MORETRENCH

Emergency Micropile Repair of the Birmingham Bridge

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Outline

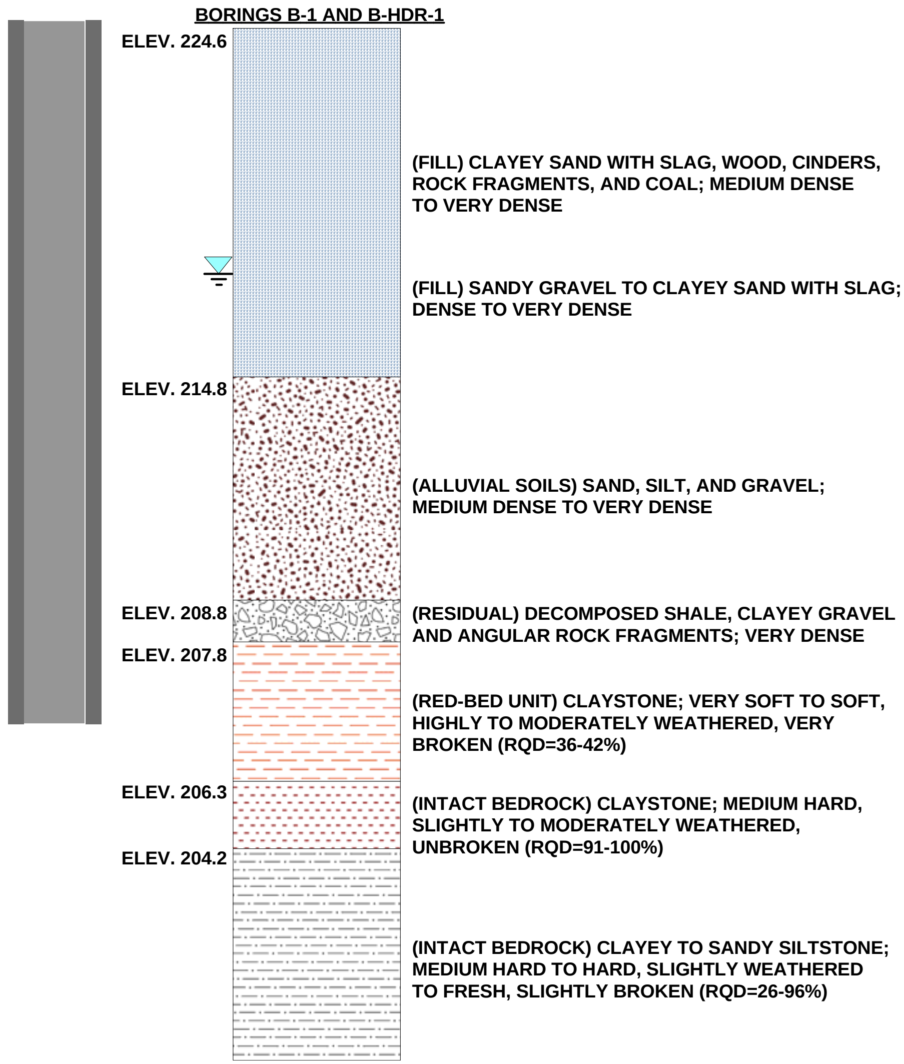
- Introduction
- Development of Constructible Solutions
- Design of Micropile Retrofit
- Load Testing Program
- Micropile Construction
- Detailed Analysis of Load Tests

