Deep Foundations and Quality Assurance

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GRL engineers, inc.

Deep Foundations and Quality Assurance

- Importance of QA/QC
  - Reduce Safety Factors
    - LRFD Resistance Factors
- Types of QA/QC
  - SLT/PDA /APPLE / Bi-Directional
    - Information Received From Tests
    - Benefits from each test
  - CSL/PIT/Thermal/Base Cleanliness/Shaft Profile & Verticality
    - Information received from each test
- Form of Construction Control
  - Blow Count Criteria / Hammer Energy
  - Verify Foundations are installed according to specifications
- Quick Case Studies
  - Relaxation Case
  - Pile Damage Case
  - CSL and Thermal comparison

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Importance of QA/QC for Deep Foundations

WHY

- To increase the resistance factors (LRFD)/reduce factor of safety (ASD) used in the design phase
- Verify design of foundation
- Verify construction methods
- Verify Ultimate Compression, Tension, or Lateral Capacities

HOW

- Dynamic Load Testing (DLT)
  - ASTM D-4945-12
- Static Load Testing (SLT)
  - ASTM D1143M-07
- Bi-Directional Static Load Test (BISLT)
  - ASTM D8169

- Base Cleanliness Elevation (SQUID)
- Drilled Shaft Profile & Verticality (SHAPE)
- Cross Hole Sonic Logging (CSL)
  - ASTM D6760-14
- Thermal Integrity Profiling (TIP)
  - ASTM D7949-14
- Low Strain Dynamic Testing (PIT)
  - ASTM D5882-07

*The last five test methods only give information on integrity of the foundation, NO CAPACITY RESULTS

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FHWA LFRD Resistance factors using Test Methods for Driven Piles

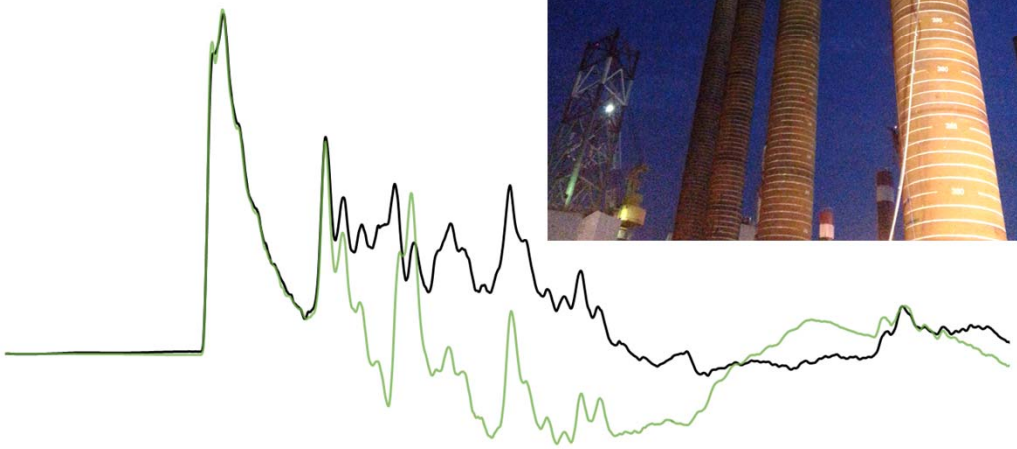
Condition	Resistance Determination Method	Resistance Factor
Nominal Geotechnical Resistance of Single Pile in Compression	Driving criteria established by successful static load test of at least one pile per site condition and dynamic testing* of at least two piles per site condition, but no less than 2% of the production piles.	0.80
Dynamic Analysis and Static Load Test Methods, ϕdyn	Driving criteria established by successful static load test of at least one pile per site condition without dynamic testing.	0.75
	Driving criteria established by dynamic testing* conducted on 100% of production piles.	0.75
	Driving criteria established by dynamic testing,*quality control by dynamic testing* of at least two piles per site condition, but no less than 2% of the production piles.	0.65
	Wave equation analysis, without pile dynamic measurements or load test, at End of Drive conditions only.	0.50
	FHWA Modified Gates dynamic pile formula (End of Drive condition only).	0.40
	Engineering News (as defined in AASHTO) dynamic pile formula (End of Drive condition only).	0.10
Nominal Geotechnical Resistance of Single Pile in Tension, ϕdyn	Static load test.	0.60
	Dynamic testing* with signal matching	0.50

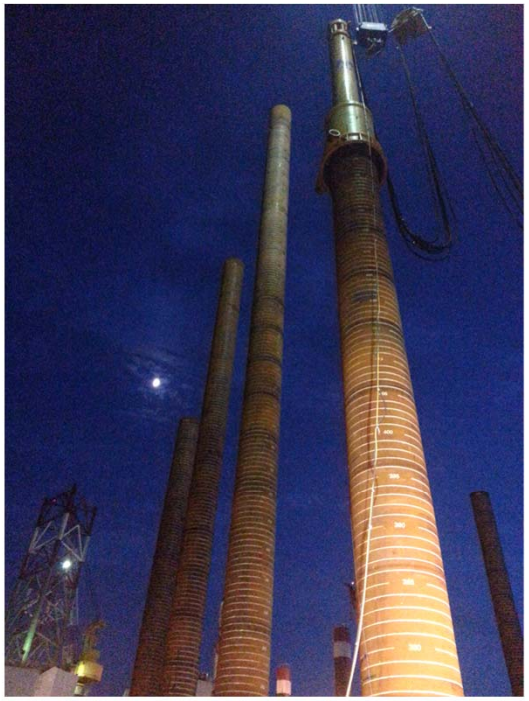
Hannigan PJ, Rausche F, Likins GE, Robinson BR, Becker ML. 2016. Geotechnical Aspects and Limit State Design. In: Geotechnical Engineering Circular No. 12 – Volume I Design and Construction of Driven Pile Foundations. U.S. Department of Transportation Federal Highway Administration. P. 226.

Dynamic Load Testing

Dynamic load testing is the measurement of pile top strain and acceleration which is then converted to pile top force and velocity measurements and used in a signal matching program.

- For Driven Piles an engineer can determine the following for each hammer impact:
  - Driving Stresses (Both Compression and Tension)
  - Hammer Performance
  - Pile integrity
  - Calculated Capacity at the time of driving
- For Drilled/Bored Piles
  - Pile Integrity
  - Calculated Ultimate Capacity
- Can test multiple piles in a day (relatively quick)
- Can test at the end of driving and restrike to determine soil setup
- Can calculate unit shaft and toe resistance values
- Must have monitoring equipment and experience to calculate capacities





Static Load Test

Static load testing is applying a force into the pile and measuring that force in the element and measuring the corresponding displacement. With the two measurements one can plot a load vs. displacement curve and use a failure criteria to determine the ultimate capacity of the foundation.

