic Test Results on Shaft with Questionable Toe



Test Results

- Rn = 4945 kips
- Rs = 3145 kips
- Rt = 1450 kips

CSX = 0.90 ksi

TSX = 0.11 ksi

Shaft Accepted

Rn > 2853 kips

High Strain Dynamic Test on Base Grouted Drilled Shaft

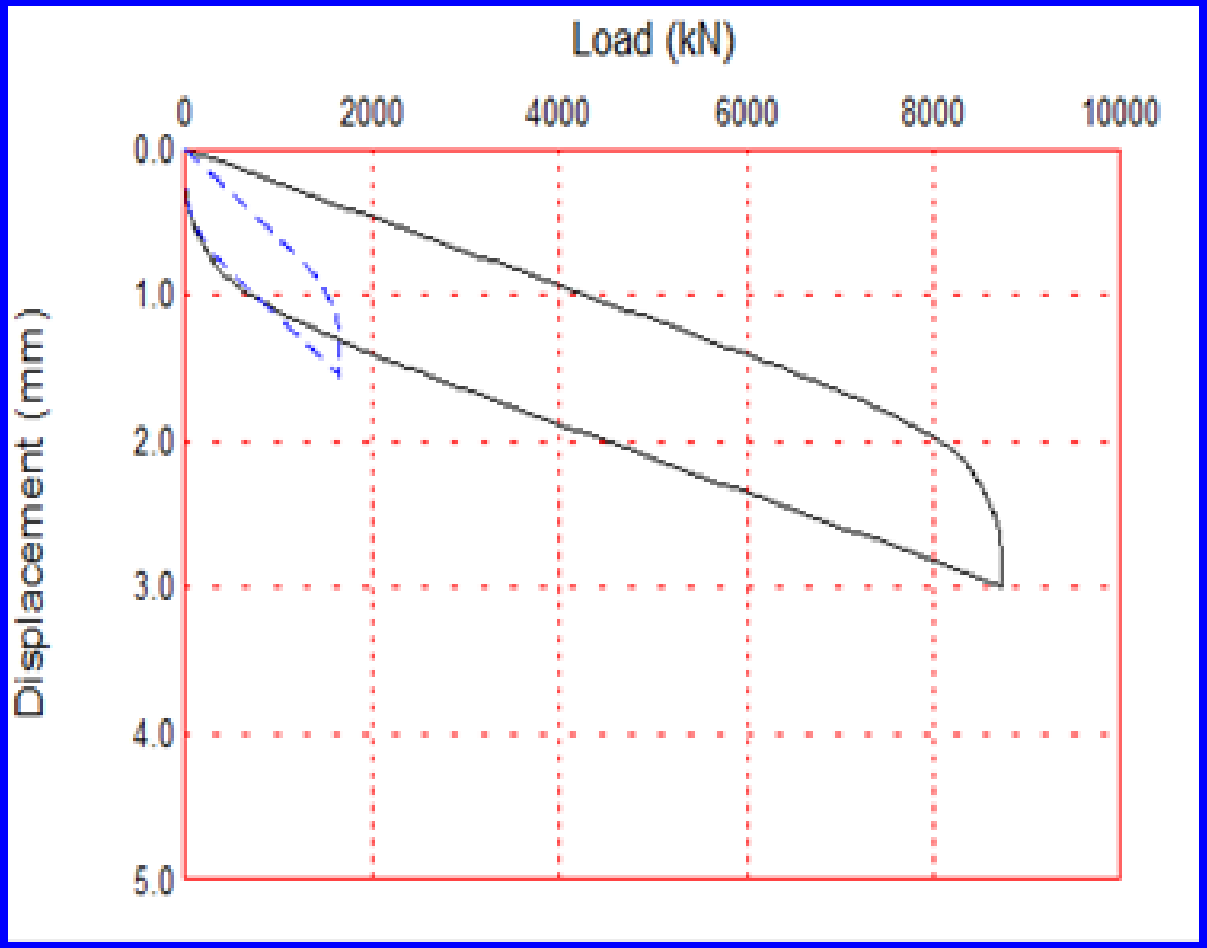
Required Nominal Resistance = 1550 kips

28 ton ram

24 inch diameter shaft top transducer. F_{max} = 2500 tons

66 inch diameter base-grouted drilled shaft.

