Micropiles – An Overview

April 1, 2009

Presented by
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HDR Engineering, Inc
Presentation Objectives

- General Overview of Micropiles
  - FHWA-NHI-05-039  (December, 2005)  
    "Micropile Design and Construction";
  - AASHTO LRFD Bridge Design Specifications  
  - et al (ISM and other resources)

- Emphasis on Applications for Structure Foundations

- Project Example
Definition - Micropile

- A small diameter (typically < 12 inches) pile,
- drilled and grouted;
- non-displacement;
- typically reinforced
Historical Overview of Micropiles
(ref: FHWA NHI-05-039 and ISM)

Early 1950s Dr Fernando Lizzi-(Technical Director) Italian Specialty Contractor-Fondedile
- **palo radice** (root piles) --- for underpinning of historic structures/monuments
- **reticoli di pali radice** (reticulated root piles) --- three dimensional network

1960s Technology introduced in UK, Germany, etc.
1973 Introduced in US on underpinning projects

Mid 1980s – Systematic field testing by specialty contractors – still continuing
1992 First “FHWA-DOT-Industry” collaborative field test - San Francisco, CA
1996 - 2001 DFI Specifications
1997 - 2000 Seismic Research at Brooklyn
1997* IWM founded; JAMP (Japan) founded
2001 New Research at WSU, CSU, Cambridge University
2001* ADSC Involvement (IWM, FHWA, etc.)
2001* States Pooled Fund Project Commences
2002* ADSC Develops Teaching Course for FHWA
2002 - MICROFOR
2003 **FOREVER Project (Foundations Reinforcees Verticalement)**
2002 - ADSC IAF and Micropile Committee
2005 ISM (International Society for Micropiles) formed
2005 Publication No. FHWA NHI-05-039 (NHI Course No. 132078)
Micropile Classification System


- Design Behavior (Case 1 and Case 2)

- Method of Grouting (Type A, B, C, D, E)
  - Affects grout/bond capacity
  - Sub Classes based on drilling method and reinforcement type
Case 1 Micropiles

90% of International Applications
~ 100% of North American Applications

- Each Micropile is Loaded Directly

- Primary Resistance is Provided by Steel Reinforcement and Side Resistance over Bond Zone

- Each Micropile Designed to Act Individually, Even When in Groups
  - AASHTO – Minimum spacing of 30 inches or 3 pile diameters, whichever is greater
  - Must check for group affects due to axial compression/tension or lateral loads
Case 1 Micropiles (After FHWA NHI-05-039)
Case 2 Micropiles
Very Few Applications in the United States

- Network of Micropiles
- Act As Group to Reinforce The Soil Mass
- Each Micropile is Lightly Reinforced
- Design Procedures Not Fully Developed
Case 2 Micropiles (After FHWA NHI-05-039)
Micropile Types

- **Type A** – Neat cement or sand-cement grout placed under **gravity head** only;
- **Type B** – Neat cement grout injected into drill hole under **pressure** (72-145 psi), while withdrawing temporary drill casing or auger;
- **Type C** - (Two-step grouting process)
  - **Gravity grouting** (Type A),
  - Then after 15 to 25 minutes,
  - Secondary “Global” pressure grouting through sleeved grout pipe w/o packer (>145psi)
- **Type D** – (Two-step grouting process)
  - Similar to Type C, but,
  - Allow full hardening of initial, primary grout, then
  - Pressure grout through sleeved grout pipe w packer (290-1160psi)
  - One or more phases of secondary grouting in specific pile or material intervals,
- **Type E** – Drill and inject grout through continuously-threaded, hollow-core steel bar,
  - Initial grout has high w/c ratio, which is replaced with thicker structural grout (lower w/c ratio) near completion of drilling.
## Micropile Classification Based on Grouting