- For Driven Piles or Drilled Shafts/Bored Piles.
- Ultimate capacity of foundation.
- If instrumented along the length of the pile, an engineer can determine ultimate unit shaft and toe resistance values.

- Static tests require reaction piles or dead load in order for testing.
- Can be quite extensive setup and expensive.
- Relatively slow compared to DLT.

Bi-Directional Static Load Test

Bi-Directional Static Load Testing applies an upward and downward force at a predetermined location in the foundation element. The upward force is resisted by the shaft resistance above the cell while the downward force is resisted by the shaft resistance below the cell as well as the base resistance.

- For Drilled Shafts or Bored Piles.
- Embedded strain gages can determine the soil/rock resistance distribution.
- Not restricted by load frame limitations.
- Must measure shaft top and shaft base displacements.

- Placement of load cell at correct location is critical for a successful test.
- Times significant preparation and planning.

Quality Control from Pile Monitoring

- From pile monitoring and static load tests a driving criteria can be developed and correlated.
  - For a driving criteria to be developed, the engineer must set a minimum number of blows per set (i.e. blows/foot, blows/inch, etc.) with a corresponding energy or hammer stroke.
  - A driving criteria can be set for either the required ultimate capacity but also an engineer can set a driving criteria to try and limit any over driving of piles (or overstressing piles).
- Verification testing can also be performed using pile monitoring
  - If drive logs indicate that unusual blow counts are encountered the responsible person can request that restrike testing is performed on the selected piles to ensure the integrity of the piles and ultimate capacity.

Integrity Methods for Drilled Shafts or Augured Piles

- Integrity methods are designed to verify the construction of a drilled shaft or augured pile.
- Integrity methods do not give any information about the capacity of the element.
- Before placement determine the amount of debris at the base as well as the profile of the hole before concrete placement.
- Try to determine any reduction in cross-sectional area which may affect the foundation.
- Try to determine the length of unknown foundation elements.

Drilled Shaft Base Cleanliness Evaluation

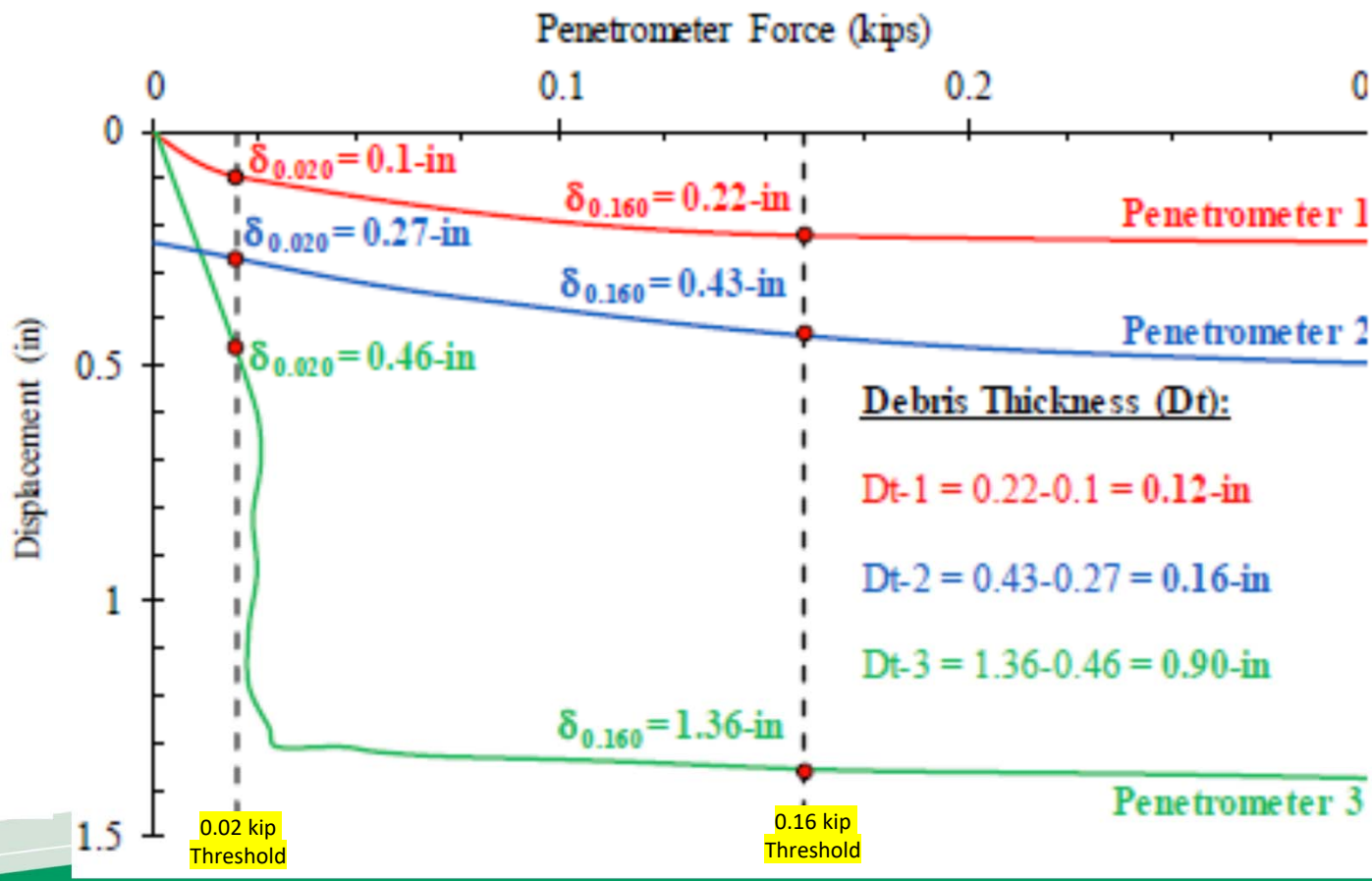
- Current methods are either visual inspection or Mini SID
- Need to determine the max debris thickness and debris area

State	Spec	Max Debris Thickness	Debris Area	Date
NCDOT	411-4(D)	1.5 inches	Min. of 50% of base area will have < ½ inch	2012
FDOT	455-15.11.4	1.5 inches	50% of bottom area with < ½ inch	2016
GDOT	524.3.07	As clean as practical	As clean as practical	2006
TDOT	SP625.27	1.5 inches	Min. of 50% of base area will have < ½ inch	2015
SCDOT	712.4.10.4	1.5 inches	50% of bottom area with < ½ inch	2007
ALDOT	506.06(B)	1.5 inches	50% of bottom area with < ½ inch	2018

Drilled Shaft Base Cleanliness Evaluation – New Technology

- Shaft Quantitative Inspection Device (SQUID)
- Three penetrometers (1.55 in^2) instrumented with strain gages to record force measurement.
- Three retractable contact plates designed to measure up to 6.25 inches of displacement.
- Capable of measuring up to 21.7 kips of force or 2000 ksf of pressure.