High Strain Dynamic Test Results on Base Grouted Drilled Shaft



Test Results

- Rn = 1960 kips
- Rs = 1590 kips
- Rt = 370 kips

CSX = 0.71 ksi

TSX = 0.08 ksi

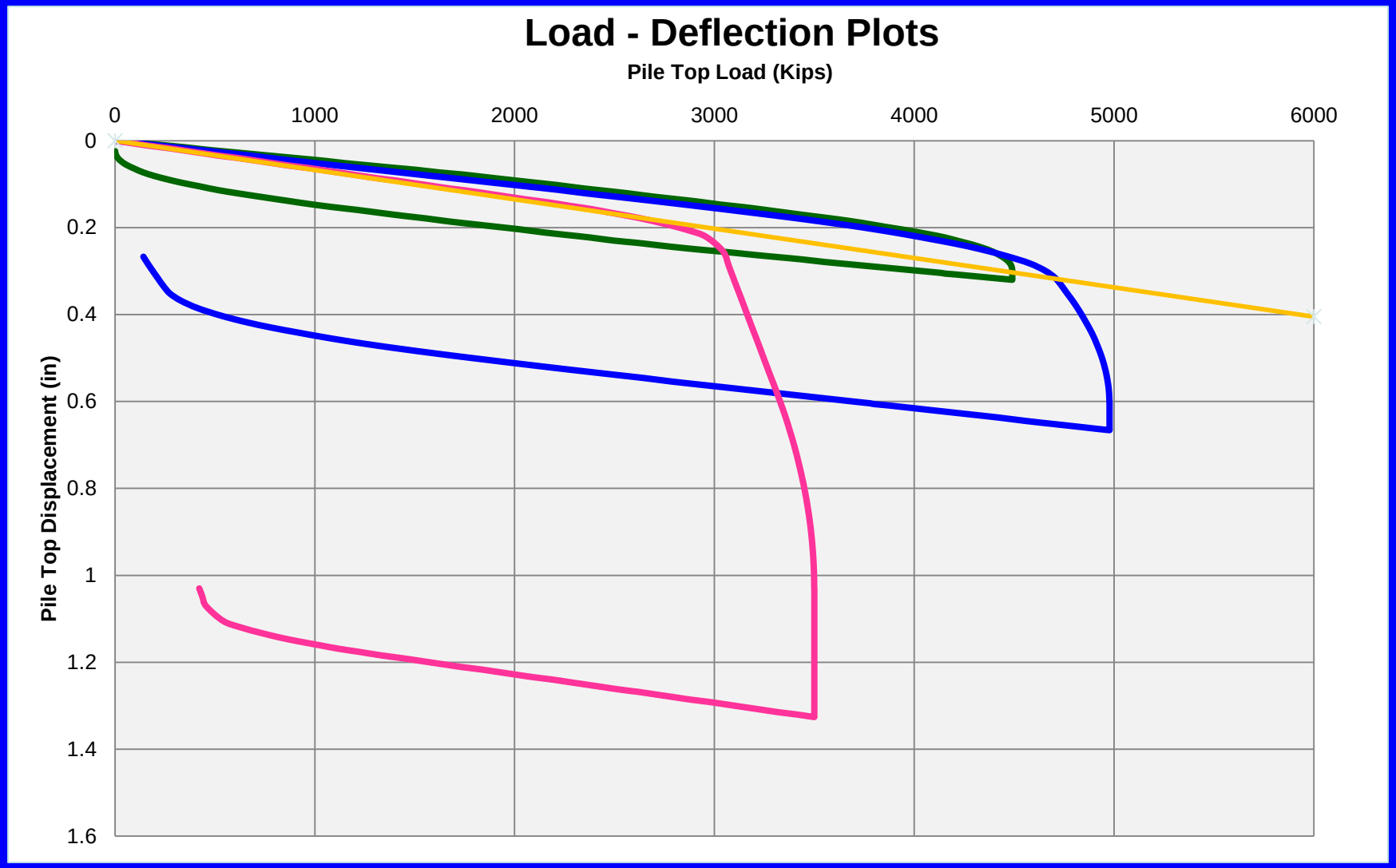
Shaft Accepted

Rn > 1550 kips

Dynamic Test with 60 Ton Ram

Test shaft in Wando, SC: 78 inch diameter over upper 25.5 feet, 72 inch diameter over lower 57.0 feet.

High Strain Dynamic Test Results



High Strain Dynamic Tests on Drilled Foundations

Advantages

- Large test load capability.
- Low cost compared to other nominal resistance verification test methods.
- Can be used on test, existing, or new production shafts.
- Economies of scale for multiple tests.
- No reaction system needed.

High Strain Dynamic Tests on Drilled Foundations

Limitations

- Test load capability high but less than bi-directional.
- Mobilization cost of drop hammer system.
- Test includes dynamic effects which must be evaluated through signal matching analysis.
- Shaft area, uniformity, and elastic modulus in upper 1 to 1.5 diameters can affect interpretation.
- The shaft shape must be considered in the data analysis.
- Multiple impacts may be required to mobilize soil resistance which may complicate data analysis.
- Test must be designed to control potentially damaging stresses.

