Drilled Shaft Design & Construction Integrity Testing Issues

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Objective

- Improve understanding of drilled shaft design and construction.
- Understand the importance of geotechnical investigations, design, and the plans and specifications.
- Educate constructors and designers about common issues so that good foundation construction practices are followed.
- To achieve quality assurance.
Outline

- Keys to a successful drilled shaft project
- Osterberg load test at the start of construction SR 57 over White River - Benefits
- Integrity testing - CSL, PIT & TIP
- INDOT experience with NDE tests
- Specific issues discussed
- Summary of INDOT experience
Keys to Success

- **Subsurface investigation**
  - Chapters 2 and 3 – GEC – 10

- **Knowledge of construction techniques**
  - Chapters 4 through 9 – GEC – 10

- **Design for constructability and reliability**
  - Chapters 10 through 17 and 22 – GEC – 10

- **Appropriate specifications**
  - Chapter 18 – GEC – 10

- **Quality assurance**
  - Chapters 19 and 20 – GEC – 10
Geotechnical Resources

NHI Course No. 132014

Drilled Shafts: Construction Procedures and LRFD Design Methods

Developed following:

NCHRP
SYNTHESIS 360

Rock-Socketed Shafts for Highway Structure Foundations

A Synthesis of Highway Practice

TRANSPORTATION RESEARCH BOARD OF THE NATIONAL ACADEMIES
Subsurface Investigations

- The best practice to reduce the risk of construction problems is early recognition of geotechnical problems during design stage and designing accordingly.
- Perform an adequate subsurface investigation in advance of final design.
Subsurface Investigations

- AASHTO LRFD Bridge Design Specifications
  - Table 10.4.2-1
  - For substructure...a minimum of 1 exploration point per substructure. For substructure widths greater than 100 ft, a minimum of 2 exploration points per substructure. Additional Exploration points should be provided if erratic subsurface conditions are encountered, especially for the case of shafts socketed into Bedrock.
  - In soil, depth of exploration should extend below the anticipated shaft tip elevation a minimum of 20 ft, or a minimum of 2 times the maximum pile group dimension, whichever is deeper.
Subsurface Investigations

AASHTO LRFD Bridge Design Specifications

Table 10.4.2-1

For shafts supported on or extending into rock, a minimum of 10 ft of rock core, or a length of rock core equal to at least 3 times the shaft diameter for isolated shafts or 2 times the maximum shaft group dimension, whichever is greater, shall be extended below the anticipated shaft tip elevation to determine the physical characteristics of rock within the zone of foundation influence.
### TABLE 2-3  RECOMMENDED MINIMUM FREQUENCY OF BORINGS, DRILLED SHAFT FOUNDATIONS FOR BRIDGES

<table>
<thead>
<tr>
<th>Redundancy Condition</th>
<th>Shaft Diameter (ft)</th>
<th>Guideline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single-column, single shaft foundations</td>
<td>All</td>
<td>One boring per shaft</td>
</tr>
<tr>
<td></td>
<td>≥ 6 ft</td>
<td>One boring per shaft</td>
</tr>
<tr>
<td>Multiple-shaft foundations in soil</td>
<td>&lt; 6 ft</td>
<td>One boring per 4 shafts</td>
</tr>
<tr>
<td>Multiple-shaft foundations in rock</td>
<td>All</td>
<td>One boring per shaft</td>
</tr>
</tbody>
</table>
Subsurface Investigations

- Thorough investigations are needed to:
  - Determine site geology and groundwater conditions.
  - Determine appropriate soil and rock strength parameters.
  - Perform engineering analyses for design.
  - Establish appropriate construction methods.
  - Make reliable cost estimates.
  - Prepare bid documents.
  - Plan construction.
  - Minimize contractor claims.
Geotechnical Engineer Role

- Perform detailed investigation and analyses.
- Prepare geotechnical design report.
- Communicate site conditions and design recommendations to other members of the design and construction teams.
- Prepare specifications.
- Recommend load testing and QA program.
- Provide technical support during design and construction.
- Role is not complete until construction is successfully completed.
Knowledge of Construction Techniques