Drilled Shaft Base Cleanliness Evaluation – New Technology



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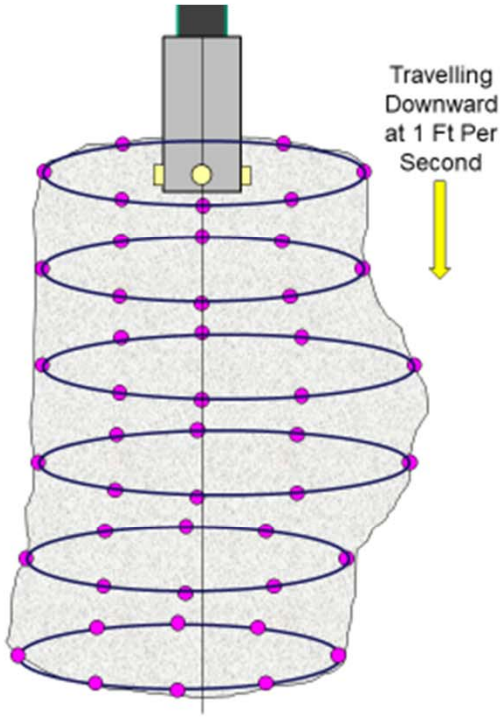
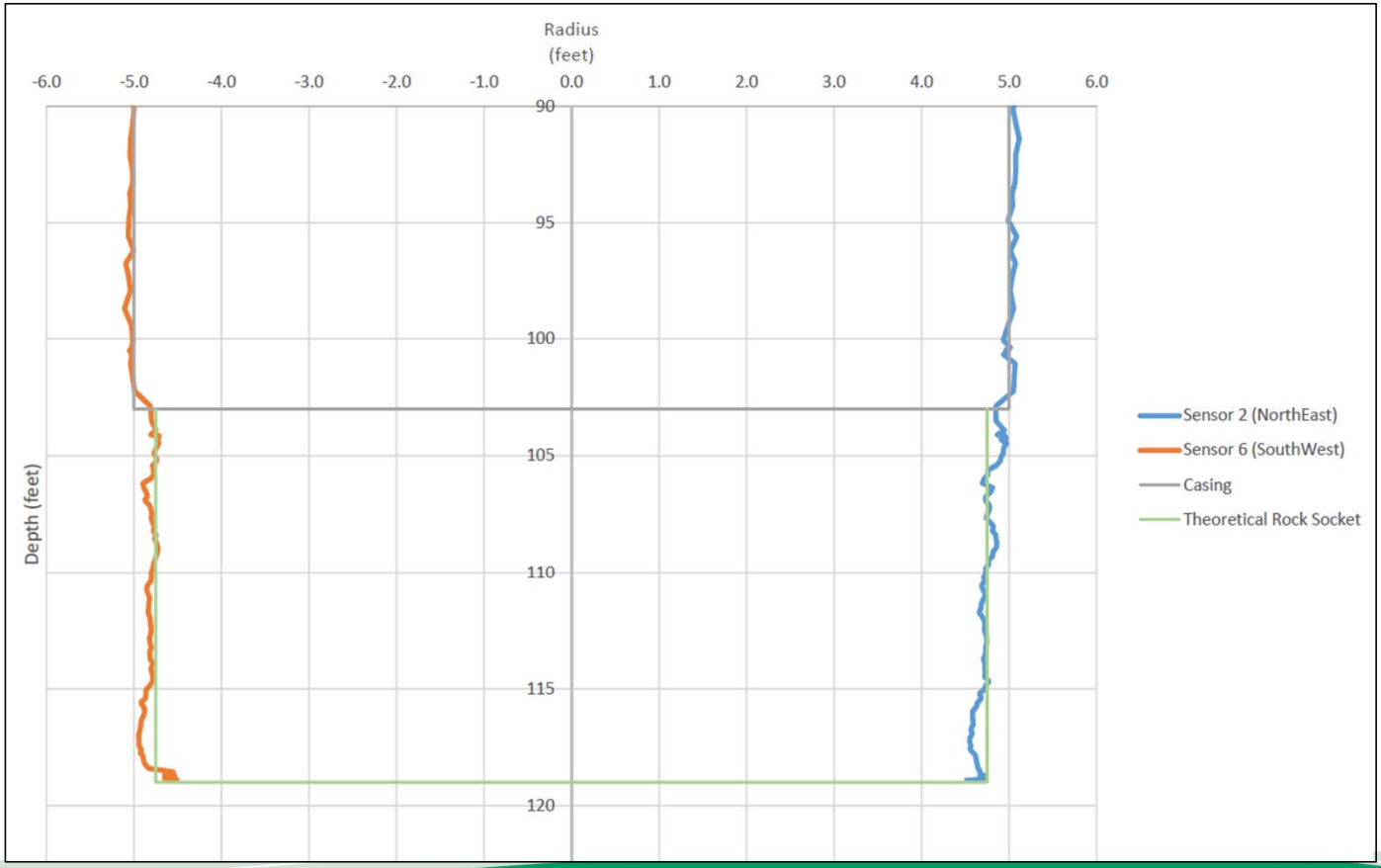
Drilled Shaft Profile and Verticality

