Unknown Bridge Foundations

Rakesh Anthony Khan, PE
Engineering Manager, Heavy Civil Group
OVERVIEW

» Company History
» NDE Methods
» Select application cases
» Program history including scour analysis
Co-Founders: 2 Civil Engineering Professors and 1 Graduate Student at NCSU

FHWA/NCDOT Funded Research:

How to nondestructively determine the depth and integrity of aging bridge timber piles that have been in the field for many years and lack original engineering documentation....
COMPANY OVERVIEW

» 700+ Person Multidisciplinary Consulting Firm
» $300M Annual Revenue
» Offices in 14 states
» U.S. patents awarded: 3
» FDHV is a fully registered professional corporation, and our staff professionals hold current licensure in 50 states, DC, Puerto Rico, Northern Marianas Islands and the Virgin Islands.
PRIMARY METHODS FOR UNKNOWN FOUNDATIONS

» Dispersive Pulse Echo
» Dispersive Bending Wave
» Dispersive Side Sonic
Dispersive Pulse Echo Testing

- Testing performed by striking a foundation from the top.
- Typical testing method utilized on telecommunication structures (caissons, pad & pier, mat, etc.)
- Testing will return length to end of the foundation or physical anomaly. (Integrity Testing)
Dispersive Pulse Echo Testing

Integrity Testing of Deep Shafts
Length / Diameter (L / D)
Limitation not an Issue
Dispersive Bending Wave Testing

- Testing is performed by striking a pile on its side.
- Dispersive Bending Wave is utilized to investigate foundations which do not have the top accessible to perform dispersive pulse echo testing.
- Typically performed on bridge piles
Mechanics of BW Test

Wave Speed in Timber $\approx 2000 \text{-} 4000 \, \text{ft/s}$

Must determine from data

Distance = (W.S.) $\times \left( \frac{1}{2} \right) t$

Impact

Top to G1

Distance

Amplitude

Time (in \( \mu s \))
Inaccessible Foundations

Dispersive Side Sonic can be used.

Pile Supported Footings
DISPERSSIVE SIDE SONIC TESTING

Also referred to as Parallel Seismic Testing
SIDE SONIC DATA (PRIOR TO POST PROCESSING)

Unknown break location in graph
RESULTS AFTER USING FDH’S PROPRIETARY DISPERSIVE ANALYSES

FDH Post Processed data taken from DS test

107 ft embedded length
So, How well does this work?

Bending wave consistently works for timber and concrete piles.

Side sonic methods are still used as the primary method of characterizing steel pile length.

Recent internal R&D for steel pile bending wave testing is currently underway, with promising results.
RAPID DEPLOYMENT: SCDOT

- 1000+ year rainfall from Hurricane Joaquin
- Major streambed profile change from scour
- Unknown pile embedment; I-95 shut down
LARGE SCALE PROGRAM: LADOTD UNKNOWN FOUNDATIONS AND BRIDGE SCOUR PROGRAM

4,127 bridges originally coded ‘U’ by Louisiana DOTD

2002 Pilot project: 107 LA bridges tested with 11 control

2004-2013 ~7500 unknown bridge piles mapped
~2081 Phase 1 scour analyses and reports
~538 Phase 2 scour analyses and reports
BRIDGE SCOUR EVALUATION PROCESS

» RECORD SEARCH
» NON-DESTRUCTIVE TESTING (NDT) INVESTIGATION
» PHASE 1 ANALYSIS
  STREAM VERTICAL AND LATERAL STABILITY ASSESSMENT
  DETERMINATION OF HYDROLOGIC PARAMETERS
  PILE PENETRATION DETERMINATION AND NBIS Rating
» PHASE 2 ANALYSIS
  FIELD SURVEY
  DEVELOPMENT OF HYDRAULIC MODEL (1D AND/OR 2D)
  DETERMINATION OF HYDRAULIC VARIABLES FOR USE IN SCOUR COMPUTATIONS
  APPLICATION OF COMPUTED SCOUR AND NBIS Rating
A thorough search (performed for each structure) of archived data to obtain supporting documentation for pile lengths, hydrology/hydraulics, historical trends, bridge geometry, etc.

