Testing of Drilled Shafts and Auger-Cast Piles for Assessments of Structural Integrity and Geotechnical Load Bearing Capacity

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Southeastern Transportation Geotechnical Engineering Conference
STGEC'2024 – Baton Rouge, Louisiana
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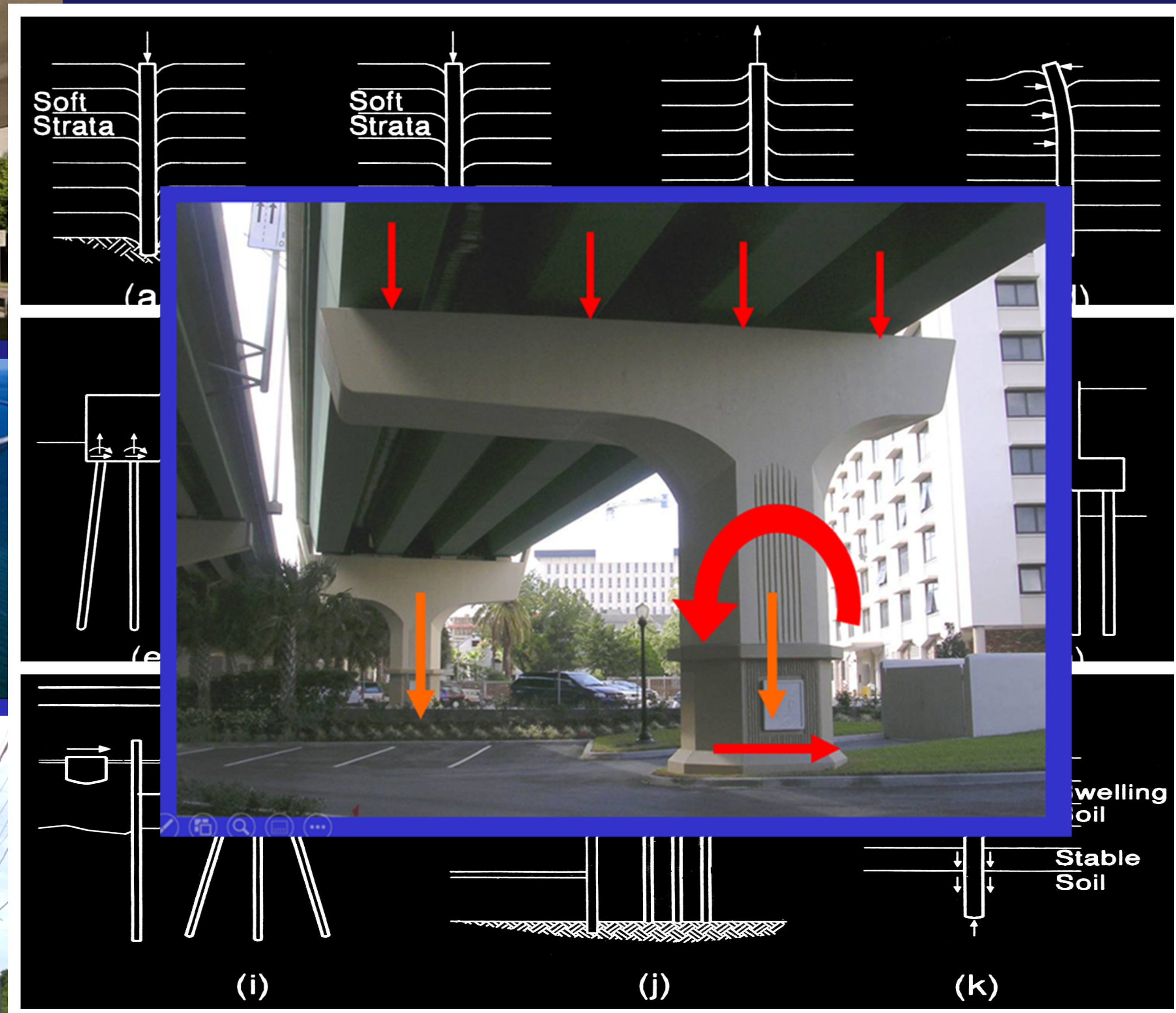
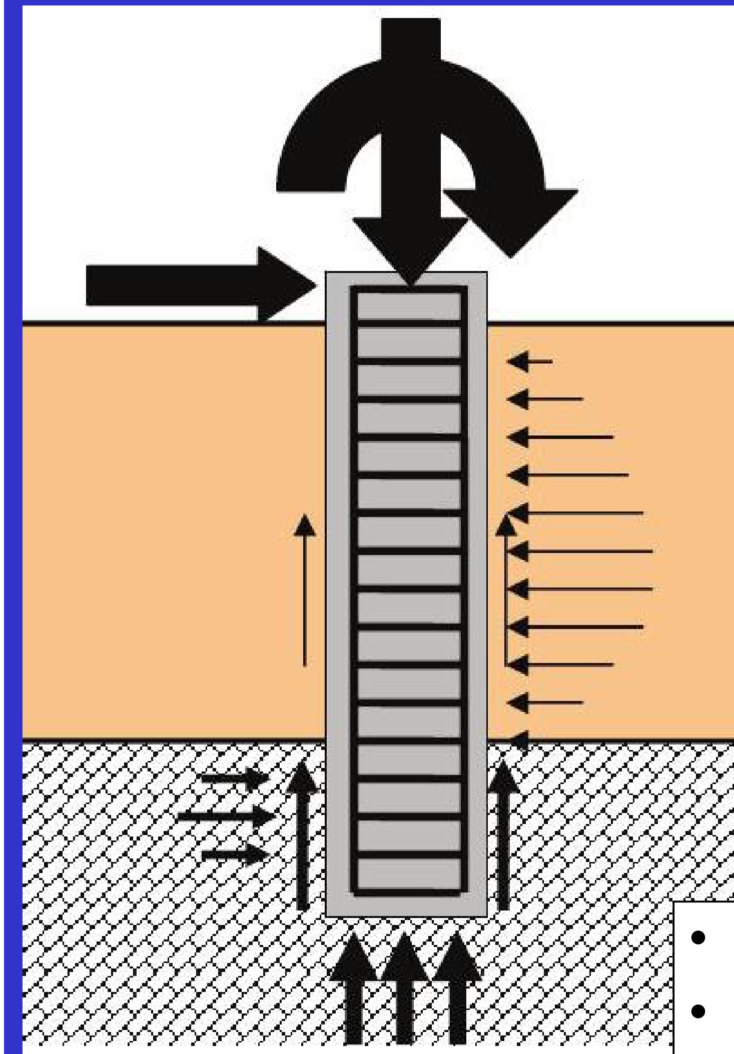
GRL Engineers, Inc.
Deep Foundation Testing & Analyses

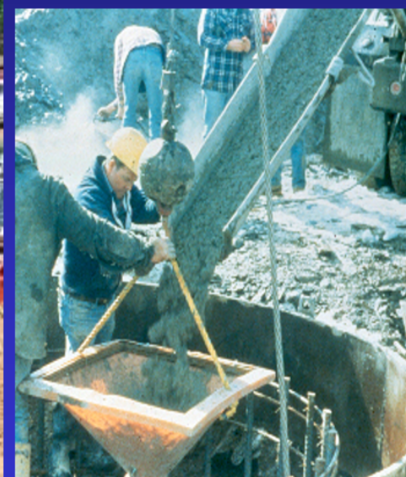
Pile Dynamics, Inc.


NORTH
95
W Palm Bch
LEFT 2 LANES
SOUTH
95
Miami


Soft
Strata
Soft
Strata
Stable
Soil
(i)
(j)
(k)

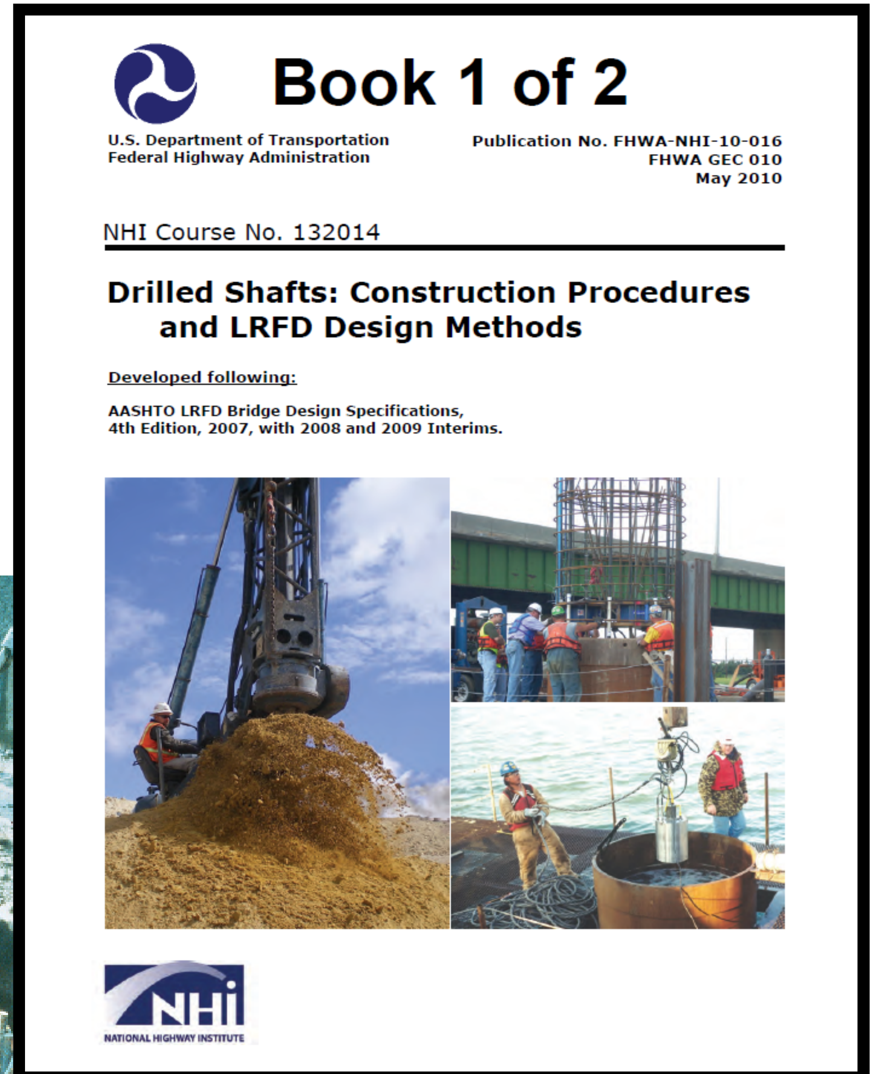
Drilled Shafts





- Cast-in-Place
- Replaces Pile Group
- Scour, Seismic, and Ship Impact Resistant
- Appropriate for Rock Sockets

Drilled Shafts



Dry Method

Casing, Wet Method

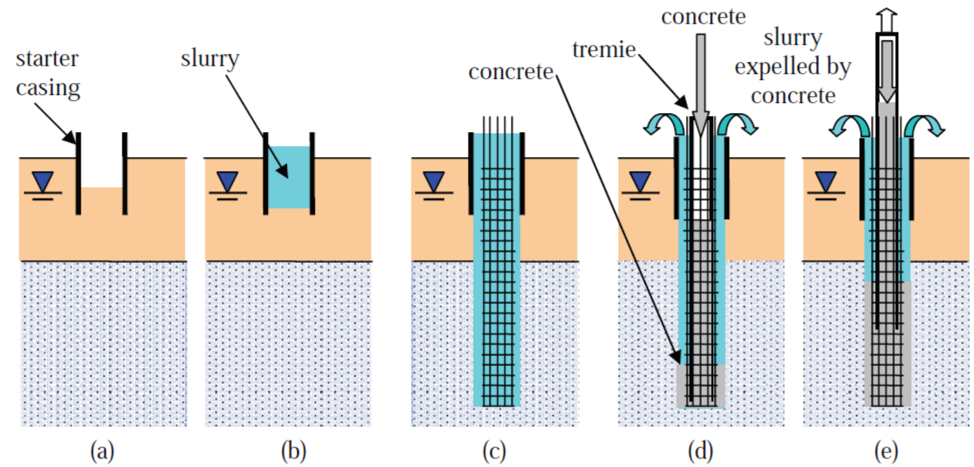
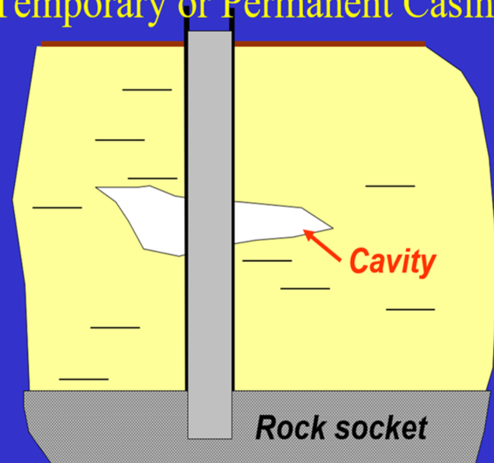
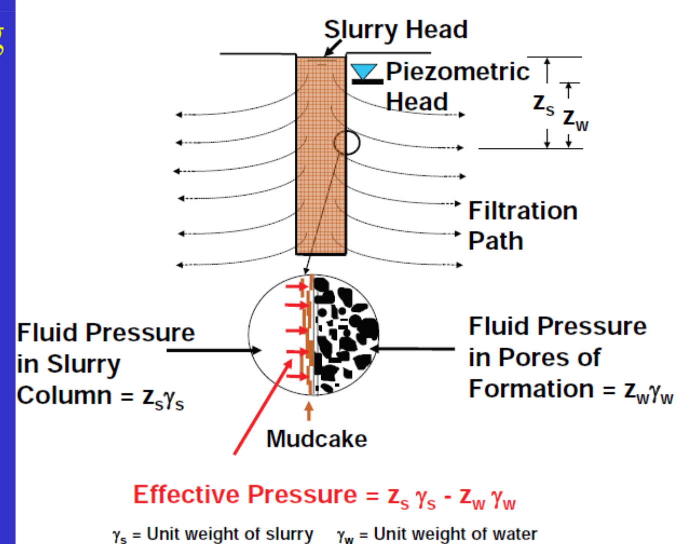


Figure 4-15 Slurry Drilling Process: (a) set starter casing; (b) fill with slurry; (c) complete and clean excavation, set reinforcing; (d) place concrete through tremie; (e) pull tremie while adding concrete

Partial or Full Depth Steel Casing
Temporary or Permanent Casing





<u>Inspections for:</u>

- Drilled Hole Profile
- Drilled Hole Verticality
- Bottom Cleanliness

ASTM INTERNATIONAL

ASTM International

ASTM International - ASTM D8232-18

Standard Test Procedures for Measuring the Inclination of Deep Foundations

Borehole Caliper

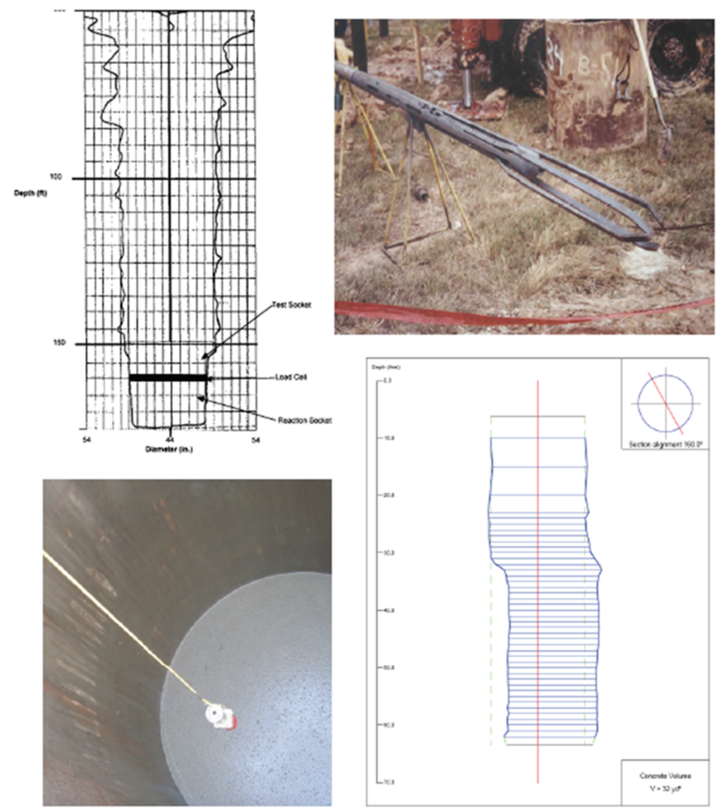
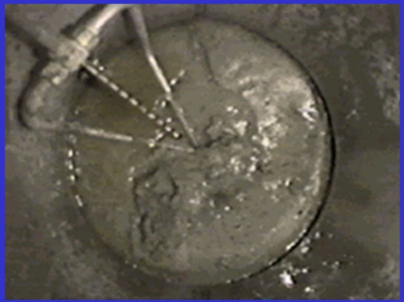


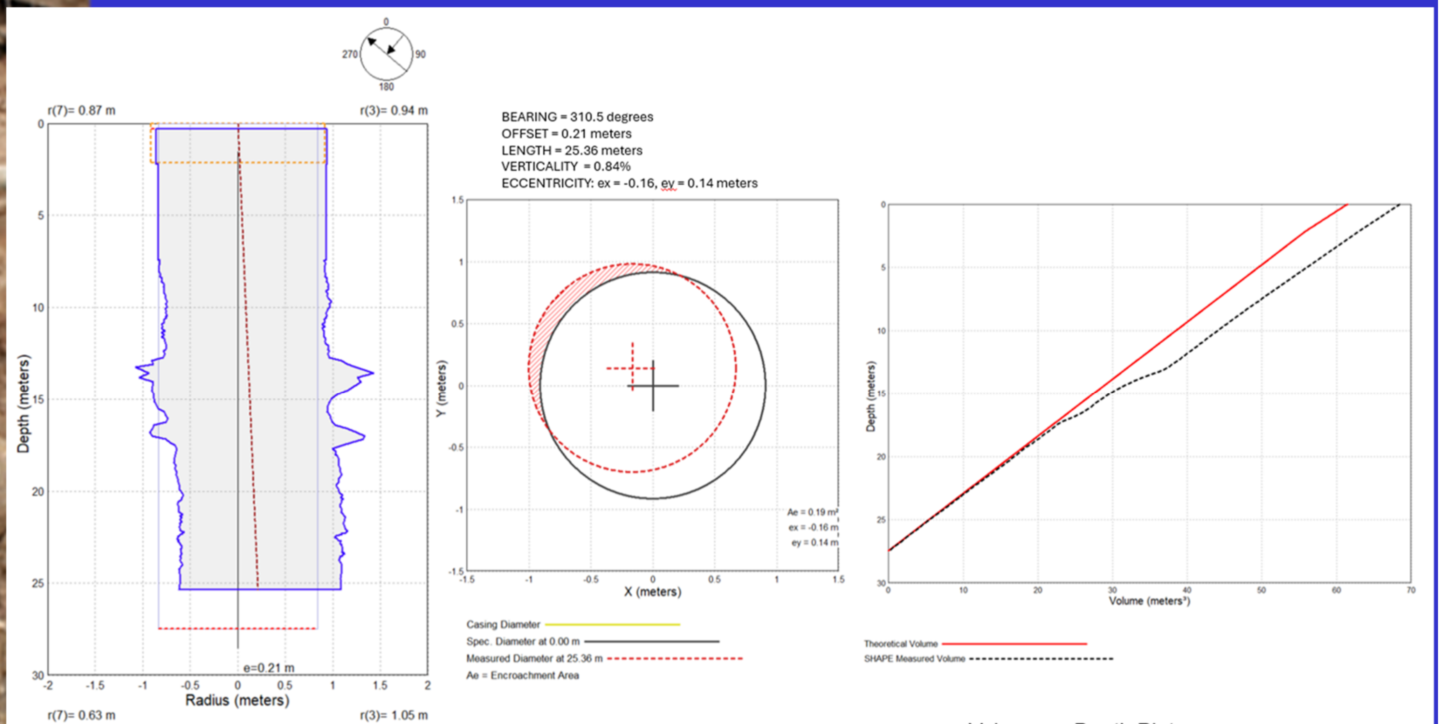
Figure 17-5 Example Borehole Calipers & Logs; Mechanical (top) and Sonic (bottom)

SID – Shaft Inspection Device



Drilled Hole Profile and Verticality

SHAFT AREA PROFILE EVALUATOR (SHAPE®)



Maximum Eccentricity Profile

Offset Plot

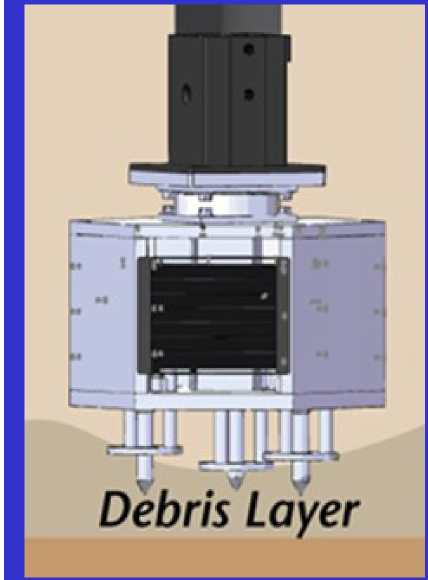
Volume vs Depth Plot

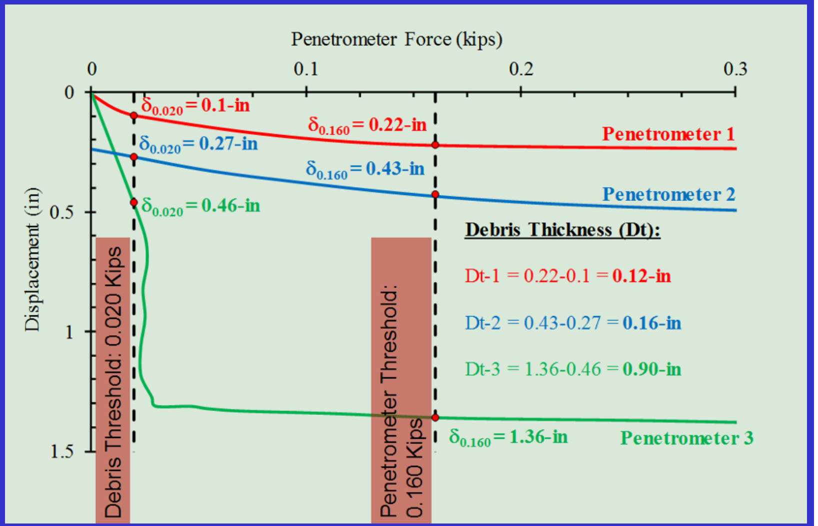
Shaft Quantitative Inspection Device - **SQUID**

Measures the cleanliness of the Drilled Shaft bottom.