*(after Pearlman and Wolosick, 1992) – modified for presentation*

<table>
<thead>
<tr>
<th>Micropile Type [Grouting Method]</th>
<th>Sub Type</th>
<th>Drill Casing</th>
<th>Reinforcement</th>
<th>Grout</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type A</strong> [Gravity only]</td>
<td>A1</td>
<td>Temporary or unlined</td>
<td>None, single bar, cage, tube or structural section</td>
<td>Tremie sand/cement mortar, or neat cement grout to base of hole (or casing), no excess pressure</td>
</tr>
<tr>
<td></td>
<td>A2</td>
<td>Permanent, full length</td>
<td>Drill casing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>A3</td>
<td>Permanent, upper shaft only</td>
<td>Upper shaft -Drill casing Lower shaft (or full length)-bars, tube</td>
<td></td>
</tr>
<tr>
<td><strong>Type B</strong> [Pressure thru casing or auger during withdrawal]</td>
<td>B1</td>
<td>Temporary or unlined</td>
<td>Monobar(s) or tube (cages rare)</td>
<td>1. Tremie neat cement grout into drill casing/auger; 2. Apply excess pressure and inject grout during withdrawal of casing/auger</td>
</tr>
<tr>
<td></td>
<td>B2</td>
<td>Permanent, partial length</td>
<td>Drill casing</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B3</td>
<td>Permanent, upper shaft only</td>
<td>Upper shaft – Drill casing Lower shaft (or full length)-bars or tube</td>
<td></td>
</tr>
<tr>
<td><strong>Type C</strong> [Gravity then “global” pressure]</td>
<td>C1</td>
<td>Temporary or unlined</td>
<td>Single bars or tube (cages rare)</td>
<td>1. Tremie neat cement grout into hole (or casing/auger); 2. Wait 15-25 minutes then inject grout under excess pressure through tube (or reinforcing pipe) from head</td>
</tr>
<tr>
<td></td>
<td>C2</td>
<td>Not conducted</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3</td>
<td>Not Conducted</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td><strong>Type D</strong> [Per Type A or B, then one or more phases of “global” pressure]</td>
<td>D1</td>
<td>Temporary or unlined</td>
<td>Single bars or tube (cages rare)</td>
<td>1. Neat cement grout by tremie (Type A) or pressure (Type B) method into casing/auger; 2. Wait several hours then inject grout under pressure through sleeve pipe (or sleeved reinforcement) via packers multiple times as needed.</td>
</tr>
<tr>
<td></td>
<td>D2</td>
<td>Possible only if regrouting tube placed full-length outside casing</td>
<td>Drill casing itself</td>
<td></td>
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Micropile Classification Based on Grouting

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
Limitations for Micropiles

- Vertical micropiles may be limited in lateral capacity;
- Cost effectiveness;
- Potential buckling under seismic loading and liquefaction

But Need to Consider Methods Available to Quantify and/or Deal With These Limitations
Overview of Micropile Applications

Ref: FHWA NHI-05-39, Table 3-1

- **In-Situ Reinforcement**
  - [Case 1 and Case 2 Micropiles](Est 0-5% of world applications)
  - Slope Stabilization
  - Ground Strengthening [Case 1 and Case 2]
  - Settlement Reduction [Case 2]
  - Structural Stability [Case 2]

- **Structural Support**
  - [Case 1 Micropiles](Est 95% of world applications)
  - Earth Retaining Structure Foundations
  - Foundations For New Structures
  - Underpinning Existing Foundations
  - Seismic Retrofitting

- Scour Protection
- Repair/Replace Existing Foundations
- Stop/Prevent Movement
- Upgrade Foundation Capacity
Micropile Construction
Micropile Installation (After: FHWA NHI-05-039)
Drill Rigs

M-9

C-12

DK-50
Drilling Techniques
May Be Proprietary or Contractor-Developed

- Overburden
  - Single Tube Advancement
  - Rotary Duplex
  - Rotary Percussion Concentric Duplex
  - Rotary Percussion Eccentric Duplex
  - Double Head Duplex
  - Hollow Stem Auger
  - Sonic
Drilling Techniques
May Be Proprietary or Contractor-Developed

- Open Hole Drilling Techniques
  - Rotary Percussive
  - Solid Core Continuous Flight Auger
  - Underreaming ("Bells")
  - Hollow-Core Bar
Drilling Techniques
May be proprietary or contractor-developed