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

Introduction

- 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

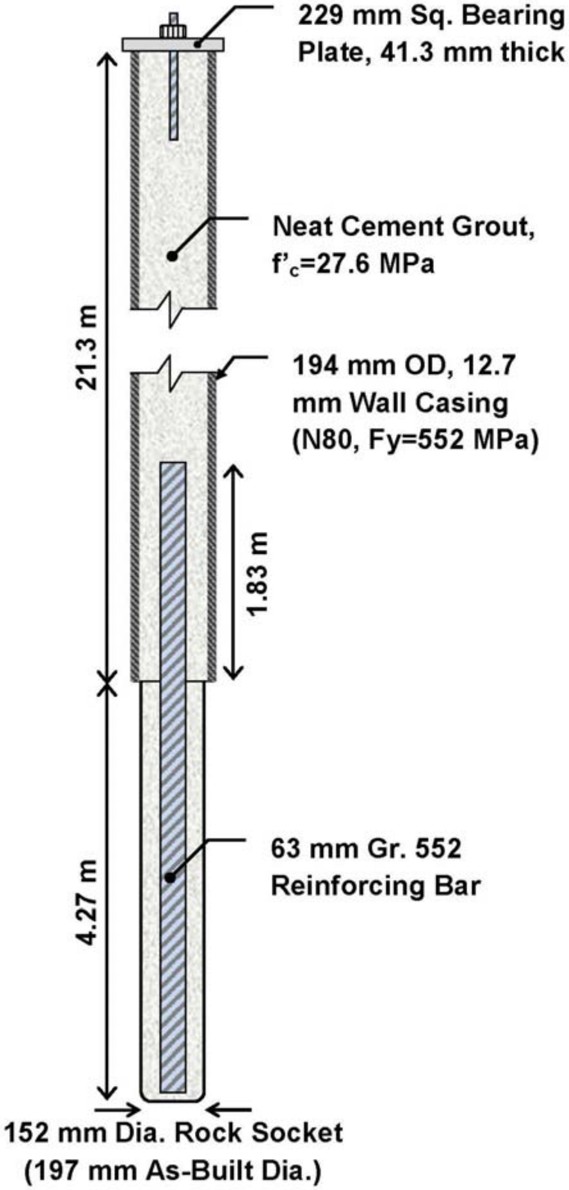
	Strength III and I		Service I	
	Minimum	Maximum	Minimum	Maximum
Axial Load (MN)	19.8	32.5	16.7	21.7
Transverse Moment (MN-m)	0.8	7.9	1.2	2.6
Longitudinal Moment (MN-m)	0.4	8.4	2.0	5.1
Transverse Shear (kN)	89.0	996.4	160.1	355.9
Longitudinal Shear (kN)	35.6	391.4	89.0	177.9

- LRFD Loads for each of 33 new micropiles

	Static Load	Load Group
Axial Compression Resistance (kN)	1355	Strength I
Max. Design Pile Axial Load (kN)	1196	
Axial Uplift Resistance (kN)	0	Strength III
Max. Design Axial Uplift Load (kN)	7	
Pile Lateral Resistance (kN)	33	Strength III
Max. Design Pile Lateral Load (kN)	33	

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



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

$$R_{cu} = \phi_{cu} R_n = \phi_{cu} \left[0.85 f_c^{'} A_g + F_{yb} A_b \right]$$

$$R_{cc} = 0.65 \left[0.85(27.6MPa)(0.0151m^2) + (552MPa)(0.00317m^2) \right]$$

$$R_{cc} = 1.37MN = 1{,}370kN > 1{,}196kN$$

LRFD Design of Micropiles – Rock Socket

- Expected ult. bond shear stress α_b 520-1,380 kPa, 1,034 kPa chosen for design
- Calculate required bond length for 152 mm min. diameter
- PennDOT design specifications

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

  - Required rock socket length 3.4 to 4.6 m depending on ϕ, design length of 4.27 m chosen