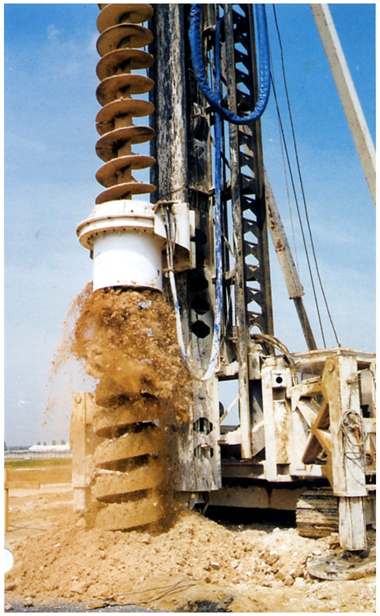
Quantifies the extent of bottom sediment / debris

- 3 cone penetrometers measure force versus displacement as pushed into the shaft bottom
- Determines the thickness of the soft soil layer and the load vs. displacement for the bearing layer





Auger-cast Piles



Geotechnical Engineering

Circular (GEC) No. 8

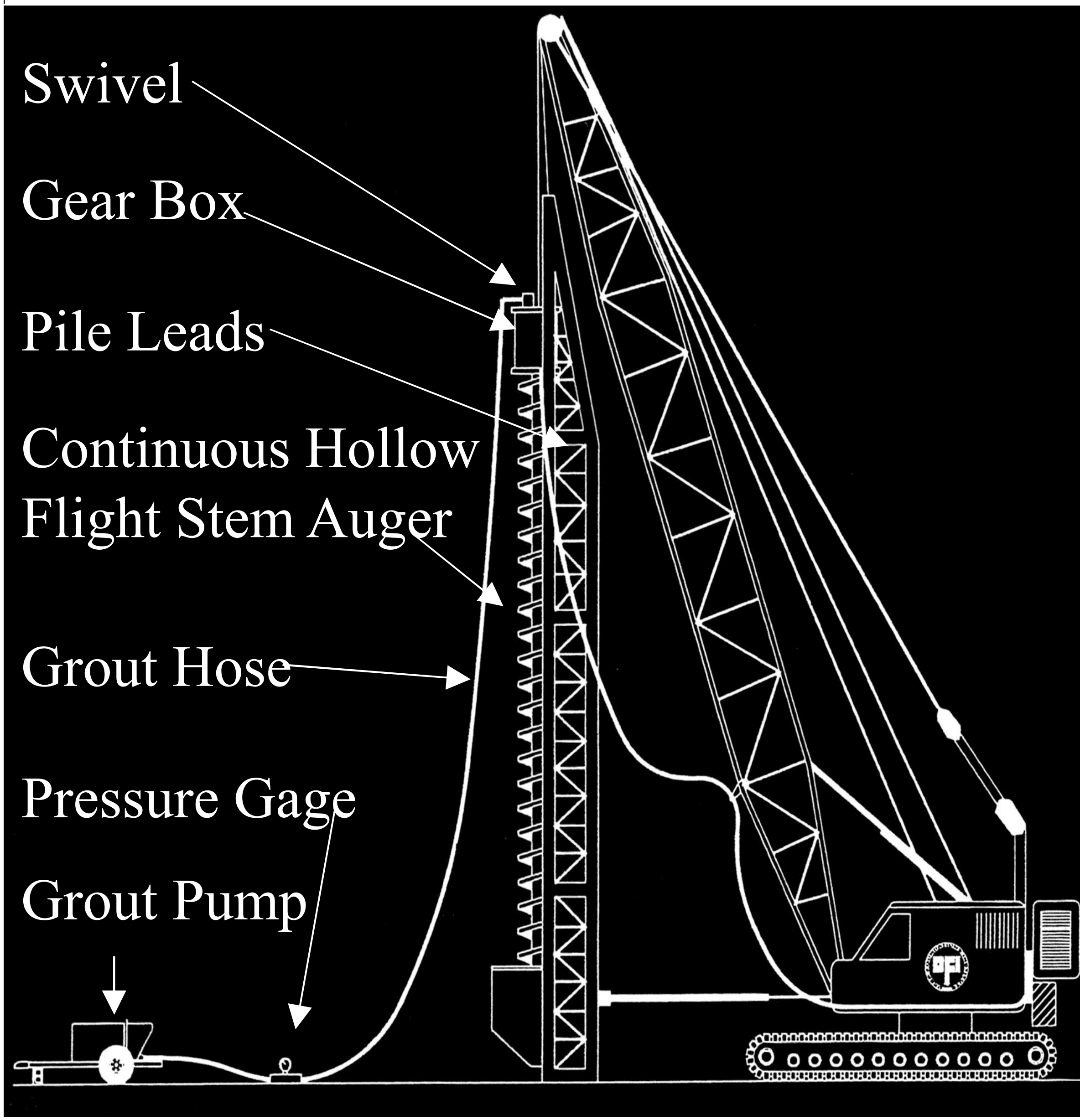
Design and Construction

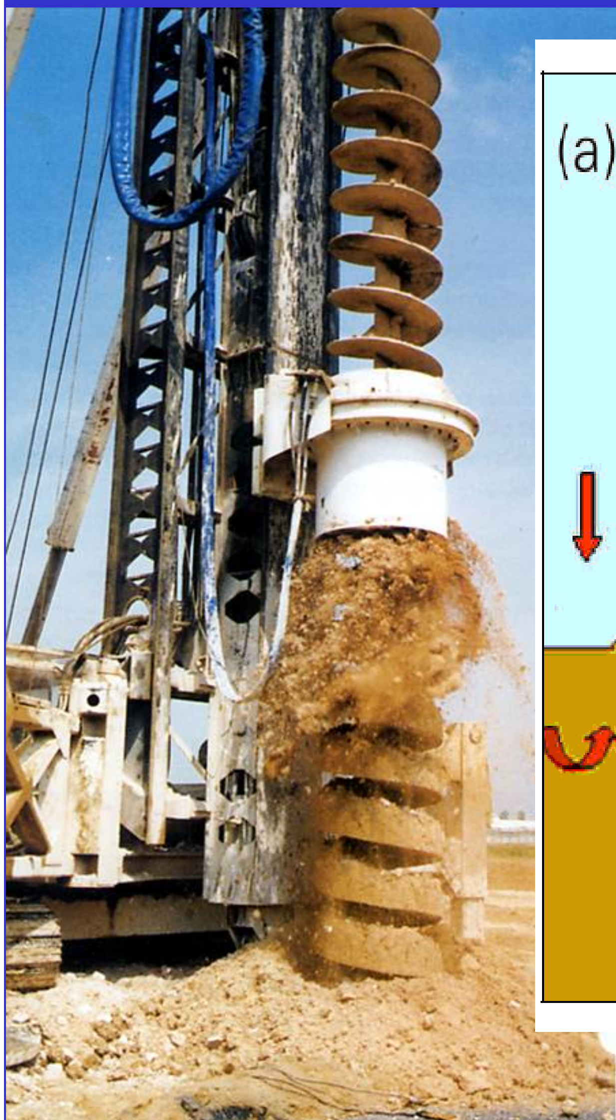
of Continuous

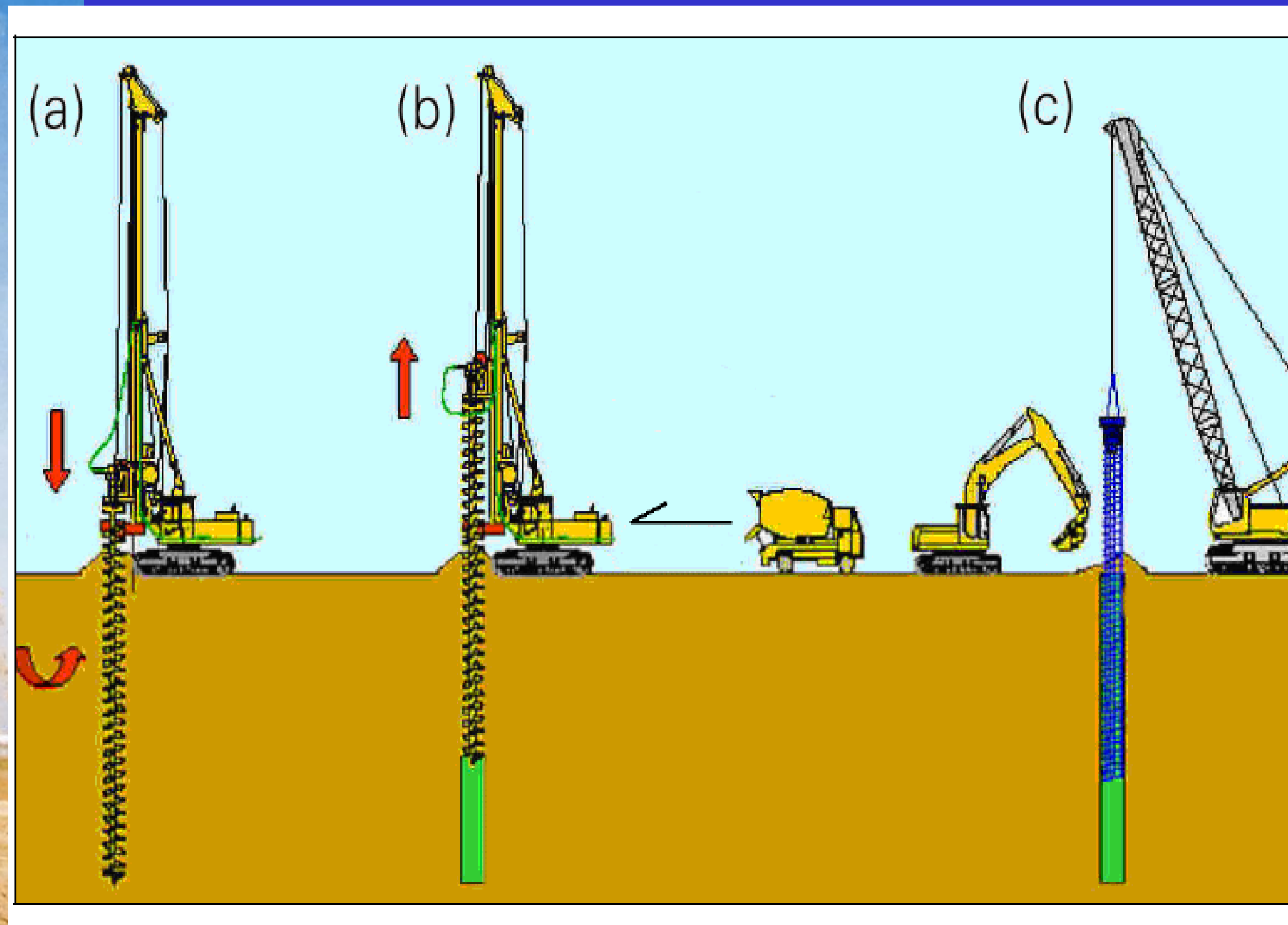
Flight Auger (CFA) Piles

April 2007

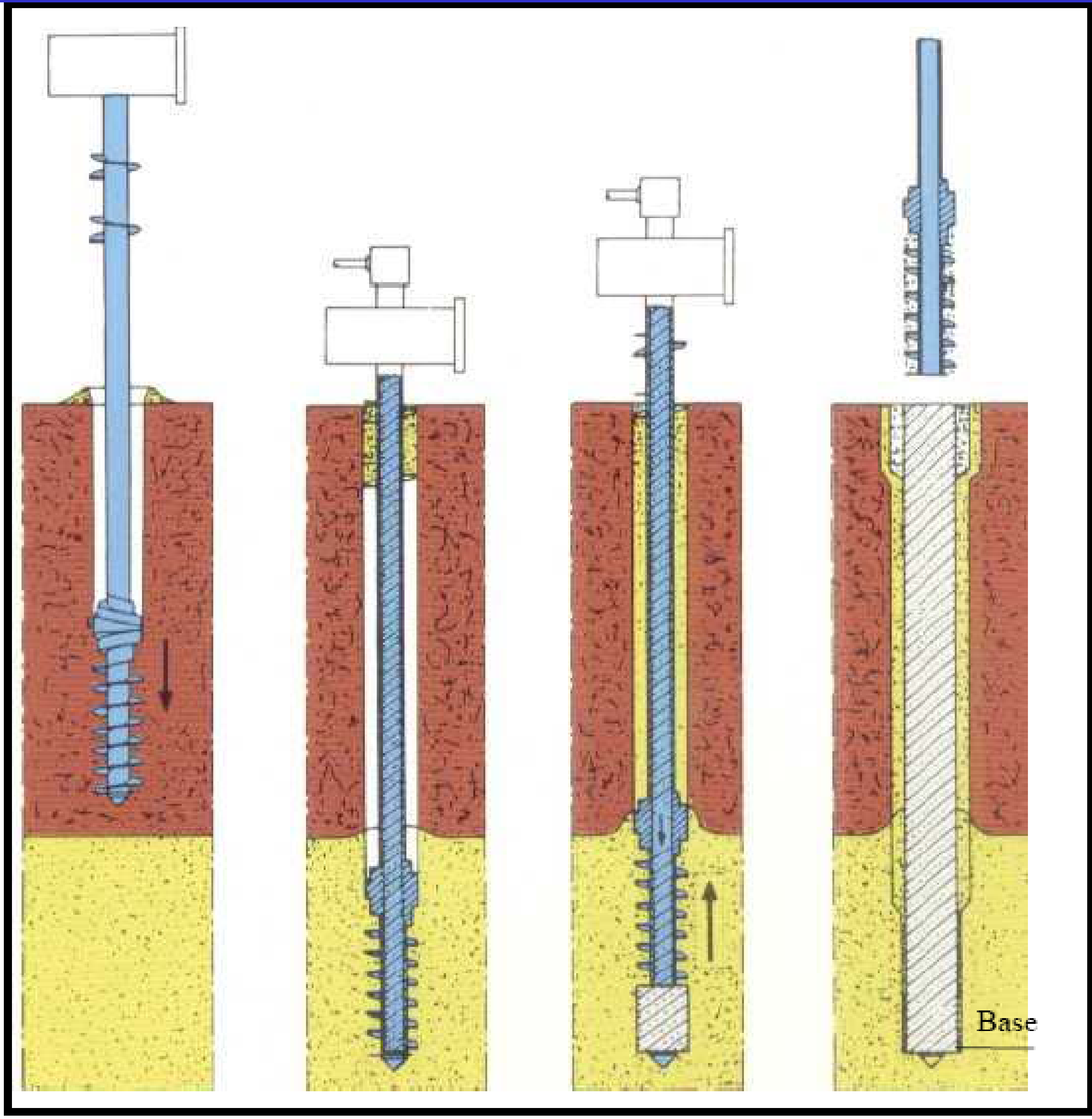

Typical ACIP Pile Rig



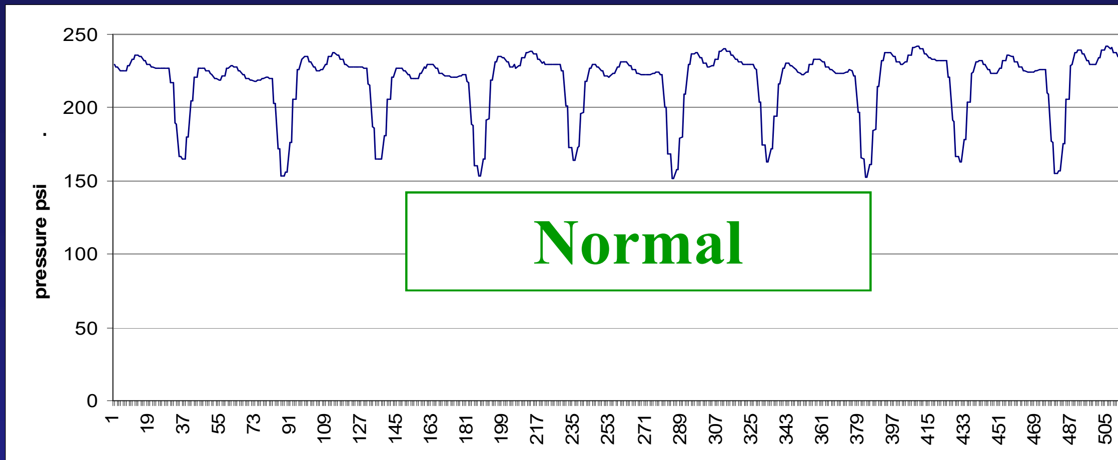



(a)
(b)
(c)

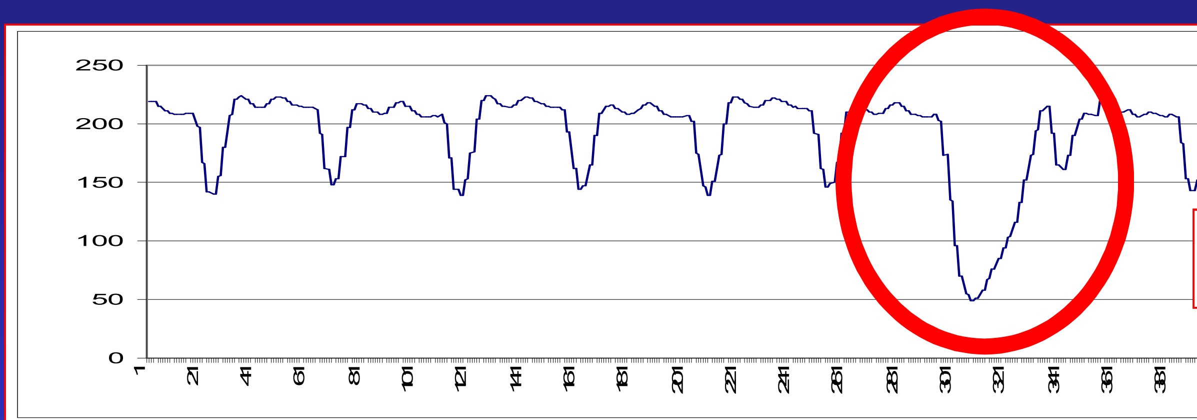
“Displacement” Auger-cast Piles



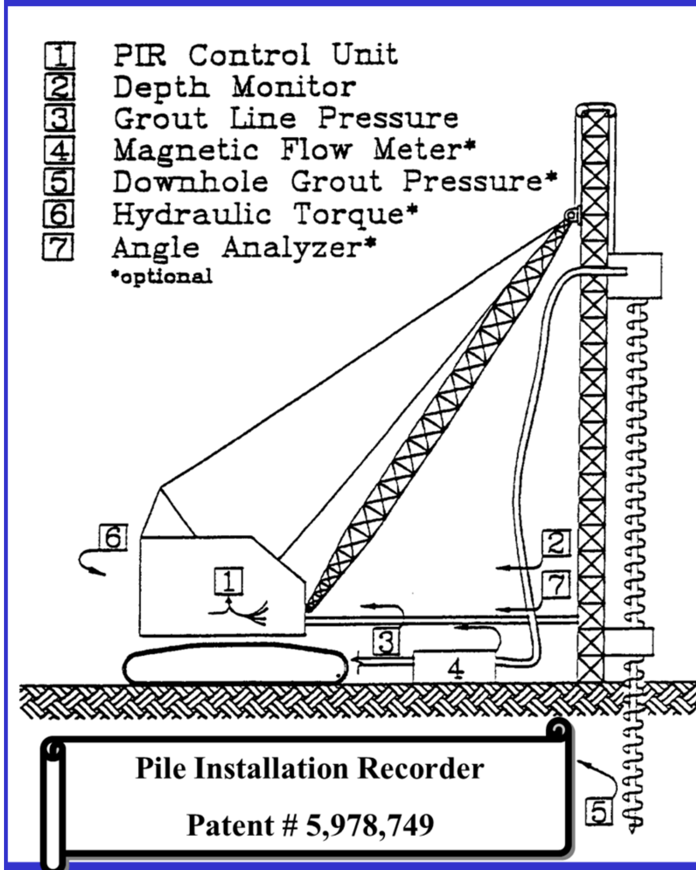

Rinker
MATERIALS



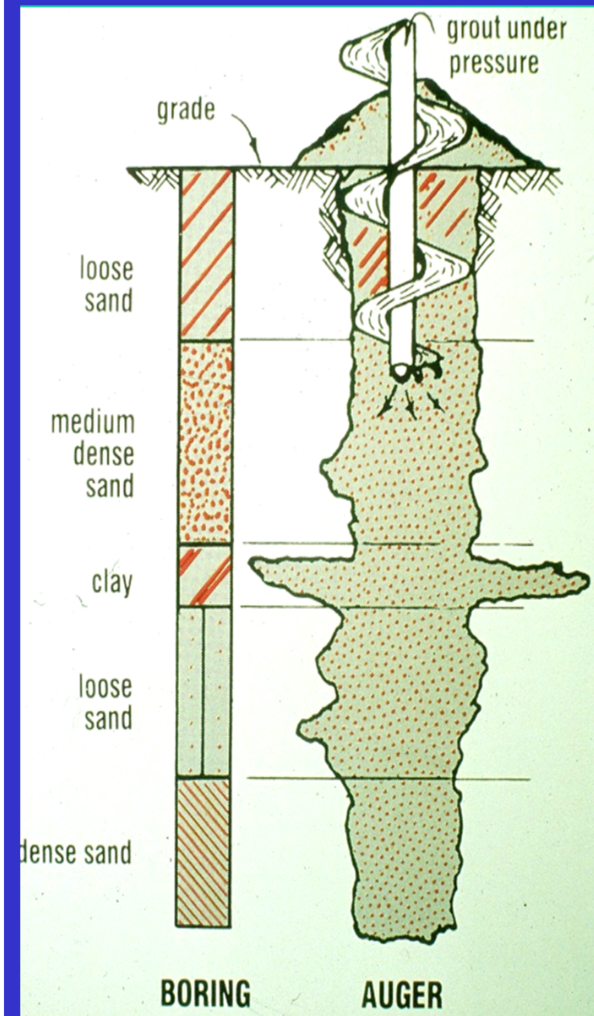
Normal
pressure psi
250
200
150
100
50
0
1 19 37 55 73 91 109 127 145 163 181 199 217 235 253 271 289 307 325 343 361 379 397 415 433 451 469 487 505



250
200
150
100
50
0



Provides real-time information to Operator during constructing the pile



Factors affecting constructed shape and structural integrity include:

- **Subsurface conditions**
- **Design**
- **Means and Methods**
- **Workmanship**

Study by O'Neill [1] indicate 20% of shafts have defects, and **"since these flaws are identifiable by NDE, they are, by definition, not 'minor'"**

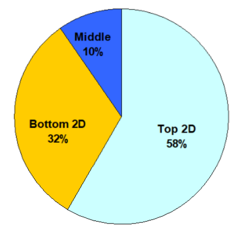
In total, study shows over 50% of all shafts have some defect or flaw.

[1] O'Neill & Sarhan, 2004, "Structural Resistance Factors for Drilled Shafts Considering Construction Flaws", ASCE Geotechnical Special Publication No. 125

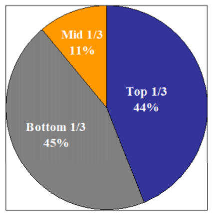
Anomaly Location (anomaly is not always a defect)

Percentage of Shafts with Anomalies

37%



Billy Camp, S&ME Inc.
Southeast USA
"Crosshole Sonic Logging of South Carolina Drilled Shafts: A Ten Year Summary" - Presentation to ADSC Expo 2012, San Antonio March 2012



38%

Jones & Wu, Geotechnology, Inc.
Missouri and Kansas

"Experiences with Cross-hole Sonic Logging and Concrete Coring for Verification of Drilled Shaft Integrity", ADSC GEO³ Construction Quality Assurance/Quality Control Technical Conference, Dallas Nov 2005






Construction, drilling or casing practices can cause various defects

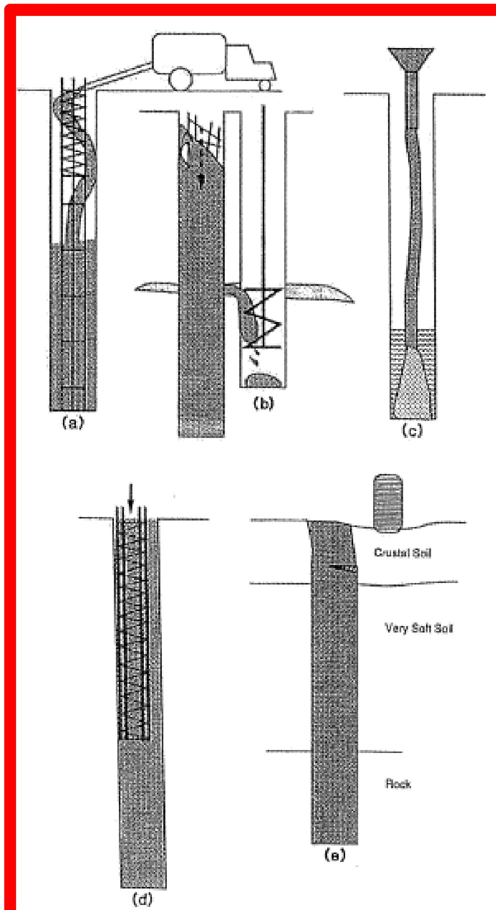


FIGURE 2 General construction problems.

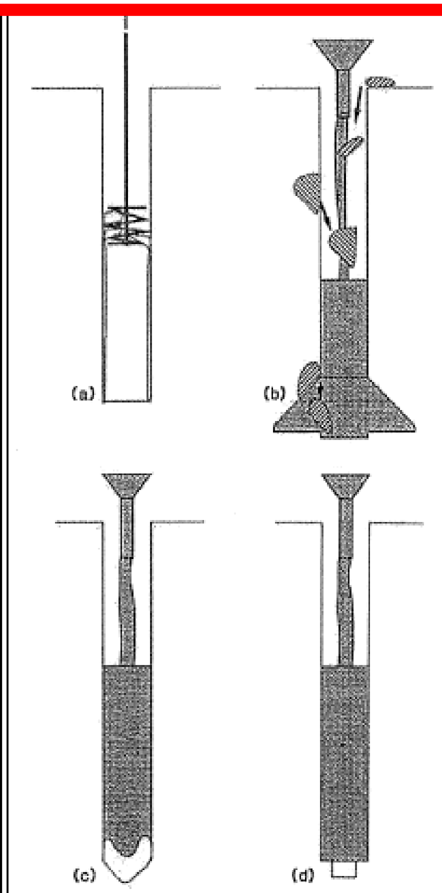


FIGURE 3 Drilling problems and consequences.

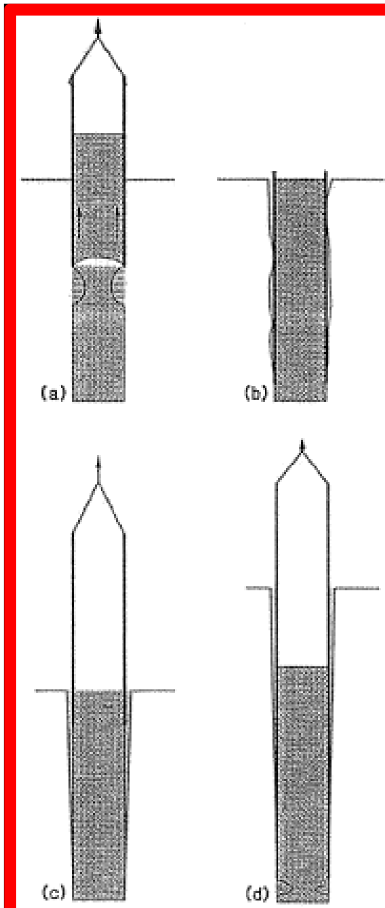


FIGURE 4 Common casing problems.