Duplex Casing and Roller Bit

Rotary Eccentric Percussive Duplex
Steel Reinforcement

- Single bar or group
  - Concrete reinforcing bars
    (Typically Grade 420, 520 or 550)
    \( F_y \) 60ksi, 75 ksi, 80 ksi;
    \( F_u \) 92ksi, 102ksi, 104ksi)
  - Diameters typically 1.0 to 2.5 inches
  - Can be with continuous full length thread
    (e.g. DSI or Williams)
  - Can be continuous full length thread
    Hollow-Core bars
    (Dwyidag, Ischebeck, Titan, MAI Int’l, Chance IBO )
Steel Reinforcement

- Steel casing or rolled shape
  - Flush Joint Threads
  - ASTM A53, A519, A252 and A106 (w/ F_y 36ksi)
  - API Grades (w/ F_y 80ksi) – More readily available;
  - Common sizes for ASTM A519, A106
    - OD  5.500-10.75 inches
    - T_wall  0.500-0.625 inches
  - Common Sizes for API N-80 sizes
    - OD  5.500-9.625 inches
    - T_wall  0.361-0.472 inch
Footing Connections
Compression

- Bearing Plate
- Steel Casing
- Bottom of Footing Elev.
Footing Connections
Compression
Footing Connections
Compression and Tension
Footing Connections
Compression and Tension

REINFORCING BAR W/NUT

BEARING PLATE AS REQUIRED

TOP OF EXISTING FOOTING

STEEL CASING

STEEL SHEAR RING (TYP)

OVERSIZED CORE HOLE (DIAMETER AS PER CONTRACT PLANS)

BOTTOM OF FOOTING ELEV.
Footing Connections
Compression and Tension
Footing Connections
Compression and Tension

- REINFORCING BAR
- BEARING PLATE AS REQUIRED
- ½ HEX NUT
- FULL HEX NUT
- NEW FOOTING
- BEARING PLATE (OPTIONAL)
- STEEL CASING
- BOTTOM OF FOOTING ELEV.
Grouting (Including Post-Grouting)
Methods Vary But Can Have Major Impact on Micropile Capacity

- **Purpose**
  - Transfer of load from reinforcement to surrounding ground;
  - Part of micropile load-bearing cross section;
  - Protect steel reinforcement
  - Extend the limits of the drill hole by permeation, densification and/or fissuring
Grouting (Including Post-Grouting)
Methods Vary But Can Have Major Impact on Micropile Capacity

- General characteristics
  - High strength and stability but pumpable;
  - Use potable water to reduce potential for corrosion;
  - Type I/II cement (ASTM C150/AASHTO M85) most common;
  - Neat water-cement grout mix most common;
  - Design compressive strengths of 4,000 to 5,000 psi possible with care;
  - Admixtures/additives used, must be compatible, one supplier only;
  - For Type E micropiles, use high w/c ratio grout for drilling then change to low w/c ratio for completion
Grouting (Including Post-Grouting)
Methods Vary But Can Have Major Impact on Micropile Capacity

“Most” Important Considerations

- Water/cement (w/c) ratio 0.40 to 0.50;
  - Pre-construction testing, specifications (grout QC plan), construction monitoring

- After completion of grouting, no significant loss of grout in load bearing zone;
  - Monitor grout take, grout to refusal, pre-grout, re-grout

- For Type B micropiles, consider possibility that target pressure may not be fully obtained during installation
  - Include verification load test program and proof testing of suspect piles in specifications
Grouting Equipment
Micropile Installation

Williamsburg Bridge

Seismic Retrofit
Foundation Arrangement
Composite Reinforced Micropile

After: FHWA NHI-05-039; Fig 5-1 (and AASHTO C10.9.1-1)
Design for Structure Foundations
Basic Design Process

Step 1 >>>Evaluate Feasibility and Requirements
Step 2 >>>Review available information and geotechnical data
Step 3 >>>Develop applicable load combinations
Step 4 >>>Prepare preliminary design
Step 5 >>>Prepare structural design of cased length
Step 6 >>>Prepare structural design of uncased length
Step 7 >>>Revise preliminary design, as necessary
Step 8 >>>Evaluate geotechnical capacity
Step 9 >>>Estimate group settlement
Step 10 >>Design cap connections
Step 11 >>Develop Load Test Program
Step 12 >>Prepare Drawings and Specifications
Basic Design Process