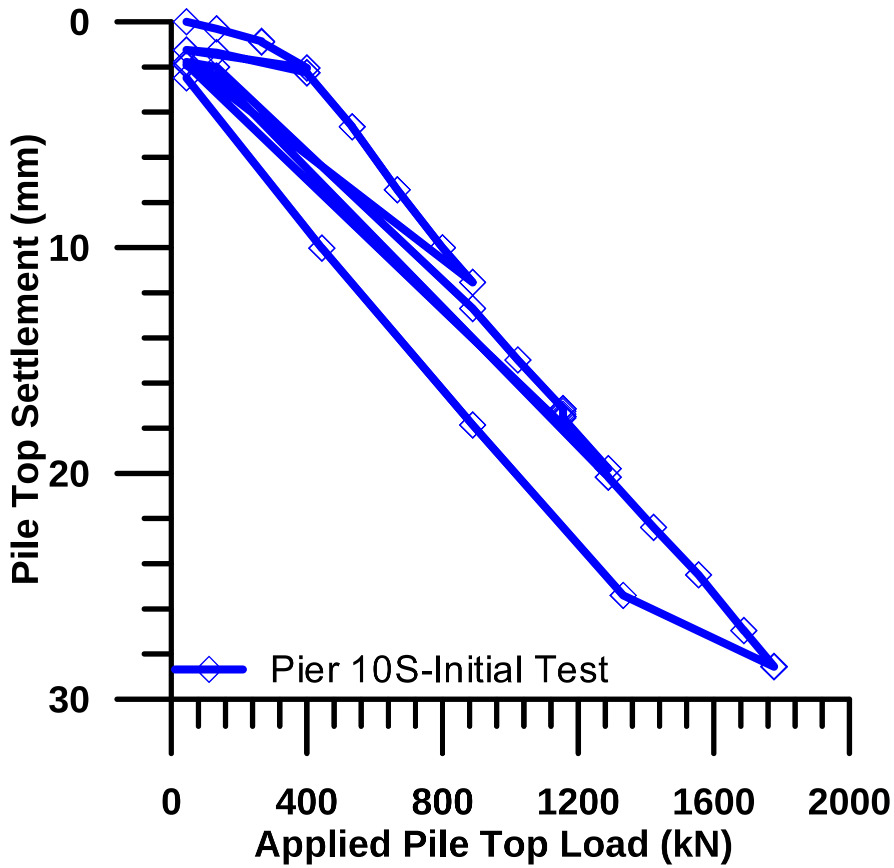
An Unexpected Problem at Pier 10N

- 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

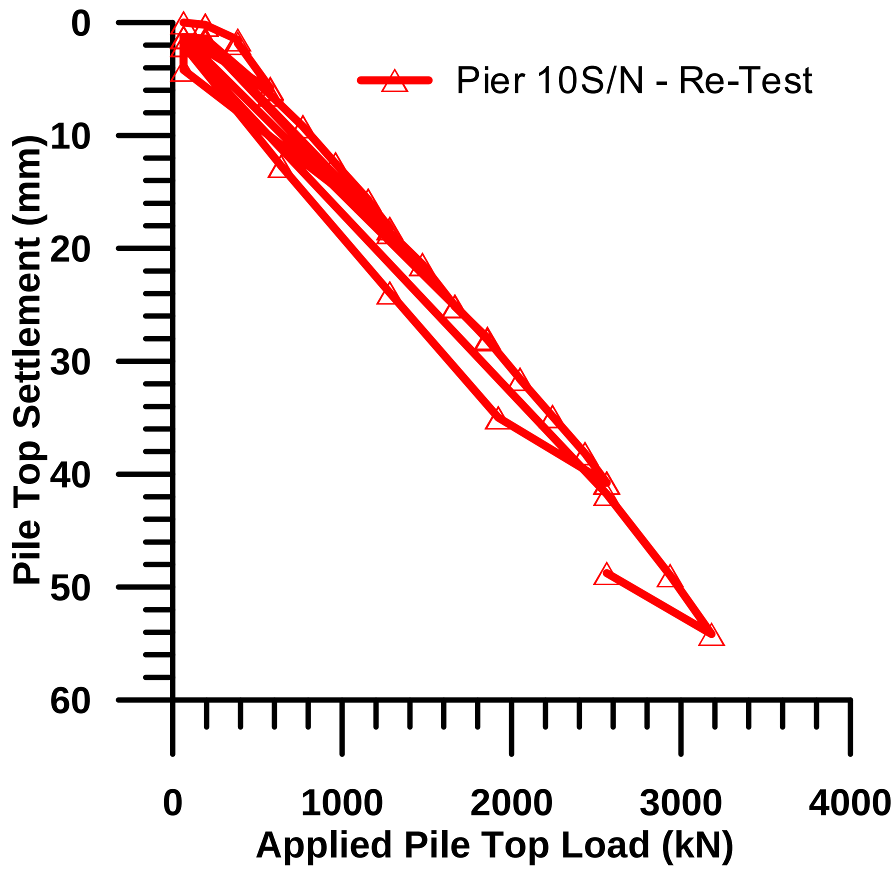
Compression Load Test – Part I



- 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