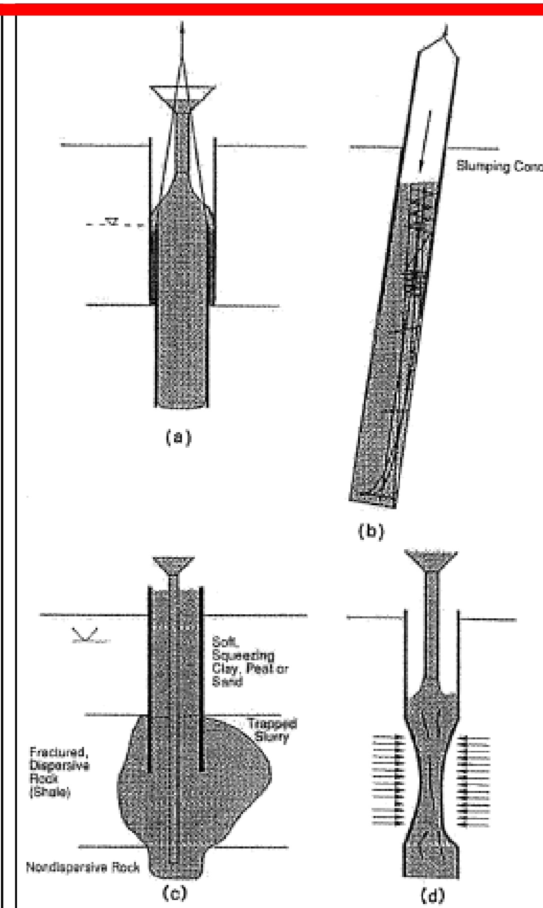


FIGURE 5 Less common casing problems.

Construction related

Casing related

"Construction Practices and Defects in Drilled Shafts",
Michael O'Neill, Transportation Research Record 1331, 1991

Slurry practice can cause various defects

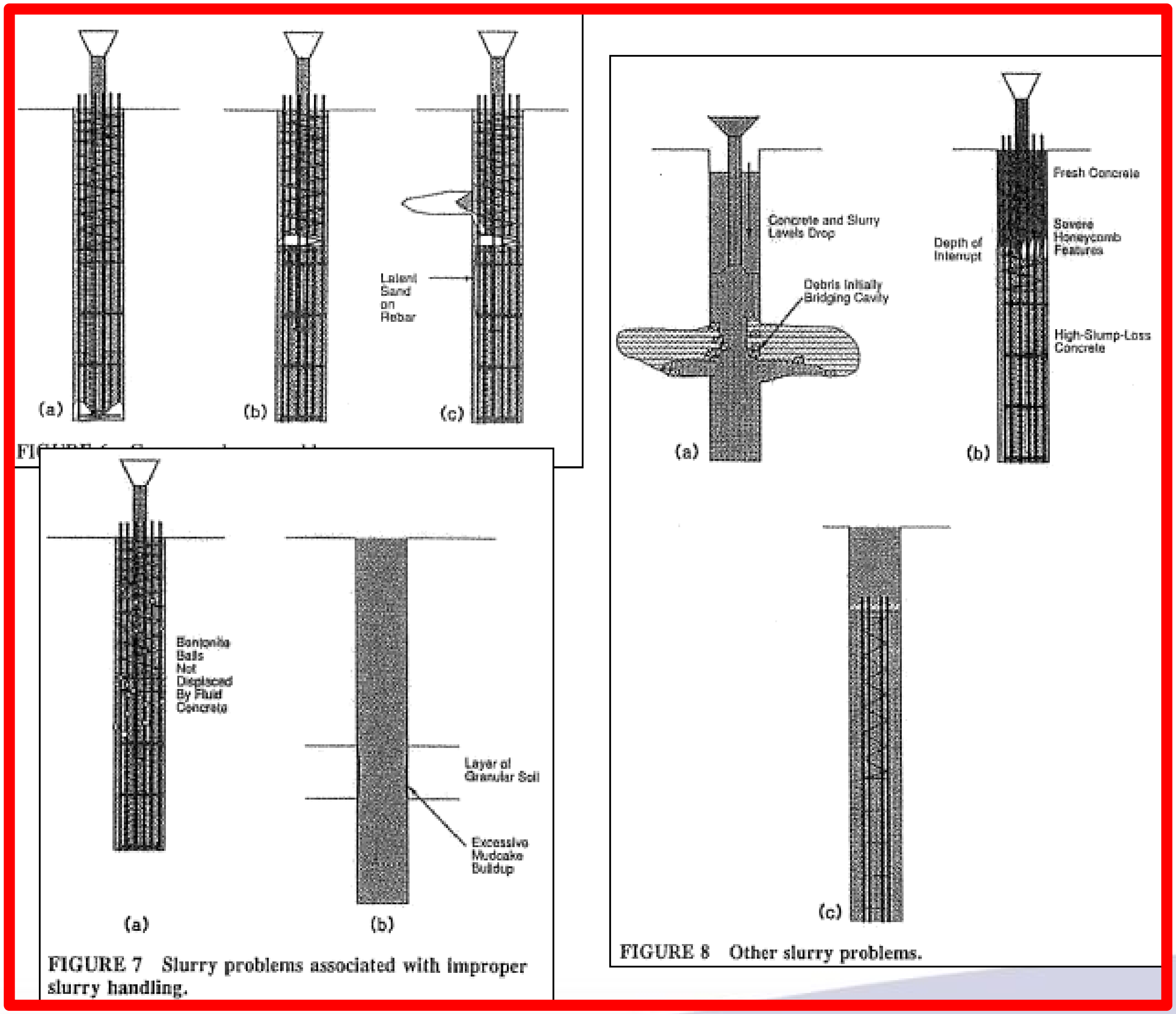


FIGURE 7 Slurry problems associated with improper slurry handling.

FIGURE 8 Other slurry problems.

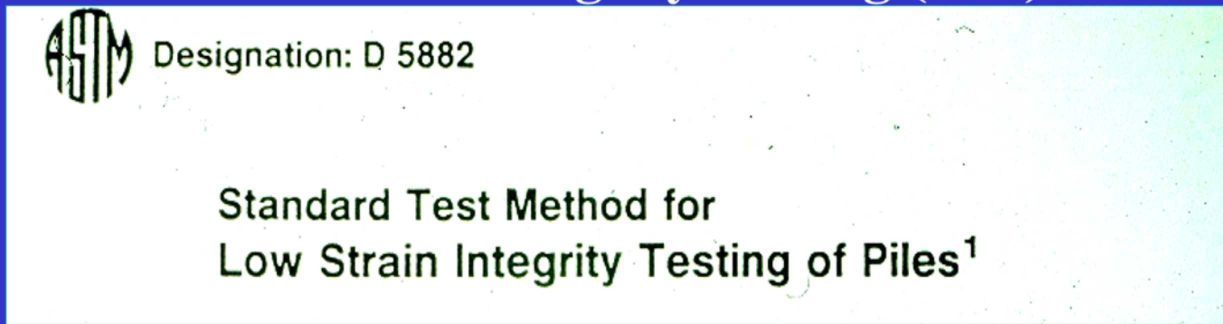
"Construction Practices and Defects in Drilled Shafts", Michael O'Neill, Transportation Research Record 1331, 1991

Integrity testing checks for flaws / defects

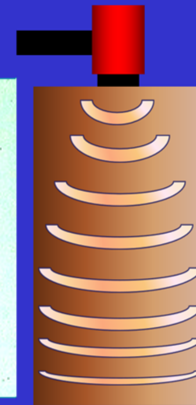
A flaw is a deviation from the planned shape or material (or both).

A defect is a flaw that because of its size or location may detract from the serviceability (capacity or durability) of the deep foundation element.

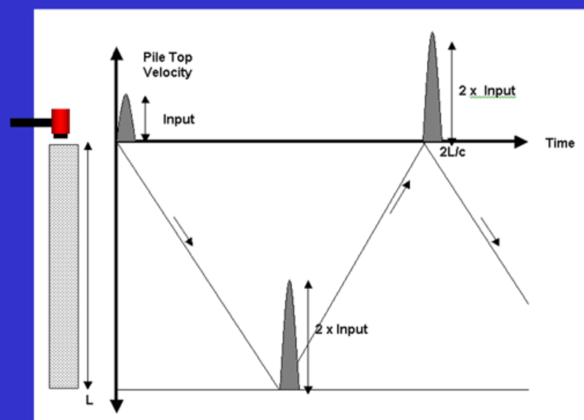
Low-Strain Integrity Testing (PIT)

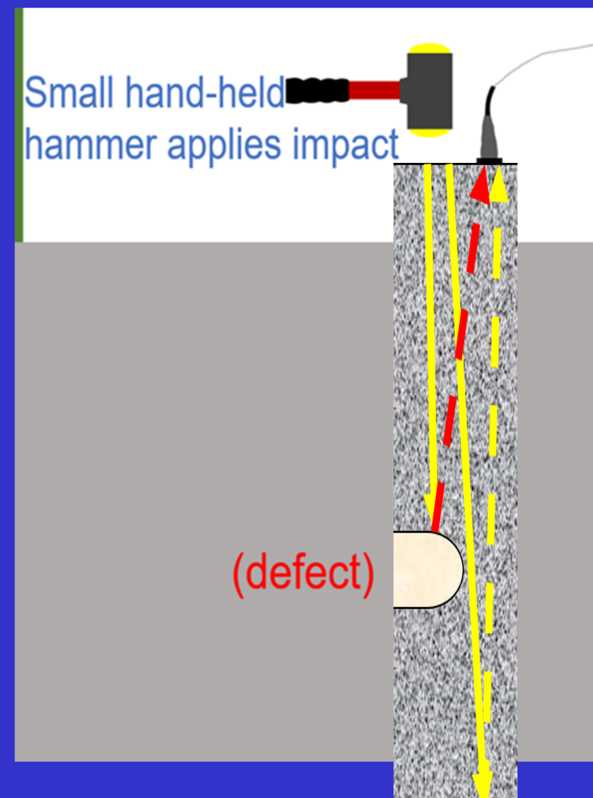

Designation: D 5882

Standard Test Method for
Low Strain Integrity Testing of Piles[1]



Wave Propagation





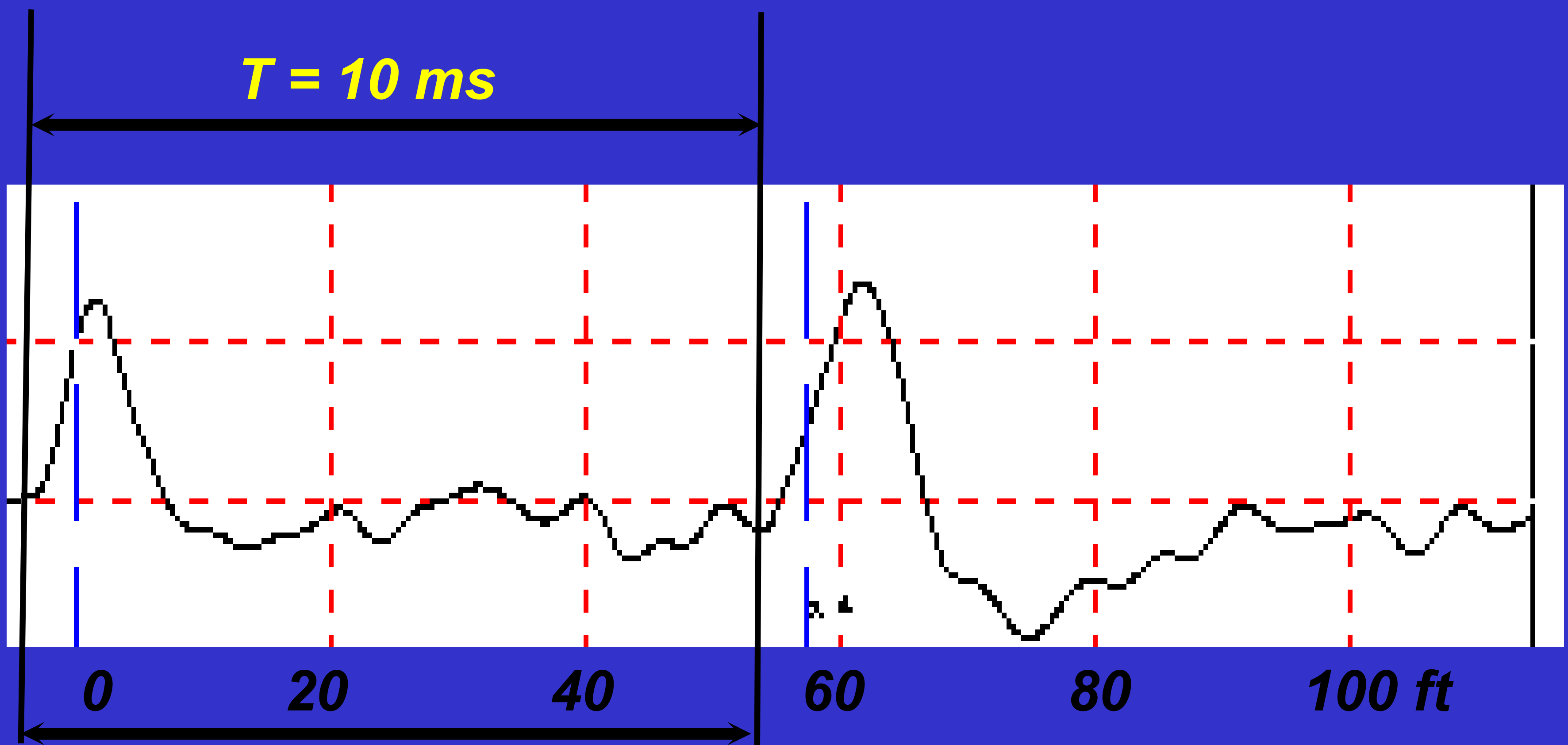
Basic Relationships

Stresswave Speed $c = (E/\rho)^{1/2}$

Pile Impedance $Z = A\,(E\,\rho)^{1/2}$

Impedance is a function of pile size and material quality.

Converting time to length scale



L = 60 ft (with c = 12,000 ft/s)

PIT Data Classifications

A - Good Shaft

Clear toe response, no other tension reflections.

B - Bad Shaft

Clear identification of serious defect; no toe signal needs contingency tests or corrective measures.

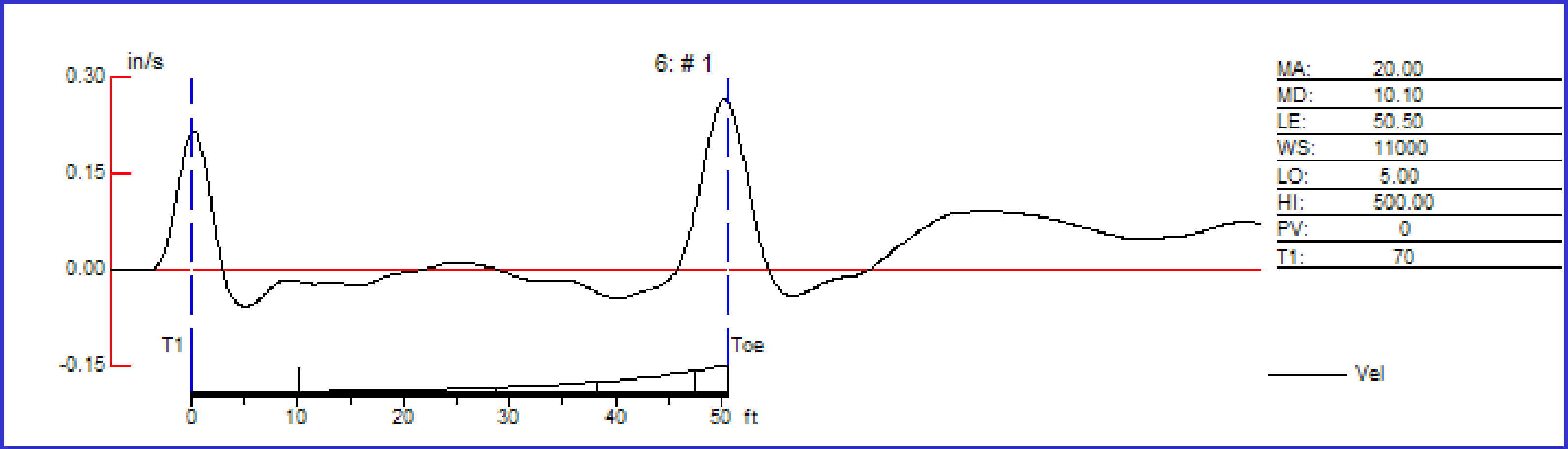
C – Defect in Shaft

Re-test, other tests, reduce capacity or replace.

D - Inconclusive Test Result

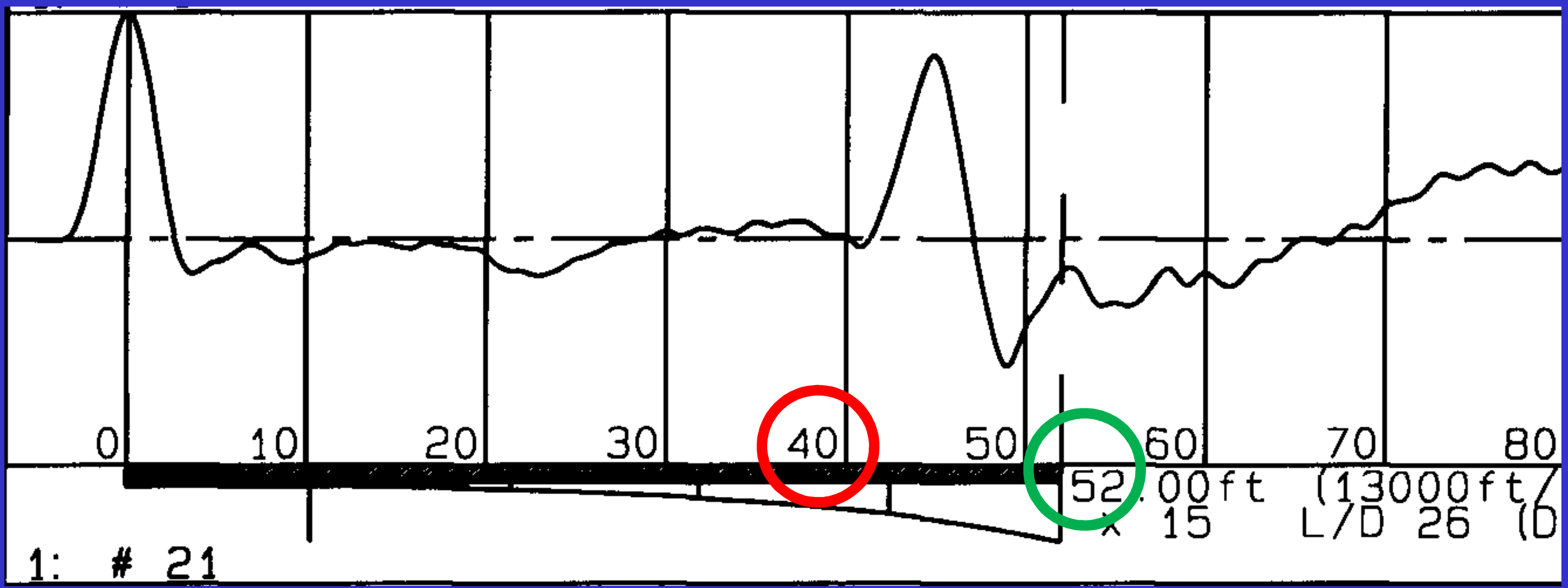
(poor pile top quality, no reflections, etc.)

Data Category: A = Good Shaft.



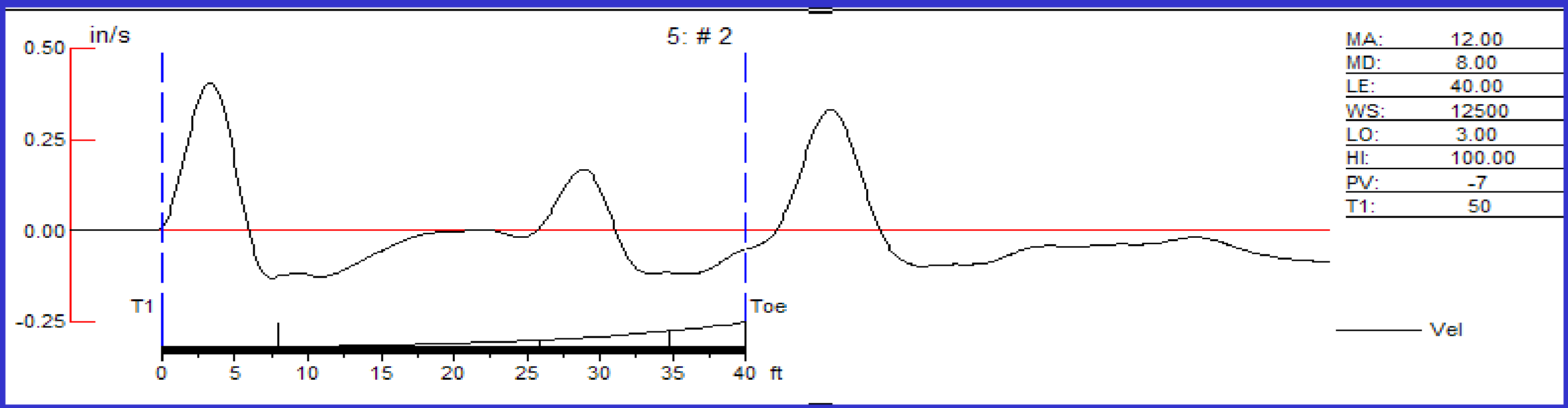
Clear toe reflection, and no intermediate tension reflections.

Data Category: B = Bad Shaft.



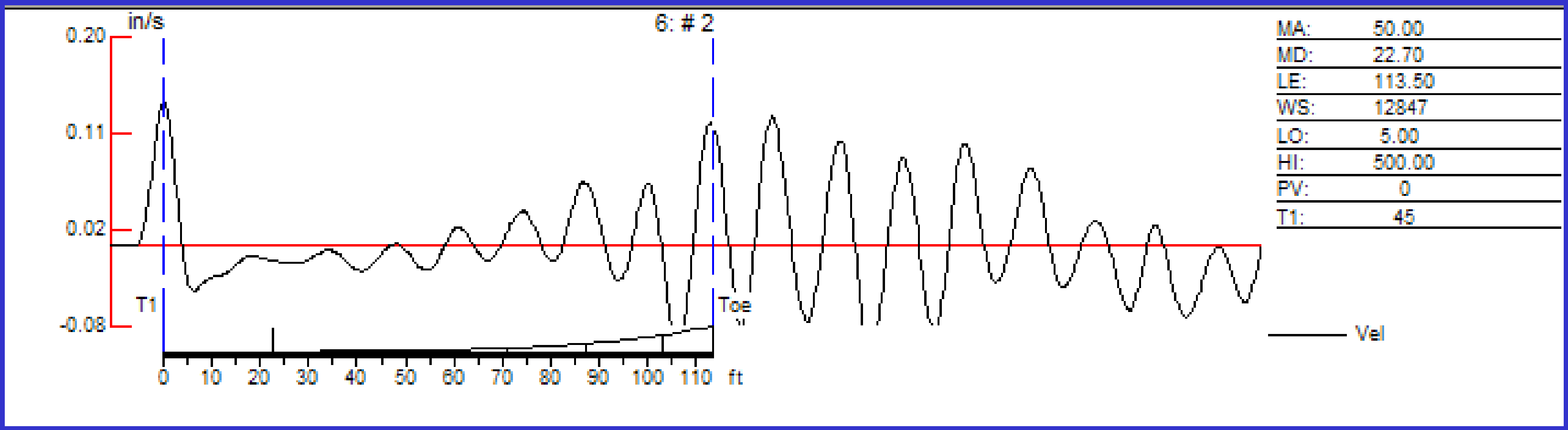
Clear reflection from 41 feet location, no toe reflection; complete reduction at 11 feet above shaft end.

Data Category: C = Shaft with Defect.



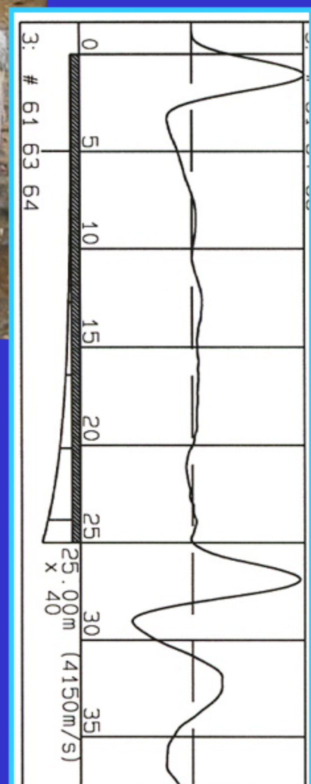
Data includes intermediate reflection and contains toe signal .

Data Category: D = Inconclusive Result.

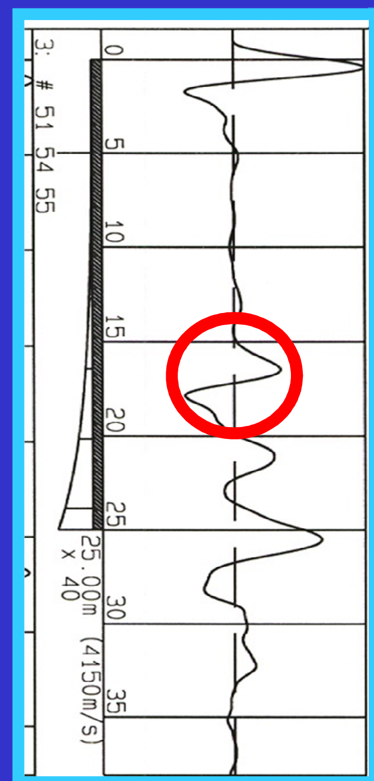


Data lacks characteristics.