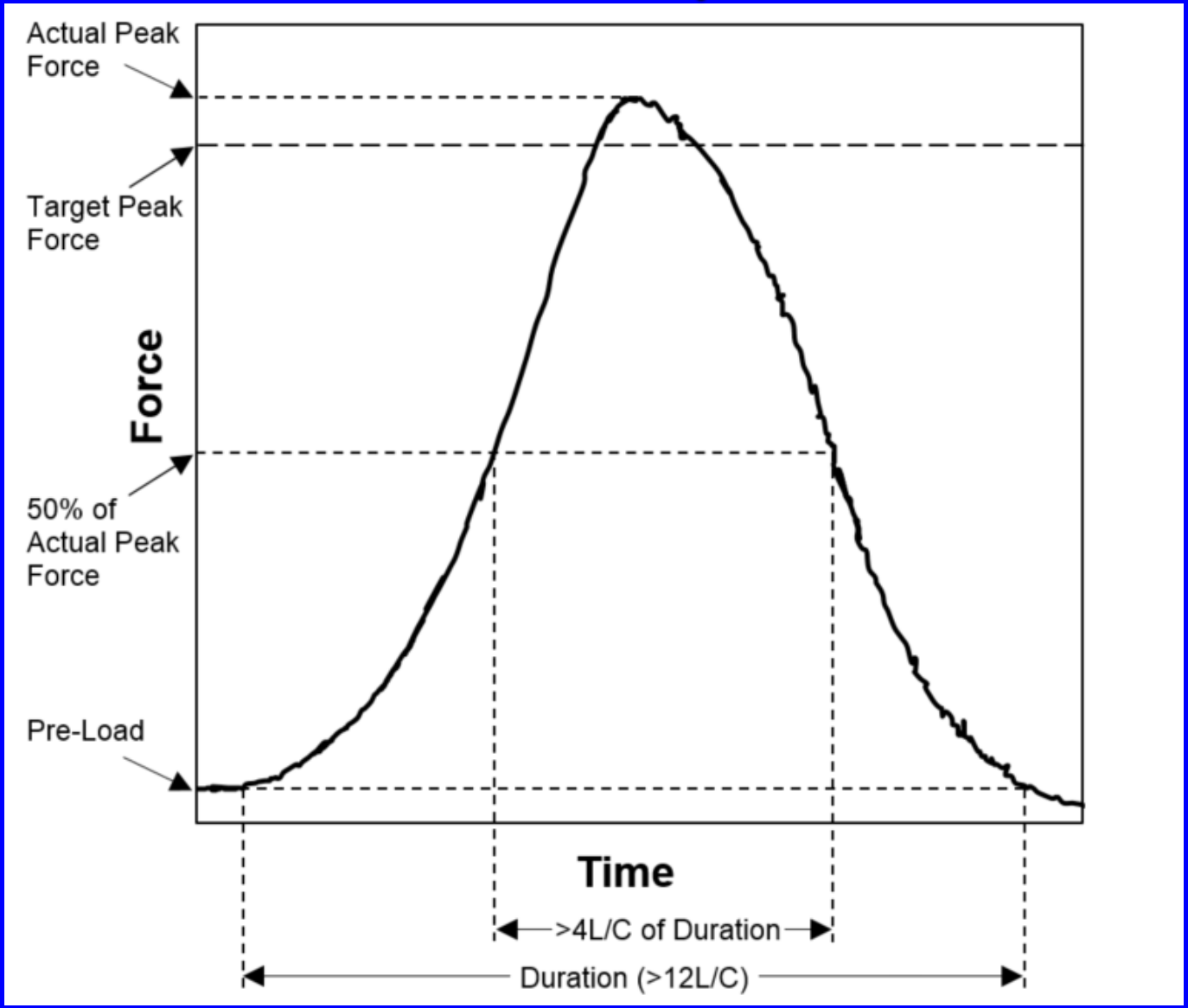
Rapid Load Tests

Rapid Load Tests

Overview

- Measure strain on shaft top load cell and either acceleration from shaft top accelerometers or displacement from theodolite to obtain load and displacement record vs time.
- Technical competence required: - High
- Relative costs: Testing - High
  Overall - High
- ASTM D 6790