- Availability of appropriate drilling equipment and tools for excavation.
- Selection of appropriate methods and materials for excavation support (dry, casing, slurry, combined).
- Match field inspection (quality assurance) procedures with construction procedures.
Schematic of axial and lateral resistance of a drilled shaft:
Design - Constructability & Reliability

- **FHWA - GEC 10**
  - LRFD design - Chapter 10
  - Design process - Chapter 11
  - Lateral loading design - Chapter 12
  - Axial loading Design - Chapter 13
  - Shaft group design - Chapter 14
  - Extreme event design - Chapter 15
  - Structural design - Chapter 16
Lateral loading conditions provided by designer at head of drilled shaft.

<table>
<thead>
<tr>
<th>LIMIT STATE</th>
<th>$F_Y$ (kips)</th>
<th>$F_Z$ Lateral Longitudinal Force (kips)</th>
<th>$F_X$ Lateral Transverse Force (kips)</th>
<th>$M_X$ Longitudinal Moment (k-ft)</th>
<th>$M_Z$ Transverse Moment (k-ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength Shaft No. 1A</td>
<td>601.6</td>
<td>52.9</td>
<td>18.0</td>
<td>1170.0</td>
<td>138.4</td>
</tr>
<tr>
<td>Strength Shaft No. 1B</td>
<td>1134.7</td>
<td>47.5</td>
<td>1.7</td>
<td>1573.7</td>
<td>261.0</td>
</tr>
<tr>
<td>Strength Shaft No. 2A</td>
<td>672.7</td>
<td>0.0</td>
<td>101.0</td>
<td>154.7</td>
<td>154.7</td>
</tr>
<tr>
<td>Strength Shaft No. 2B</td>
<td>1309.5</td>
<td>46.6</td>
<td>6.5</td>
<td>1645.8</td>
<td>301.2</td>
</tr>
<tr>
<td>Strength Shaft No. 3A</td>
<td>221.1</td>
<td>0.0</td>
<td>92.5</td>
<td>50.9</td>
<td>185.0</td>
</tr>
<tr>
<td>Strength Shaft No. 3B</td>
<td>1125.7</td>
<td>50.1</td>
<td>4.0</td>
<td>1609.3</td>
<td>258.9</td>
</tr>
</tbody>
</table>
## Loading for Pushover Analysis - Pier 4 Shaft 3 Load Case B

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Force Effect</th>
<th>Pm, avg. Transverse*</th>
<th>Pm, avg. Longitudinal*</th>
<th>Shear Force, V (lbs)</th>
<th>Moment, M (in-lbs)</th>
<th>Axial Force, Q (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.25</td>
<td>0.41</td>
<td>0.58</td>
<td>12565</td>
<td>4,889,978</td>
<td>1,125,700</td>
</tr>
<tr>
<td>2</td>
<td>0.50</td>
<td>0.41</td>
<td>0.58</td>
<td>25130</td>
<td>9,779,955</td>
<td>1,125,700</td>
</tr>
<tr>
<td>3</td>
<td>0.75</td>
<td>0.41</td>
<td>0.58</td>
<td>37695</td>
<td>14,669,933</td>
<td>1,125,700</td>
</tr>
<tr>
<td>4</td>
<td>1.00</td>
<td>0.41</td>
<td>0.58</td>
<td>50259</td>
<td>19,559,911</td>
<td>1,125,700</td>
</tr>
<tr>
<td>5</td>
<td>1.25</td>
<td>0.41</td>
<td>0.58</td>
<td>62824</td>
<td>24,449,888</td>
<td>1,125,700</td>
</tr>
<tr>
<td>6</td>
<td>1.50</td>
<td>0.41</td>
<td>0.58</td>
<td>75389</td>
<td>29,339,866</td>
<td>1,125,700</td>
</tr>
</tbody>
</table>

* Design P-multiplier (for soil) calculated by Geotechnical Engineer based on shaft spacing. Deflection under Load case 6 is 1.22 inches <10%D - OK
Design - Constructability & Reliability

