Foundation Testing Program for the US-378 Bridge over the Great Pee Dee River

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ACKNOWLEDGMENTS

• OWNER - SCDOT (Berner Amado, Jeff Sizemore)

• Bridge Designer & Geotechnical Engineer – Florence & Hutcheson (now ICA)

• Load Test Design, Testing & Analyses – S&ME, Dan Brown

• Statnamic Testing – Applied Foundation Testing

• Lee Construction - GC
US 378 over the Great Pee Dee

- 4032 ft long (river & floodplain)
- 26-foot roadway
- High volume of traffic
- Long detour if it were to close
- Top 10 on SCDOT priority list for replacement
Proposed Replacement Bridge

- 4'-0" Diameter Columns
- 6'-6" Diameter Drilled Shafts
Advantages of Cylinder Piles

- Pile Replaces the Shaft and Column
- Cylinder pile alternate could provide competition for drilled shafts
- GCs could self-perform
Disadvantages of Cylinder Piles

- Poor/No history in South Carolina
- Unknowns associated with installation and capacity
- Possible detrimental effects on existing bridge due to driving large piles
- Availability of hammers to install cylinder piles
Design-Phase Test Program

Objective - Develop Information Necessary for Drilled Shaft and Concrete Cylinder Pile Alternates

1. Cylinder pile installation & driveability
2. Cylinder pile design values
3. Effects of pile installation on existing bridge
4. Reduce uncertainties at bidding
5. Obtain knowledge for use of cylinder piles on this and other SCDOT projects
6. Drilled shaft axial design values
Subsurface Conditions

1. **Overburden (El +24 to -14)**
   Very loose to loose sand, liquefiable or scoured away

2. **Calcareous Sand (El -14 to -47)**
   Fine to coarse, loose to dense, variable cementation, appreciable fines, occasional hard lenses

3. **Pee Dee Formation (El -47 to ?)**
   Med dense to dense or hard to v. hard, calcareous fine clayey sand or sandy clay, occasional hard lenses
Subsurface Conditions

**Simplified Subsurface Profile**

- Mostly loose to medium dense sand; N values of 5 to 17
- Calcareous Sand: loose to medium dense, with cemented lenses, N Values of 6 to 14
- Pee Dee Formation: N values of 40 to 50+

**Graphs**

- Depth (ft) vs. Tip Resistance $q_t$ (tsf)
- Depth (ft) vs. Sleeve Friction $f_s$ (tsf)
- Depth (ft) vs. Pore Pressure $u_p$ (tsf)
- Depth (ft) vs. Friction Ratio $R_f$ (%)
Possible Cylinder Pile Behavior

Closed-ended (plugged)  Open-ended  Rising head?
Test Elements

• 60-inch diameter drilled shaft (90 feet long)
  – Smaller than production shafts
  – Reduced testing requirements

• Two 54-inch PSC cylinder piles (90 feet long)
  – One with CIP concrete filling ("Pile B")
  – One without concrete filling ("Pile A")

• 18-inch PSC square pile (30 feet long)
  – "Proxy" pile for existing bridge
  – Installed prior to cylinder pile
Planned Testing

- Statnamic Load Testing
  - Drilled Shaft
  - Both Cylinder Piles

- Static Testing of Pile A
  - Comparison of Static and Statnamic Tests (soil plug)
  - Could be eliminated from contract

- Dynamic (PDA) Testing of Cylinder Piles
  - Installation
  - Re-Strikes
Instrumentation Plan

**Legend**
- 🍥 Survey Hub
- 🛠️ Vibration Monitor
- 🔛 Piezometer
- 🔥 Cone Penetrometer Sounding

**Scale in Feet**

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18" Square Pile

Drilled Shaft

Pile A

Pile B

VM8396

VM BM

C-2

H-1

B-1

B-2

B-3

H-2

H-3

H-4

H-5

H-6

H-7

H-8

H-9

H-10

H-11

83' from Pile A
Instrumentation
Instrumentation and Testing
Embedded VWPs
Pile Installation

• Pre-drilled to 40 ft (to reduce template requirements)
Pile Hammer

- APE 400u hydraulic hammer (400 ft-kips)
- Ram wt = 80 kips, Max Stroke = 5 ft
Driving Logs

Simplified Driving Log - Pile A

Simplified Driving Log - Pile B

Top Spalling
Hammer Alignment

Hammer “scars”
Consequences of Hammer Misalignment
Pile Plug Behavior

Distance from Ground Surface to Soil

Plug (ft)

Pile Penetration (ft)

36.5 42 49 51 55 81.5

-35 -30 -25 -20 -15 -10 -5 0

-35 -30 -25 -20 -15 -10 -5 0

-30 -20 -10 0

-25 -15 0

-30 -20 -10 0

-35

S&ME
No activity on Pile A

Pile A Installation

VWP Data – Pile A Embedded
VWP Data – Pile A Ground

1. Before restriking Pile A
2. After hammer placed on Pile A
3. Driving began
4. Driving halted
5. Driving resumed with 2 ft stroke
6. Driving halted again
7. Driving resumed with 30 in. stroke
8. Driving halted again
9. Driving resumed with 30 in. stroke
10. Driving halted again
11. Driving resumed with 30 in. stroke
12. Driving halted again
13. Driving resumed with 32 in. stroke
Statnamic Testing
## Unit Design Values and Capacity Comparison

**Simplified Subsurface Profile**

- **Cylinder Pile:**
  - Mostly loose to medium dense sand; N values of 5 to 17
  - Calcareous Sand: loose to medium dense, with cemented lenses, N Values of 6 to 14
  - Pee Dee Formation: N values of 40 to 50+

### Computed Unit Side Shear (ksf)

<table>
<thead>
<tr>
<th>Depth (ft)</th>
<th>Statnamic Testing</th>
<th>PDA</th>
<th>PDA</th>
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<tr>
<td></td>
<td>Pile A</td>
<td>Pile B</td>
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</table>

**Unit End Bearing (ksf):**

- 64
- 40
- 203
- 103

**Ultimate Capacity (kips):**

- 2800
- 2500
- 2200
- 2750
Vibration Monitoring

Graph showing PPV (in./sec) vs Frequency (Hz) with various data points and a threshold line for AASHTO/USBM threshold for cosmetic damage in buildings.
Test Program Outcome

Drilled Shaft – Performance as expected

Cylinder Piles - Pro:

• Successful installation
• Adequate capacity
• No settlement on proxy pile or hubs
• Vibrations generally below very conservative limits
Outcome – Cont.

Cylinder Pile - Con:
• Existing bridge in very poor condition with heavy traffic
• Cylinder pile locations would actually be within several feet of existing piles, not 8’ as expected
• Hammer selection would be critical (but limited supply of suitable hammers)
• Uncertainty about pre-drill requirements
• Uncertainty about monitoring requirements for existing bridge

**Cylinder Pile Option Not Bid**
Thank You!

???
Planned Monitoring

- Monitoring of Earth-Borne Vibrations During Pile Driving

- Settlement Monitoring of Ground Surface

- Monitoring Pore Pressures in Surrounding Soil
  - Before, during, after pile installation
  - Piezometers in soil and embedded in piles

- Monitoring Proxy Pile
  - Settlement monitoring
  - Re-strikes before/after cylinder pile installation
Soil Plug Accelerometer
Post Installation Testing
Properties of the Pee Dee Formation

- Classifies as a Clayey Sand (SC)
- Fines Content of 40% to 45%
- PI of 17 (clay-like behavior)
- OCR of about 5 (cementation)
- $S_u$ of 3 to 4 ksf per UU testing
- $\Phi'$ of 45° per CU testing