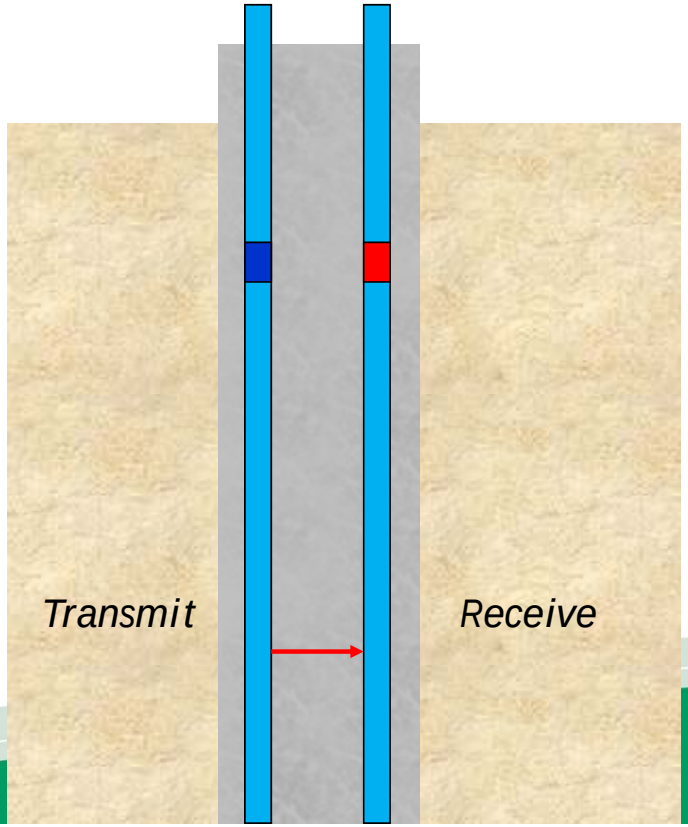
- Current method to determine the profile of a drilled hole is Sonic Caliper.
- New technology – Shaft Area Profile Evaluator
  - Device uses ultra sonic transmitters and receivers to scan the sidewall of wet poured drilled shafts.
  - Data is collected at a rate of approximately 1 foot per second
  - 8 Sensors scan simultaneously while onboard sensors constantly calibrate the wave speed of the drilling fluid.

Drilled Shaft Profile and Verticality

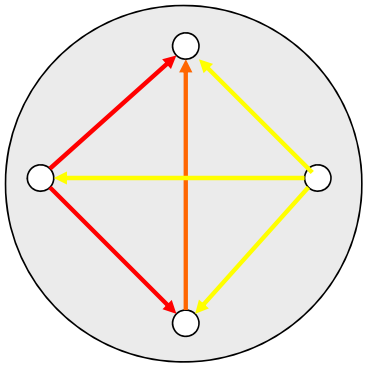




Cross Hole Sonic Logging

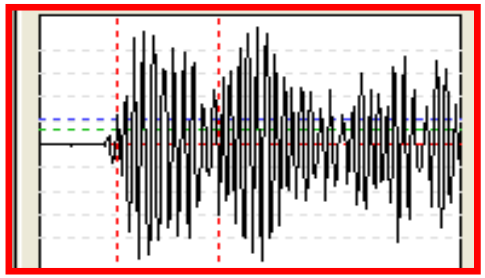


Plan view of shaft with 4 access tubes



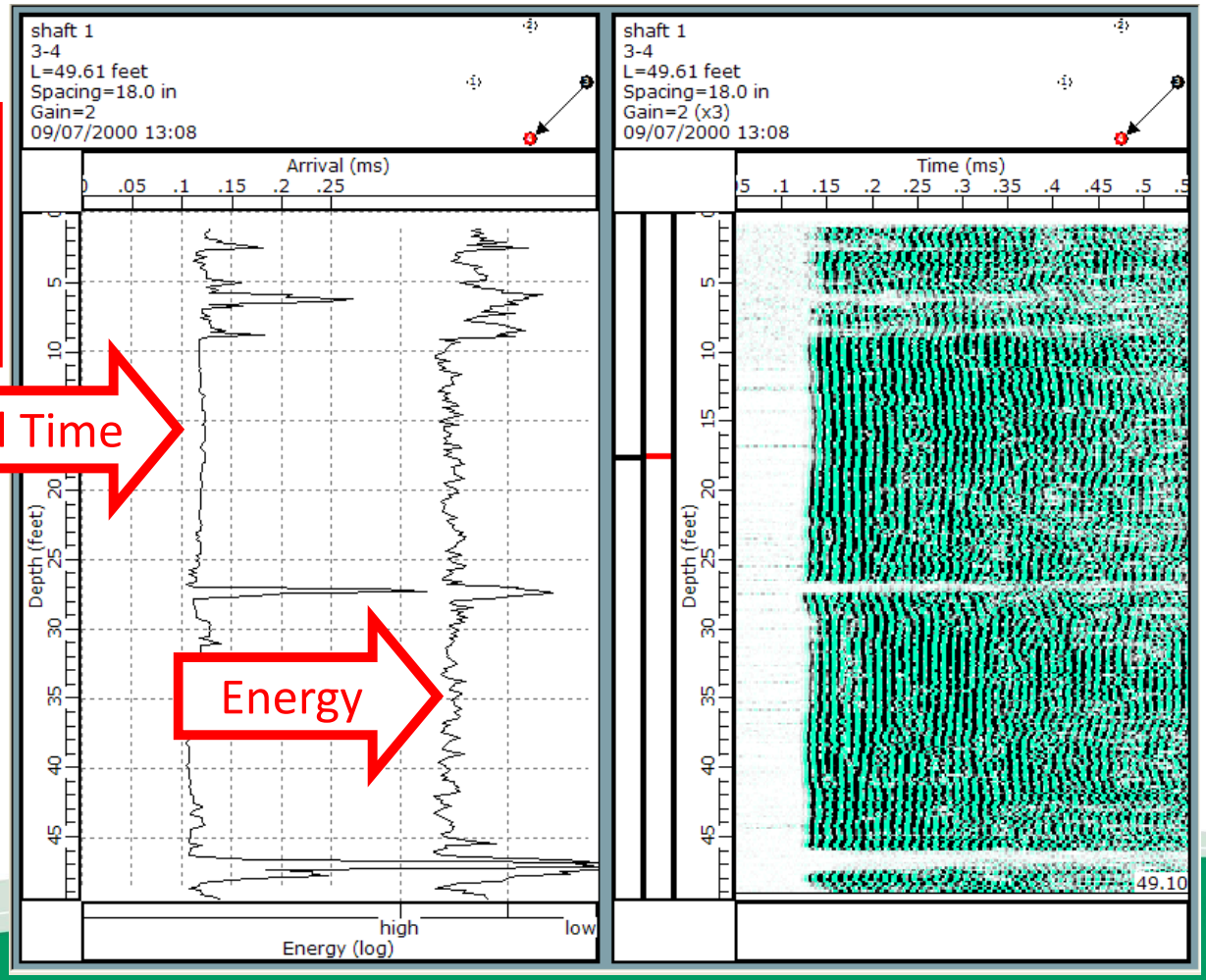
Sonic Waves, emitted in one tube are received in another one if concrete quality is satisfactory