Force Effect vs. Deflection at Head of Drilled Shaft

Force Effect vs Shaft Head Deflection - Pier 4

Deflection at Head of Drilled Shaft, inches

- Pier 4-1A
- Pier 4-1B
- Pier 4-2A
- Pier 4-2B
- Pier 4-3A
- Pier 4-3B
Appropriate Specifications

http://www.in.gov/dot/div/contracts/standards/rsp.sep13/sec700.htm
Quality Assurance

- Drilled shaft has excellent strength in flexure and high axial resistance.
- Therefore, the completed drilled shaft must be a competent structural element that provides sufficient structural strength in compression, tension and flexure to transfer the loads from the structure.
- Carefully planned construction methods in conjunction with careful field observation and oversight are critical to a successful drilled shaft.
<table>
<thead>
<tr>
<th>Test Feature</th>
<th>Crosshole Sonic Logging (CSL)</th>
<th>Gamma-Gamma</th>
<th>Sonic Echo/Impulse Response (SE/IR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM Standard</td>
<td>D 6760</td>
<td>None</td>
<td>D 5882</td>
</tr>
<tr>
<td>Basic Concept</td>
<td>Acoustic signals generated in embedded access tubes are measured in adjacent tubes, providing evaluation of concrete quality between the tubes</td>
<td>Gamma rays emitted from a source are backscattered by concrete and measured by a detector; measured gamma ray counts correlate to concrete density; source and detector are located in a single probe lowered into access tubes</td>
<td>Generate stress wave at the head of the shaft; measure wave reflections to assess shaft length and potential defects</td>
</tr>
<tr>
<td>Primary Application</td>
<td>Assessment of concrete quality inside the reinforcing cage</td>
<td>Assessment of concrete quality around the perimeter of the shaft</td>
<td>Verification of shaft length; crude tool for identifying potential defects</td>
</tr>
<tr>
<td>Limitations</td>
<td>Difficulty locating defects outside the line of sight between tubes; Tubes must be installed prior to concrete placement</td>
<td>Difficulty locating defects &gt; 4 inches away from tubes; Readings complicated by rebar nearby; Tubes must be installed prior to concrete placement; Need to handle, transport, and store radioactive materials</td>
<td>Effective depth limited by stiff soil or rock; difficulty locating small or thin defects; shadow effect</td>
</tr>
<tr>
<td>Advantages</td>
<td>Relatively accurate and relatively low cost</td>
<td>Relatively accurate and relatively low cost</td>
<td>Low cost; Rapid data acquisition; can accommodate unplanned evaluations</td>
</tr>
<tr>
<td>Variations and Related Tests</td>
<td>Cross-Hole Tomography; Perimeter Sonic Logging; Single Hole Sonic Logging</td>
<td></td>
<td>Bending Wave; Parallel Seismic; Internal Stress Wave</td>
</tr>
</tbody>
</table>
Survey of State DOT Practice:

Use of NDE for Drilled Shafts

- 94% use CSL
- 3% use G-G
- 3% use PIT

Ref: Khamis Haramy, FHWA Denver 2008
Quality Assurance

Drilled Shaft Concrete Placement Report
US 50 over Mutton Creek
INDOT Contract No. IR-34452-A
Jackson County, Indiana

<table>
<thead>
<tr>
<th>Shaft ID</th>
<th>Date: 7/24/2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pier 3 - Center</td>
<td>Actual Length of Shaft, ft</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Concrete Load #</th>
<th>Time Concrete Placed</th>
<th>Concrete Volume Placed, cu. yds.</th>
<th>Total Concrete Volume Placed, cu. yds.</th>
<th>Actual Measured Depth to Top of Concrete Surface, ft</th>
<th>Theoretical Depth to Top of Concrete Surface, ft</th>
<th>Difference Between Theoretical Depth to Concrete Surface and Measured Depth, ft</th>
<th>Length of Tremie Pipe in Shaft, ft</th>
<th>Height of Concrete Above End of Tremie Pipe, ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1:43 p.m.</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>N/A</td>
<td>0</td>
<td>56.25</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1:54 p.m.</td>
<td>8</td>
<td>13.5</td>
<td>29.0</td>
<td>26.3</td>
<td>2.7</td>
<td>45.0</td>
<td>16</td>
</tr>
<tr>
<td>3</td>
<td>2:02 p.m.</td>
<td>8</td>
<td>21.5</td>
<td>12.0</td>
<td>9.1</td>
<td>2.9</td>
<td>33.0</td>
<td>21</td>
</tr>
<tr>
<td>4</td>
<td>3:05 p.m.</td>
<td>5</td>
<td>26.5</td>
<td>0</td>
<td>0</td>
<td>15.0</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:
See attached narrative for remarks regarding concrete placement of shaft.
2.5 CY was subtracted from Load 1, as concrete was lost in priming the pump truck, concrete left in priming pump, and loss from failed start.
After concrete cures, casing to be cut off and concrete chipped away to El 549.69, at the bottom of proposed pile cap.