Rapid Load Test
Force Pulse Requirements



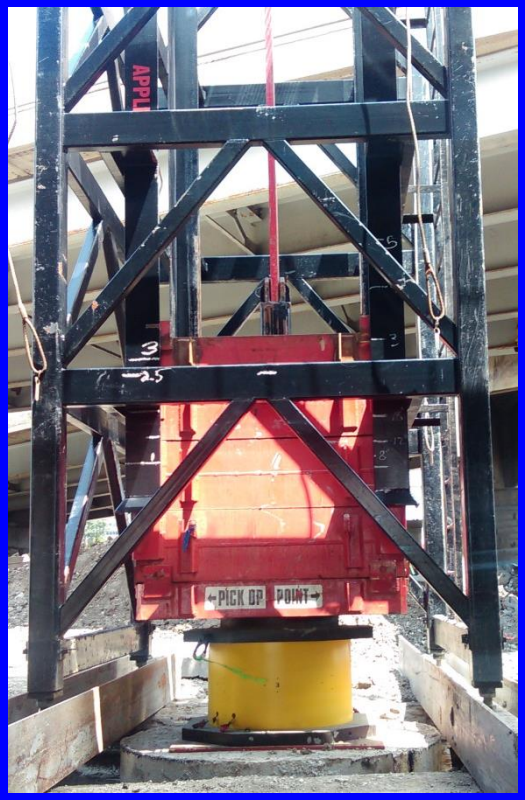
ASTM D 6790

Rapid Load Test Systems

9000 kip Statnamic gravel