Signal Amplitude Provides Information



First Arrival Time

"Energy" is integration of signal amplitude



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Cross Hole Sonic Logging

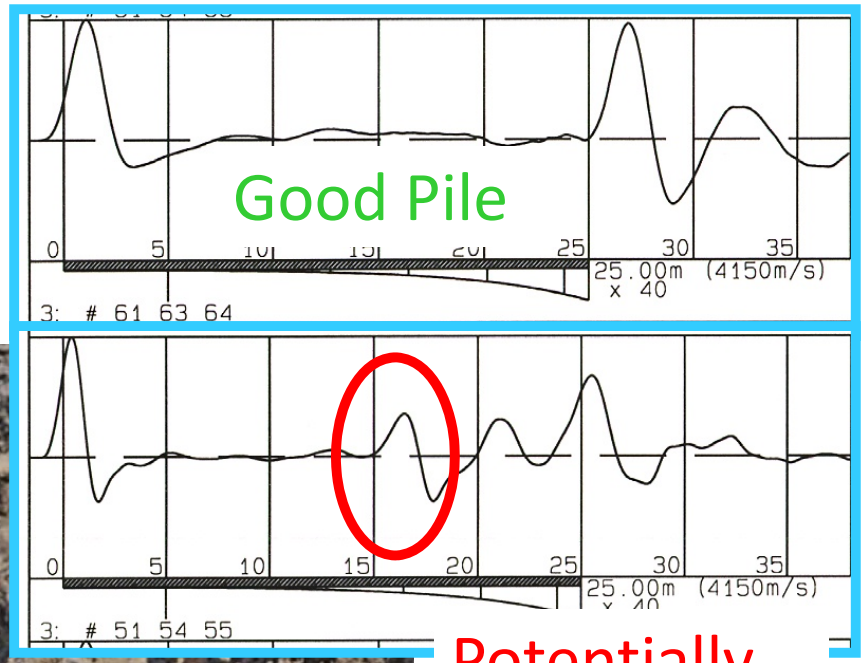
Advantages

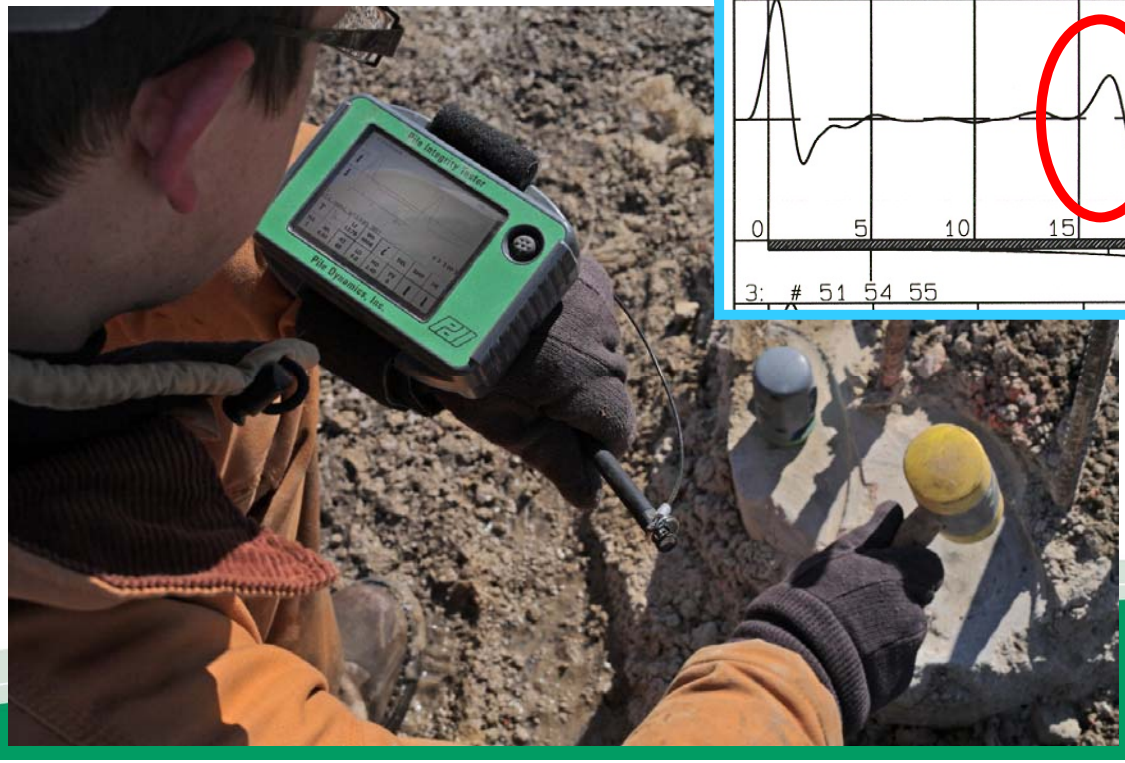
- Evaluates concrete quality inside cage
- Provide results by depth and by quadrant
- Tomography available for complex cases

Limitations

- Wait a minimum of 3-4 days prior to testing
- Requires access tubes
  - Post grouting
- Cannot evaluate concrete cover
- Debonding and bleed water may lead to unnecessary coring

Low Strain Pile Integrity Test





Potentially Bad Pile

Low Strain Integrity Testing

Advantages

- Fast and economical
- Can test any/all piles on site with no special installation requirements
  - No access tubes
  - No pile build up

Limitations

- Limited L/D ratio
  - Difficult to get toe reflection when L/D > 30 or in very dense soils
- Non-uniform piles create many reflections making data interpretation difficult
- Reinforcing cage extending above pile top can cause interference
- Site vibrations can cause interference

Thermal Integrity Profiling

- Heat generated by hydrating cement used to assess the quality
- Provides evaluation of shaft integrity between 12 and 48 hours after placement
- Evaluates rebar cage alignment and concrete cover of rebar
- Generates 3-D model of shaft profile
- Evaluates the <u>entire</u> shaft, inside and outside rebar cage