Theoretical depth based on 3.5 ft diameter socket and 4.0 ft diameter shaft. Steel volume and larger diameter outer casing not considered.
2.81 ft of rock socket length per cu.yd of concrete, 2.15 ft of shaft length per cu. yd of concrete
* Depth as measured from top of Permanent casing, surveyed El = 554.0
## Concrete Condition Rating Criteria

<table>
<thead>
<tr>
<th>Velocity Reduction, VR (%)</th>
<th>Signal Distortion/Strength</th>
<th>Concrete Rating</th>
<th>Indicated Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 10</td>
<td>none/normal energy reduction ≤ 6 dB</td>
<td>Good (G)</td>
<td>Acceptable quality concrete</td>
</tr>
<tr>
<td>10 – 20</td>
<td>minor/lower energy reduction 6.1 to 9 dB</td>
<td>Questionable (Q)</td>
<td>Minor contamination, intrusion, or questionable quality concrete</td>
</tr>
<tr>
<td>&gt; 20</td>
<td>severe/much lower energy reduction &gt; 9 dB</td>
<td>Poor/defect (P/D)</td>
<td>contamination, intrusion, and/or poor quality concrete</td>
</tr>
<tr>
<td>No signal</td>
<td>None</td>
<td>No Signal (NS)</td>
<td>Intrusion or severe defect; could also be caused by tube debonding</td>
</tr>
<tr>
<td>≈ 60</td>
<td>severe/much lower energy reduction ≥ 12 dB</td>
<td>Water (W)</td>
<td>water intrusion or water-filled gravel intrusion with few or no fines</td>
</tr>
</tbody>
</table>
Quality Assurance - CSL

- **Satisfactory (G) (Good)**
  - FAT increase 0 to 10% and
  - Energy reduction < 6 db

- **Anomaly (Q) (Questionable)**
  - FAT increase 11 to 20% and
  - Energy reduction of < 9 db

- **Flaw (P/F) (Poor/Flaw)**
  - FAT increase 21 to 30% or
  - Energy reduction of 9 to 12 db

- **Defect (P/D) (Poor/Defect)**
  - FAT increase > 31% or
  - Energy reduction > 12 db
Quality Assurance

Figure 1. Temperature versus Depth Results from Pier 3 Center.

Figure 2. Apparent Ratios versus Depth Results from Pier 3 Center.
## SUMMARY OF LOADING FOR DRILLED SHAFTS

