Emergency Micropile Repair of the Birmingham Bridge

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Outline

- Introduction
- Development of Constructible Solutions
- Design of Micropile Retrofit
- Load Testing Program
- Micropile Construction
- Detailed Analysis of Load Tests
Introduction

- Birmingham Bridge is critical link in Pittsburgh area transportation system, built in early 1970s
- Pier 10S dropped 200 mm on 2/8/2008
  - Bearings over-rotated, pier columns cracked
  - Emergency shoring operation
Likely causes of failure:

- Sudden punching failure of driven H-pile foundation
- H-piles not bearing in sound rock as intended
  - Soft, broken “Red-Bed” claystone
  - Induction field (IF) testing
- Factor of safety ≈ 1.0
Development of Constructible Solutions

- Complicated work zone geometry, 4.9 m clear space, 17 m vertical

- Construction techniques considered
  - 33 Micropiles with new below grade cap
  - 4 Drilled shafts through existing cap
  - 33 Micropiles with at-grade cap
    - Selected to eliminate impact on shoring towers
    - Ability to drill through existing concrete cap
Development of Constructible Solutions

- **LRFD Loads at top of new pile cap**

<table>
<thead>
<tr>
<th></th>
<th>Strength III and I</th>
<th>Service I</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Maximum</td>
</tr>
<tr>
<td>Axial Load (MN)</td>
<td>19.8</td>
<td>32.5</td>
</tr>
<tr>
<td>Transverse Moment (MN-m)</td>
<td>0.8</td>
<td>7.9</td>
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<tr>
<td>Longitudinal Moment (MN-m)</td>
<td>0.4</td>
<td>8.4</td>
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<tr>
<td>Transverse Shear (kN)</td>
<td>89.0</td>
<td>996.4</td>
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<tr>
<td>Longitudinal Shear (kN)</td>
<td>35.6</td>
<td>391.4</td>
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</tbody>
</table>

- **LRFD Loads for each of 33 new micropiles**

<table>
<thead>
<tr>
<th>Static Load</th>
<th>Load Group</th>
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</thead>
<tbody>
<tr>
<td>Axial Compression Resistance (kN)</td>
<td>1355</td>
</tr>
<tr>
<td>Max. Design Pile Axial Load (kN)</td>
<td>1196</td>
</tr>
<tr>
<td>Axial Uplift Resistance (kN)</td>
<td>0</td>
</tr>
<tr>
<td>Max. Design Axial Uplift Load (kN)</td>
<td>7</td>
</tr>
<tr>
<td>Pile Lateral Resistance (kN)</td>
<td>33</td>
</tr>
<tr>
<td>Max. Design Pile Lateral Load (kN)</td>
<td>33</td>
</tr>
</tbody>
</table>
Development of Constructible Solutions

- Desired micropile section for rapid procurement and construction
  - Cased length to rock, 194 mm OD
  - Rock socket in competent rock at or below Elev. 203
  - Reinforcement designed for compression loading

[Diagram showing micropile specifications: 229 mm Sq. Bearing Plate, Neat Cement Grout with $f'_c = 27.6$ MPa, 194 mm OD Wall Casing, 63 mm Gr. 552 Reinforcing Bar, 152 mm Dia. Rock Socket (197 mm As-Built Dia.).]
LRFD Design of Micropiles - Structural

- PennDOT design specifications
  - Cased Length to Rock

\[ R_{cc} = \phi_{cc} R_n = \phi_{cc} \left[ 0.85 f'_c A_g + F_{yc} A_c \right] \]
\[ R_{cc} = 0.65 \left[ 0.85(27.6MPa)(0.0192m^2) + (552MPa)(0.00723m^2) \right] \]
\[ R_{cc} = 2.89MN = 2,890kN >> 1,196kN \]

