Crosshole Sonic Logging: A 10 Year Perspective

Kyle Murrell, PE
S&ME, Inc.
Charleston, SC
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

Slide courtesy of PDI
CSL Equipment & Procedure

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

Procedure – cont.

Fill Tubes with water

Put probes in bottom of tubes.

Pull Probes From Bottom To Top

Put probes in bottom of tubes.

Top view of pile with 4 access tubes

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

Slide courtesy of PDI
Data Processing

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

- Cannot Evaluate Integrity Outside of the Reinforcing Cage
- Cannot be performed soon after concrete placement (typically test no sooner than 3 days)
SCDOT Experience - Background

- SCDOT On-call Foundation Testing Contract
- CSL Since 2000
- Responsible for $\approx \frac{1}{2}$ testing
On-Call Consultant Directive

1. Perform CSL on all SCDOT Shafts
2. Identify Anomalies
Anomaly Identification

• **Good:**
  – Velocity decrease of 10% or less
  – Constant energy

• **Questionable:**
  – Velocity decrease of 10% to 20%

• **Poor/Defect:**
  – Velocity decrease >20%
  – Drop in energy or loss of signal

1. Perform CSL on all SCDOT Shafts
2. Identify Anomalies
3. Review Drilled Shaft Inspection Reports
4. Provide Recommendation
   - “Good” Shaft – Accept
   - “Poor/Defective” Shaft – Additional Evaluation Required
Additional Evaluation

• Re-evaluate design requirements (wrt anomaly size, location, magnitude, etc.)
  – Individual Shaft Loading
  – End Bearing Requirement
  – Lateral Loading/Response

• Chipping/Sounding

• Coring
Example – Hellers Creek (2005)

- Dry Construction
- Concrete Placed by Tremie
- CSL Performed 9 Days After Concrete Placement
- First of Four Shafts
Hellers Creek – Cont.

- Classification – “Poor/Defective”
- Recommendation - Coring

<table>
<thead>
<tr>
<th>Tube Pair</th>
<th>Presence of Anomalies?</th>
<th>Anomaly Depth (ft)</th>
<th>Maximum First Arrival Time Delay (%)</th>
<th>Increment Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-2</td>
<td>YES</td>
<td>54 – 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>2-3</td>
<td>YES</td>
<td>54 – 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>3-4</td>
<td>YES</td>
<td>55 – 57½</td>
<td>75</td>
<td>P/D</td>
</tr>
<tr>
<td>4-5</td>
<td>YES</td>
<td>56 – 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>1-5</td>
<td>YES</td>
<td>54½ - 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>1-4</td>
<td>YES</td>
<td>54½ - 57½</td>
<td>41</td>
<td>P/D</td>
</tr>
<tr>
<td>1-3</td>
<td>YES</td>
<td>54 – 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>2-4</td>
<td>YES</td>
<td>54½ - 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>2-5</td>
<td>YES</td>
<td>55 -57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
<tr>
<td>3-5</td>
<td>YES</td>
<td>55 – 57½</td>
<td>&gt;100</td>
<td>P/D</td>
</tr>
</tbody>
</table>
Hellers Creek – cont.

- Cores from 54’ to 60’
  (signal loss from 54’ to 58’
   – no CSL below 58’)
- No Irregularities Found
SCDOT CSL Testing Statistics
(2000 – 2011)

- Number of Projects: 66
- Number of Shafts: 850
- Number of Contractors: 12
- Number of “Wet” Shafts: 658
- Number of “Dry” Shafts: 192
- Projects in Soil: 24 (469 shafts)
- Projects in Rock: 42 (381 shafts)
Project Size Distribution

More than $\frac{1}{2}$ have 8 shafts or less
Diameter Distribution

2/3 are < 6 ft
CSL Testing Statistics - Anomalies

- Number of Projects: 66
- Number of Shafts: 850
- Shafts with Anomalies: 316 (37%)
- Projects with Anomalies: 56 (85%)
- Projects with No Anomalies: 10 (15%)
- No. of Shafts on No-Anomaly Projects: 43 (5%)
Comparison with Other Studies

Jones & Wu, Geotechnology, Inc.      Missouri and Kansas


37% Bottom 2D 32%

58% Top 2D

38% Bottom 1/3 45%

44% Top 1/3

11% Mid 1/3
CSL Testing Statistics – Cont.

- Number of “Good” Shafts: 730
- Percentage of “Good” Shafts: 86%
- Number of “Poor/Defective Shafts: 120
- Percentage of “Poor/Defective” Shafts: 14%
- Projects with coring: 12+
  - Core Findings
    - Bleed water features
    - Minor to significant segregation
    - Lumber (missing 4x4)

- Shafts Requiring Remediation: 2
Case Histories & Examples

- Top Anomalies
  - 6-ft Diam Shaft in River
  - Mudline is 12 to 18 ft below top of shaft
  - Casing is 30 ft below top of shaft
  - Anomalies in the top of every shaft
Aggressive Manual Picks
Explanations?

• De-bonding (SCDOT access tubes are steel)
• Flowing water created large thermal gradients leading to micro-cracking during curing
• Bleed water causing flow paths through concrete
  – Supported by coring
Subsequent Information

• Different Project – Same Problem
Consequences of Bleed Water Features

Wavespeed at 97.39 ft = 13,351 fps

Possible interpretations at 99.55 and 99.88 ft:

No signal or

1) Wavespeed of 8,564 (36% reduction)
2) Wavespeed of 4,647 (65% reduction)
Top Anomaly
Top Anomaly – continued
Case Histories & Examples

Bottom Anomalies

• From the inspector’s logs
  – 4.5 ft diameter, 30 ft long shaft (approx 18 cy vol)
  – Permanent casing with rock socket below
  – No drilling fluid
  – Concrete placed via pump line
  – No problems noted
20’ to 25’: Gravel or No Recovery
Middle Anomaly
Middle Anomaly – cont.
Middle Anomaly – cont.
Summary – Major Delay/No Signal
Summary – SCDOT Experience

• Concrete quality, not necking or soil intrusion, is the cause of anomalies
  – Bleed water, segregation, contamination?
• Vast majority of anomalies ≠ defect
• ≈90% of anomalies are found near the top or the bottom
• An anomaly free project is very rare
• Research should address concrete issues