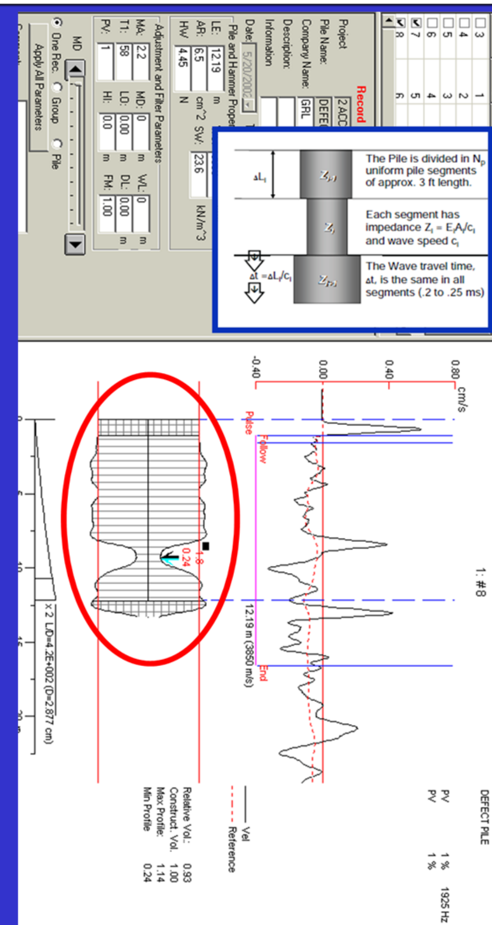
Good Shaft



Shaft with Defect



Profile Calculations

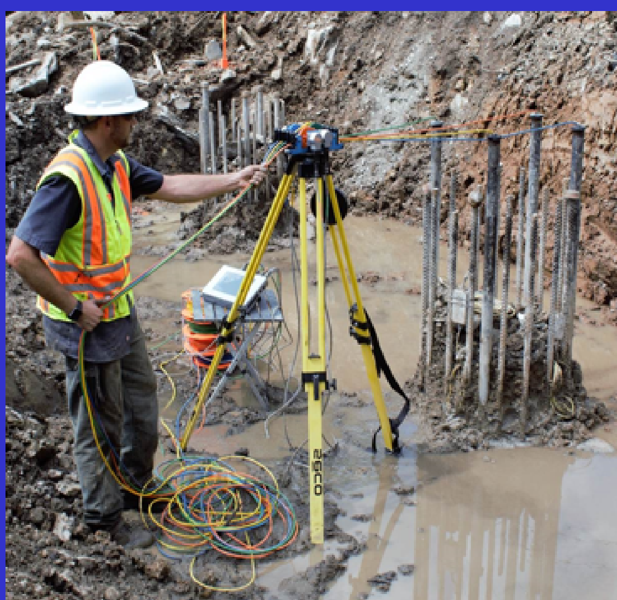


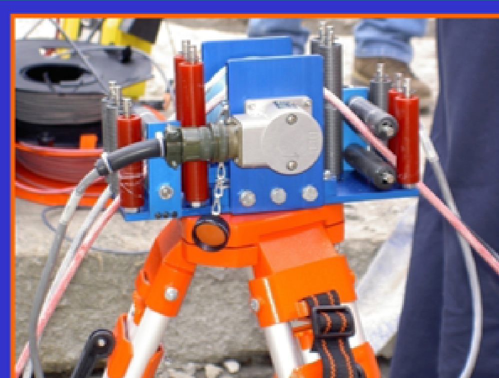
Testing for unknown pile length with PIT

Cross-hole Sonic Logging - CSL

Designation: D 6760 – 02

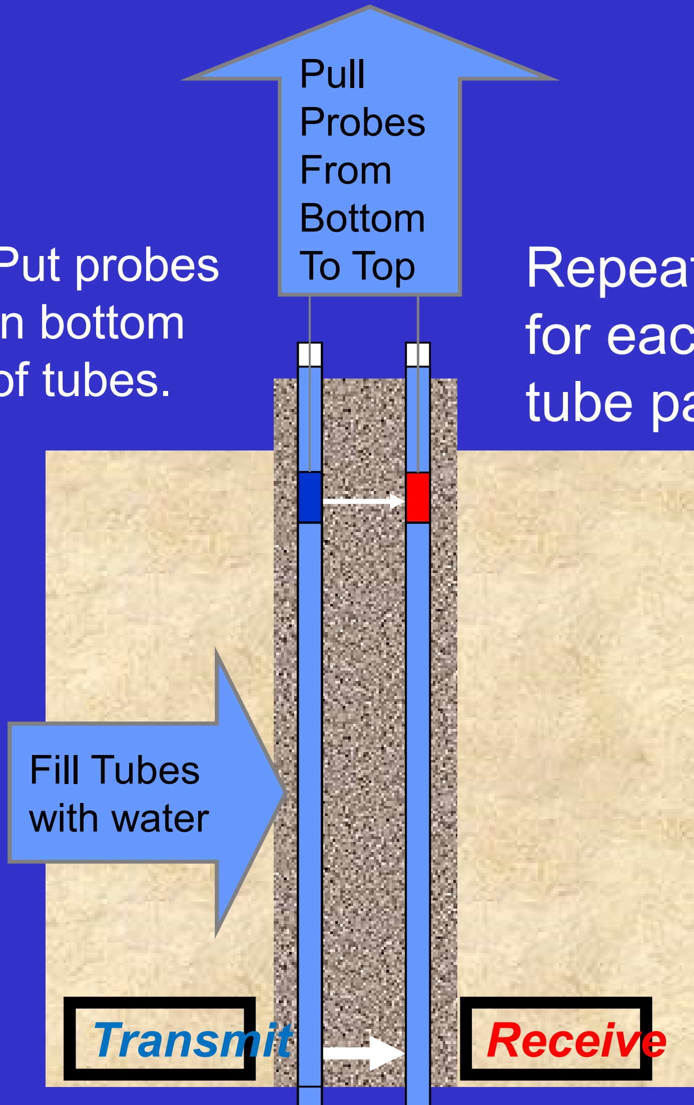
Standard Test Method for Integrity Testing of Concrete Deep Foundations by Ultrasonic Crosshole Testing[1]



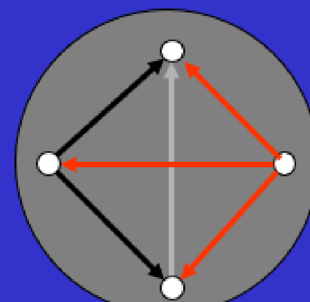


CSLTest

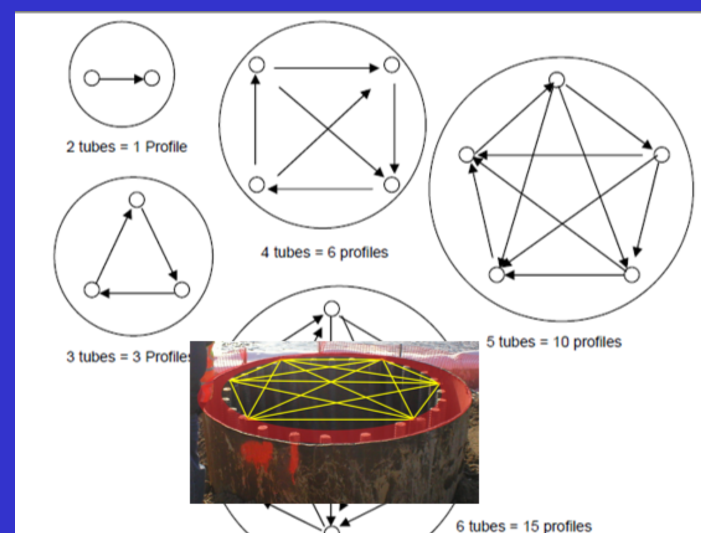
Put probes in bottom of tubes.



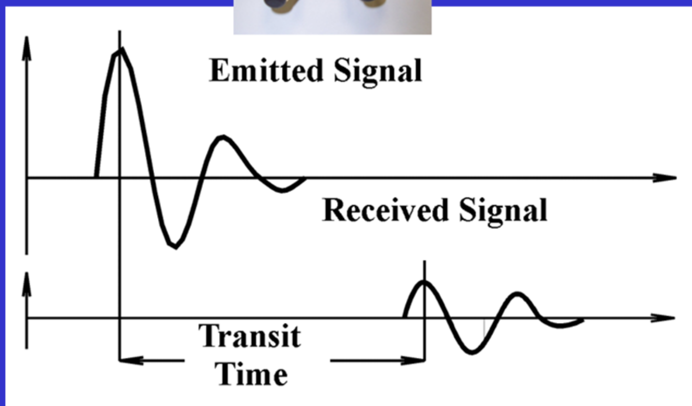
Repeat test for each tube pair



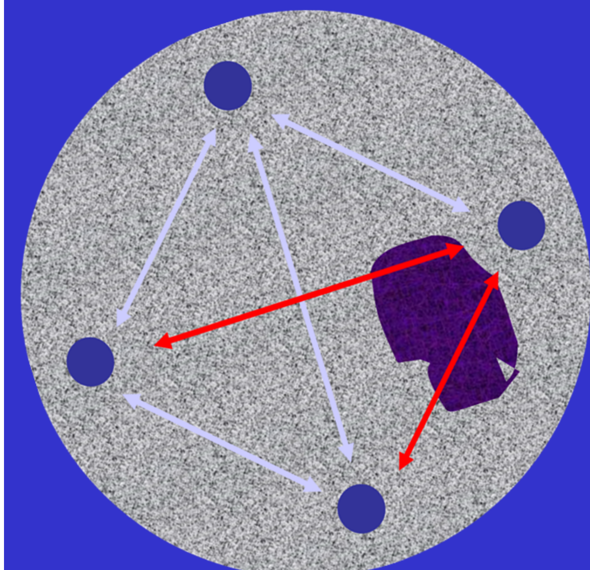
Top view of pile with 4 access tubes



Number of scans for n tubes = $(n^2 - n) / 2$

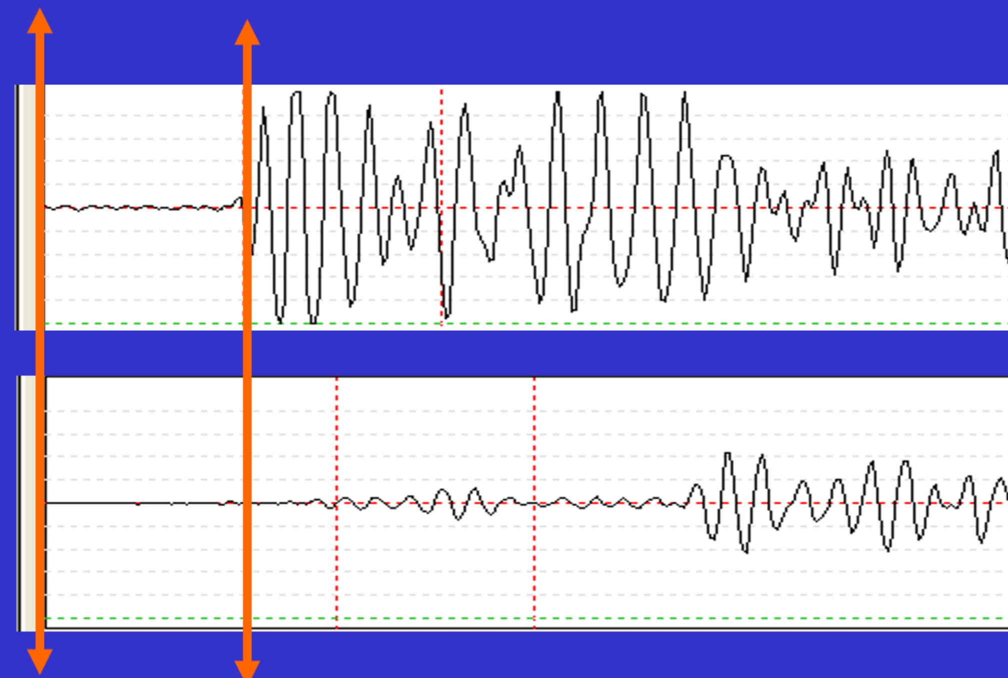


How to find defects?



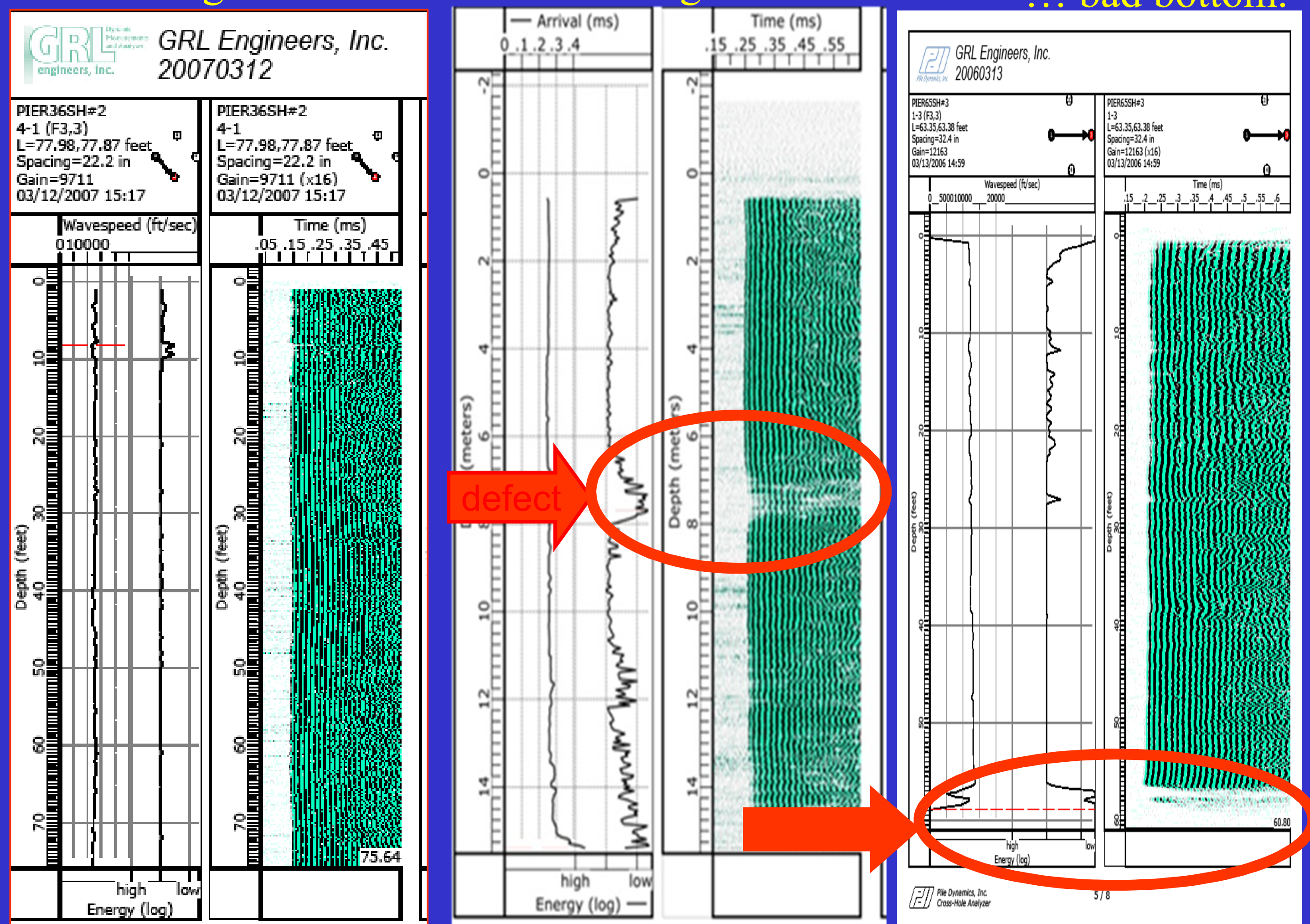
Normal

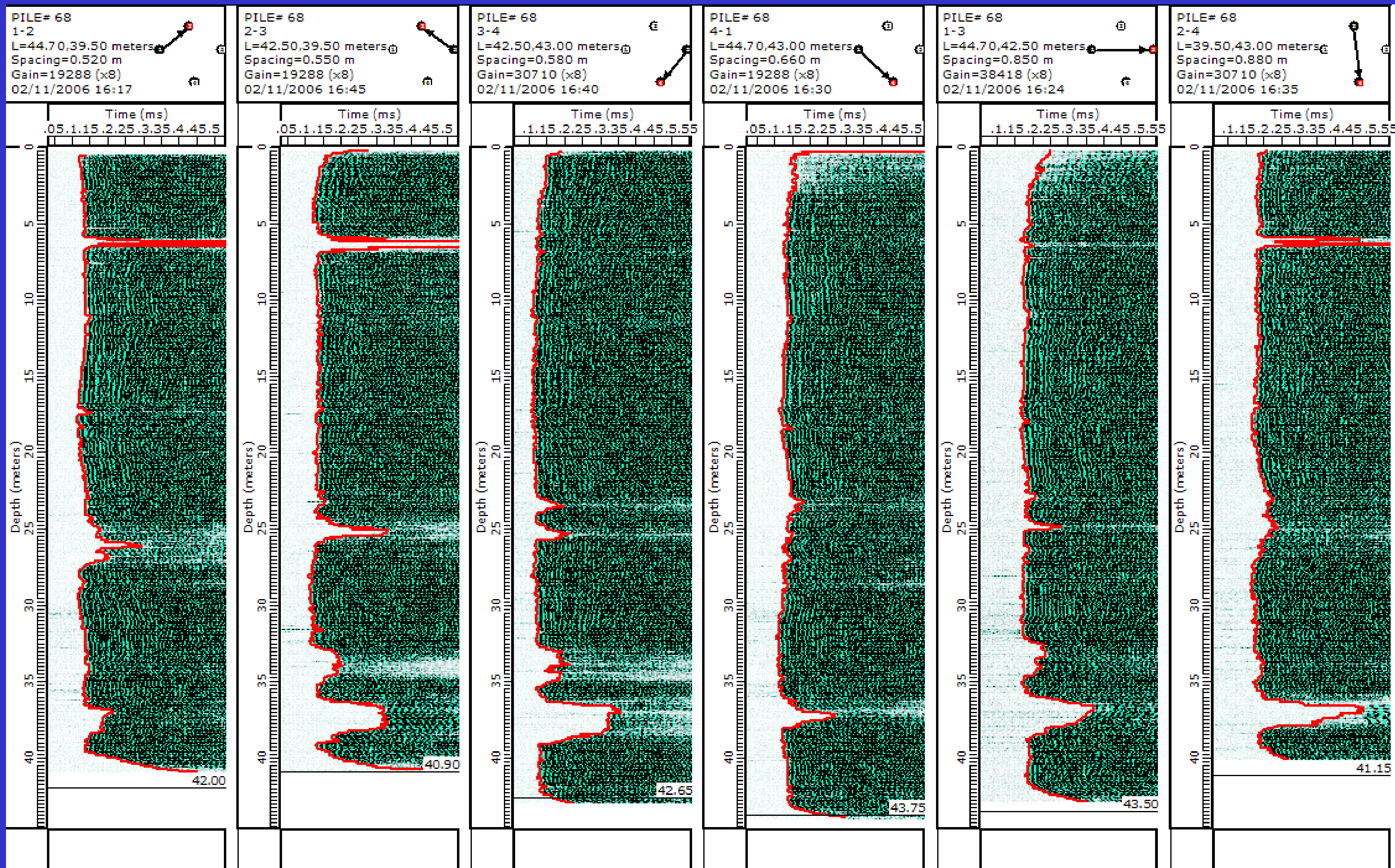
Delayed & weakened



1. Delayed First Arrival Time (FAT)
2. Reduced signal strength (lower energy)

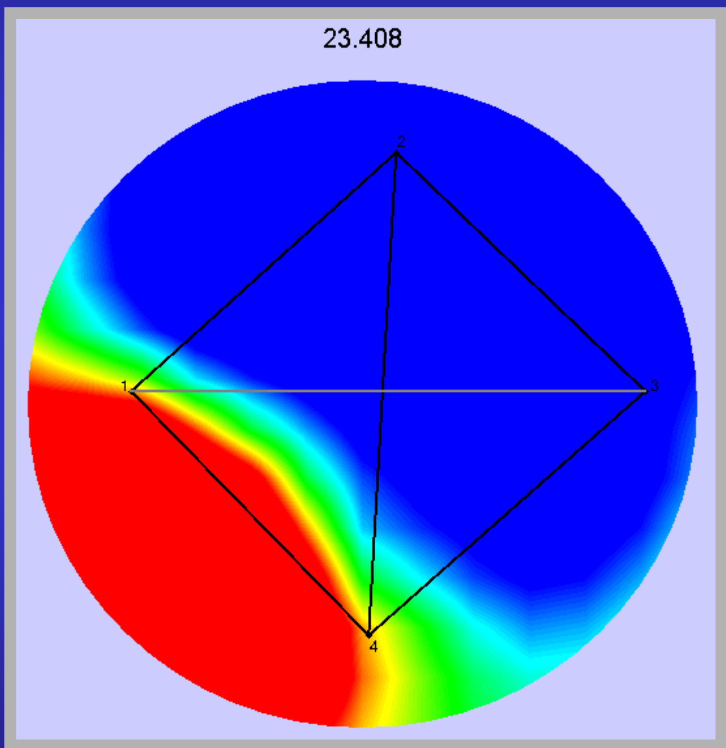
Scan with good result. … showing defect. … bad bottom.



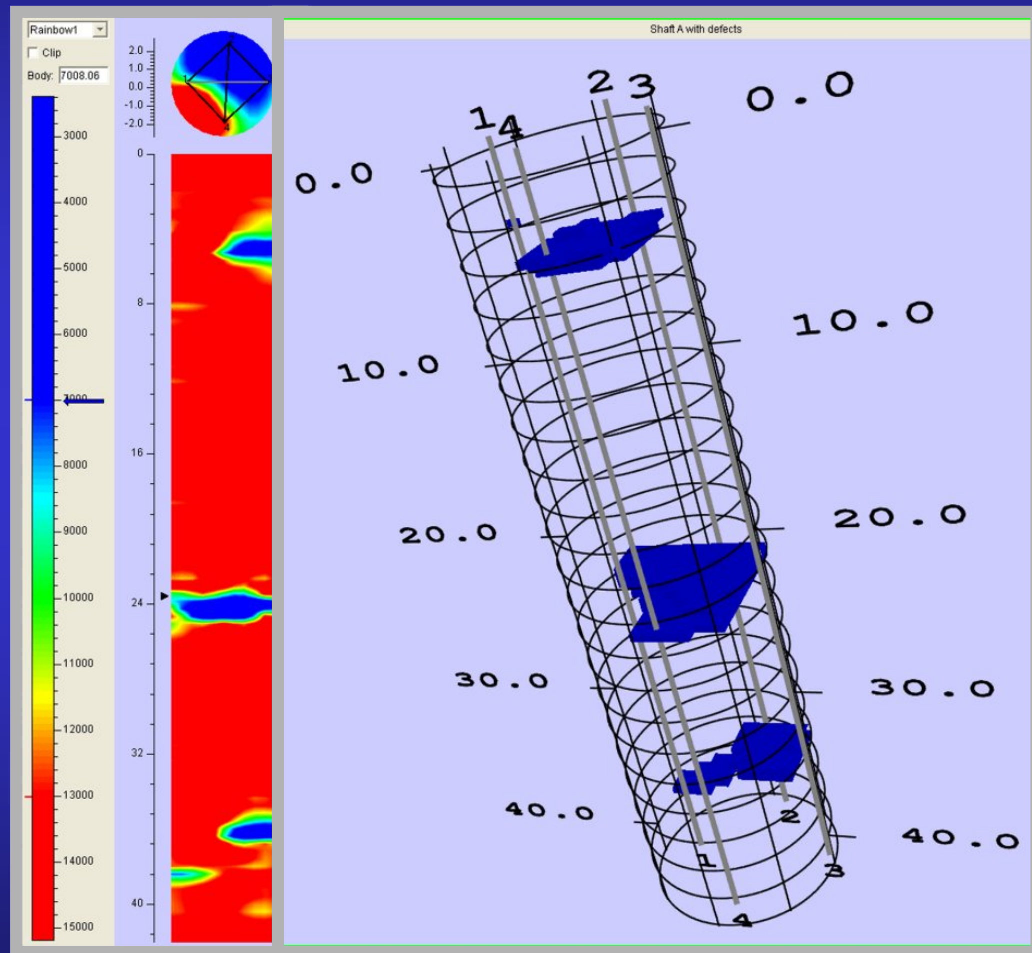


Pile Dynamics, Inc.
Cross-Hole Analyzer

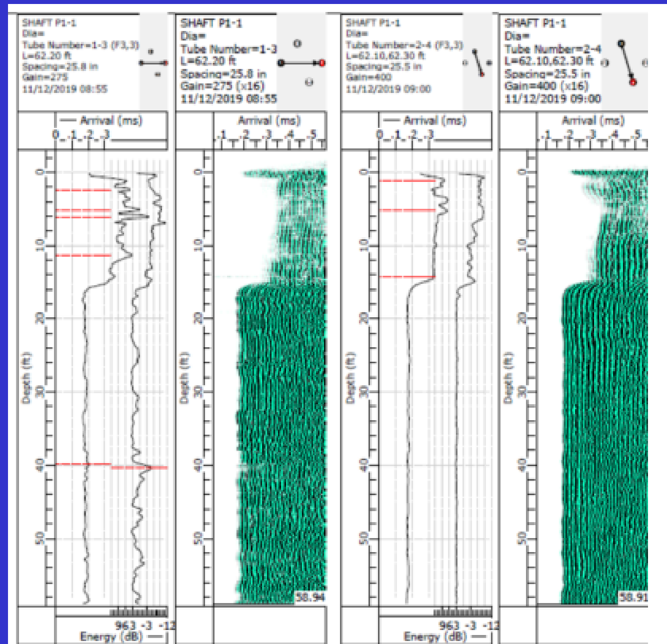
Cross Hole Sonic Logging
3-D Tomography



2D horizontal slice
view of a defect

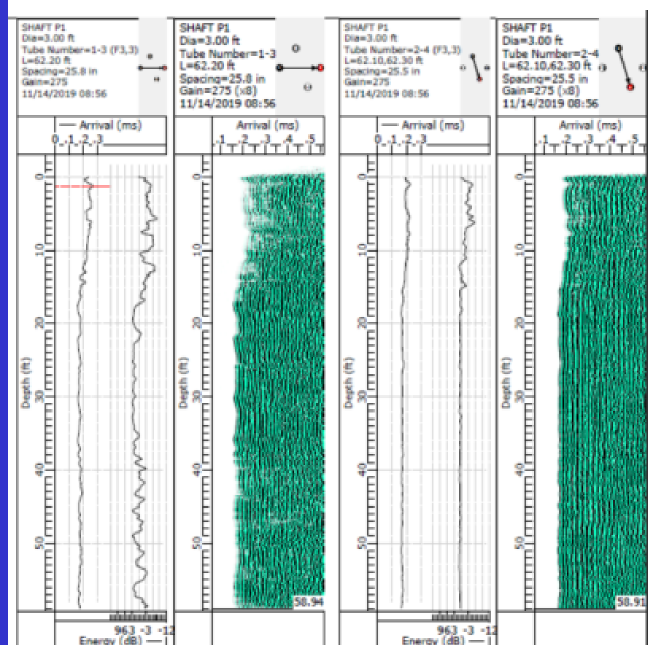


3-D body view



presentative CSL data for shaft P1-1.