1000 kip Statnamic hydraulic

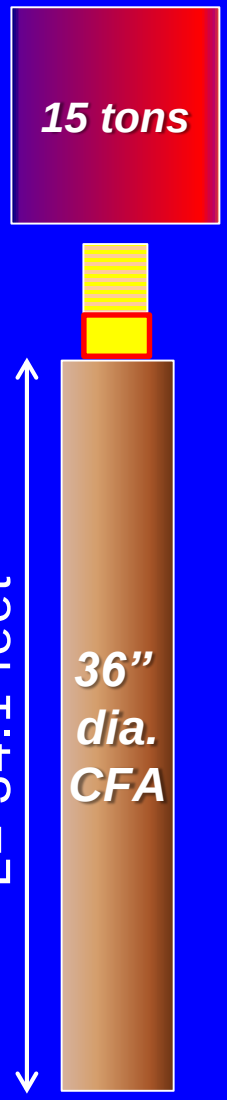
790 kip Fundex device

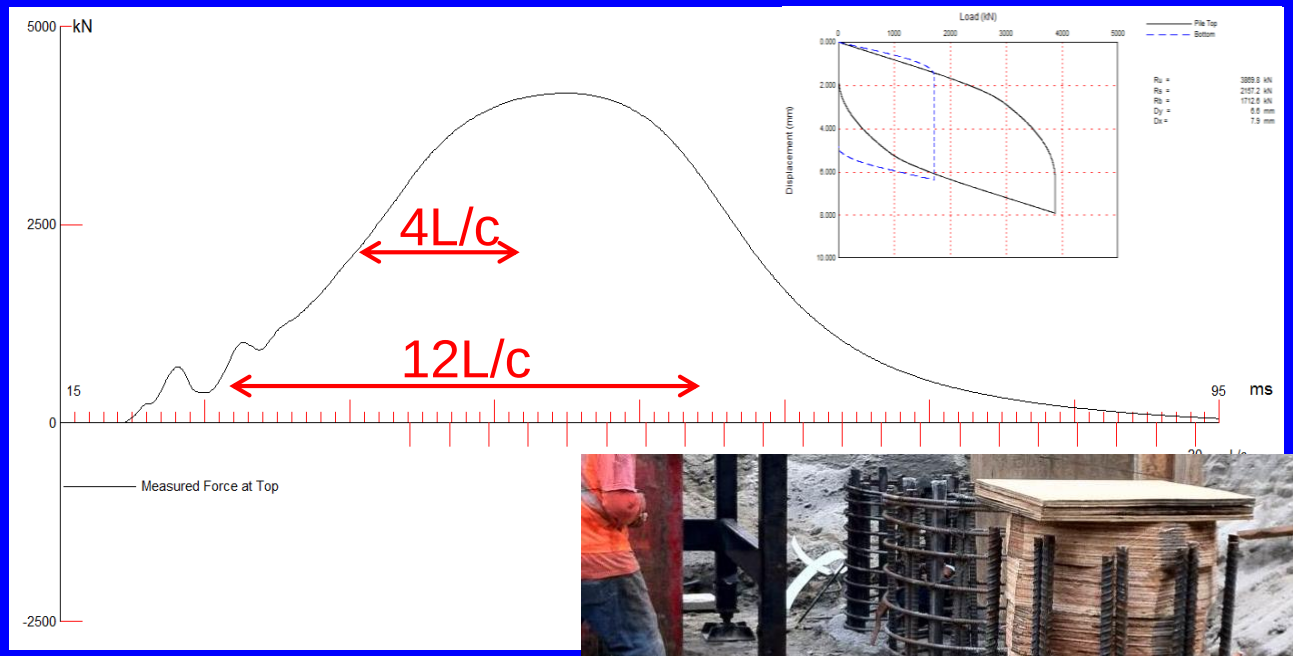