Step 1 >>> Evaluate Feasibility and Requirements
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Step 12 >> Prepare Drawings and Specifications
Step 4 >>> Prepare Preliminary Design

- **Select Micropile Spacing**
  - Min 30 inches or 3 diameters, whichever is greater
  - Based on situation (e.g., existing footing, clearances, etc)
  - Allow Contractor alternate for number of piles and capacities

- **Select Micropile Length**
  - Based on geotechnical capacity (side resistance) in bond zone
  - Consider compression, uplift, lateral loads, scour, downdrag, group affects
  - Max length using common track-drilling equipment is > 300 feet
    but most are on order of 100 feet
Step 4 >>> Prepare Preliminary Design

- **Select Micropile Cross Section**
  - Allow use of common US casing sizes (OD) for material availability;
  - Better with less, larger capacity vs more, lower capacity micropiles;
  - Use casing vs rebar reinforcement >>better lateral and axial capacity

- **Select Micropile Type (Type A, B, C, D, E)**
  - Should be left to Contractor but require information on proposed method;
  - Owner may disallow certain Types based on site constraints;
  - Owner should provide specific performance criteria in bid package
Basic Design Process

Step 1 >>> Evaluate Feasibility and Requirements
Step 2 >>> Review available information and geotechnical data
Step 3 >>> Develop applicable load combinations
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**Step 8 >>> Evaluate geotechnical capacity**
Step 9 >>> Estimate group settlement
Step 10 >>> Design cap connections
Step 11 >>> Develop Load Test Program
Step 12 >>> Prepare Drawings and Specifications
Step 8 >> Evaluate Geotechnical Capacity

- Establish Stratum for Bond Zone
  - Certain soils not generally suitable (e.g., organics, cohesive soils with LL>50, PI>20); (if must be used, include comprehensive testing, increased FS)

- Select Ultimate Bond Strength ($\alpha_{\text{bond}}$) and Compute Bond Zone Length ($L_b$)
  - $P_{G,\text{Allowable}} = P_{\text{Ultimate}} / FS = 1/FS (q_p A_p) + 1/FS (\alpha_{\text{bond}} \pi D_b L_b)$
  - $R_R = \phi R_n = \phi_{qp} R_p + \phi_{qs} R_s = \phi_{qp} (q_p A_p) + \phi_{qs} (\pi d_s \alpha_{b} L_b)$
  - Consider end bearing in high quality rock only with adequate verification of rock quality and construction methods to obtain good contact;
  - Provide minimum bond length in contract documents;
  - Assume Type A for bond zone in rock and Type B for bond zone in soil;
<table>
<thead>
<tr>
<th>Soil/Rock Type</th>
<th>Grout-to-Ground Bond Ult. Strength/Nominal Resistance, ksf (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type A</td>
</tr>
<tr>
<td>Silt &amp; Clay (some sand)</td>
<td>0.7-1.4 (5-10)</td>
</tr>
<tr>
<td>(soil, medium plastic)</td>
<td></td>
</tr>
<tr>
<td>Silt &amp; Clay (some sand)</td>
<td>0.7-2.5 (5-17)</td>
</tr>
<tr>
<td>(stiff, hard to very hard)</td>
<td></td>
</tr>
<tr>
<td>Sand (some silt)</td>
<td>1.4-3.0 (10-21)</td>
</tr>
<tr>
<td>(fine, loose-medium dense)</td>
<td></td>
</tr>
<tr>
<td>Sand (some silt, gravel)</td>
<td>2.0-4.5 (14-31)</td>
</tr>
<tr>
<td>(fine-coarse, medium-very dense)</td>
<td></td>
</tr>
<tr>
<td>Gravel (some sand)</td>
<td>2.0-5.5 (14-38)</td>
</tr>
<tr>
<td>(medium-very dense)</td>
<td></td>
</tr>
<tr>
<td>Glacial Till (silt, sand, gravel)</td>
<td>2.0-4.0 (14-28)</td>
</tr>
<tr>
<td>Medium-very dense, cemented)</td>
<td></td>
</tr>
<tr>
<td>Soft Shale (fresh-moderate fracturing, little or no weathering)</td>
<td>4.3-11.5 (30-80)</td>
</tr>
<tr>
<td>Slate to Hard Shale (fresh-moderate fracturing, little to no weathering)</td>
<td>10.8-28.8 (75-200)</td>
</tr>
<tr>
<td>Limestone (fresh-moderate fracturing, little or no weathering)</td>
<td>21.6-43.2 (150-300)</td>
</tr>
<tr>
<td>Sandstone (fresh-moderate fracturing, little or no weathering)</td>
<td>10.8-36.0 (75-250)</td>
</tr>
<tr>
<td>Granite and Basalt (fresh-moderate fracturing, little or no weathering)</td>
<td>28.8-87.7 (200-609)</td>
</tr>
</tbody>
</table>