<table>
<thead>
<tr>
<th></th>
<th>Pier 2</th>
<th>Pier 3</th>
<th>Pier 4</th>
<th>Pier 5</th>
<th>Pier 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft Diameter, ft</td>
<td>6.5</td>
<td>6.5</td>
<td>6.0</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>Drill Shift Diameter, ft</td>
<td>54.4</td>
<td>47.2</td>
<td>54.5</td>
<td>68.8</td>
<td>75.1</td>
</tr>
<tr>
<td>Rock Socket Diameter, ft</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Rock Socket Length, ft</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
<td>22.5</td>
</tr>
<tr>
<td>Estimated Shaft Tip Elevation in Rock</td>
<td>397.0</td>
<td>397.2</td>
<td>408.4</td>
<td>440.5</td>
<td>393.7</td>
</tr>
<tr>
<td>Factored Design Load, $Q_F$ (kips)</td>
<td>1518</td>
<td>1515</td>
<td>1491</td>
<td>1877</td>
<td>1695</td>
</tr>
<tr>
<td>Factored Design Resistance, $R_R$ (kips)</td>
<td>1518</td>
<td>1515</td>
<td>1491</td>
<td>1877</td>
<td>1695</td>
</tr>
<tr>
<td>Downdrag Load, $DD$ (kip)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Resistance Factor $\phi_{dyn}$</td>
<td>0.5, 0.55</td>
<td>0.5, 0.55</td>
<td>0.5, 0.55, 0.70</td>
<td>0.5, 0.55</td>
<td>0.5, 0.55</td>
</tr>
<tr>
<td>Nominal Resistance, $R_n$ (kip)</td>
<td>2849.1</td>
<td>2843.6</td>
<td>2800</td>
<td>2314.0</td>
<td>3501.8</td>
</tr>
<tr>
<td>Testing Method</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Special Provision in Contract Book or ISS Section 728
Osterberg Load Test SR 57

Station 1266+02 Line "PR-N"

Revised Drilled Shaft Tip - From O Cell Test

Original Design Tip
## Partial Cost Savings

<table>
<thead>
<tr>
<th></th>
<th>Unit Bid Prices</th>
<th>Drilled Shaft</th>
<th>Rock Socket</th>
<th>Permanent Casing</th>
<th>Cost Savings (per shaft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osterberg Cell Test:</td>
<td>$263,000.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drilled Shaft (72 in):</td>
<td>$810.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rock Socket (60 in):</td>
<td>$1,090.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Permanent Casing (72 in):</td>
<td>$682.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Pier 4
- **Original (LFT):** 54.59
  - **Revised (LFT):** 25.99
  - **Change (LFT):** 28.6
- **Cost Savings (per shaft):** $23,166.00

### Pier 5
- **Original (LFT):** 68.84
  - **Revised (LFT):** 55.3
  - **Change (LFT):** 13.54
- **Cost Savings (per shaft):** $10,967.40

### Pier 6
- **Original (LFT):** 75.09
  - **Revised (LFT):** 64.4
  - **Change (LFT):** 10.69
- **Cost Savings (per shaft):** $8,658.90

### Total Cost Savings:
- **$147,610.92**
Why do we test? How do we test?
Cross-hole Sonic Logging

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

Put probes in bottom of tubes

Fill Tubes with water

Pull Probes From Bottom To Top

Transmit

Receive

Top view of pile with 4 access tubes

provided by pdi
CSL tests every tube combination
Cross-hole Analyzer - CHAMP
Cross-hole Analyzer - CHA

(wave speed) = (tube spacing) / (arrival time)

Traditional "water fall"
Signal amplitude provides information.

“Energy” is integration of signal amplitude.
Can evaluate either energy or signal amplitude.
PDI shaft – when to test?

ASTM D6760 suggests test after 3 days

728-B-203 DRILLED SHAFT FOUNDATIONS

INDOT requires test no sooner than 5 business days after placement of concrete
7/12 first test

8/19 no real change
Comparison of CHA results with purpose-built defects in test shafts
<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Desc.</th>
<th>Legend</th>
<th>GRL CHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 (5)</td>
<td></td>
<td>NE, SE, EW</td>
<td></td>
</tr>
<tr>
<td>3.0 (10)</td>
<td>fiberglass outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.6 (15)</td>
<td>12&quot; dia pail inside</td>
<td>void</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fiberglass outside</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>6.1 (20)</td>
<td></td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>7.7 (25)</td>
<td>4&quot; tube coil</td>
<td>SW, SE, NE, EW (minor NW, NS)</td>
<td></td>
</tr>
<tr>
<td>9.2 (30)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.7 (35)</td>
<td>cardboard tube</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16&quot; dia pail inside</td>
<td>void</td>
<td></td>
</tr>
<tr>
<td></td>
<td>fiberglass outside</td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>12.2 (40)</td>
<td></td>
<td>NE</td>
<td></td>
</tr>
<tr>
<td>13.7 (45)</td>
<td>16&quot; dia pail inside</td>
<td>SE</td>
<td></td>
</tr>
<tr>
<td>15.2 (50)</td>
<td></td>
<td>SW, NW, EW</td>
<td></td>
</tr>
</tbody>
</table>

