Design and Installation of Micropile Foundations for a Bridge in Karst Topography

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Presentation Overview

• Project Location
• Karst
• Geotechnical Explorations
• Foundations Type Selection Considerations
• Design and Construction Considerations
  • Lateral Loading
  • LRFD
  • Installation and Testing
• Construction and Observations
• Load Testing
• Concluding Comments
Route 340 Project Location/Geology Map

Physiographic Map of Virginia
1999
C. M. Bailey, College of William & Mary

Appalachian Plateau province
AP- Rugged, well dissected landscape with dendritic drainage pattern. Elevation 1000-1500', with High Knob rising to over 4000'.

Valley & Ridge province
RV- Ridge & Valley subprovince: long linear ridges separated by linear valleys with traits drainage pattern. Elevation: 1000-4500'.
GV- Great Valley subprovince: broad valley with low to moderate slopes underlain by carbonate rocks. Elevation: 500-1500' north of Roanoke, 1500-2300' south of Roanoke.
M- Massanutten Mountains: Series of long linear ridges that rise to 3000' above the Great Valley.

Blue Ridge province
nBR- northern Blue Ridge subprovince: rugged region with steep slopes, narrow ridges, broad mountains, and high relief. Elevation 1500-4500'.
sBR- southern Blue Ridge subprovince: broad upland plateau with moderate slopes. Elevation 2400'-3000' with higher peaks rising above upland, including 5729' Mt. Rogers.

Piedmont province
F- Foothills subprovince: region with broad rolling hills and moderate slopes. Elevation 400-1000' with peaks rising to 1500'-2500'.
ML- Mesozoic Lowlands subprovince: region with modest relief and low slopes underlain by Mesozoic sedimentary and igneous rocks. Elevation 200-400'.
OP- Outer Piedmont subprovince: broad upland with low to moderate slopes. Elevation 600-1000' west, gradually diminishing to 200' in east.

Coastal Plain province
CU- Upland subprovince: broad upland with low slopes and gentle drainage patterns. Elevation 400-900'.
CL- Lowland subprovince: flat, low-relief region along major rivers and near the Chesapeake Bay. Elevation 0-60'.
BM- Barrier Islands & Salt Marshes: low, open areas covered with vegetation and sediment in direct proximity to the Chesapeake Bay and Atlantic Ocean. Elevation 0-15'.

Project
This is Karst!

Project Site Geology
• Highly Soluble, Carbonate, Sedimentary Rocks (Beekmantown Group)
# Boring Logs – Abutment A

<table>
<thead>
<tr>
<th>Station</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>559.35</td>
<td>20 LT</td>
</tr>
<tr>
<td>559.35</td>
<td>20 RT</td>
</tr>
<tr>
<td>559.31</td>
<td>20 RT</td>
</tr>
<tr>
<td>559.35</td>
<td>20 LT</td>
</tr>
</tbody>
</table>

Diagram showing boring logs at different stations and depths, labeled 'Abutment A'.
Boring Logs – Pier 2
Boring Logs – Abutment B
Foundation Type Selection Considerations

- Variable Conditions (i.e.; erratic and intermittent quality of rock; soil layers and infilling; possible voids)
- Verification of Support Conditions;
- Design for Axial Loads;
- Design for Lateral Loads;
- Settlement and Possible NSF at Abutment Fills

Driven Piles, Drilled Shafts and Micropiles Considered
- Micropiles Selected
Possible Applications of Micropiles

- Restricted Access/Headroom or A Remote Area;
- Support System Close to Existing Structure;
- Supplemental Support For An Existing Structure (e.g. Settlement Control);
- **Difficult Ground Conditions** (e.g., karst, mines, boulders, uncontrolled fill);
- Risk of Liquefaction From Pile Driving;
- Need To Minimize Vibration And/Or Noise;
- Need To Reduce Or Eliminate Spoil At Hazardous Or Contaminated Sites
- As Alternate Deep Foundation Type, Especially Where Piles Penetrate Rock;
- Where Spread Footings Are Feasible but There Is Potential For Erosion or Scour

Ref: FHWA-NHI-05-039
Micropiles in Karst

- Other Experiences and Published Resources
**Micropile Construction in Karst Terrain**

- Drill cased hole through soil, boulders and voids;
- Drill through full bond zone to verify conditions;
- No open hole drilling – Drill casing through bond zone;
  
  (Use rotary percussive, eccentric duplex method)
- Monitor drilling rates and use to verify bond zone;
- Water testing and seal grouting.
  
  (in highly broken/fractured rock or voided karstic rock)
Design and Construction Considerations

- Bond Zone Design (Nominal & Factored Resistance)
- Provide Preliminary Micropile Design
- Structural Design of Micropiles
- Design for NSF Loads at Abutments
- Design for Possible Void (20' Unsupported Length)
- Specifications for Construction
  - Experience of Specialty Contractor and Personnel
  - Drilling Methods
  - Allow Alternate Designs
  - Installation Plan including MP Documentation
  - Load Testing (Verification and Proof Load Tests)
Micropiles at Abutments

Micropile Grouted Inside Vertical 16-inch OD Casings for Lateral Load Design
Alternate Micropile Positions, If Needed

Micropiles at Piers
Abutments

Casing OD 7"x 0.453" Wall N80 Grade

Piers

Bottom of Pile Cap

Casing Plunge Length 2'