Advantages

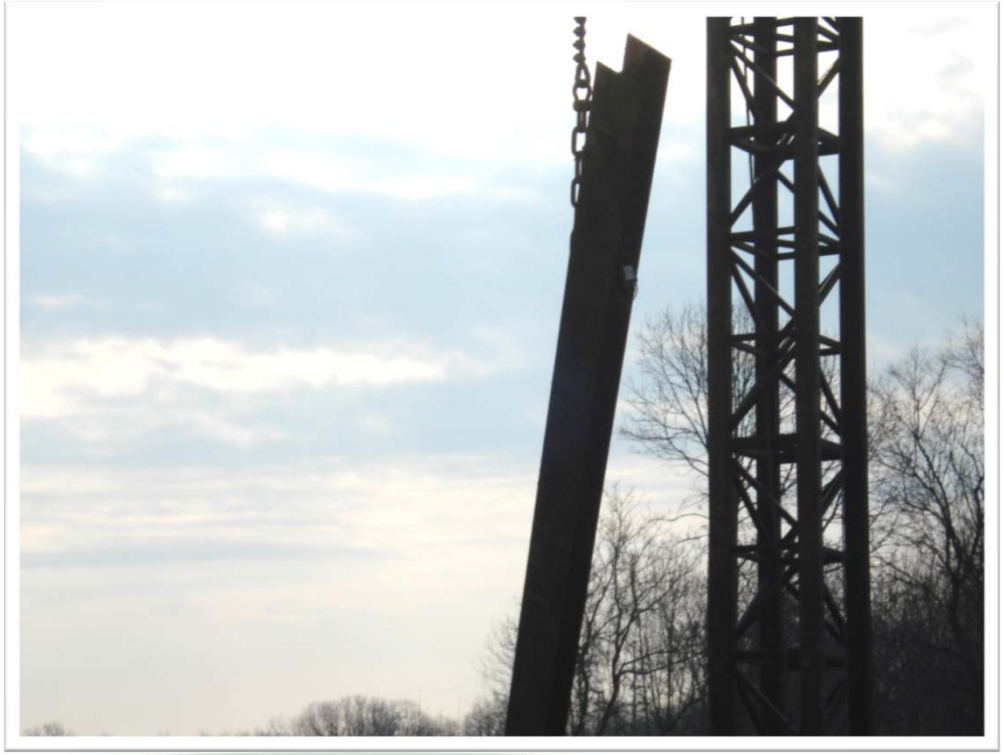
- Ability to analyze the full cross section of shaft – Including estimation of concrete cover outside reinforcing cage
- Assess reinforcing cage alignment
- Insensitive to debonding
- Insensitive to bleed water
- Access tubes eliminated – wire method
- Less post construction requirements – wire method
- Accelerated Schedules
  - TIP Results – 24-48 hours
  - CSL Results – 4-7 days

Limitations

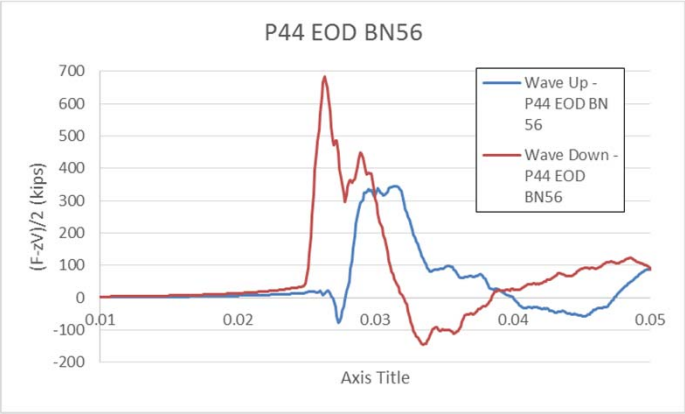
- Thermal Wire® cables require preplanning
  - Lengths and quantities of cables needs to be calculated
- Early testing window
  - Data is collected for analysis near the time of peak temperature which is early in the hydration process
  - After peak temperature of concrete is reached temperatures normalize and anomalies are less evident
- Requires drilled shaft installation records, concrete volume logs, and soil borings to perform high level analysis when drastic boundary conditions are present

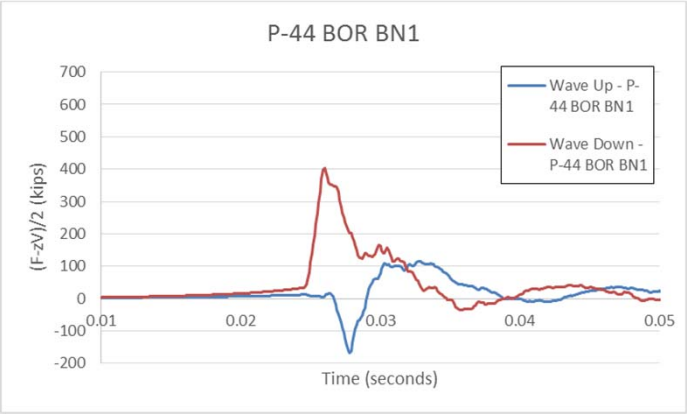
Quick Case Studies – Dynamic Pile Monitoring – Soil Relaxation

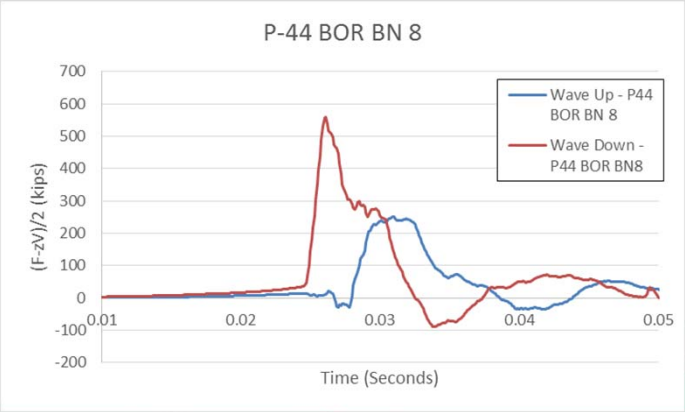
- Dynamic pile monitoring was specified for a project where the pile foundations were driven through sandy/clayey silts into the underlying weathered shale bedrock formation.
- Pile type: HP 14x89 Steel H-Pile
- Required Ultimate Capacity: 110 tons (220 kips)
- Specifications were to monitor the piles during initial driving as well as a minimum 12 hour restrike.



Quick Case Studies – Dynamic Pile Monitoring – Soil Relaxation Cont.







Summary

EOD BN56 – CASE = 703 kips, BLC = 10/in
BOR BN01 – CASE = 232 kips, BLC = 8/in
BOR BN08 – CASE = 502 kips, BLC = 8/in

Corrective Measures were to overdrive the piles and allow to sit for 24 hours and then "reseat" piles with a single hammer dead blow. Structural calculations were performed to check for the allowable settlement.