Amherst Shaft 1 Correlation (Sept 2000)
<table>
<thead>
<tr>
<th>Diameter change</th>
<th>16&quot; dia. pail (inside)</th>
<th>12&quot; dia pail inside fiberglass outside</th>
<th>Cardboard tube 16&quot; dia pail inside fiberglass outside</th>
<th>16&quot; dia. pail (inside) soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 (5)</td>
<td></td>
<td>16&quot; dia pail (inside)</td>
<td>fiberglass outside</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16&quot; dia pail (inside)</td>
<td>NE, SE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fiberglass outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.0 (10)</td>
<td></td>
<td>fiberglass outside</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>NE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.6 (15)</td>
<td></td>
<td>12&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fiberglass outside</td>
<td></td>
<td></td>
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<tr>
<td>6.1 (20)</td>
<td></td>
<td>fiberglass outside</td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>NE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.7 (25)</td>
<td></td>
<td>4&quot; tube coil in &amp; outside</td>
<td>SW, SE, NE, EW, NW, NS</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>necking</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9.2 (30)</td>
<td></td>
<td>cardboard tube</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fiberglass outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.7 (35)</td>
<td></td>
<td>cardboard tube</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fiberglass outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12.2 (40)</td>
<td></td>
<td>cardboard tube</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>16&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>fiberglass outside</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13.7 (45)</td>
<td></td>
<td>16&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>soil</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15.2 (50)</td>
<td></td>
<td>16&quot; dia pail inside</td>
<td>NE, SE, EW, NE, EW</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>soil</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A. Plastic Bucket (0.4 m/16 in. dia.) with fiberglass insulation on outside
B. Plastic Bucket (0.3 m/12 in. dia.) with fiberglass insulation on outside
C. 0.1 m/4 in dia. Plastic tubing coiled outside cage
D. 0.1 m/4 in dia. Plastic tubing coiled inside cage
E. Cardboard tube and plastic pail (0.4 m/16 in dia) w/ fiberglass insulation
<table>
<thead>
<tr>
<th>Shaft 1</th>
<th>As Built</th>
<th>GRL CHA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>Desc.</td>
<td>Legend</td>
</tr>
<tr>
<td>m (ft)</td>
<td></td>
<td>NE, SE, EW</td>
</tr>
<tr>
<td>1.5 (5)</td>
<td>16&quot; dia pail (inside)</td>
<td>NE, SE, EW</td>
</tr>
<tr>
<td>3.0 (10)</td>
<td>fiberglass outside</td>
<td></td>
</tr>
<tr>
<td>4.6 (15)</td>
<td>12&quot; dia pail inside</td>
<td>void</td>
</tr>
<tr>
<td></td>
<td>fiberglass outside</td>
<td></td>
</tr>
<tr>
<td>6.1 (20)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dia change</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.7 (25)</td>
<td>4&quot; tube coil in &amp; outside (necking)</td>
<td>SW, SE, NE, EW (minor NW, NS)</td>
</tr>
<tr>
<td>9.2 (30)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10.7 (35)</td>
<td>cardboard tube</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16&quot; dia pail inside</td>
<td>void</td>
</tr>
<tr>
<td>12.2 (40)</td>
<td>fiberglass outside</td>
<td>NE</td>
</tr>
<tr>
<td>13.7 (45)</td>
<td>16&quot; dia pail inside</td>
<td>SE</td>
</tr>
<tr>
<td>15.2 (50)</td>
<td></td>
<td>SW, NW, EW</td>
</tr>
</tbody>
</table>
CSL Finds:

• defects on direct perimeter path
• multiple defects: by depth and quadrant
• “soft bottoms” if tubes go to bottom

Limitations:

• cannot find defect if not on direct path
• cannot find defect outside cage (e.g. bulges)
• may not find small defects in center of pile

Other considerations:

• needs access tubes; if too few tubes, can miss defects
• not sensitive to surrounding soils or pile length
Canary Wharf Testing