Grout, fc = 5 ksi

Alternate Micropile Design
## Micropile Axial Load Design (LRFD)

<table>
<thead>
<tr>
<th>Foundation</th>
<th>Design Case</th>
<th>Factored Design Load</th>
<th>Nominal Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>Compression</strong></td>
<td></td>
</tr>
<tr>
<td>Abutments</td>
<td>I</td>
<td>295k</td>
<td>536k</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>170k</td>
<td>309k</td>
</tr>
<tr>
<td>Piers</td>
<td>III</td>
<td>392k</td>
<td>713k</td>
</tr>
<tr>
<td></td>
<td>Tension Load – 0 kips</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Grout-to-Ground** $\alpha_{Bond}$, **Nominal Resistance** = 19.2ksf [135psi]

**Resistance Factor (RF) = 0.55**

**Design Case - Refers to Pile Locations in Foundation**
Micropile Installation and Testing
Numa T-150 Eccentric Percussive Drill Bit

- OD Casing = 7.000"
- ID Casing = 6.094"
- D Retracted Bit = 5.905"
- D Expanded Bit = 7.750"
- D Hole min = 7.750"
Pier 2 MP Installation
Communication During Drilling
Example
Micropile Log

Abutment B - Pile 14
- Drilling
- Initial Grouting
Example Micropile Log

Abutment B - Pile 14
- Re-Drilling
- Re-Grouting

<table>
<thead>
<tr>
<th>SOIL / ROCK DESCRIPTION</th>
<th>COMMENTS / DIFFICULTIES</th>
<th>TIME</th>
<th>FROM</th>
<th>TO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grout</td>
<td>Redrill</td>
<td>1:45</td>
<td>JULU</td>
<td>JULU</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2:26</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rock Socket Time Start:

Rock Socket Time Stop:

**GROUTING INFORMATION**

<table>
<thead>
<tr>
<th>DATE GROUTED</th>
<th>10/4/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUT TAKEN</td>
<td>228.7 gallons</td>
</tr>
</tbody>
</table>

**MATERIALS USED / COMMENTS**

<table>
<thead>
<tr>
<th>DATE GROUTED</th>
<th>10/4/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUT TYPE</td>
<td>CENTRAL REINFORCEMENT: 25' #8 bar</td>
</tr>
</tbody>
</table>

**GROUT COMMENTS**

**GENERAL COMMENTS**

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DATE DRILLED: 10/14/2011
PROJECT #: 11-0203
DRILLER: G.B.

HOLE #: Abut. B - H14 REDRILL
TIME START: 1:45

DRILL RIG: MD 1
TIME STOP: 2:26

HOLE DIA.: 7.75"
FILE LENGTH (FROM CUTOFF): 103.00

DRILL EL.: 652.93
TIP EL.: 553.33
Abutment B-Pile 14

Penetration Rate (Ft/Min)

Depth (in Feet)

- Grout
- Rock Ledge
- Clay & Rock
- Rock Ledge
- Rock & Clay

Pile 14
Abutment B-Pile 34

Penetration Rate (Ft/Min)

Depth (in Feet)

- Grout
- Rock ledge
- Rock ledge
- Rock ledge
- Pile 34
Load Testing Arrangement
Verification Load Test – Pier 1

For 18’ x 7.75” Dia Bond Zone (No EB)
• 700k is 19.2 ksf [133 psi]
Verification Load Test (Supplemental) – Pier 1

Static Verification Test Results - Pier 1 - Supplemental Test to 910k

For 18’ x 7.75” Dia Bond Zone (No EB)
• 910k is 25.2 ksf [173 psi]
Verification Load Test – Pier 2

Static Verification Test Results - Pier 2

Verification Load Test – Pier 2
For LBZ 18’ x 7.75” Dia Bond Zone (No EB)
• 630k is 17.3 ksf [120 psi] < 700k

Proof Test – Pier 2 (w increased LBZ)
For 20’ x 7.75” Dia Bond Zone (No EB)
• 490k is 12.1 ksf [84 psi] < 700k

Modify MP Design at Pier 2
Use 9.625” OD Casing
10.4” Dia Bond Zone; 84 psi; LBZ = 22’

Increase bond zone length 10%...get a 20% reduction in capacity!
Schematic Sections with Micropile Bond Zones

Abutment A

Pier 1

NOTES:
- Bond zones are approximate
- Pile locations on section are not per plan

NOTES:
- Bond zones are approximate
- Pile locations on section are not per plan
Schematic Sections with Micropile Bond Zones

Pier 2

NOTE: Bond zones are approximate. Pile locations on section are not per plan.

Abutment B

NOTE: Bond zones are approximate. Pile locations on section are not per plan.
Alternate Load Testing Methods

[Review for Limitations]

GRL’s Apple

Birmingham hammer – AFT Statnamic
View from Abutment A – looking north.
View south, Pier 2, with Pier 1 in background.
Concluding Comments

• Design and construction in karst geology is uniquely challenging.
• Micropiles are a feasible deep foundation support elements in karst.
• Care must be taken to sufficiently characterize subsurface conditions during design and confirm during construction.
• Contract documents need to be developed to capture the design intent without being overly restrictive; karst demands the ability to adapt to erratic and varying conditions.
• Experience is essential.
Thank You

Questions?