Ref: FHWA NHI-05-039 & AASHTO LRFD 4th Ed 2007, Interim 2008 Table C10.9.3.5.2-1
Step 8 >> Evaluate Geotechnical Capacity

- Evaluate Micropile Group Compression Capacity
  - Cohesive or Cohesionless Soils (Block & Punching Failures)

- Evaluate Micropile Group Uplift Capacity
  - Cohesive or Cohesionless Soils (Block Failures)

- Evaluate Micropile Group Lateral Capacity
  - Refer to procedures for driven piles and drilled shafts (FHWA-NHI-05-42 and FHWA-IF-99-025; AASHTO LRFD Int 2008, Section 10.7)
  - Evaluate structural capacity of pile(s)
  - Evaluate Soil-Structure Interaction (e.g. LPILE)
  - Consider Battered Piles, Buckling and/or Seismic Effects
Other Design Considerations

- Corrosion
- Plunge Length \( (\text{See Section 5.15 and Fig 5-1}) \)
- Downdrag
- Design for Lateral Loading \( (\text{Single and Group}) \)
- Buckling \( (\text{e.g. Voids, Scour}) \)
- Seismic
Design for Lateral Loading

- Same Methods as Driven Piles and Shafts (e.g. LPILE)
- Evaluate Lateral Load Capacity at Threaded Casing Joints
- If Above Analysis Fails, Consider Additional Methods

Evaluate on a project by project basis:

- Install oversized casing in top section of pile;
- Construct a larger micropile diameter at top;
- Embed the pile cap deeper into ground surface to increase passive resistance;
- Batter some micropiles
Design for Seismic Loading

“…seismic response of pile foundation involves distribution of a set of superstructure loads into surrounding soil mass through [micro]pile members.”

- Subsurface conditions (e.g. soil stiffness, liquefaction potential);
- Stiffness of micropile system, including use of batter;
- Stiffness sharing with foundation cap and/or existing foundations (on retrofits) and superstructure;
Basic Design Process

Step 1 >>> Evaluate Feasibility and Requirements
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Step 11 >>> Develop Load Test Program
Step 12 >>> Prepare Drawings and Specifications
Step 11 >>> Develop Load Test Program

- Scope of Program
  - Include or not include??
  - Consistent with selected FS or φ for grout/ground bond strength in geotechnical capacity evaluations;
  - $FS_{\text{min}}$ for verification and proof testing is 2.0
  - $φ = Table\ 10.5.5.2.3-1\ (For\ Driven\ Piles)$ but no greater than 0.70
  - Max test load should not exceed 80% of ultimate structural capacity
Load Testing Program

- **“Verification” Load Testing on Pre-Production Piles**
  - Verifies design assumptions regarding bond zone strength/deformation (taken to design load x FS [1/ϕ] or can be taken to failure);
  - Verifies adequacy of Contractor’s installation methods;
  - May include creep tests, if conditions apply;
  - Performed prior to installation of production piles;
  - Authorization to proceed on production pile after successful verification tests;
  - May require modification of installation procedures if results unsuitable;
  - If installation procedures change, perform addition testing

- **“Proof” Load Testing on Selected Production Piles**
  - Provides QA to confirm installation procedures
  - Performed on specified number of pile
  - Confirm capacity of suspect piles
Load Testing Program

[Test Frequency]

- “Verification” Load Testing
  - Compression/Tension - Minimum one/project
  - Lateral Loads – If design requires