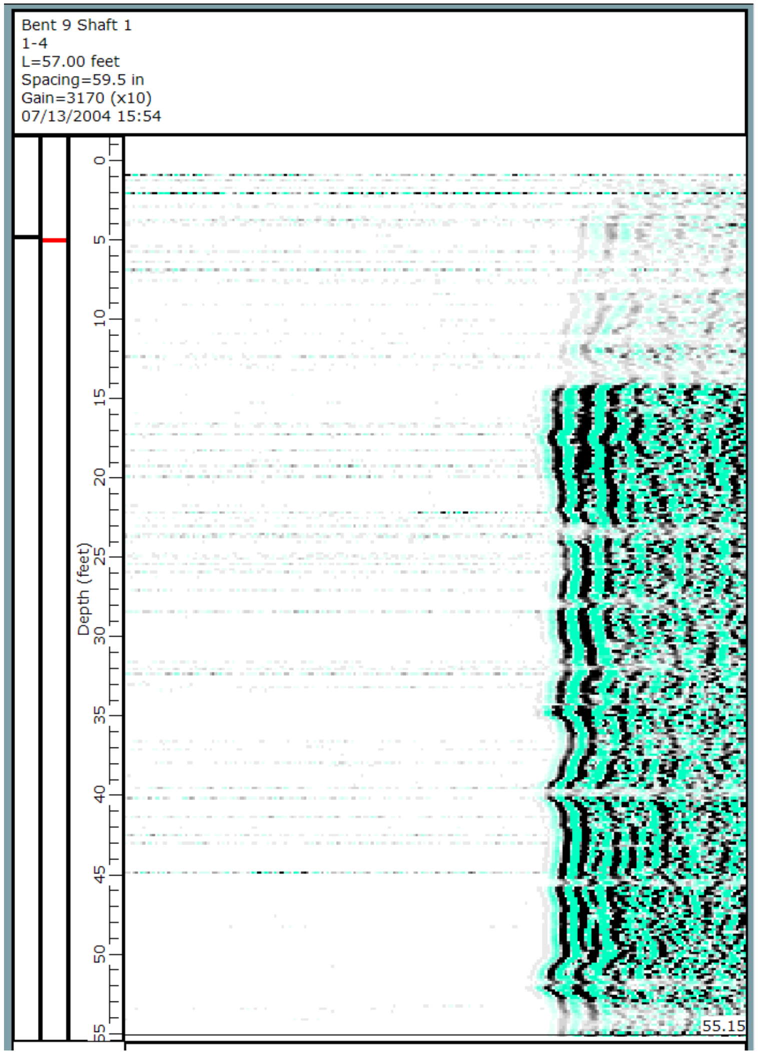
4 days after casting

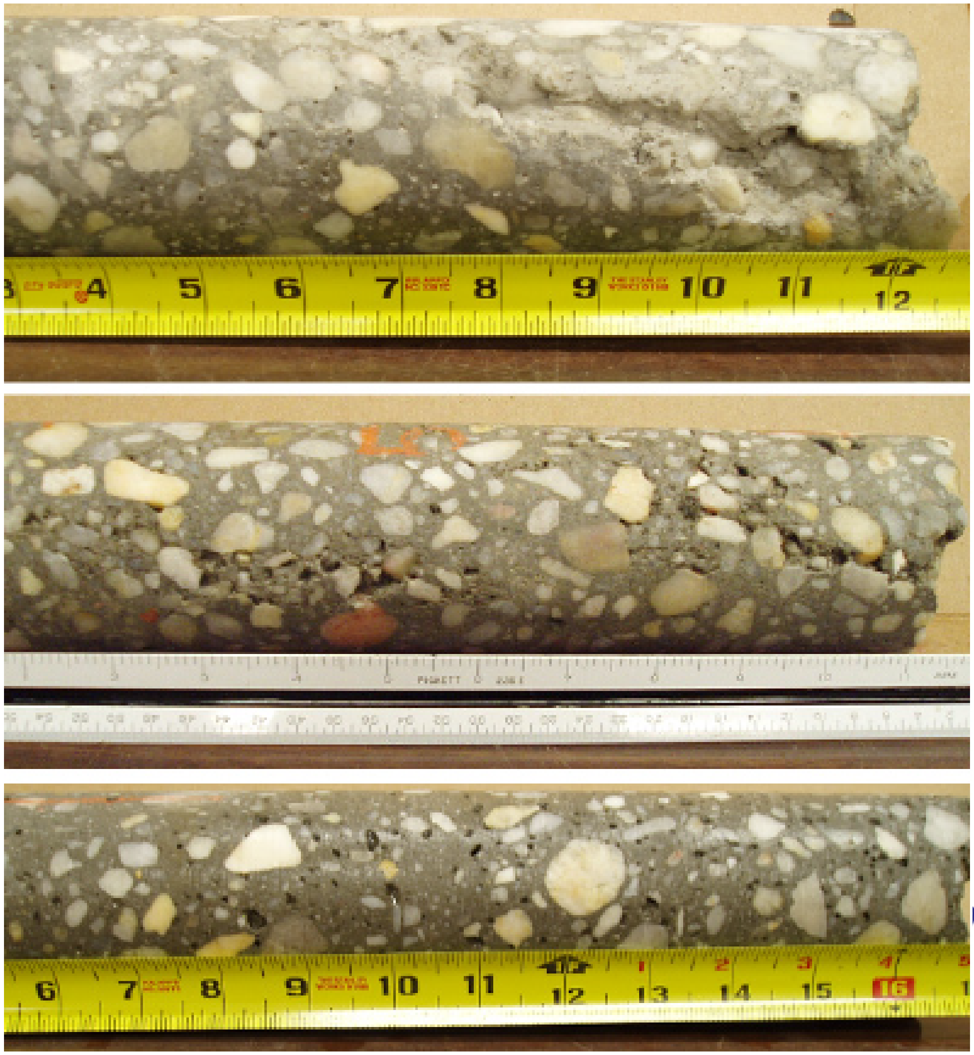


sentative CSL data for shaft P1-1 retest.

6 days after casting

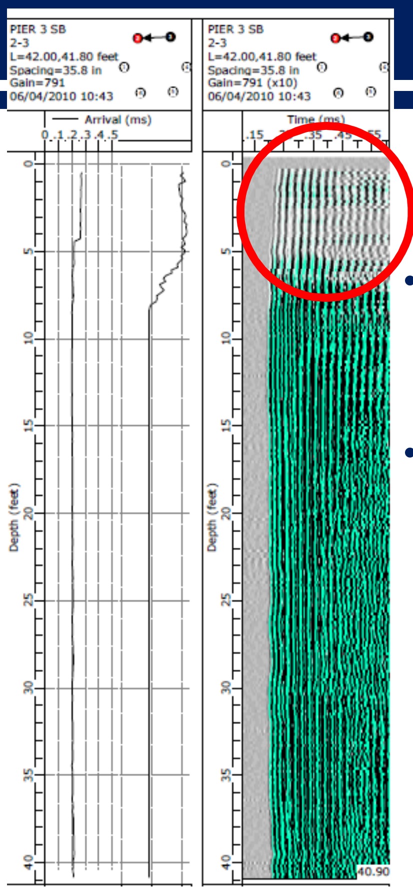
CSL data within permanent steel casing Bleed Water Channel Effect





DEBONDING

Initial test

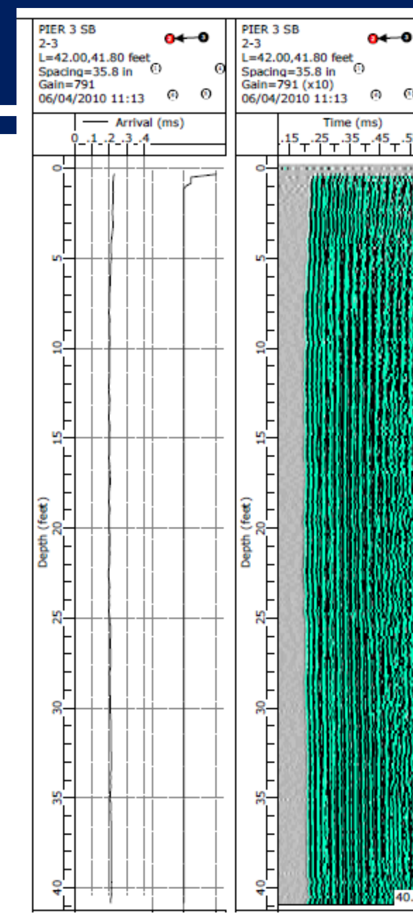


Weakening of bond between tube & concrete

- Thermal Expansion Coefficient
  - Concrete & steel – 12x10^{-6}/°C
  - PVC – 50x10^{-6}/°C
- Almost always relatively near top

To minimize

- Use steel access tubes
- Fill tubes with water ASAP
- **To mitigate: flood shaft top with water**



30 min later

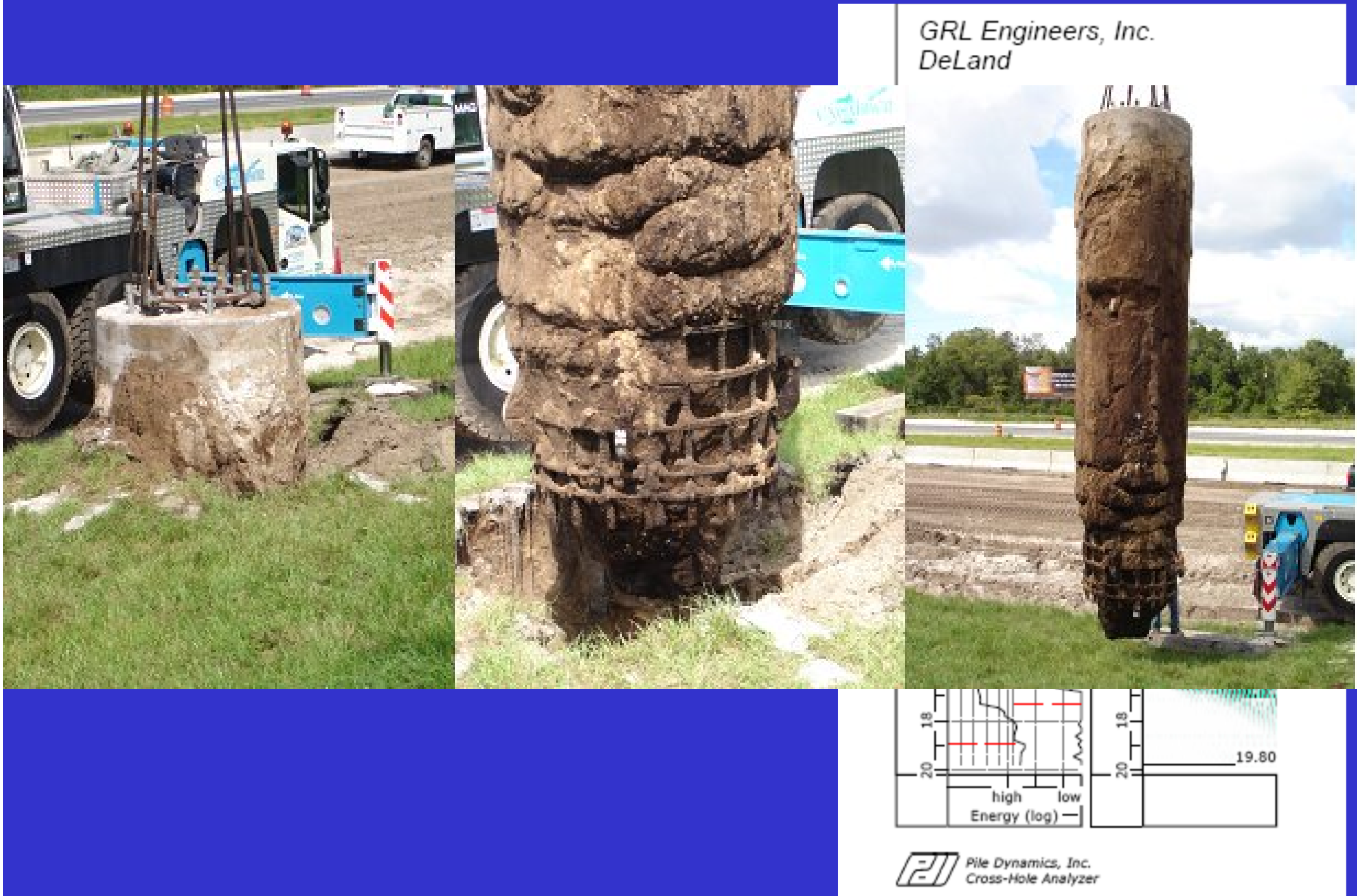
Test after flooding top of shaft

Case Study: FDOT Shaft for a miscellaneous structure.

PIT & CSL testing.

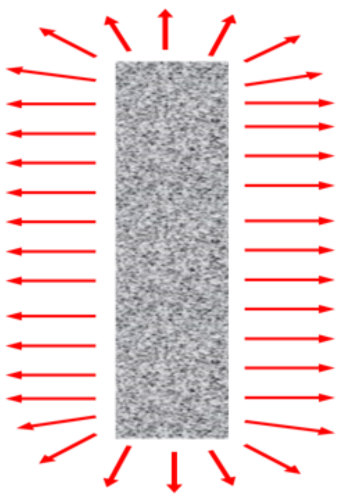
Extracted.

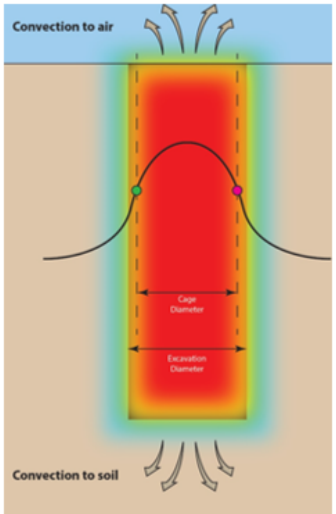
CSL test results.

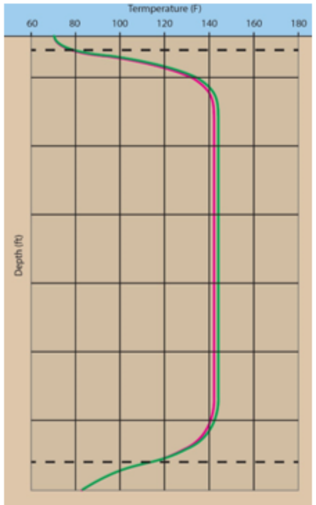


Thermal Integrity Profiling (TIP)

Temperature measurements during curing throughout the deep foundation element allow for evaluation of concrete consistency and drilled shaft or pile shape regularity.



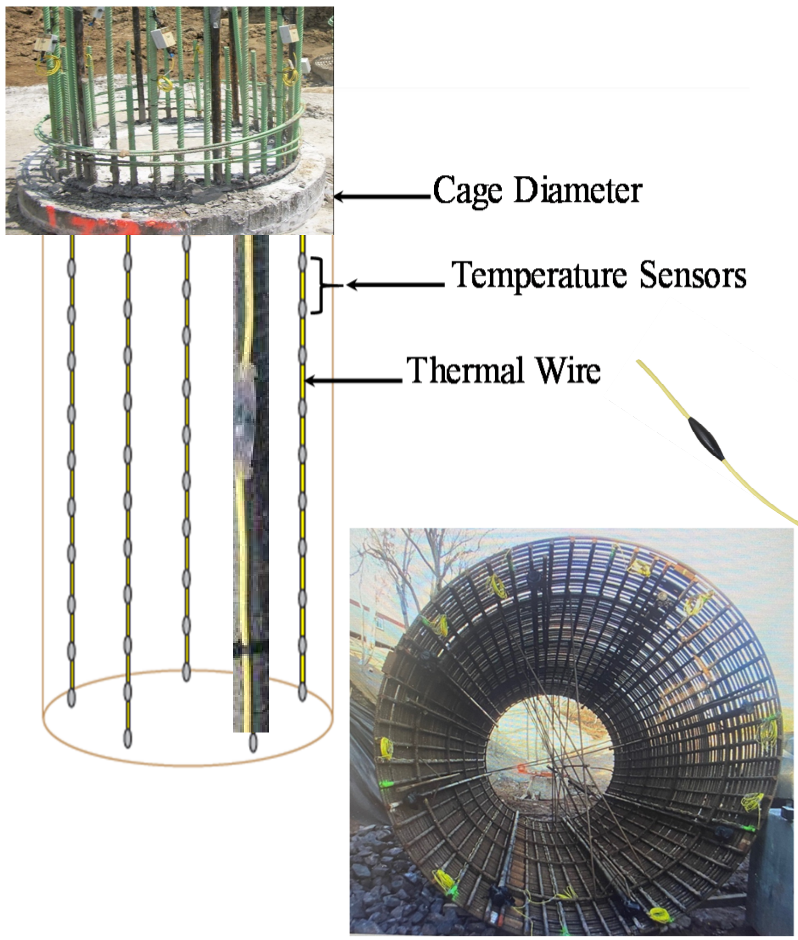


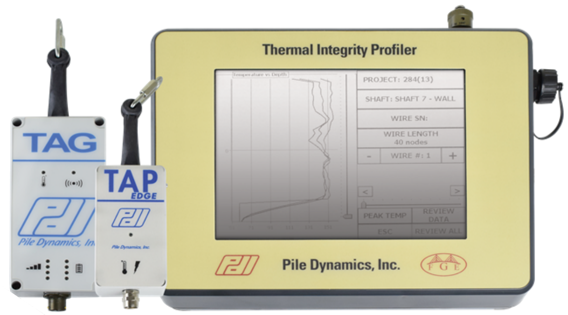


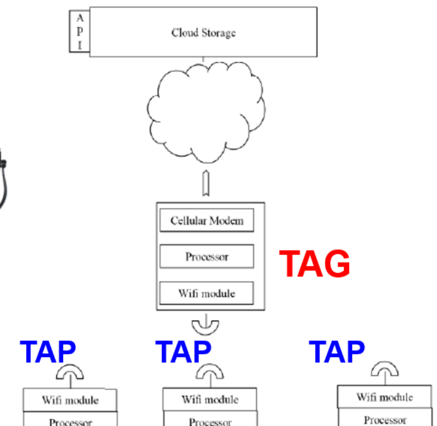
ASTM D7949 - 14

Standard Test Methods for Thermal Integrity Profiling of Concrete Deep Foundations

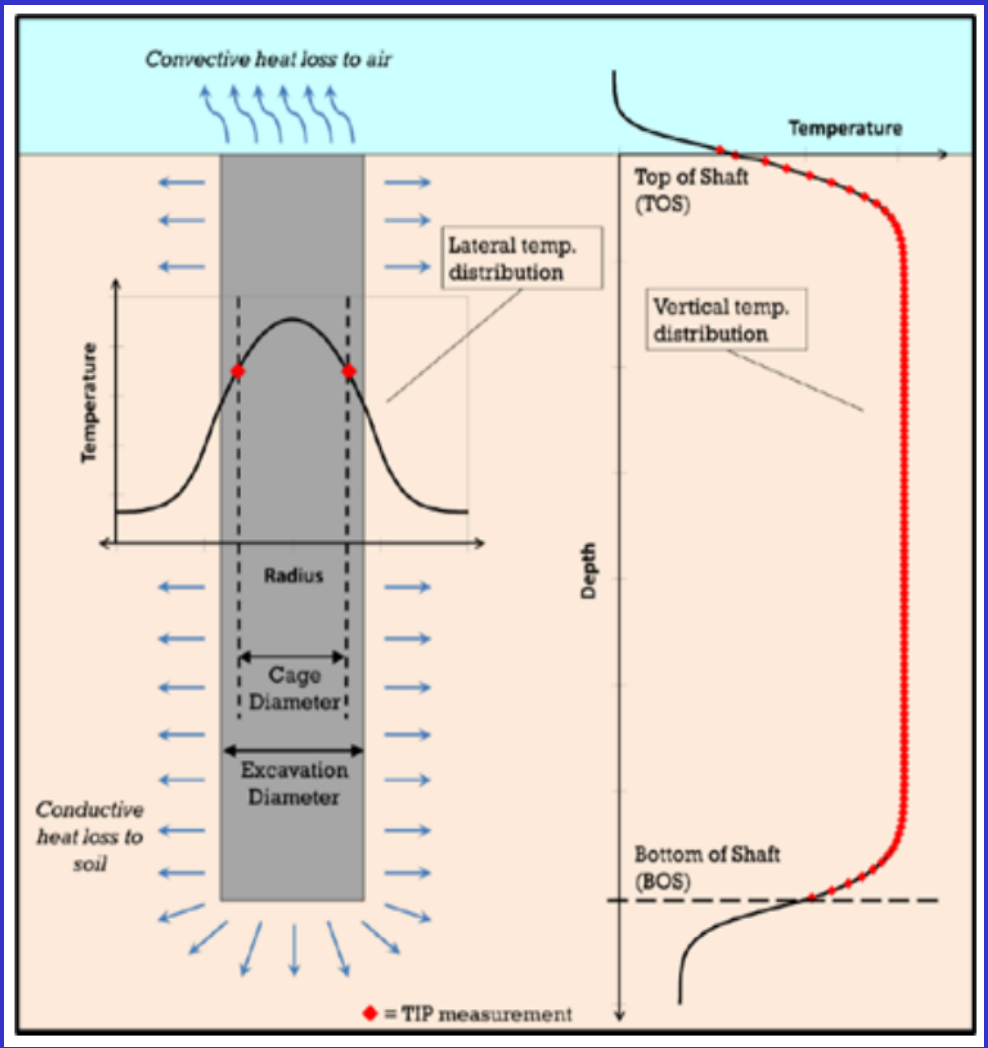
THERMAL INTEGRITY PROFILE Testing





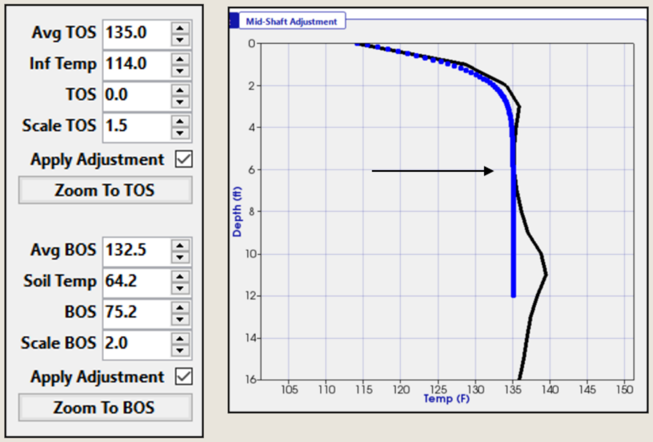


For uniform shaft, temperature is constant, except one diameter at top and bottom roll-off



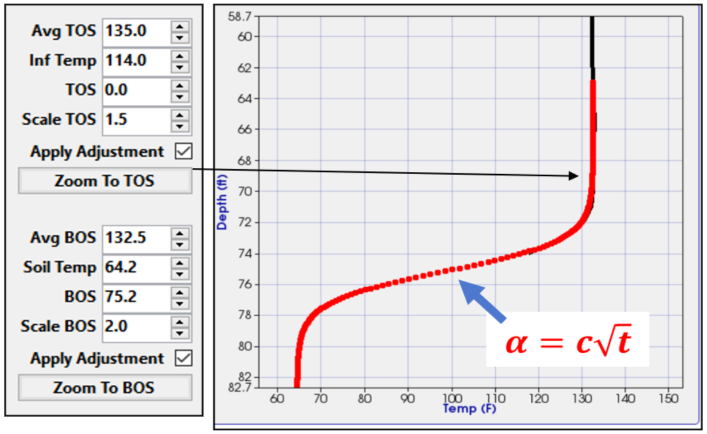
Recommended TOS Hyperbolic Adjustment Paramete

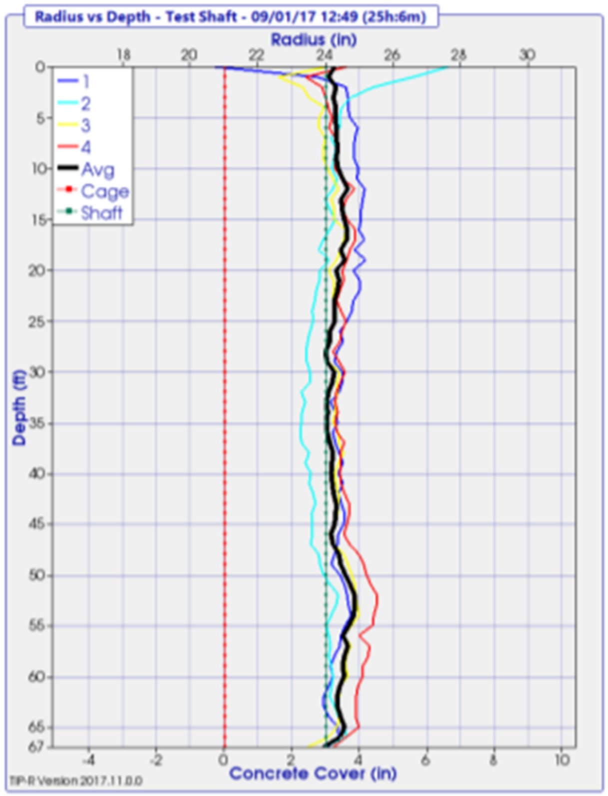
Avg TOS: Average temperature below roll-off region. Generally equal to the temperature observed one diameter below top of concrete (up to 6 feet).