Pile 465 - small defect
Canary Wharf Testing
Pile 448 - large shell defect
FL DOT sign shaft
Low Strain Integrity Testing:
- Looks for major defects

Small hammer impact device

Accelerometer measures response

(defect)
Indiana Shafts—PIT results
Indiana examples of drilled shafts. Testing/coring/evaluating
Core of drilled shaft: Above 23ft and below 26ft are fine.
Significant defect between 31 and 35 ft

PIT: IV35 Inconclusive record below depth of 35 ft due to spurious vibrations
Good concrete core

5’9” to 15’10”

15’10” to 25’9”
“Concrete” in a jar

Cored North and South sides of shaft just inside cage
2/27/12: 8:20 am, checked hole depth. Bottom of hole is solid, weight bounces crisply.
2/28/12: 11:00 am, water pumped out of shaft. 11:05 am, concrete pour started.

PIT = AA
with lower apparent wave speed
6 ft shaft, 2 ft hole
down all the way 58 ft
Core 3 ft diameter out of center of shaft, clean rock socket and cage, repour.
Results aren’t always so clear
No signal near surface, multiple defects
Void in core

Core C-3 taken 18 inches from Tube 5 and 23 inches from Tube 3 – In line between Tubes 1 and 4
3 inch diameter core: 54 inches cored on Friday, 2-8-13, until equipment failure with coring machine

Top 11 inches were broken off mechanically to advance core barrel.
PIT = AB
inconclusive
Top 5 ft chipped, cleaned and repoured
Another shaft, less than 100 feet away

Flaws and defects in 9 of the 10 profiles!

AB : No major defect indicated; the records indicate neither reflections from significant reductions or pile size or material quality nor a clear toe response. Records in this category do not give indications of a significant deficiency, however, neither do they yield positive evidence of the shaft being flawless over its full length.
7 feet of shaft cored. Generally solid, no voids. Conclusion, likely “debonding”.
Adjacent shaft. Similar CSL/PIT

PIT: AB, no major defects, cannot confirm it’s flawless
Cored in 3 lowest velocity areas: loose aggregate, poor concrete confirmed
Failed sounding for loose concrete near surface.

Soil contaminated concrete.
Construction observation

Pulling Inner Casing

Concrete Not over flowed

Pulling Outer Casing
Localized defects

PIT: AB
CONCRETE CORE STRENGTH TESTS (ASTM C-42 & C-39) --

Deviations from the test method: Cores were tested in an as-received condition.

<table>
<thead>
<tr>
<th>Core No.</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date &amp; Time Drilled</td>
<td>10/22 to 10/24</td>
<td>10/24 6-9pm</td>
</tr>
<tr>
<td>Max. Aggregate Size:</td>
<td>3/4&quot;</td>
<td>3/4&quot;</td>
</tr>
<tr>
<td>Date &amp; Time Ends Prepared</td>
<td>10/26/12</td>
<td>10/26/12</td>
</tr>
<tr>
<td>Date &amp; Time Tested</td>
<td>10/26/12</td>
<td>10/26/12</td>
</tr>
<tr>
<td>Uncapped Length (in)*</td>
<td>10.97</td>
<td>11.00</td>
</tr>
<tr>
<td>Diameter (in)</td>
<td>5.64</td>
<td>5.67</td>
</tr>
<tr>
<td>Area (in²)</td>
<td>25.10</td>
<td>25.13</td>
</tr>
<tr>
<td>Capped Length (in)</td>
<td>11.19</td>
<td>11.20</td>
</tr>
<tr>
<td>Length / Dia. Ratio</td>
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<td>1.98</td>
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<tr>
<td>Correction Factor</td>
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<td>1.000</td>
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<tr>
<td>Age (days)</td>
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<td>39</td>
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<tr>
<td>Break Type**</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Total Load (lbf)</td>
<td>88780</td>
<td>88810</td>
</tr>
<tr>
<td>Compressive Strength (psi)</td>
<td>3,540</td>
<td>3,450</td>
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</table>
Coring Through a Void
Coring Through a Void
Construction Issues

Parallel CSL Tubes?
Thermal Integrity Profiling

Thermal sensors every 1 foot
Centering the Reinforcing Steel
GRL Engineers, Inc.
Mutton Creek