- “Proof” Load Testing
  - Underpinning >>>>>> 1 per substructure unit
  - Seismic Retrofit >>> 1 per substructure unit
  - New construction >>> 1 per substructure unit but not less than 5% of total production piles
QA/QC
Pre-Construction

- Contractor and Employee qualifications;
- Performance Criteria (location, orientation, size, cross section, capacity);
- Equipment List;
- Installation Plan;
- Grout Mix Design;
- Load Test Procedures including calibration information;
- Materials Disposal Plan;
- Remedial Action Plan for Problems
- Pre-Construction Meeting to Review Subsurface Conditions/Procedures/Installation Plan/etc.
QA – During Construction

Contractor Set Up

Drilling

Reinforcement

Grouting

Post Installation
Example Project
Birmingham Bridge
Retrofit for Capacity Improvement
Numa T-150 Eccentric Percussive Drill Bit

Open

Closed

OD_{Casing} = 7.625"
ID_{Casing} = 7.125"
D_{Expanded Bit} = 7.750"
D_{Hole max} = 8.125"
Installing Casing
Drill and Clean Out Casing
Flush the Hole Clean During Drilling

Cuttings from Rock Socket
Install Grout Tube
Installing Reinforcing Bar with Spaces

No 20 Continuously Threaded Bar
Type II Cement
Birmingham Bridge Subsurface Profile at Load Tested Micropile

**Case 1, Type A Micropile**

- **Ground surface**
- **Grout (Gravity)**
- **7-5/8" OD Casing**
  - 0.5" Thickness
  - $f_y = 80$ ksi
- **$L_p = 1'$ Casing plunge**
- **$L_b = 14'$**
- **$d_b = 6''$ (Grouted bond zone diameter)**

** Depths and Materials:**
- 740: Silty Sand & Gravel
- 720: Sand & Gravel w wood frags
- 700: Silty Sand & Gravel w wood frags
- 680: Gravel-size shale frags
- 660: Shale & Siltstone
- 640: Shale & Claystone
- 620: Claystone
- 600: Silty Sandstone
- 580: No 20 Bar
DL = 287 kips (Max Service Load)

\[ 2DL = 574 \text{ kips} \]

\[ X_{\text{Davisson}} \text{ (in feet)} = 0.0125 + \frac{D}{120} = 0.20 \text{ inch} \]
## Typical Ultimate $\alpha_{\text{bond}}$ Micropile Design Values

For Preliminary Design

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Ref: FHWA NHI-05-039 & AASHTO LRFD 4th Ed 2007, Interim 2008 Table C10.9.3.5.2-1
Birmingham Bridge Pier 10N Strengthening
Construction Drawing- Typical Details

Typical Details

- 10 spaces at 5'-3" = 52'-6"
- Existing Steel H-Pile Below (Typ)
- NEW Micropile (Typ)
- Existing Crashwall To Remain

Pile Plan

1'-6"
1'-6"

1'-6"
1'-6"

1'-6"
1'-6"

4'-1 1/2"
4'-1 1/2"

4'-1 1/2"
4'-1 1/2"

60'-9"

15'-0"

2'-6"
2'-6"

5'-0"
5'-0"

5'-0"
5'-0"

1'-6"
1'-6"

11 spaces at 5'-3" = 57'-9"

4" = 1'-0"

1/8" = 1'-0"
Birmingham Bridge Pier 10N Strengthening
Construction Drawing - Typical Details

ELEVATION
MICROPILE DETAILS
NOT TO SCALE

SECTION E-E

SECTION F-F
Birmingham Bridge Pier 10N Strengthening Construction Drawing- Typical Details

FOUNDATION NOTES:

1. USE MICROPILE FOUNDATIONS AT PIER 10N.
   THE PROPOSED BOTTOM OF PILE CAP (P.C.E.) AND ESTIMATED TIP ELEVATIONS ARE:

<table>
<thead>
<tr>
<th>SUBSTRUCTURE</th>
<th>P.C.E. (FEET)</th>
<th>FOUNDATION TYPE</th>
<th>ESTIMATED MICROPILE/PILE TIP ELEVATION (FEET)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIER 10N</td>
<td>735.0</td>
<td>MICROPILES</td>
<td>651.0</td>
</tr>
</tbody>
</table>