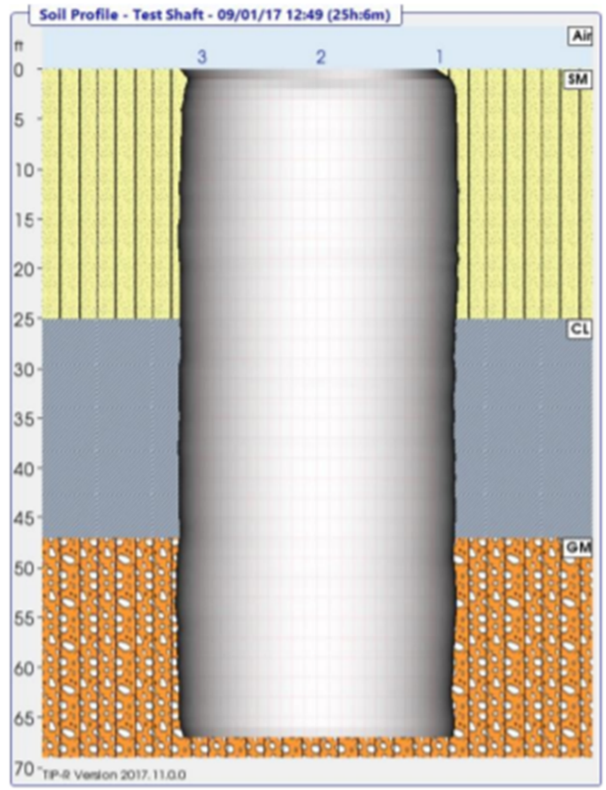


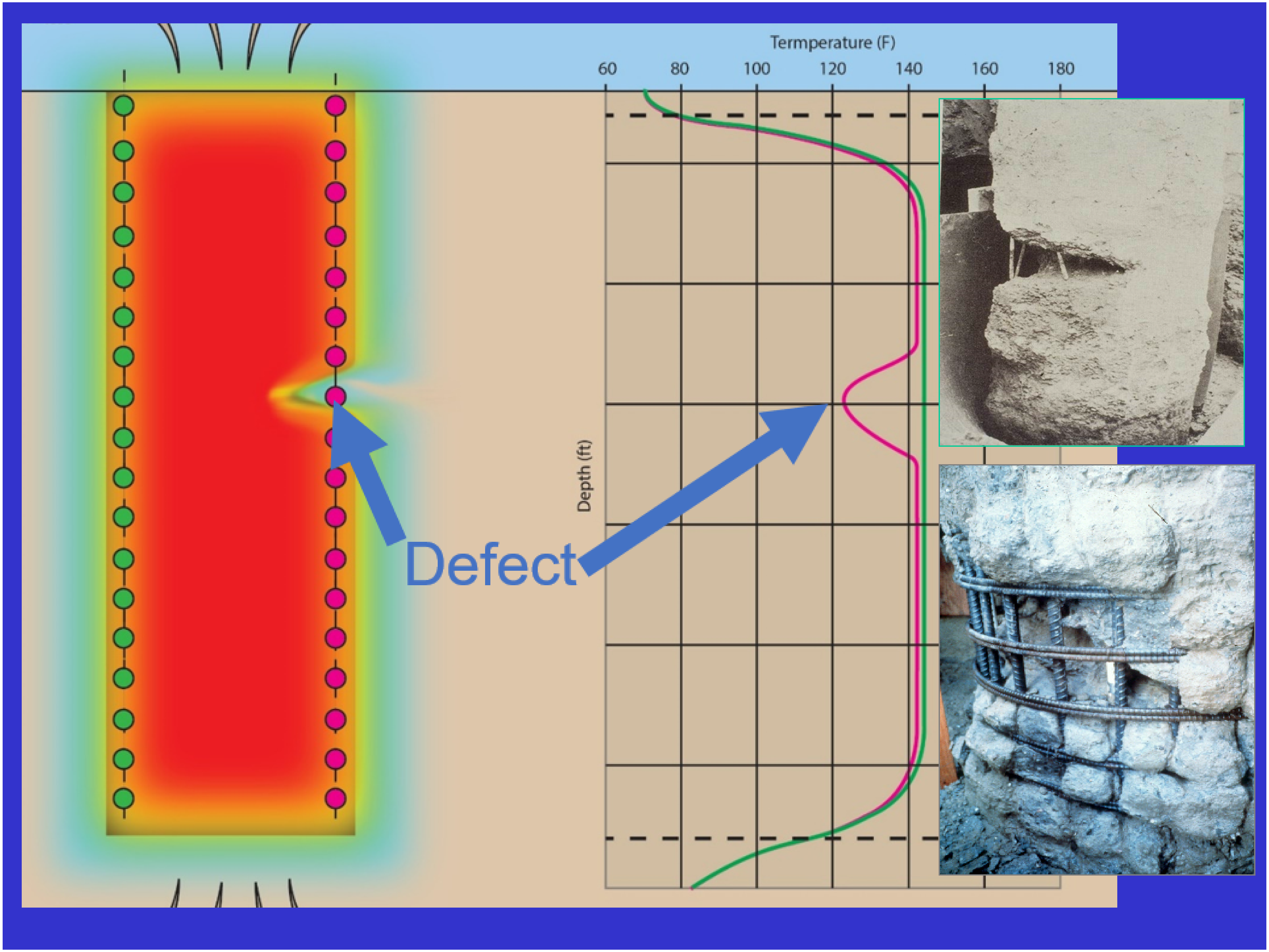
RECOMMENDED BOS HYPERBOLIC ADJUSTMENT PARAMETERS

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).

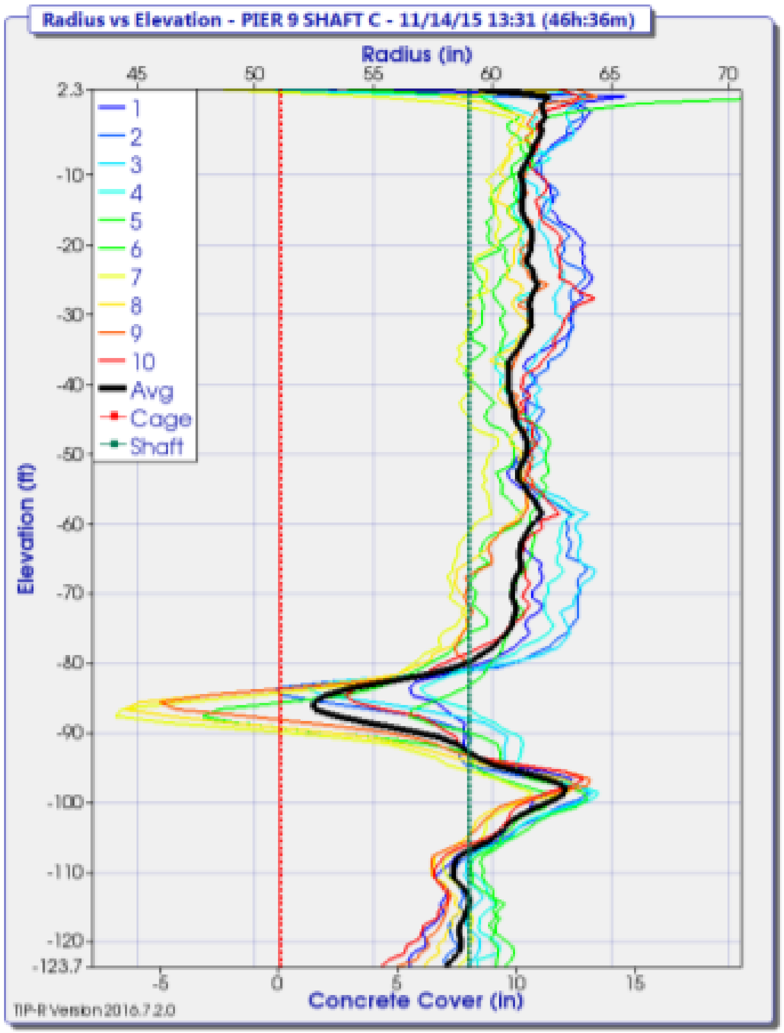


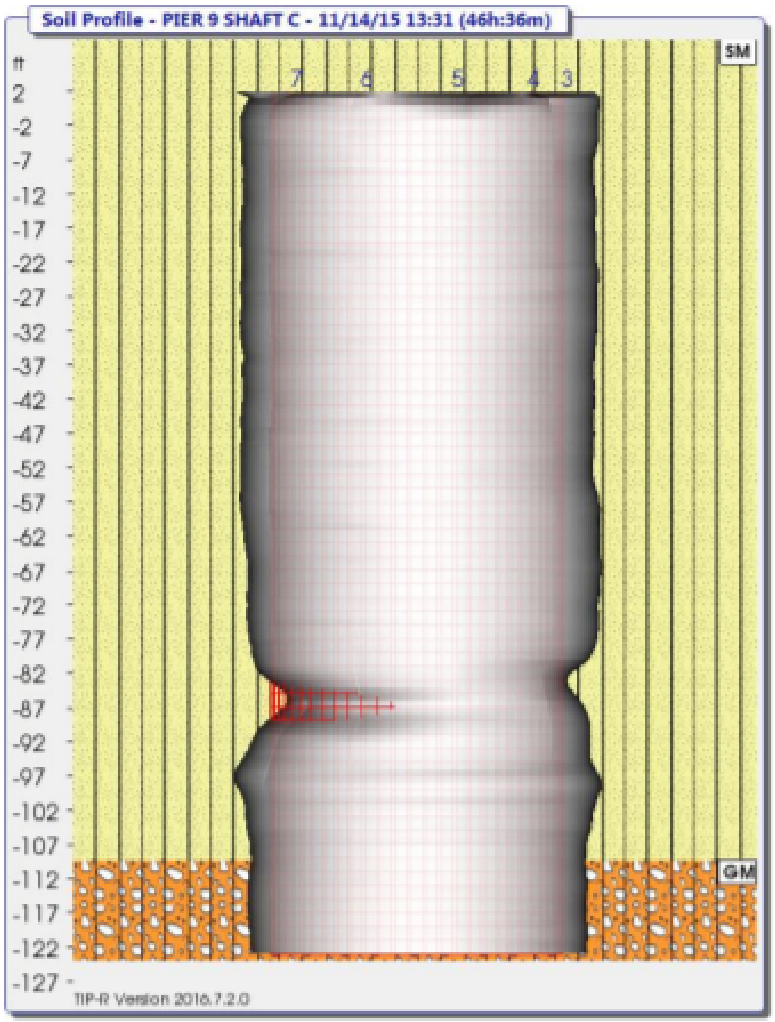

Radius vs Depth - Test Shaft - 09/01/17 12:49 (25h:6m)
Radius (in)
18 20 22 24 26 28 30
1
2
3
4
Avg
Cage
Shaft
Depth (ft)
0 5 10 15 20 25 30 35 40 45 50 55 60 65 67
-4 -2 0 2 4 6 8 10
Concrete Cover (in)
TIP-R Version 2017.11.0.0


Soil Profile - Test Shaft - 09/01/17 12:49 (25h:6m)
ft
Air
SM
CL
GM
3
2
1
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70
TIP-R Version 2017.11.0.0

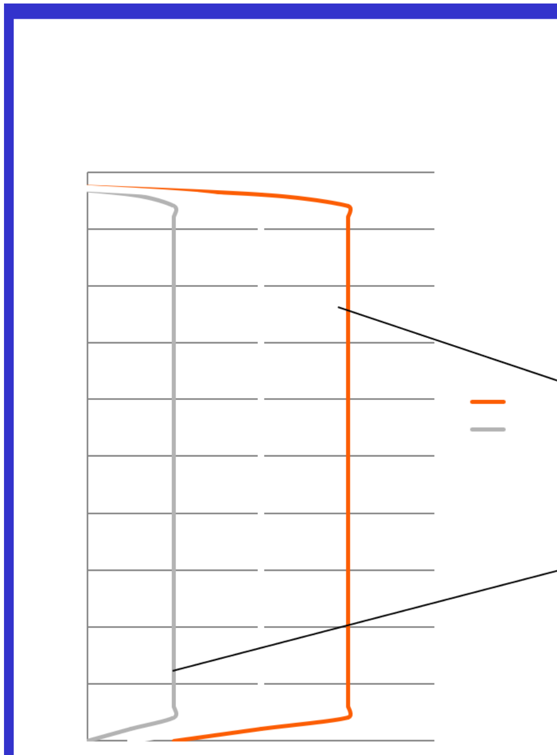


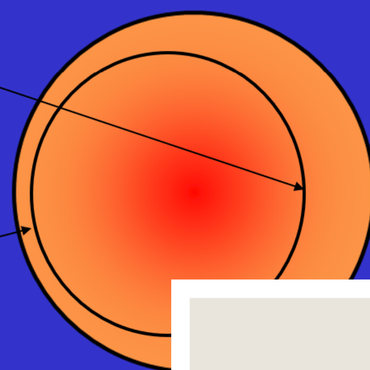
Termperature (F)
60
80
100
120
140
160
180
Depth (ft)
Defect

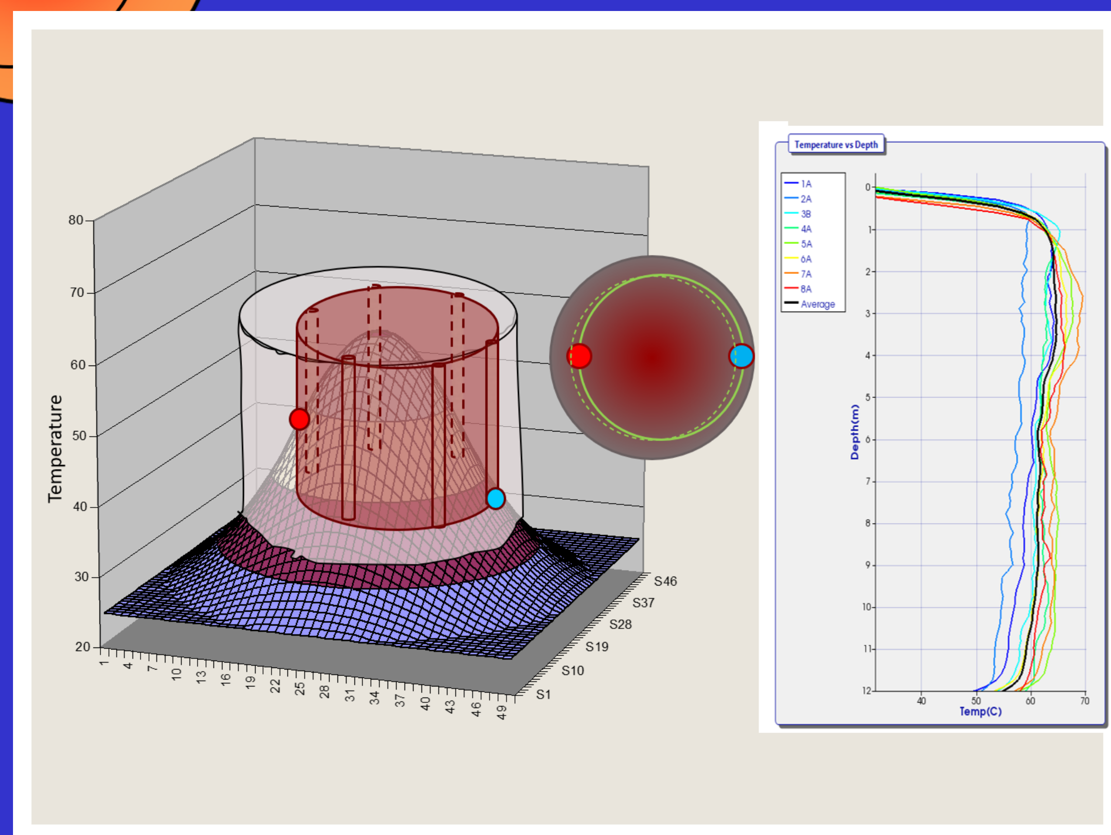

Radius vs Elevation - PIER 9 SHAFT C - 11/14/15 13:31 (46h:36m)
Radius (in)
Elevation (ft)
Concrete Cover (in)
1
2
3
4
5
6
7
8
9
10
Avg
Cage
Shaft
TIP-R Version 2016.7.2.0


Soil Profile - PIER 9 SHAFT C - 11/14/15 13:31 (46h:36m)
ft
SM
GM
TIP-R Version 2016.7.2.0

Thermal Integrity Cage Misalignment Detection







TEMPERATURE TO RADIUS CONVERSION

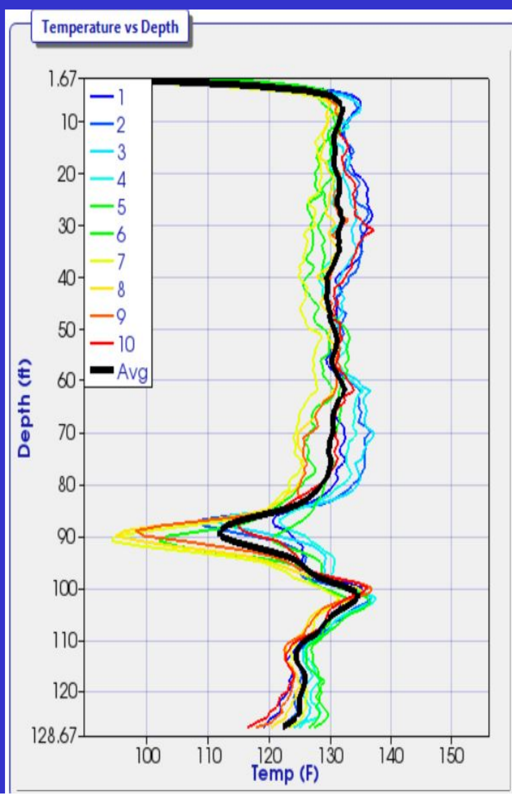
- From actual concrete volume placed in the shaft, calculate the average radius:

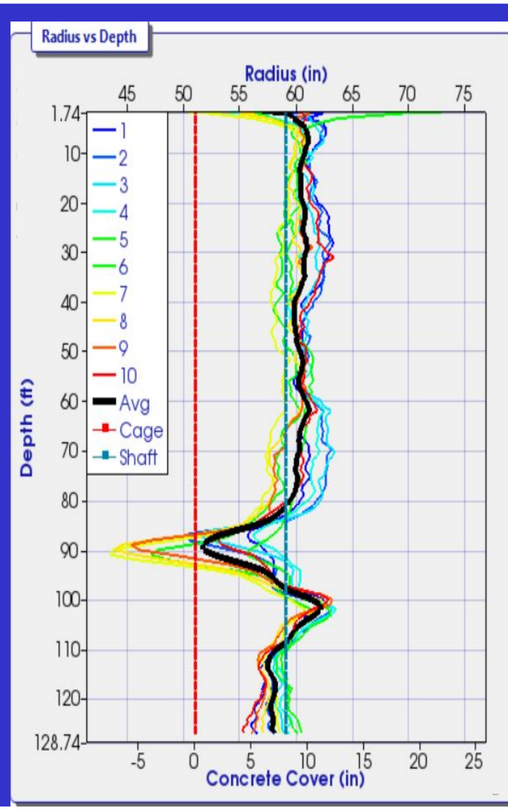
$$\text{Average Radius} = \sqrt{\frac{Volume}{Length * \pi}}$$

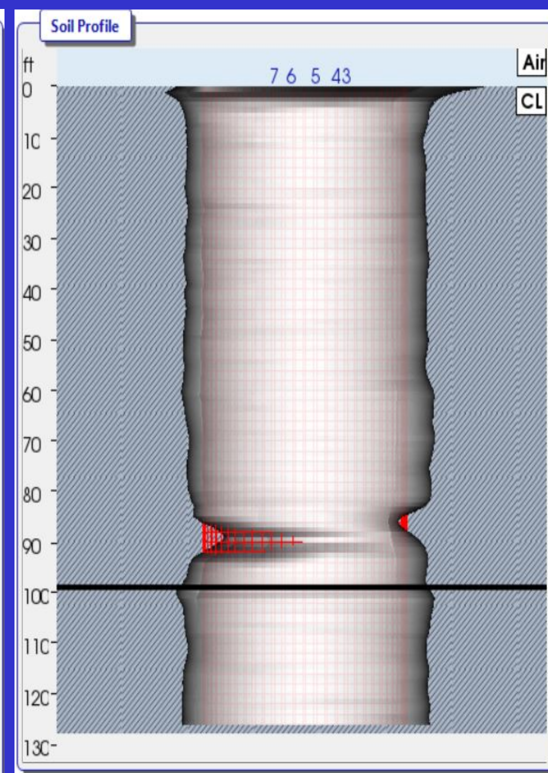
- From the overall average temperature along the shaft length (ignoring the top and bottom roll-off zones, and sharp variations), calculate the:

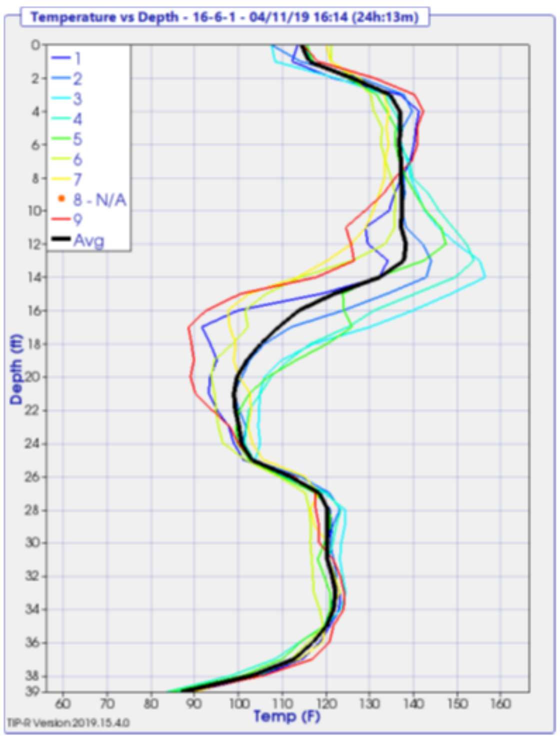
$$\text{Local Effective Radius} = \left(\left(\frac{average\ radius}{average\ temp}\right) * local\ temp\right)$$

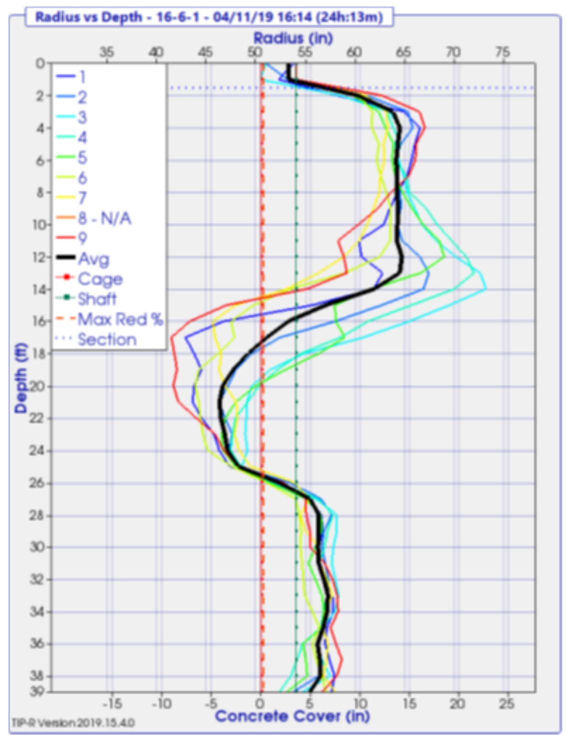
(Effective Radius encompasses concrete geometry and quality effects)