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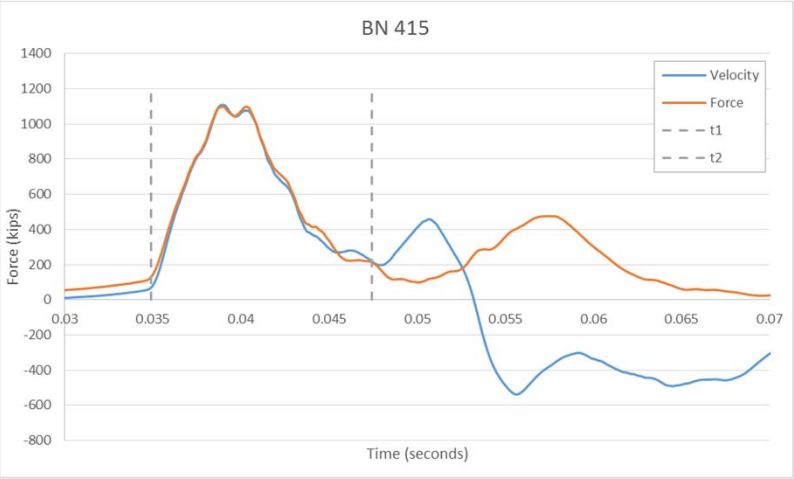
Quick Case Studies – Dynamic Pile Monitoring – Pile Damage

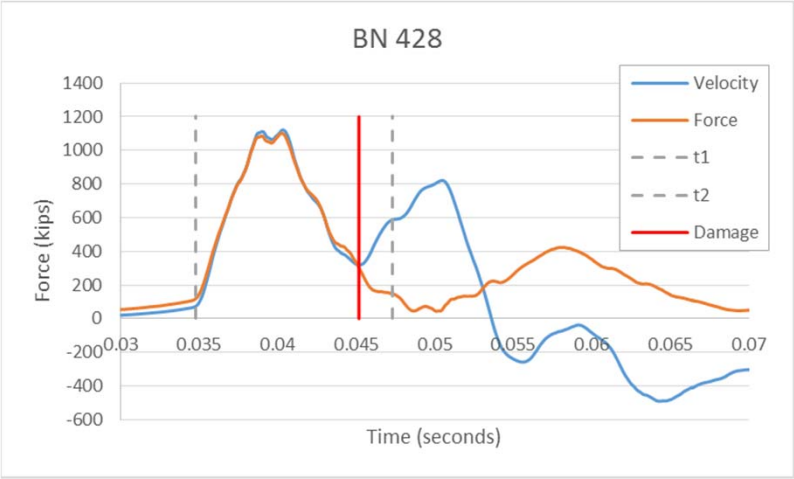
- During driving it is important to monitor the pile top compression stress and to try to limit the hammer stroke if stresses are an issue.
- For concrete piles in easy driving conditions usually the tension stresses are critical.
- Pile monitoring cannot calculate eccentric bending stresses along the pile length.

For this project, pile monitoring was specified for the test pile program.

- Pile Type: 20 inch square precast concrete piles with a 5 foot HP10X57 stinger section.
- Required Ultimate Capacity – 440 tons (880 kips)

Quick Case Studies – Dynamic Pile Monitoring – Pile Damage Cont.





With knowledge of the material wave speed and total pile length, it is possible to detect damage during driving.

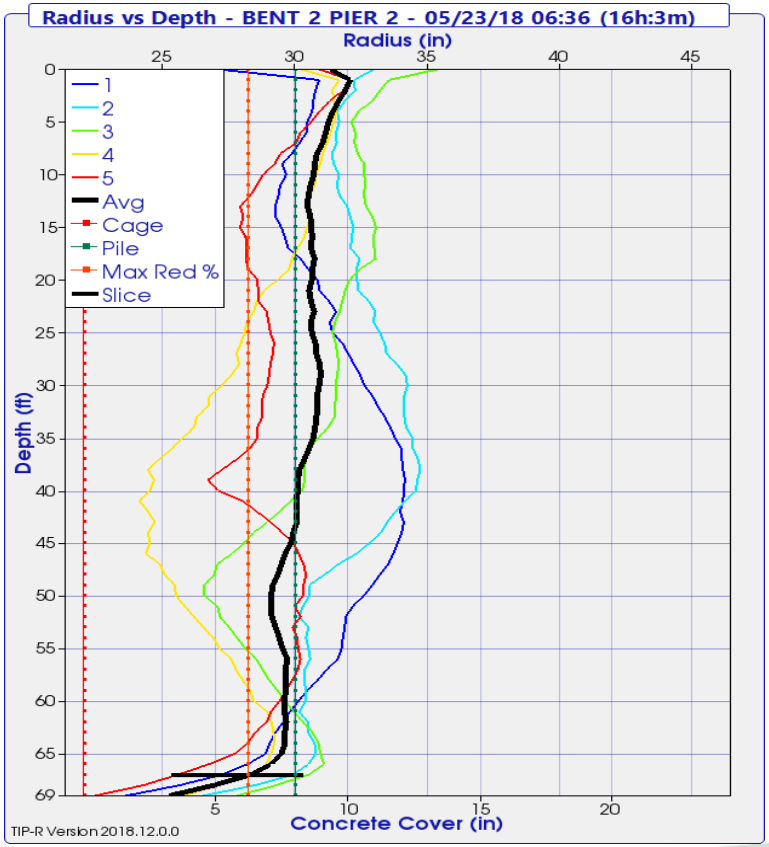
Quick Case Studies – Dynamic Pile Monitoring – Pile Damage Cont.

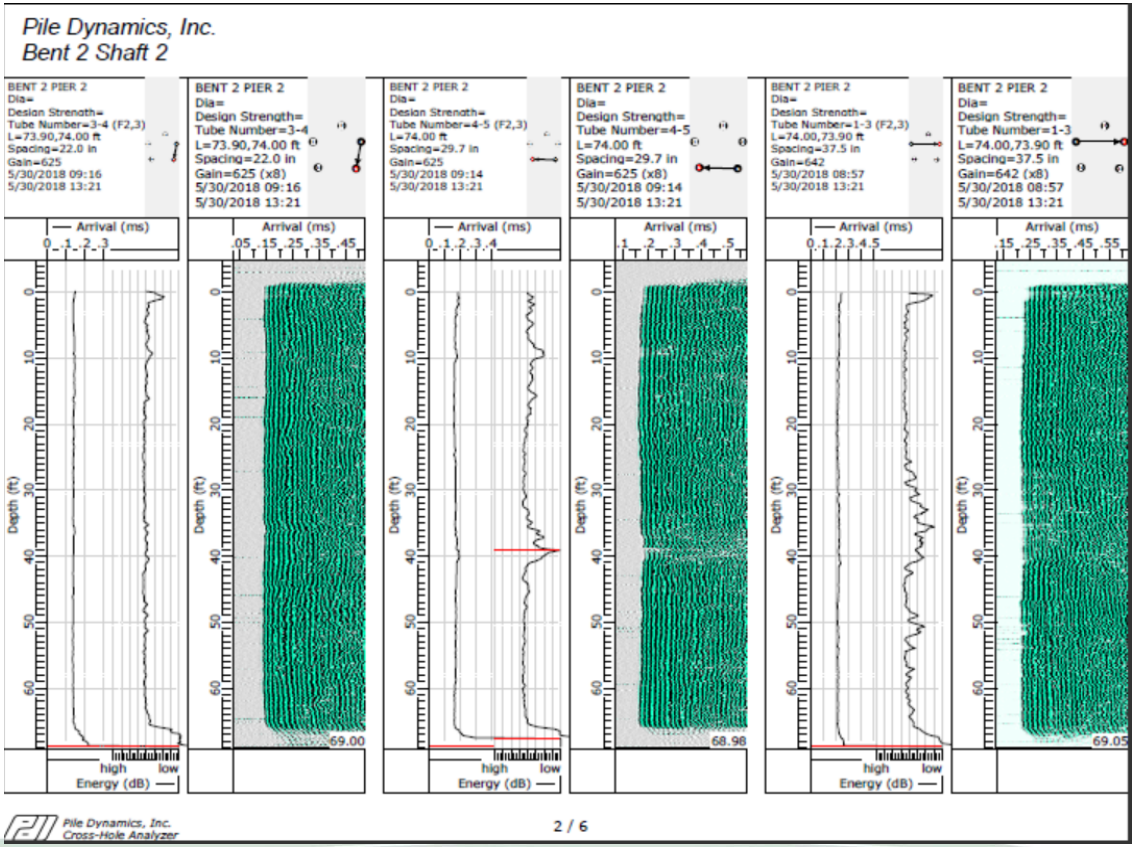
- Driving stresses at the pile top were below the allowable driving stress limit.
- Eccentric bending stresses developed in the pile due to stinger penetration into dense sand layer.
- Blow count was initial suspicion of pile damage. PDA testing was used to confirm suspicion. Ultimately the pile was extracted for visual confirmation.
- Corrective measures were taken to reduce the hammer stroke and increase the driving criteria. PDA was then used on restrikes to verify pile capacity.