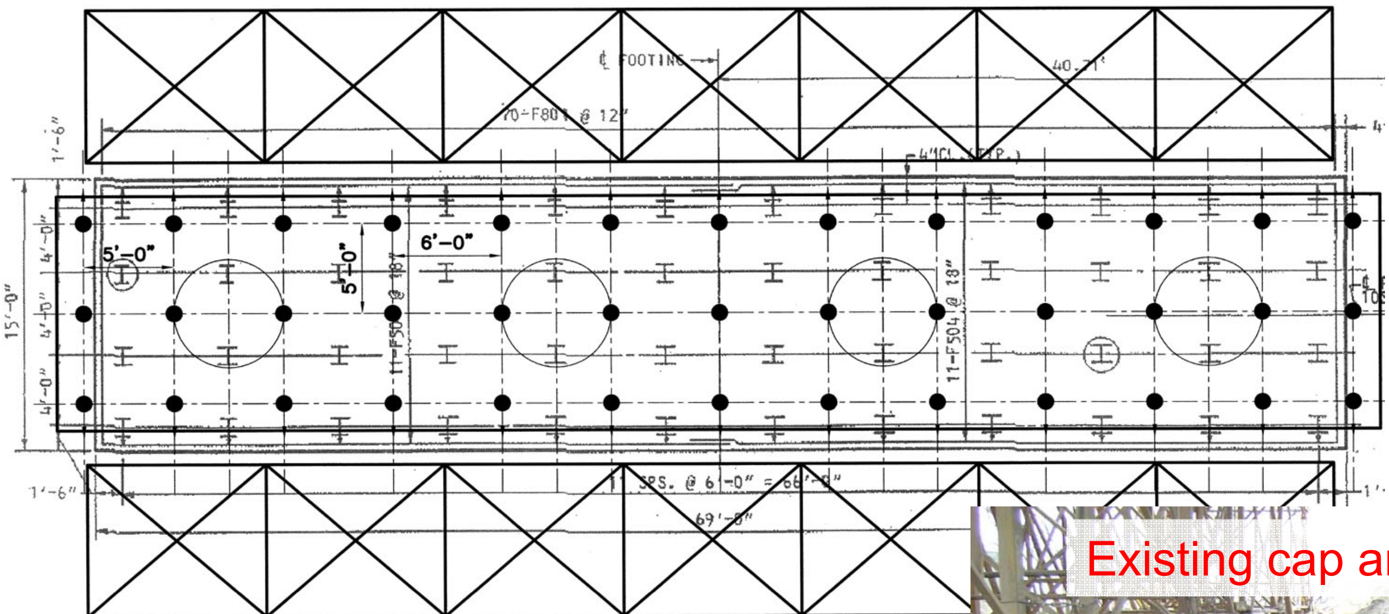
- Re-test of original test pile to substantiate higher design load of 1,280 kN for Pier 10N with intention to test to failure
  - Max. test load 3,180 kN
  - Total settlement 18 mm at DL, 54 mm at TL, approx. 3 mm residual.