2. USE A 6-INCH (MINIMUM) DIAMETER ROCK SOCKET FOR MICROPILES AT PIER 10N. ENCASE THE MICROPILES IN A 7 5/8-INCH MINIMUM OUTSIDE DIAMETER STEEL CASING WITH A 1/2-INCH MINIMUM WALL THICKNESS. PROVIDE A 14-FOOT MINIMUM ROCK SOCKET LENGTH. REFER TO THE MICROPILE DETAILS AND THE SPECIAL PROVISIONS FOR ADDITIONAL INFORMATION. USE 0.09 KSI FOR FACTORED GROUT-TO-GROUND BOND STRENGTH FOR MEDIUM HARD, GRAY SILTSTONE AND SANDSTONE. USE VERTICAL MICROPILES TO PROVIDE LATERAL RESISTANCE.

3. BASED ON RECENT BORINGS, BEDROCK IS ANTICIPATED TO BE ENCOUNTERED AT EL 680. THIS MATERIAL IS ANTICIPATED TO CONSIST OF SOFT, RED TO REDDISH BROWN CLAYSTONE TO APPROXIMATELY EL 665.0. THE BEDROCK ENCOUNTERED BELOW EL 665.0 IS ANTICIPATED TO CONSIST OF MEDIUM HARD, GRAY SILTSTONE AND SANDSTONE. THE MICROPILE BOND ZONE IS LOCATED BELOW EL 665.0. THE ANTICIPATED CONDITIONS IN THE BOND ZONE SHOULD BE VERIFIED DURING DRILLING BY REVIEWING CUTTINGS AND DRILLING RATES.

4. THE CONTRACTOR IS PERMITTED TO SUBMIT AN ALTERNATE MICROPILE DESIGN FOR THE FOUNDATION AT PIER 10N. FOOTING DIMENSIONS AND NUMBER AND SPACING OF MICROPILES ARE NOT PERMITTED TO BE MODIFIED. MICROPILE LOAD TESTS ARE REQUIRED IF THE ALTERNATE MICROPILE DESIGN PROPOSES USING A RESISTANCE FACTOR OF 0.80 FOR THE GROUT-TO-GROUND BOND STRENGTH. REQUIRED MICROPILE TESTING WILL BE INCIDENTAL TO ITEM 9100-0002. REFER TO THE SPECIAL PROVISIONS FOR ADDITIONAL INFORMATION.
**Birmingham Bridge Pier 10N Strengthening Construction Drawing – Typical Details**

<table>
<thead>
<tr>
<th>FOUNDATION PARAMETERS (KIPS)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STATIC LOADS (KIPS)</strong></td>
</tr>
<tr>
<td>AXIAL PILE COMPRESSION RESISTANCE = 380.0</td>
</tr>
<tr>
<td>MAXIMUM DESIGN AXIAL PILE LOAD = 365.3</td>
</tr>
<tr>
<td>PILE UPLIFT RESISTANCE * = 0</td>
</tr>
<tr>
<td>MINIMUM DESIGN AXIAL PILE LOAD * = 0</td>
</tr>
<tr>
<td>PILE LATERAL RESISTANCE = 8.2</td>
</tr>
<tr>
<td>MAXIMUM DESIGN LATERAL PILE LOAD = 8.2</td>
</tr>
<tr>
<td>MAXIMUM SERVICE AXIAL PILE LOAD = 286.9</td>
</tr>
</tbody>
</table>

*SEE DESIGN CALCULATIONS FOR DETERMINATION OF UPLIFT FORCE SHOWN.*

**Design Notes:**
- Design Bond Zone Nominal Resistance, ($\dot{a}_b$) = 150 psi
- Bond Zone Nominal Resistance, ($R_s$) = 475 kips
- Maximum Unfactored Axial Load, = 287 kips
- Load Test to Minimum 2.0 Maximum Unfactored Axial Load = 574 kips
- Factored Axial Pile Compression Resistance, ($\phi q_s R_s$) w/ $\phi q_s = 0.8$ = 380 kips
Thanks to the following for selected photos used:

(ISM) International Society of Micropiles
Mary Ellen Bruce, Executive Director
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- info@ismicropiles.org

Tom Richards - Nicholson Construction Company
Questions?