- Bridge inspection and maintenance reports
- Pile driving records
- Original and as-built bridge plans
NDT Investigation

Determination of Pile Lengths for Selected Bents at Bridge

<table>
<thead>
<tr>
<th>Pile ID</th>
<th>Pile Size (inches)</th>
<th>Computed Overall Length (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2P3</td>
<td>43</td>
<td>29.0</td>
</tr>
<tr>
<td>B4P1</td>
<td>43</td>
<td>27.0</td>
</tr>
<tr>
<td>B6P2</td>
<td>42</td>
<td>25.0</td>
</tr>
</tbody>
</table>
**Phase 1 Analysis**

**Stream Vertical and Lateral Stability Assessment**

**Geomorphic Indicators from Site and Aerial Photos**

**Comparison of Inspection and Stream Gage Records**

**Watershed Influences (i.e. mining activities, development, reservoirs, dams, relief structures, etc.)**

**Determination of Hydrologic Parameters (peak discharges and drainage area)**
Phase 1 Analysis (continued)

Determination of NBIS Rating

The Phase I Analysis is concluded by assigning the bridge an NBIS Item 113 Rating based on the relationships of pile penetration percentage, drainage area, discharges, and engineering judgment.

- 3: Scour critical
- 6: Scour susceptible
- 8: Scour stable
- N: Bridge not over water
- T: Tidal influence
- U: Unknown foundation
Phase 2 Analysis

Site Survey

Bridge Dimensions

Photos of bridge(s), channel(s), floodplains, vegetation, etc.

Floodplain and channel cross sections (upstream, downstream, at bridge, at any additional structures, etc.)
Phase 2 Analysis (continued)

Two Dimensional Hydraulic Model
2D models compute flow in multiple directions and therefore yield more precise hydraulic variables around the bridge elements susceptible to scour (i.e. piers and abutments).

Finite Element Mesh (FEM) for Multiple opening bridge system
PHASE 2 ANALYSIS (CONTINUED)

SCOUR SUMMARY AND NBIS RATING

PHASE II SCOUR ANALYSIS OF SCOUR SUSCEPTIBLE BRIDGES

<table>
<thead>
<tr>
<th>Date</th>
<th>District Code</th>
<th>Structure No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5/20/2012</td>
<td>B1</td>
<td>P170098002051</td>
</tr>
</tbody>
</table>

**Scour Summary**

- **Structure Information**
  - **Span:*** 230 ft
  - **Year of ADT:*** 1966
  - **Year Built:*** 1966
  - **Adverse Gradation:** 12
  - **Cumulative Scour:** 11.1 in.
  - **Site:** 1.0
  - **Foundation:** 1.1
  - **Pipe Size:** 1.0

**Foundation Information From Phase I Analysis (Worst-Case)**

- **Pipe Length:** 1.1 mil
- **Pipe Penetration:** 1.1 mil
- **Percent Penetration:** 15.62%

**Computed Scour Data**

<table>
<thead>
<tr>
<th>Scour Component</th>
<th>Computed Scour (ft)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>LT Overbank</td>
</tr>
<tr>
<td>Long-Term Degradation</td>
<td>0.04</td>
</tr>
<tr>
<td>Contraction Scour</td>
<td>0.61</td>
</tr>
<tr>
<td>Pressure Loss, Vortex</td>
<td>0.61</td>
</tr>
<tr>
<td>Air Pocket Scour</td>
<td>0.49</td>
</tr>
<tr>
<td>Total Scour</td>
<td>1.36</td>
</tr>
</tbody>
</table>

*Total Scour Depth based on the Worst-Case Combination of Load & General Scour that Results in the Minimum Streambed Elevation per Section (LT Overbank, Channel, RT Overbank)*

**Pipe and Stream-Bed Information**

- **Min. Stream Bed Elevation Before Scour (ft):**
  - LT Overbank: 70.22
  - Channel: 61.30
  - RT Overbank: 78.66

**Worst-Case Condition Based on Maximum Scour Depths and Remaining Penetration Lengths**

<table>
<thead>
<tr>
<th>Condition</th>
<th>Before Scour</th>
<th>After Scour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LT Overbank</td>
<td>Channel</td>
</tr>
<tr>
<td>Min. Bed Elevation</td>
<td>70.22</td>
<td>61.30</td>
</tr>
<tr>
<td>High Flv Tip Elev.</td>
<td>24.10</td>
<td>29.26</td>
</tr>
<tr>
<td>Penetration Length</td>
<td>28.40</td>
<td>32.69</td>
</tr>
<tr>
<td>Percent Penetration</td>
<td>78.3%</td>
<td>88.8%</td>
</tr>
<tr>
<td>Bent Number</td>
<td>Bent 6</td>
<td>Bent 1</td>
</tr>
</tbody>
</table>