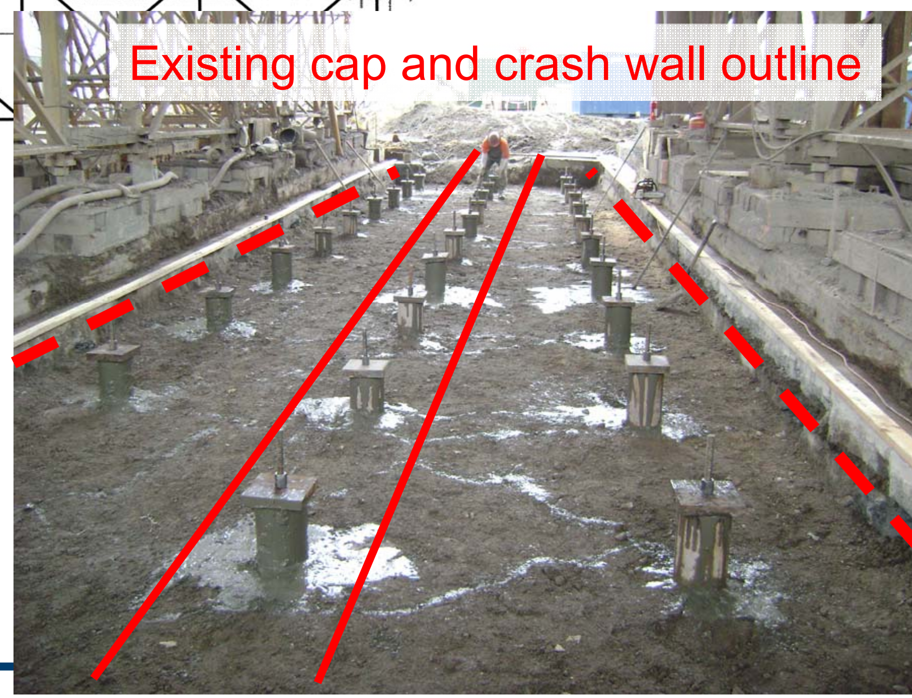


Production Micropile Construction

- 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



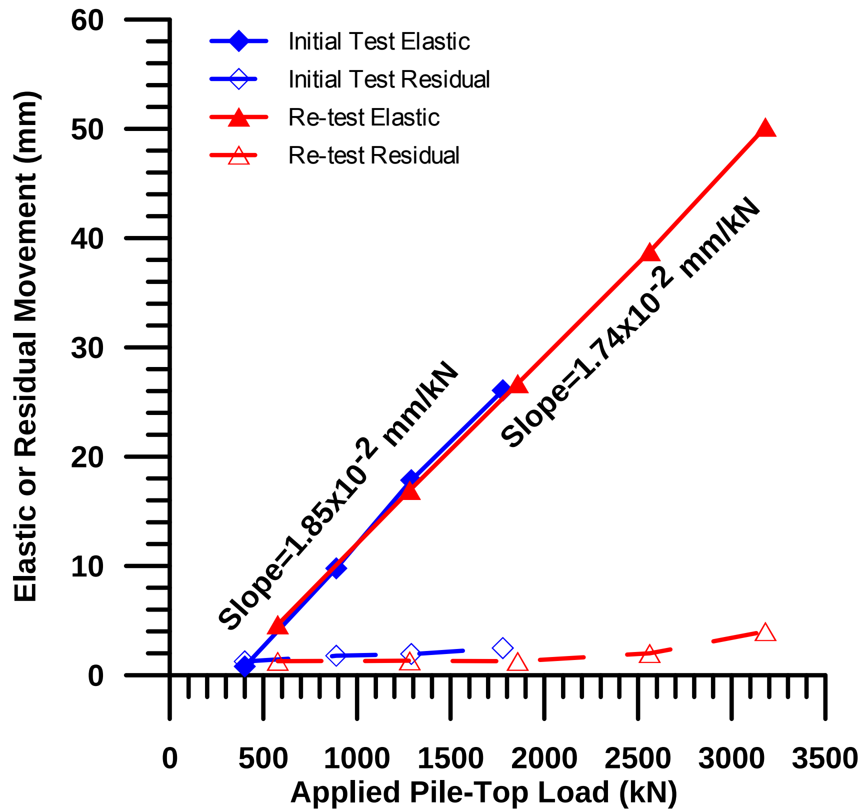


Production Micropile Construction-Connections

- Pier 10S→ conventional bearing plate connections
- Pier 10N→ Need to tie micropiles into existing cap and crash wall with post-tensioning bars