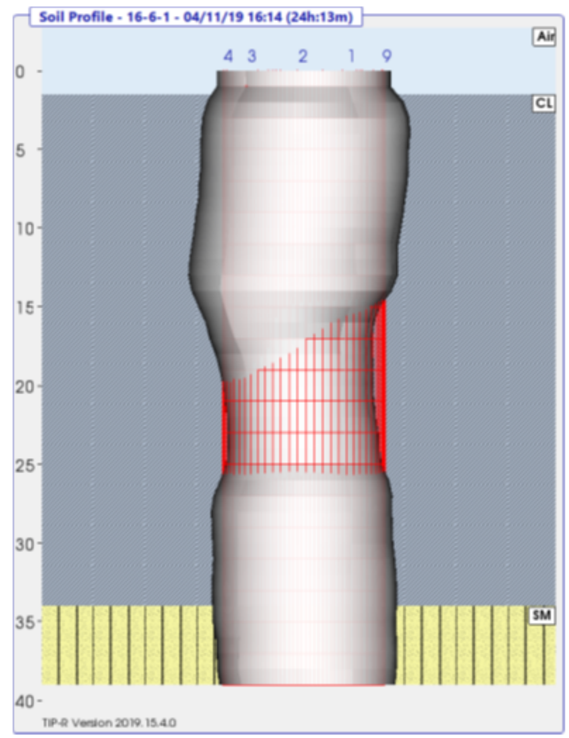










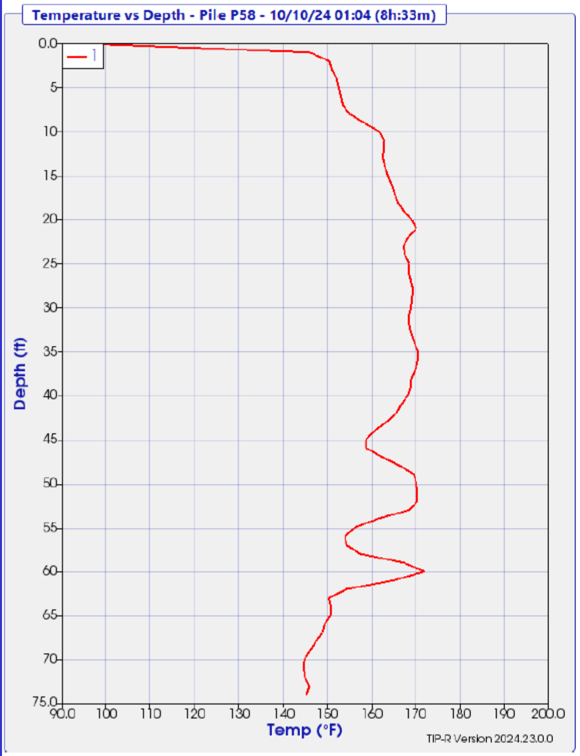


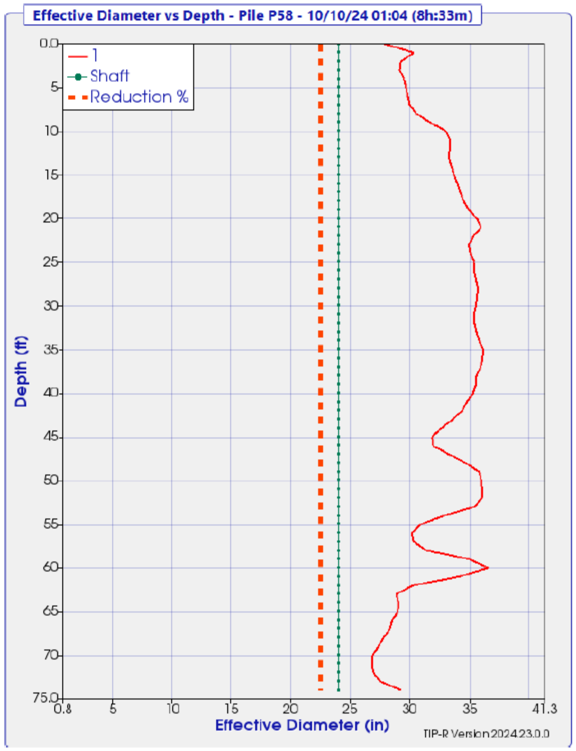
Temp vs Depth **Radius vs Depth**

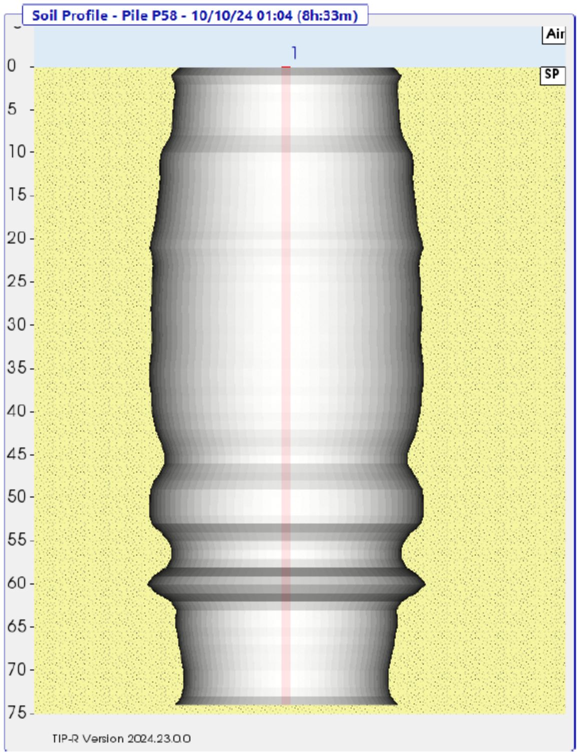
Reduction in concrete quality in middle of shaft – " One Bad Truck"

Table 1. Reported Pile Installation Details

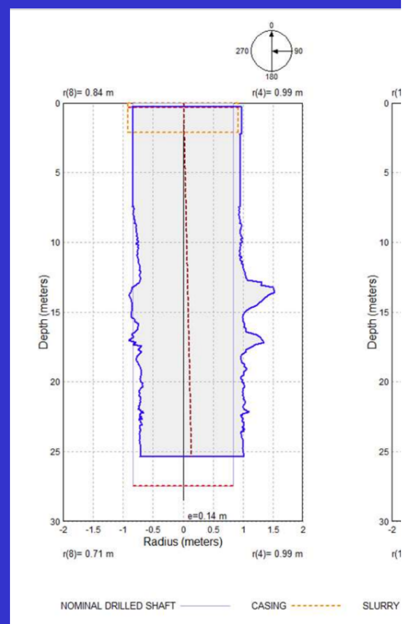
Pile No.	Pile Installation Date	Drilled Diameter (in)	Approx. Pile Length (ft)	Theoretical [1] Grout Volume (Design) (yd³)	Reported [2] Grout Volume Placed (yd³)	Percent of Theoretical Volume (%)
Pile P58	10/09/2024	24	75	8.7	16.2	186

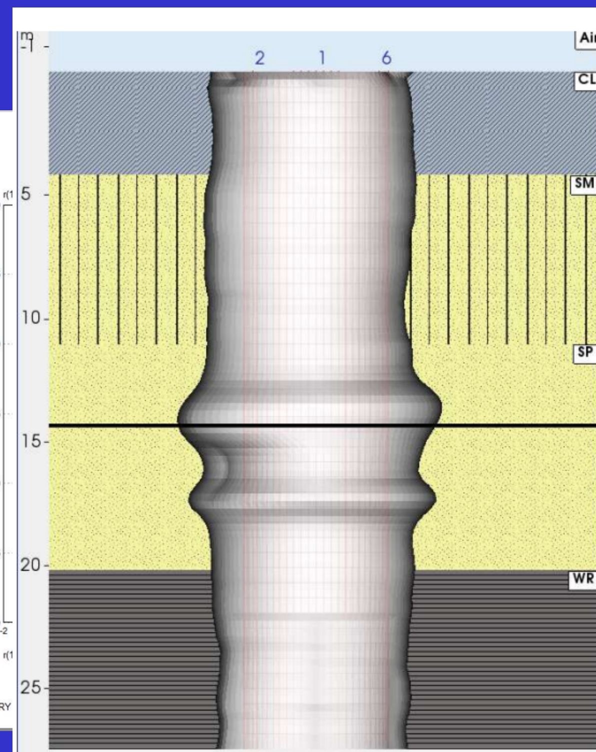


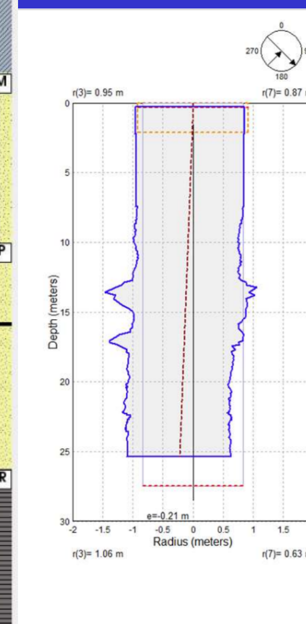




SHAPE Inspection Results



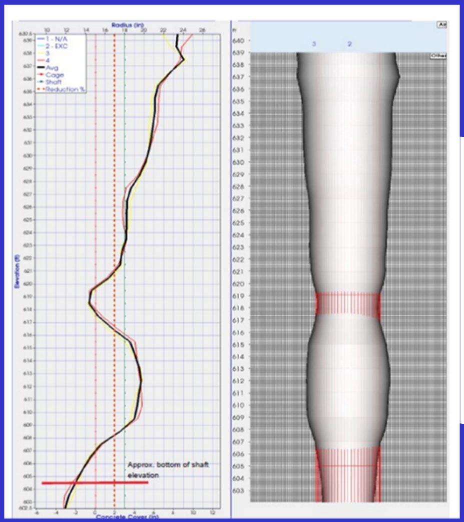


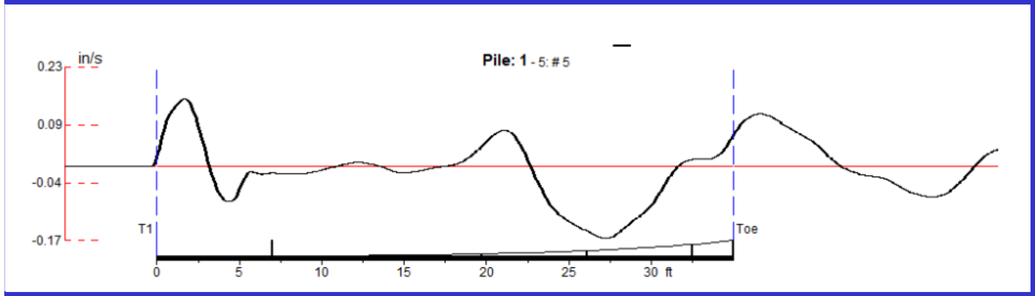


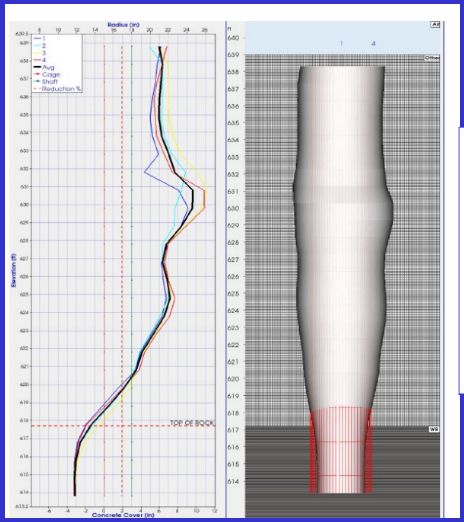
Thermal Integrity Profile,
T.I.P.

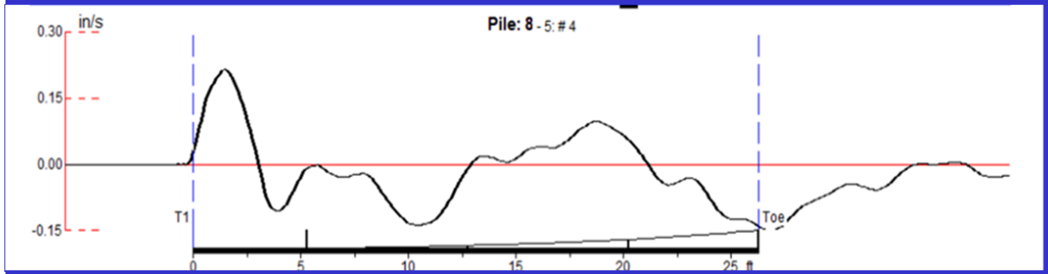
T.I.P. Results

P.I.T. Results









Low-strain Integrity Testing

High-strain Capacity Testing

High Strain Dynamic Load Testing - DLT

Uses a heavy ram to generate a pile set thereby activating the pile bearing capacity

Designation: D 4945

Standard Test Method for High-Strain Dynamic Testing of Piles[1]

This standard is issued under the fixed designation D 4945; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

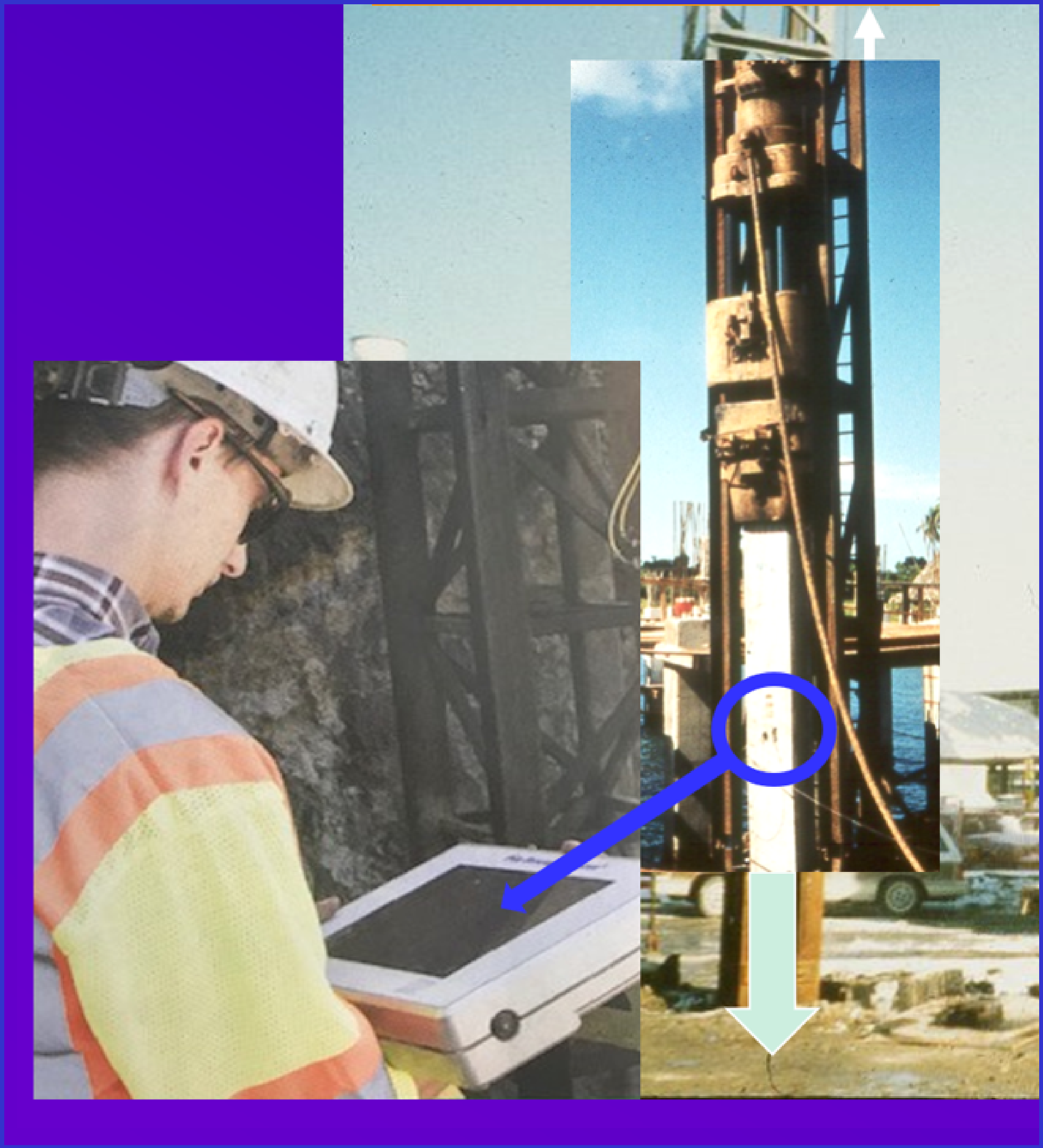
1. Scope

1.1 This test method covers the procedure for testing

hammer striker plate and the drive cap on top of the pile (also called hammer cushion).

3.2.2 *cushion*—the material inserted between the drive

Dynamic Pile Testing

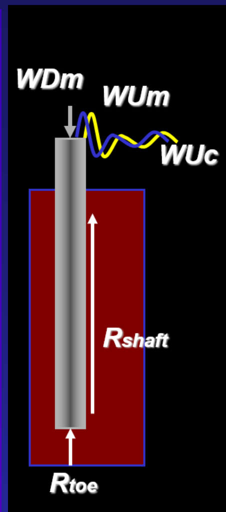


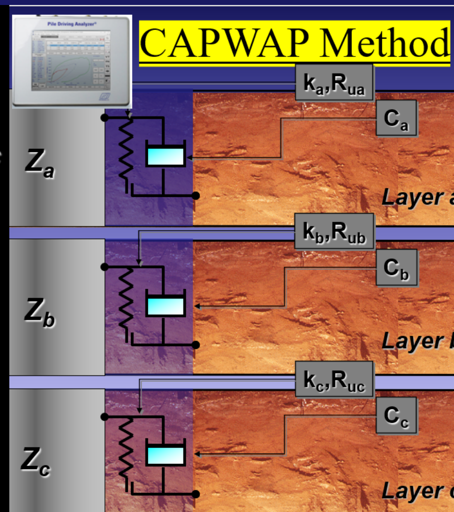
Dynamic Load Testing (DLT) for Bearing Capacity Assessment

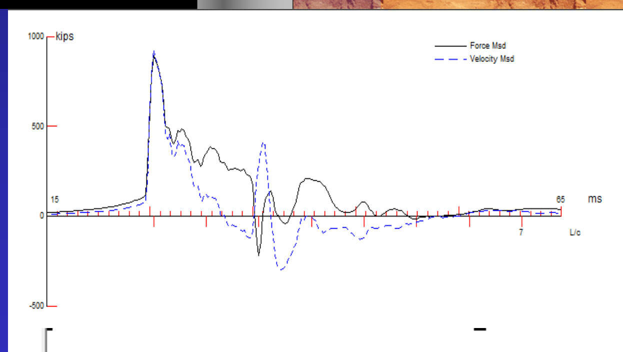
Auger-cast pile

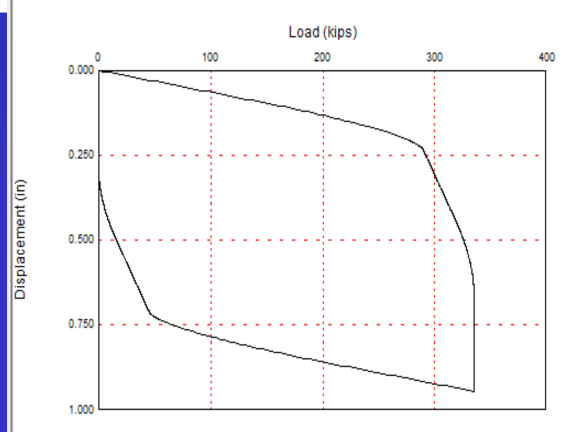
Drilled Shaft

Dynamic Load Testing

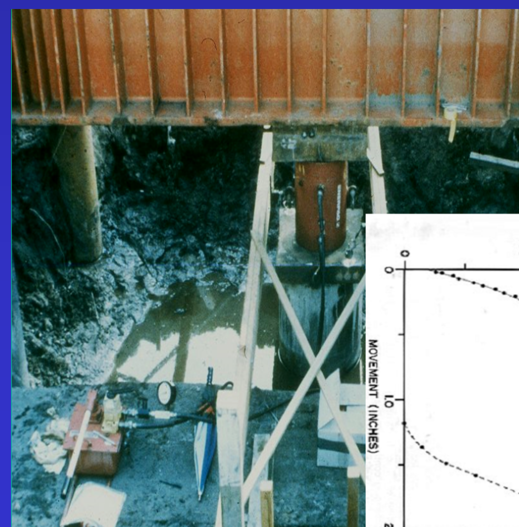


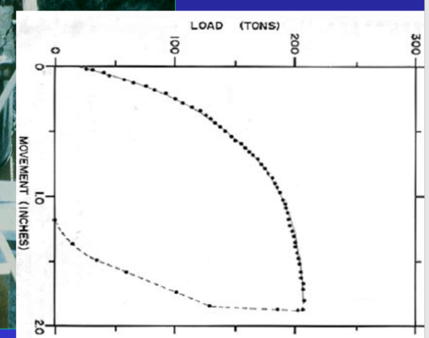




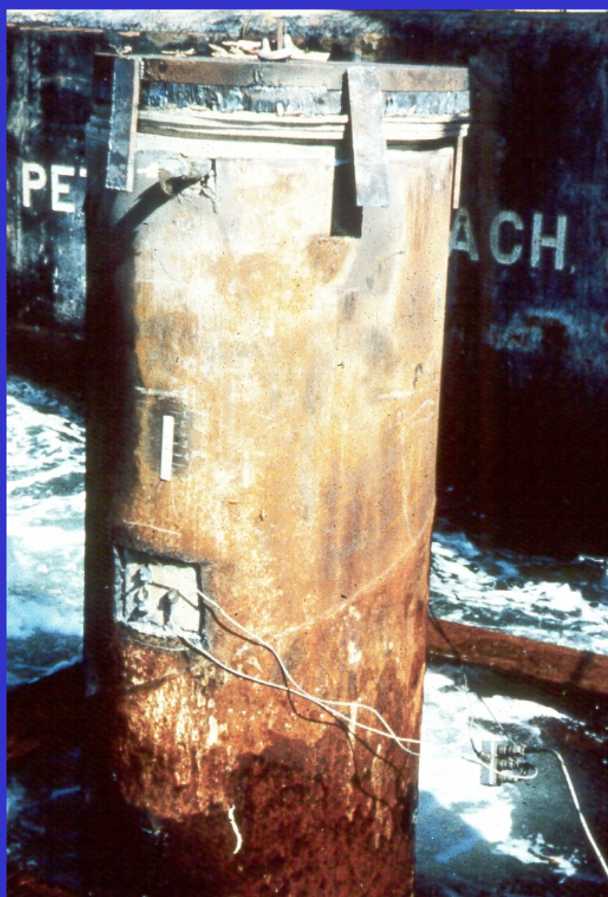


Conventional Static Load Testing





Tampa, Florida 1981



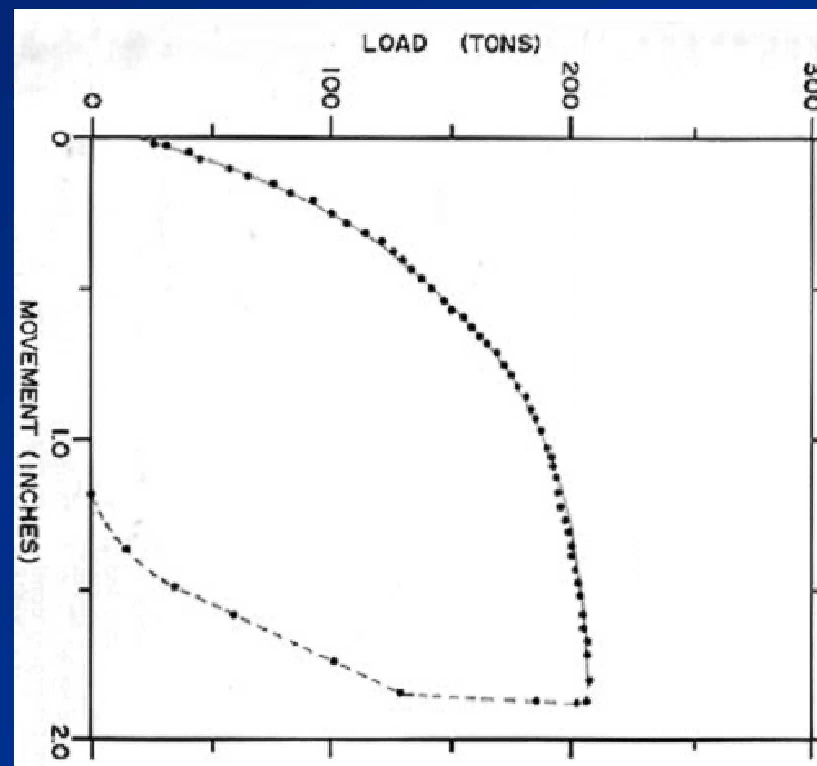

Shaft instrumentation

Conventional Static Load Testing

Designation: D 1143

AMERICAN SOCIETY FOR TESTING AND MATERIALS
100 Barr Harbor Dr., West Conshohocken, PA 19428