- Bond Zone/Rock Socket

\[ R_{cu} = \phi_{cu} R_n = \phi_{cu} \left[ 0.85 f'_c A_g + F_{yb} A_b \right] \]
\[ R_{cc} = 0.65 \left[ 0.85(27.6MPa)(0.0151m^2) + (552MPa)(0.00317m^2) \right] \]
\[ R_{cc} = 1.37MN = 1,370kN > 1,196kN \]
- Expected ult. bond shear stress $\alpha_b$ 520-1,380 kPa, 1,034 kPa chosen for design
- Calculate required bond length for 152 mm min. diameter
- PennDOT design specifications

$$Q_r = \phi_s Q_s = \phi_s \pi d_b \alpha_b L_b = (0.60 \text{ to } 0.80)(\pi)(0.152\text{m})(1,034\text{kPa})(L_b)$$

- Required rock socket length 3.4 to 4.6 m depending on $\phi$, design length of 4.27 m chosen
An Unexpected Problem at Pier 10N

- Bearing over-rotation
- No obvious damage to pier column or substructure
- Existing crash wall to be left in place
- 22 new micropiles designed and specified with greater strength limit design resistance
  - Re-ran load test to higher test loads
Load Test – Construction of Test Pile

- Sacrificial test pile and anchors
- Test pile installed using concentric overburden system
  - Rock socket diameter incr. to 197 mm
  - Cased length 22.8 m, 4.9 m bond length
Compression Load Test – Part I

- Cyclic load test
- “Design” load taken to be 890 kN, test load 1780 kN
- Acceptable settlements observed
  - 11.4 mm at DL
  - 28.6 mm at TL
  - 2.5 mm at AL (residual)
Compression Load Test – Part II

- Re-test of original test pile to substantiate higher design load of 1,280 kN for Pier 10N with intention to test to failure
  - Max. test load 3,180 kN
  - Total settlement 18 mm at DL, 54 mm at TL, approx. 3 mm residual.
Production Micropile Construction

- Began work at Pier 10S pre-drilling through existing pile cap
  - DTHHs, overburden systems
  - Only single layer of reinforcement at cap bottom
- Average total pile length of 25.6 m
Production Micropile Construction

Existing cap and crash wall outline
Production Micropile Construction-Connections

- Pier 10S ➔ conventional bearing plate connections

- Pier 10N ➔ Need to tie micropiles into existing cap and crash wall with post-tensioning bars
Pile Performance Evaluation

- Cyclic load tests offer opportunity to examine pseudo-elastic behaviors
  - Separated elastic and residual displacement
  - Apparent elastic length of total pile and in rock socket
  - Incremental load transfer behavior
Pile Performance Evaluation

- Total elastic length calculated using net applied load, assumed constant $E_pA_p$
- Decomposition possible to separate rock socket behavior

![Graphs showing the development of total apparent elastic length $L_e$ and apparent elastic length $L_{er}$ in the rock socket.](image-url)
Pile Performance Evaluation

- Apparent elastic length data can be used to estimate mobilized uniform bond stress within rock socket.
- Note that $L_e$ did not approach cased pile length until net load of 844 kN applied.
- Very significant load was transferred from casing to surrounding soils (up to $\frac{1}{4}$).

<table>
<thead>
<tr>
<th>Load Cycle</th>
<th>Net Pile Top Load (kN)</th>
<th>Net Load at Top of Socket (kN)</th>
<th>Calc. $L_{es}$ (m)</th>
<th>Calc. LTR (kN/m)</th>
<th>Calc. Ave. $\tau_{mob}$ (kPa)</th>
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<tr>
<td>Initial</td>
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<td>1244.3</td>
<td>399.9</td>
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<td>1733.1</td>
<td>888.8</td>
<td>2.64</td>
<td>336</td>
<td>543</td>
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<td>Re-Test</td>
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<td>3116.4</td>
<td>2604.0</td>
<td>3.84</td>
<td>678</td>
<td>1095</td>
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</table>
Summary

- PennDOT’s willingness to engage with GC and specialty contractor for development of constructible solution was critical to success.

- Testing to structural limit of reaction frame and pile allowed for verification of much larger loads for addl. unanticipated condition at Pier 10N.

- Cyclic load testing, while not preferred over strain gauge usage, provided insights into nature of “elastic” behavior of pile sections and the resulting load transfer between pile and rock.
Acknowledgements

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QUESTIONS?