1600 kip Apple RLT

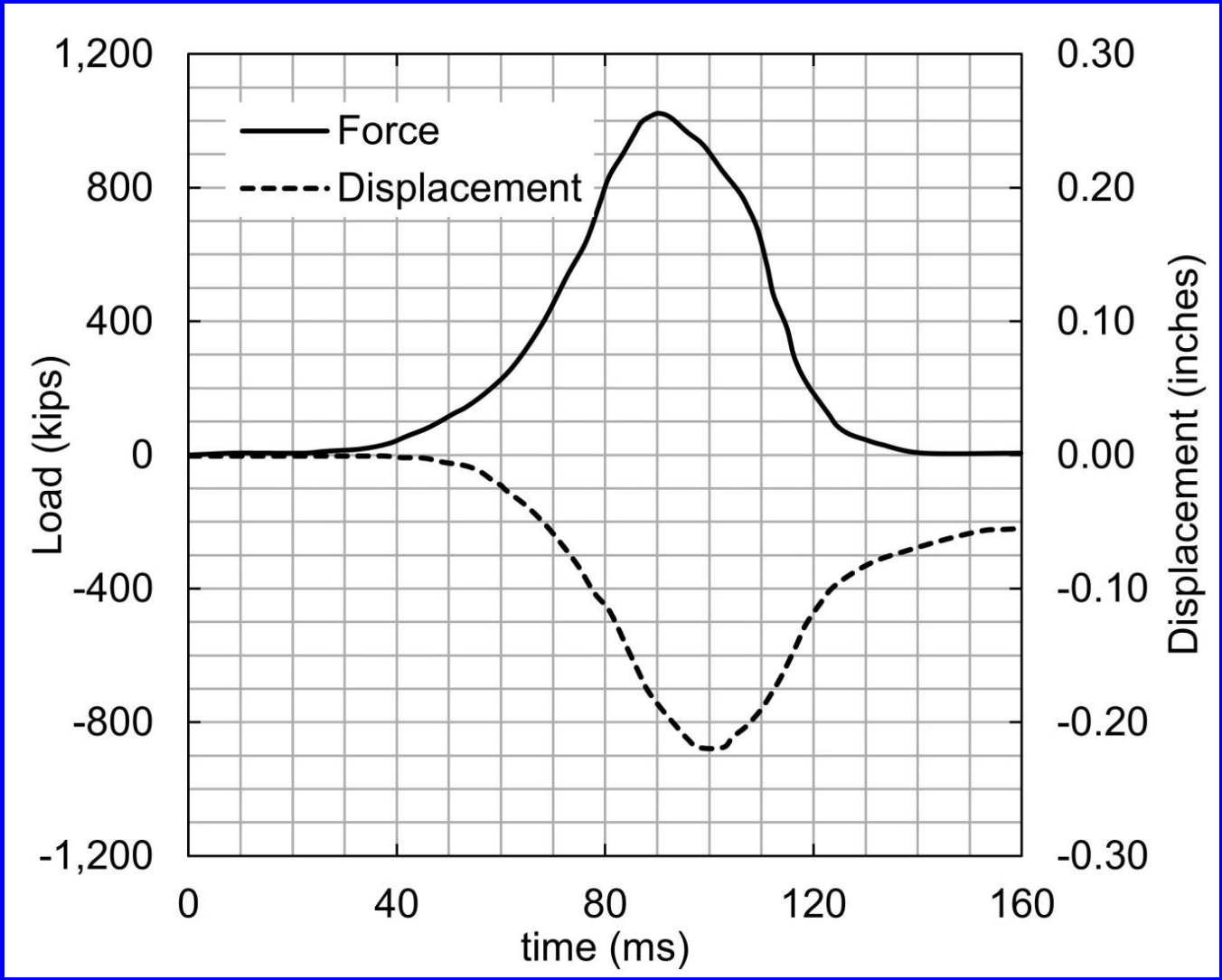
Rapid Load Test Force Pulse with Drop Weight System

(7% ram weight; thick cushion)