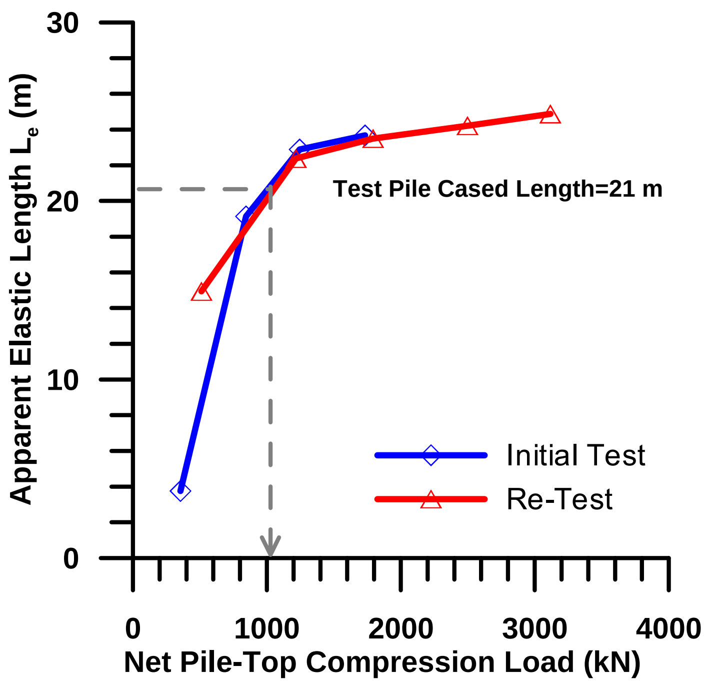
Pile Performance Evaluation

- 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

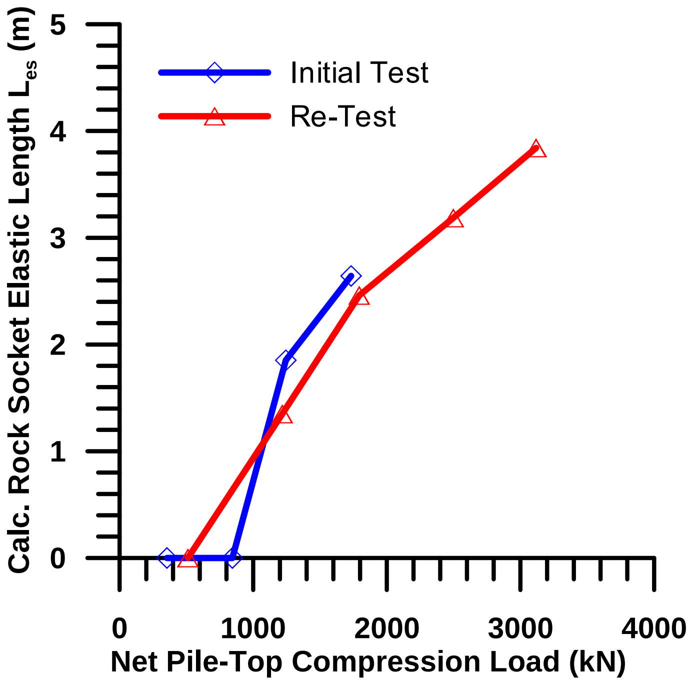


Pile Performance Evaluation

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



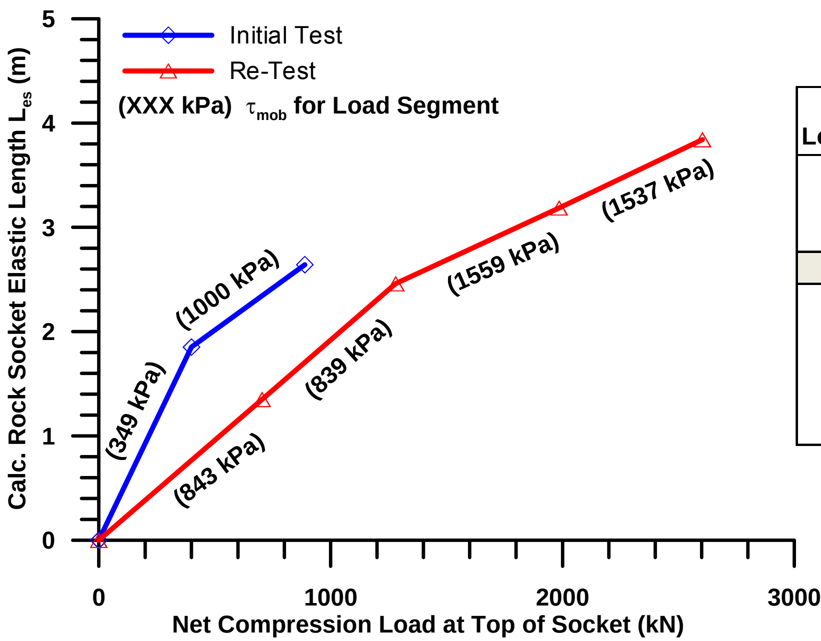
Development of total apparent elastic length L_e



Development of apparent elastic length L_{er} in the rock socket

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 ¼)



Load Cycle	Net Pile Top Load (kN)	Net Load at Top of Socket (kN)	Calc. L_{es} (m)	Calc. LTR (kN/m)	Calc. Ave. τ_{mob} (kPa)
Initial	844.3	0.0	0.00	-	-
	1244.3	399.9	1.85	216	349
	1733.1	888.8	2.64	336	543
Re-Test	512.4	0.0	0.00	-	-
	1217.0	704.6	1.35	522	843
	1793.5	1281.1	2.46	521	841
	2498.1	1985.7	3.19	623	1007
	3116.4	2604.0	3.84	678	1095

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?