Standard Test Method for Piles Under Static Axial Compressive Load[1]



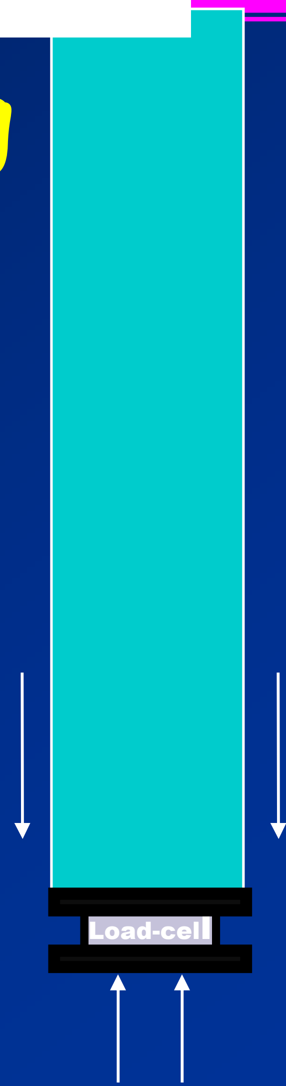


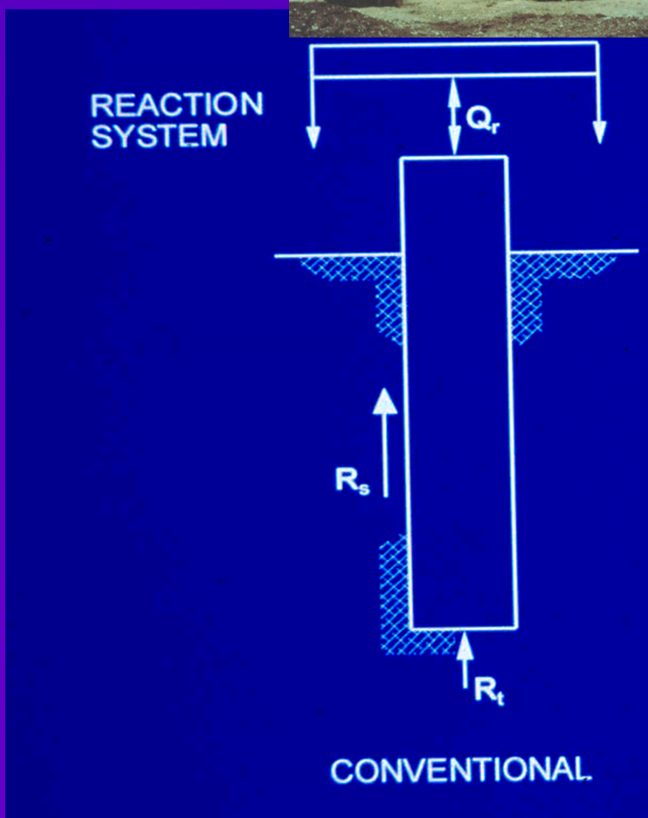

Designation: D8169/D8169M – 18

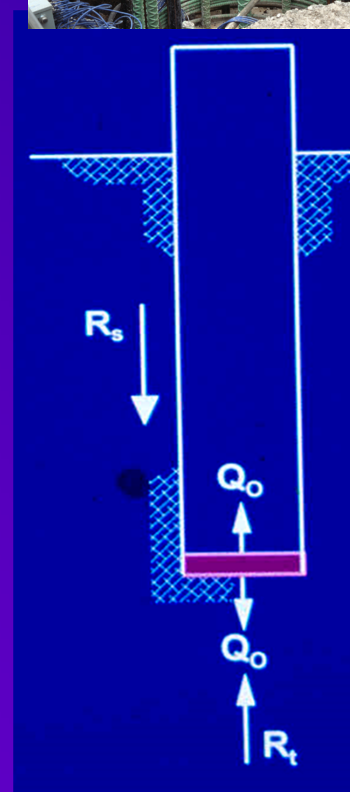
Standard Test Methods for Deep Foundations Under Bi-Directional Static Axial Compressive Load[1]

Bi-Directional Testing

- **Calibrated, embedded, sacrificial jack within the test shaft**
- **Concept: Load base of the shaft against the side shear, & eliminate reaction system**

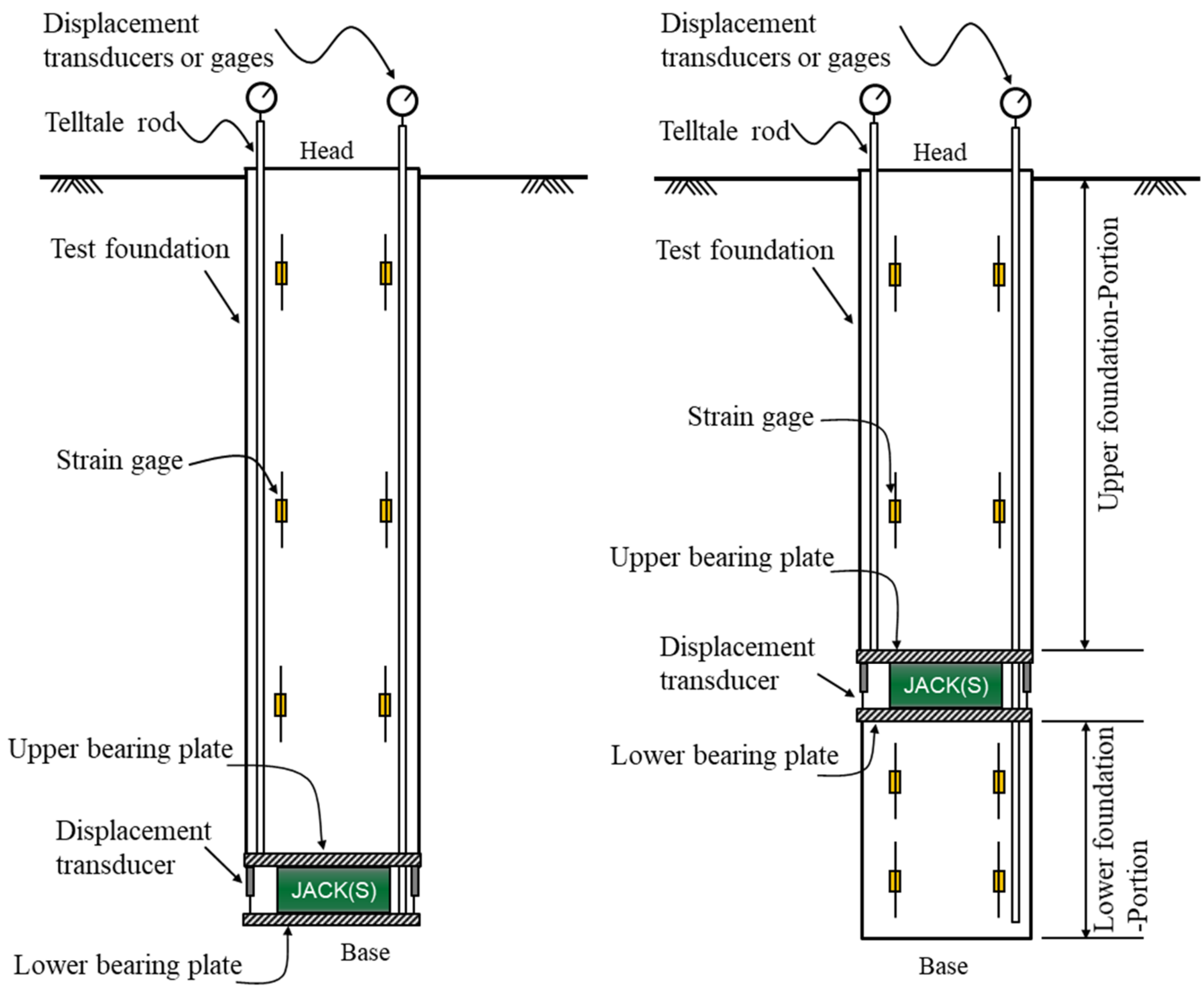



REACTION SYSTEM
Q_r
R_s
R_t
CONVENTIONAL

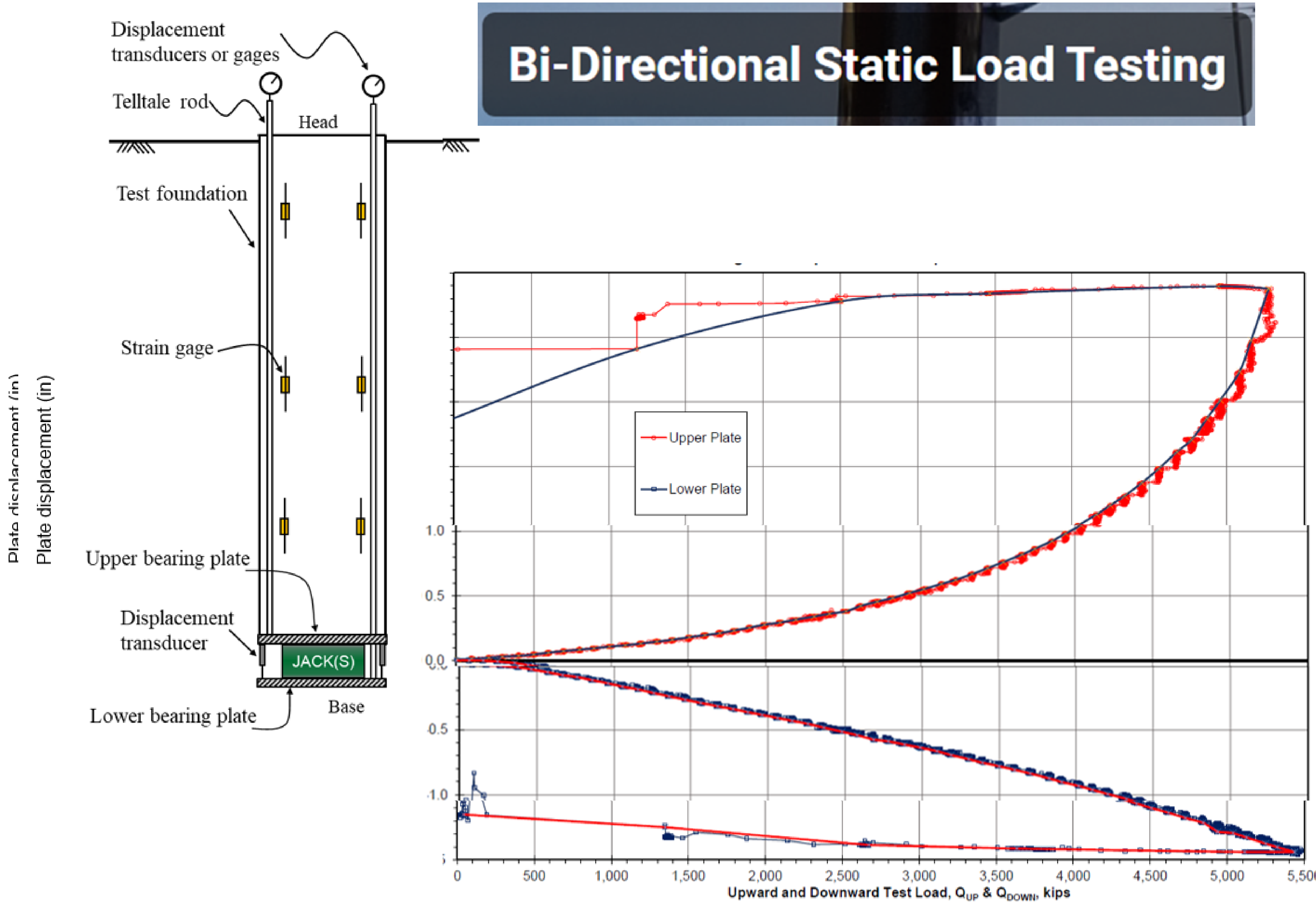

R_s
Q_O
Q_O
R_t


GRL
engineers, inc.

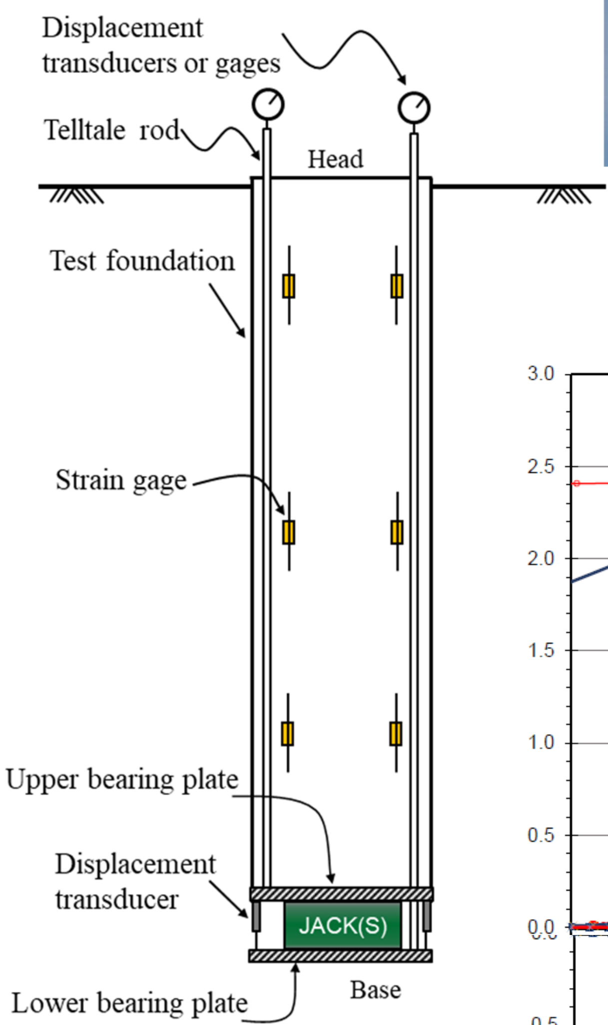
Bi-Directional Static Load Testing

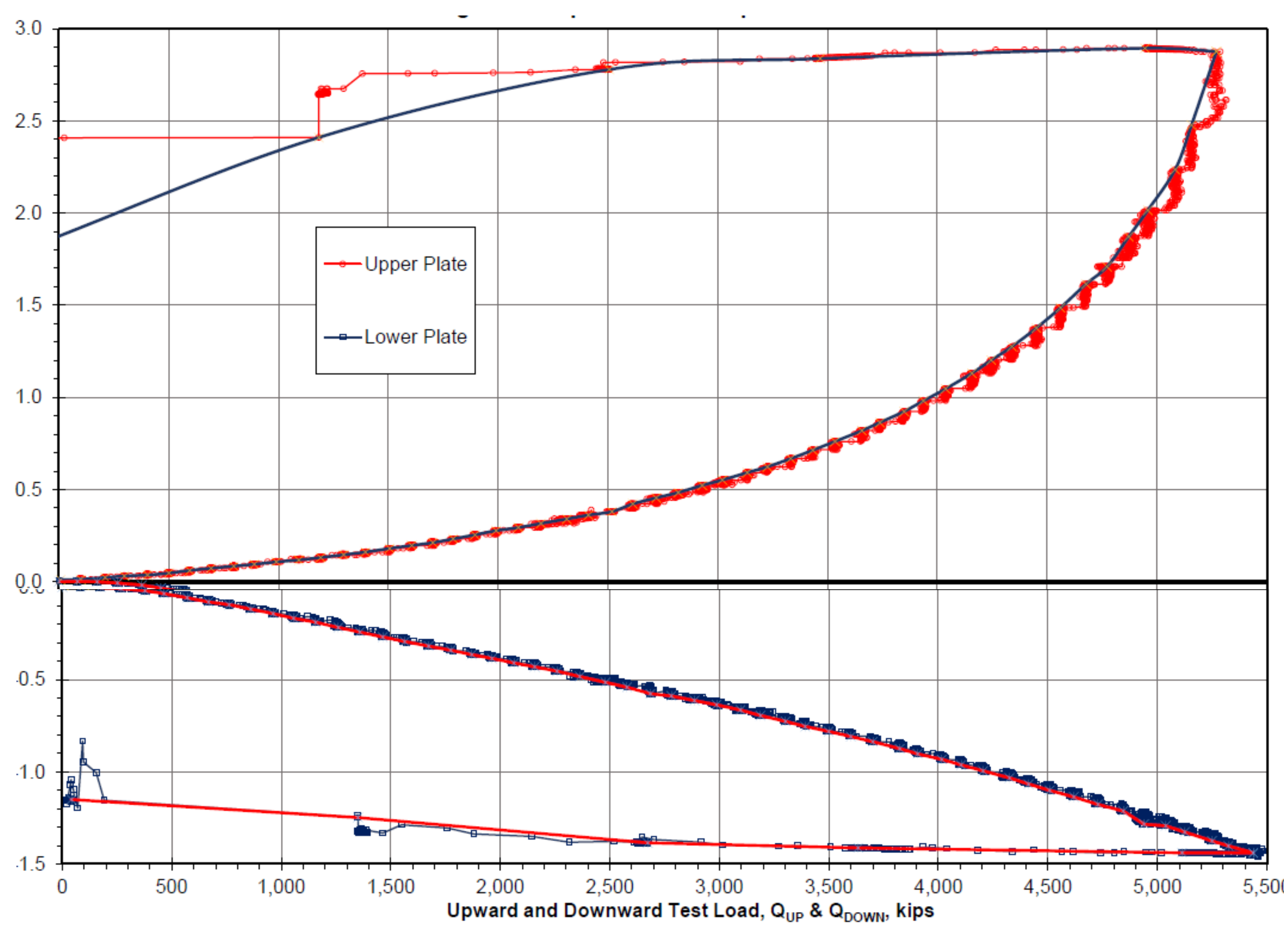


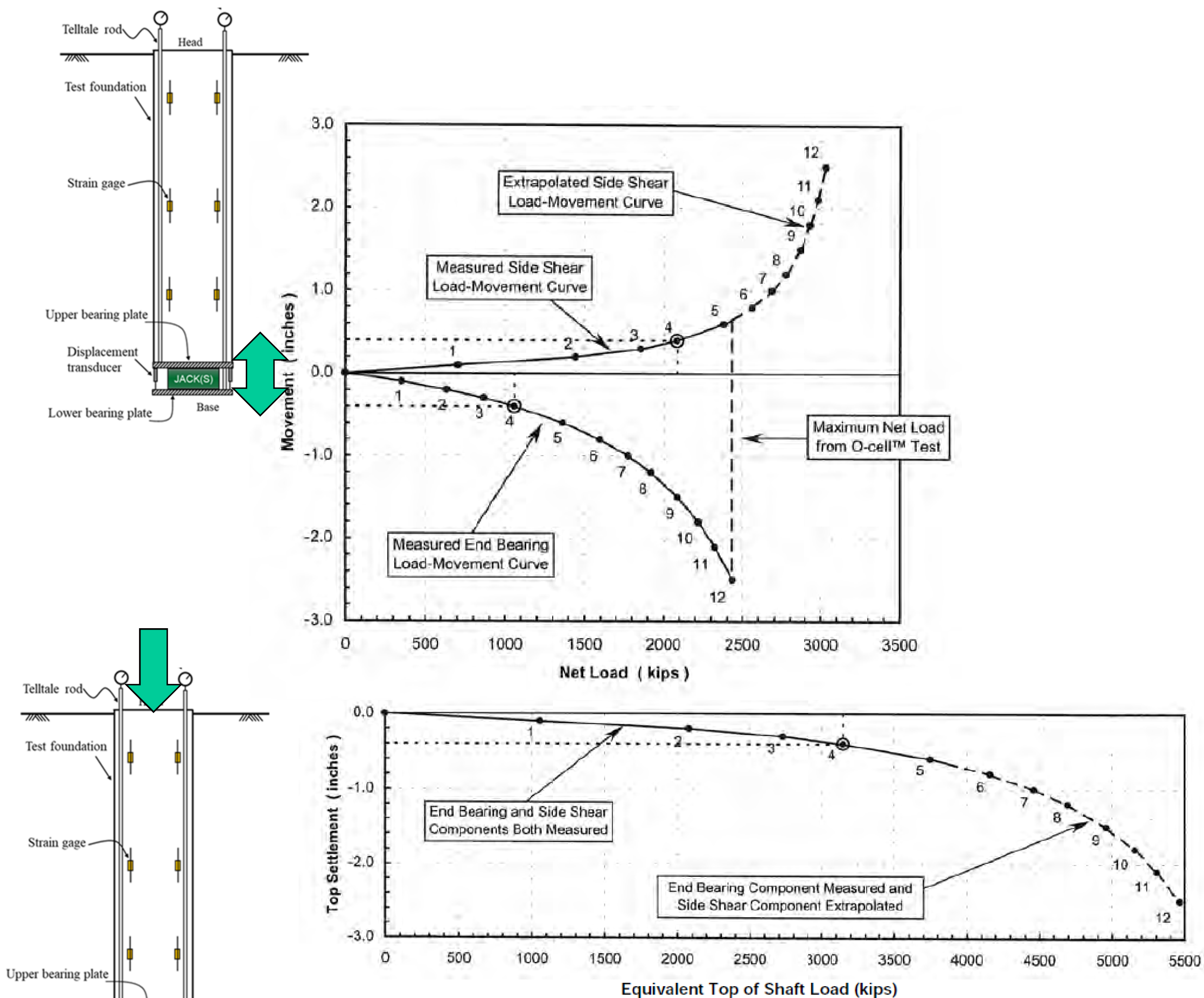
Bi-Directional Static Load Testing



Bi-Directional Static Load Testing





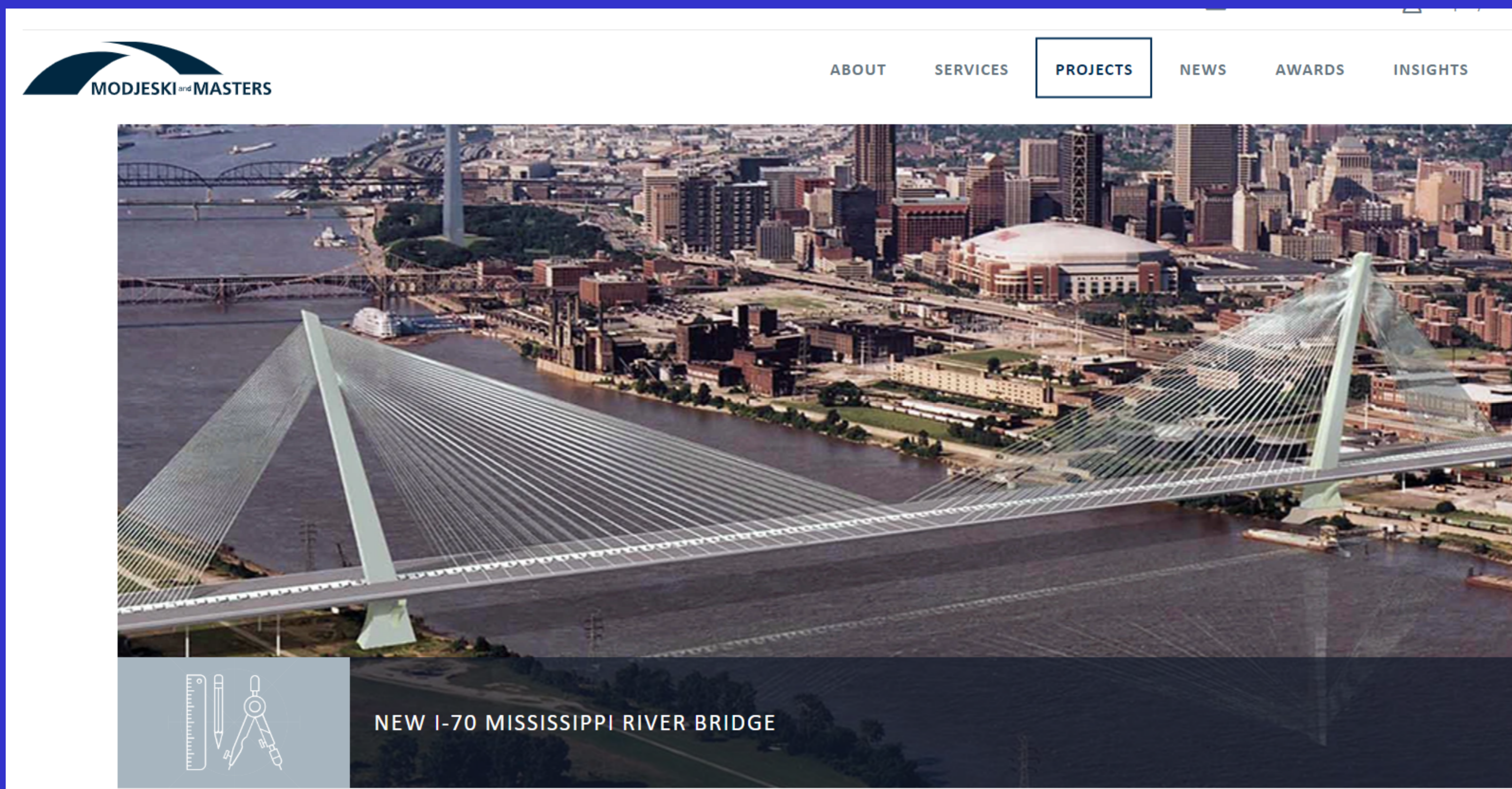


igure 17-17 Construction of Equivalent Top-Loaded Settlement Curve from O-cell Test Results

World records Bi-Directional load test

36,000 tons!

The rock socket was about 23ft deep and 11ft in diameter in very hard limestone



Thank You.

MHussein@GRLengineers.com