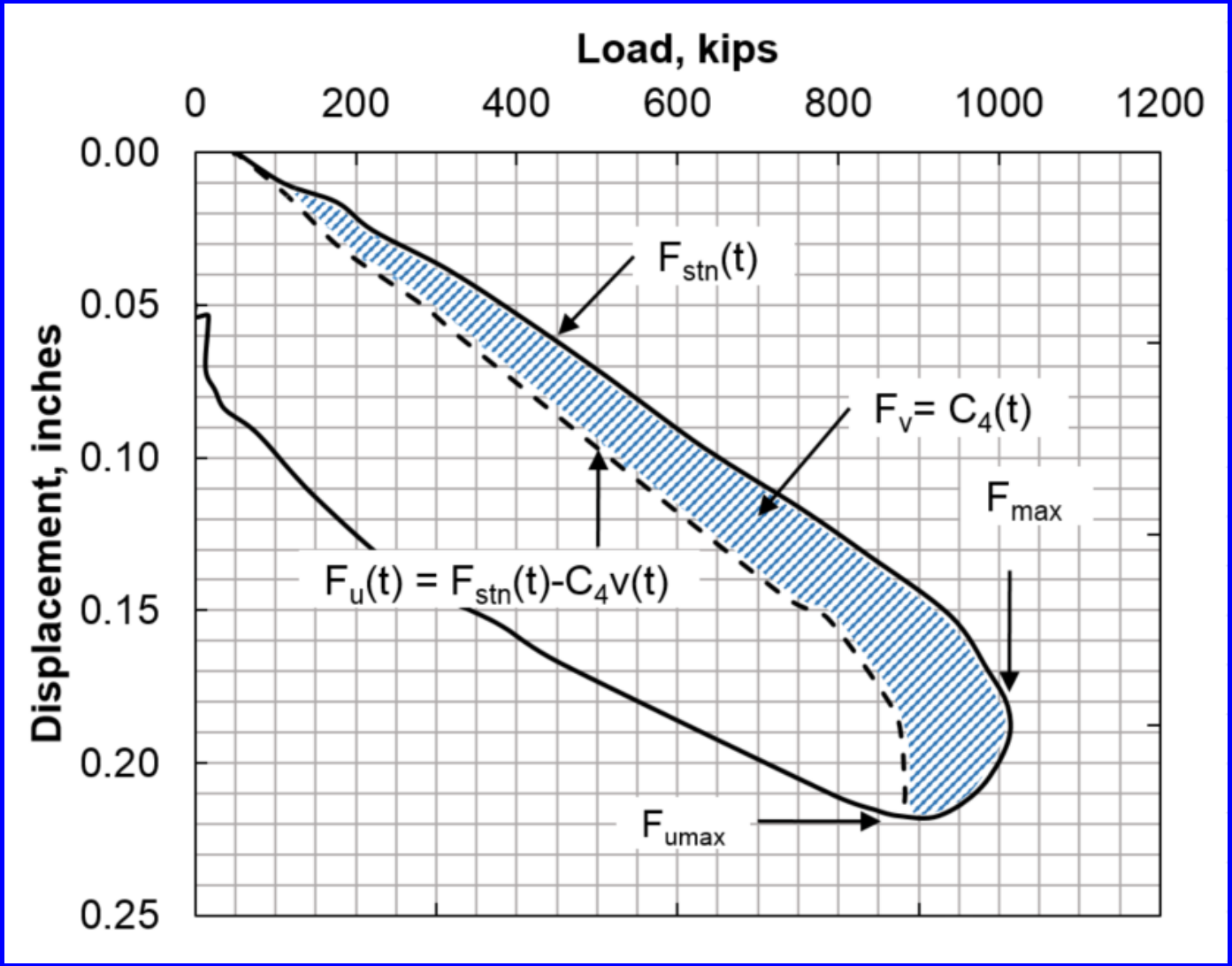




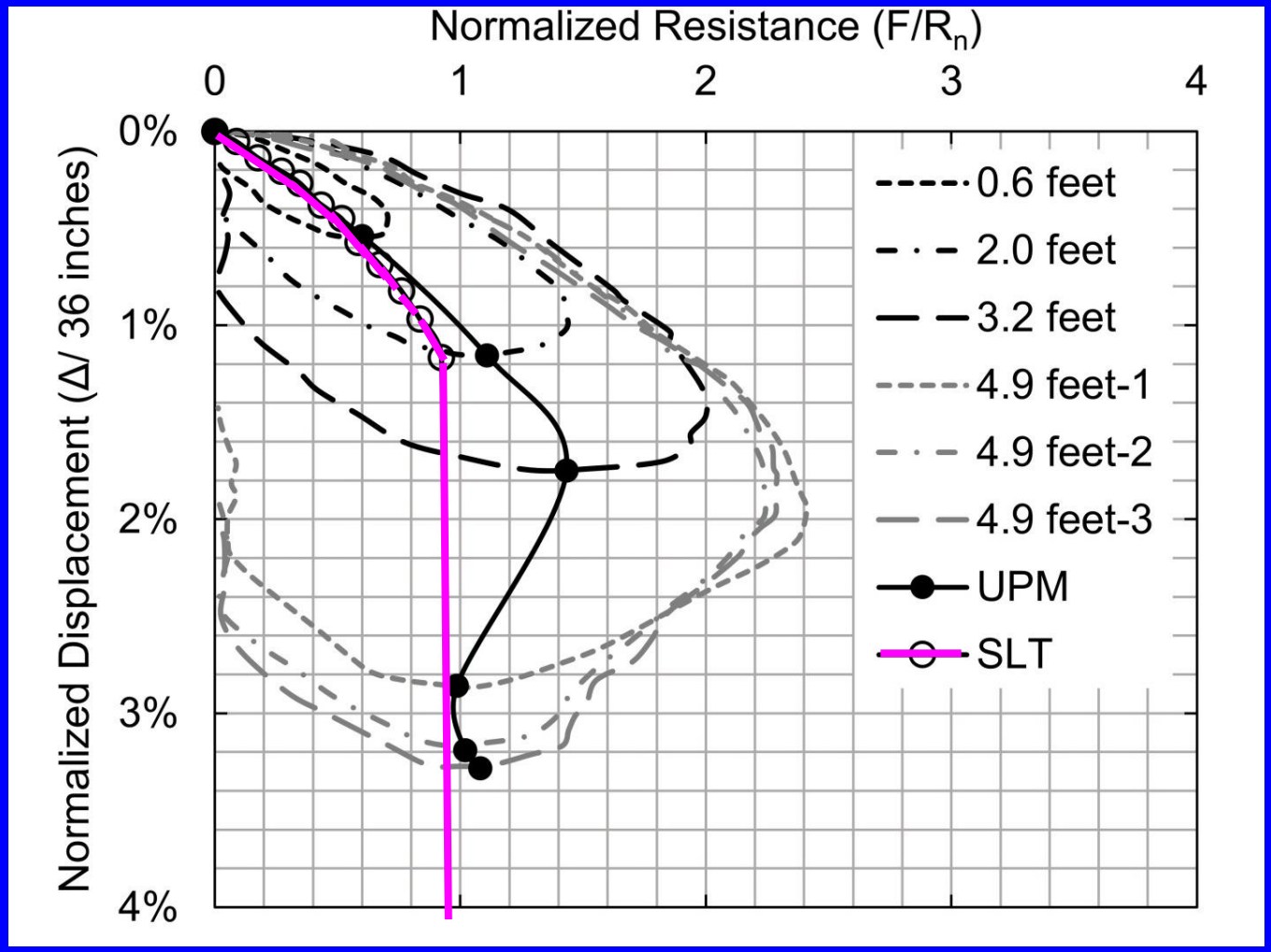
Rapid Load Test
Force and Displacement Records



Rapid Load Test
Load - Displacement Results



Comparison of Rapid and Static Load Test Results



Miyasaka et al., (2012) proposed obtaining a minimum net permanent displacement of at least 3% of the pile diameter to avoid overpredictions.

Rapid Load Tests on Drilled Foundations

Advantages

- Large test load capability.
- Can be used on test, existing, or new production shafts.
- Economies of scale for multiple tests.
- No reaction system needed.

Rapid Load Tests on Drilled Foundations

Limitations

- Test load capability high but less than bi-directional.
- Mobilization cost of drop hammer system.
- Rate effects must be considered and evaluated due to rapid loading rate.

Thank You !

Any Questions ???