**Phase II Scour Analysis NBIS Rating**

**3 - Scour Critical; Bridge Foundations Unstable for Calculated Scour Conditions**

Prepared By: AID
Checked By: MMD
Signature and Seal: [Signature]
Phase 2 Analysis (continued)

Graphical Scour Depiction

TOTAL SCOUR ESTIMATE FOR DESIGN FLOOD DISCHARGE
OVERTOPPING EVENT
(LOOKING 3/4)

STONEY POINT BIRCH ROAD OVER SANDY CREEK
BRIDGE # P1730389905281

CALCULATED SCOUR (FT.)

SCOUR LEGEND
ONGOING SCOUR PROGRAM REFINEMENTS

» Orderly Procedure for Obtaining Flood Study Effective Models
» All Field Surveys tied to Datum using GPS
» Increased Centerline of Stream Shots for Profile Generation/Determination
» Use of GIS to Develop Hydraulic Model
» Use of Flexible Mesh Based 2D Modeling
» High Performance Computing using Tesla K40 GPU
» Programming to Integrate Hydraulic Modeling & HEC-18 Analysis
<table>
<thead>
<tr>
<th>Location</th>
<th>Customer</th>
<th>Period of Performance</th>
<th>POC</th>
<th>Project Title/Description</th>
<th>Unknown Bridge Foundations Mapped</th>
<th>Phase I Scour Analyses</th>
<th>Phase II Scour Analyses</th>
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</thead>
<tbody>
<tr>
<td>Alabama</td>
<td>ALDOT</td>
<td>1998 - 2010 (Various times)</td>
<td>Various ALDOT Districts, multiple Contacts and single projects.</td>
<td>Parallel Seismic Testing/Bending Wave Testing of Bridges</td>
<td>25</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Louisiana</td>
<td>LADOTD</td>
<td>2002-2015</td>
<td>Gil Gutreau, PE David Nash, PE Steven Sibley, PE LADOTD Bridge Maintenance Engineer (ret), 1201 Capitol Access Road (PO Box 94245, Baton Rouge, LA, 70804-9245</td>
<td>Unknown foundation mapping pilot program; Initial NDT Testing</td>
<td>2804</td>
<td>2081</td>
<td>538</td>
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<tr>
<td>Mississippi</td>
<td>MSDOT</td>
<td>1999 - 2000</td>
<td>Harry Lee James, Mississippi DOT, PO Box 1850, Jackson, MS 39215-1850, 601.359.7200 (Retired)</td>
<td>Determining Unknown Lengths of Existing Bridge Piles</td>
<td>100</td>
<td>N/A</td>
<td>N/A</td>
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<td>North Carolina</td>
<td>NCDOT</td>
<td>2003 - 2011</td>
<td>David Henderson, NCDOT, 919.250.4100 (Retired)</td>
<td>Determining the Lengths of Installed Bridge Piles Beneath NCDOT Bridges for the NCDOT Hydraulics Division Using Dispersive Wave Propagation</td>
<td>350</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Oregon</td>
<td>ODOT</td>
<td>2011-12</td>
<td>Jan Six, ODOT, 4040 Fairview Industrial Drive, SE, MS#4, Salem, OR 97301</td>
<td>Nondestructive Testing for Bridge Foundations</td>
<td>66</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>South Carolina</td>
<td>SCDOT</td>
<td>2009-2013</td>
<td>Richard &quot;Lee&quot; Floyd, PE, SCDOT Bridge Maintenance Engineer, 955 Park Street, Room 324, Columbia, SC, 803.737.1290, <a href="mailto:floydrl@dot.state.sc.us">floydrl@dot.state.sc.us</a></td>
<td>Determining Unknown Lengths of Existing Bridge Piles</td>
<td>353</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>Alaska, Hawaii, Japan, Korea, CA, IL, NJ, SC</td>
<td>USACE</td>
<td>2009-2013</td>
<td>Phil W. Sauser, MVP, USACE--St. Paul District, 651.290.5722, <a href="mailto:phillip.w.sauser@usace.army.mil">phillip.w.sauser@usace.army.mil</a></td>
<td>Foundation Mapping, Scour Analysis, and NDT location of embedded rebar.</td>
<td>14</td>
<td>N/A</td>
<td>16</td>
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</tbody>
</table>

**Totals**: 3712 2081 554