CSL Results
Pile Integrity Testing Results

GRL Engineers, Inc.
US 50 OVER MUTTON CREEK
US 50 OVER MUTTON CREEK PIT

8/2/2013

PIT-W 2009-1

Pile: PIER 3 - CENTER - 4: # 25

WT 3.0 LB
6/1/2013 6:52:45 AM

x5.00 L/D=13 (D=48 in)
53.90 ft (16500 ft/s)

V 0.074 in/s (0.074)

Pile: PIER 3 - CENTER - 4: # 31

WT 6.0 LB
6/1/2013 6:55:44 AM

2W 3.90 ft 1750.0 Hz

V 0.070 in/s (0.079)

Pile: PIER 3 - CENTER - 4: # 38

WT 8.0 LB
6/1/2013 6:58:21 AM

F delay: -0.05 ft
Z: 7.909 kips/ft/s
M: 8.0 lb

V 0.070 in/s (0.070)
F/Z 0.039 in/s (0.039)
Construction observation

Field Notes for Drilled Shaft Report

US 50 over Mutton Creek
INDOT Contract No. IR-34452-A
Jackson County, Indiana

Pier 3 Shaft: Center

On Monday 7-15-2013 drilling began with a 60 in. soil auger at 11:00 a.m. Material being removed was wet, gray, silty clay and sand. A 60 in. core barrel was used until 11:40. An outer casing (5 ft. diameter x 15 ft. long) was set and advanced into the ground by twisting and pushing downward until the top of outer casing was at EL 549.06. A 48 in. auger was then used. At a depth of 23 ft. below the top of the outer casing large gas bubbles were noticed coming up from the water within the shaft. Water was pumped into the outer casing and a slurry was made by adding Polybore within the shaft. Drilling continued until reaching EL 514 at a depth of 35 ft. below the top of the outer casing. The permanent casing (4 ft. diameter x 42 ft. long) was set and advanced into the ground by twisting and pushing downward to a top of permanent casing EL 548.30. Gas bubbles were noticed around the outside of the outer casing. The water inside the permanent casing started flowing on the top of the permanent casing. Drilling continued with the auger and at 3:30 p.m. the permanent casing started to turn.

On Tuesday 7-16-2013 drilling continued with the auger. As the water level within the permanent casing dropped from the auger removing material, water between the permanent casing and the outer casing could be seen flowing into the permanent casing. The permanent casing was advanced further into the ground by twisting and pushing downward to a top of permanent casing EL 547.9. Drilling continued with an auger until reaching top of rock at a depth of 41 ft. below the top of permanent casing. The type of rock consisted of shale as observed after removal of the auger. The outer casing was removed and the permanent casing was advanced further to the ground to a top of permanent casing EL 547.0. Water started being pumped to a storage tank outside of the shaft.

On Wednesday 7-17-2013 a 10.5 ft. extension of casing was welded to the top of the permanent casing changing the top of permanent casing to EL 557.5. Drilling continued with a truck bucket followed by a core barrel at 2:10 p.m. Gas bubbles could be seen bubbling around the outside of the permanent casing and within the permanent casing.

On Thursday 7-18-2013 water was slightly above the welded extension mark but was leaking out the weld. The weld was fixed and the truck bucket was used until 9:00 a.m. reaching a depth of 60.7 ft. below the top of permanent casing. Gas bubbles could be seen bubbling around the outside of the permanent casing and within the permanent casing. As water accumulated in the area outside of the shaft it was pumped into storage tanks.

On Friday 7-19-2013 the water level within the permanent casing was at 9.5 ft. below the top of the permanent casing at 12:00 p.m. Water mark could be seen on the inside of the permanent casing indicating the water level fluctuations.

On Monday 7-22-2013 at 8:00 a.m. the water level within the permanent casing measured 8.75 ft. below the top of permanent casing (water level = 548.8).
TIP Results

Temperature vs Depth

Radius vs Depth

Total Vol (cy) 26.3
Avg Rad (in) 23.94
Only 5% of the shafts required corrective measures.
Questions?