Quick Case Studies – CSL and Thermal Results

- Project Overview: Seven 5 foot diameter drilled shafts were installed for a new bridge bent.
- Construction Method: Permeant casing for 1 shaft and temporary casing for the remaining six shafts.
- Both CSL and TIP testing were part of the specified inspection.

Quick Case Studies – CSL and Thermal Results – Cont.

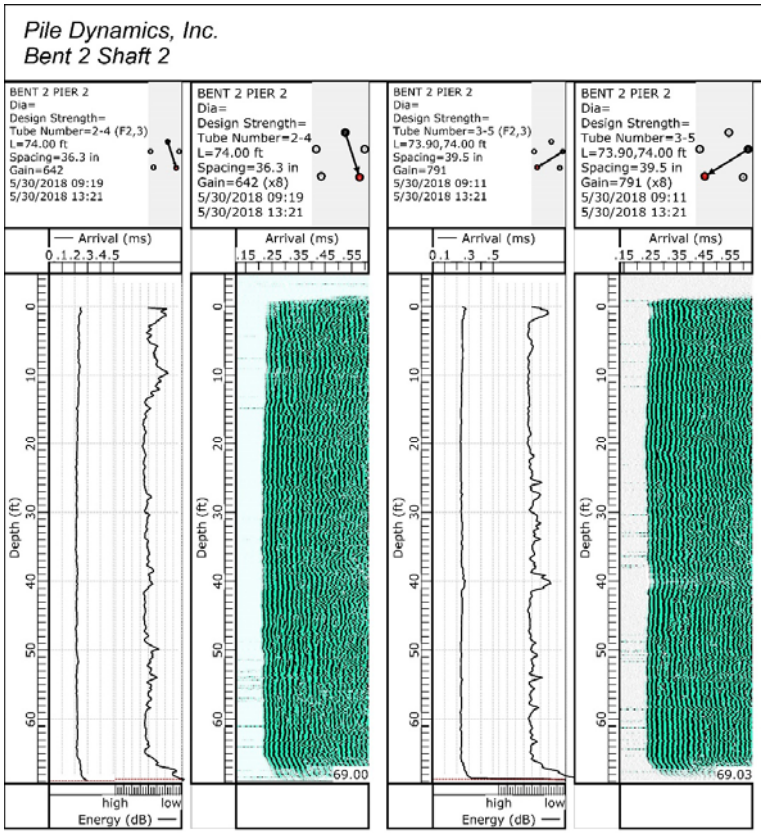




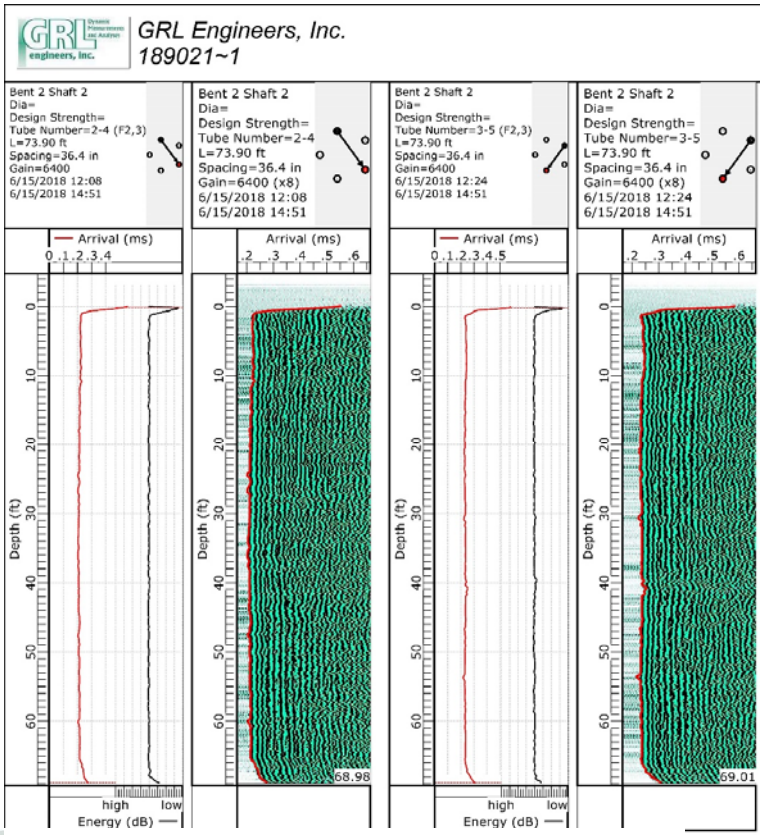
Quick Case Studies – CSL and Thermal Results – Cont.

- Coring was required to verify the CSL and TIP results.
- Cores showed that approximately the bottom 2.5 feet had much lower quality concrete.
- Remediation was required and hydro-blasting and pressure grouting was performed.

Quick Case Studies – CSL and Thermal Results – Cont.



Initial CSL Test Results



After Remediation - CSL Test Results

Thank You

Questions?

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