BRAUN INTERTEC

The Science You Build On.

FINANCIAL AND SCHEDULE BENEFITS OF PROJECT-SPECIFIC LOAD TESTING

109th Annual TEAM Conference

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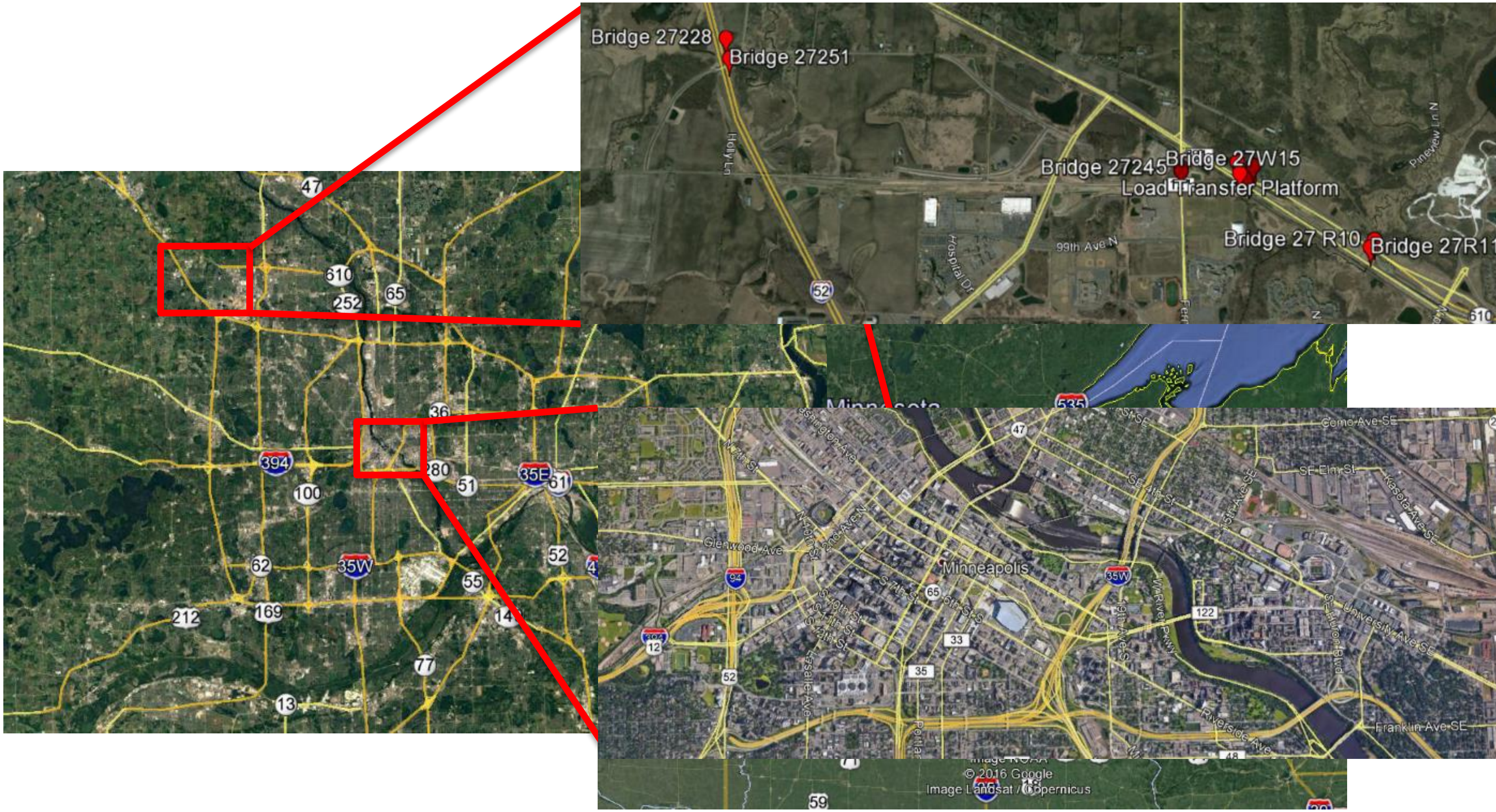
Introduction

- Foundation design process
- I-35W Bridge Replacement
- TH 610
- Conclusions

Foundation Design Process – Idealized!

- Structure need identified
- Preliminary structure design
- Subsurface exploration
  - Design-phase load test
- Final design
- Construction
  - Construction-phase load test

Project Locations



(©Google Earth 2016, 2018; MnDOT 2016)

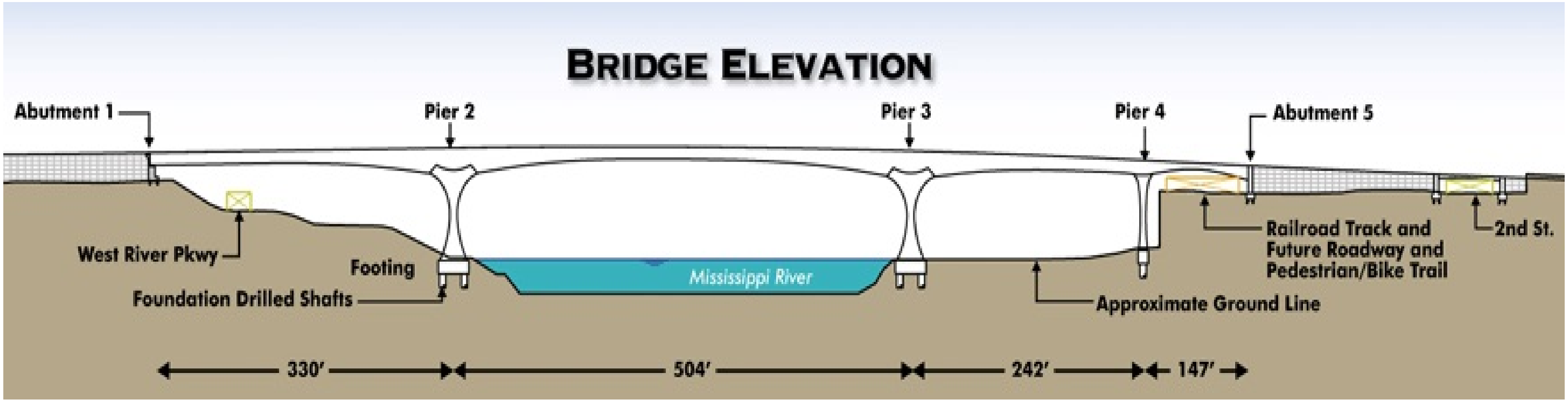
I-35W Bridge – Collapse

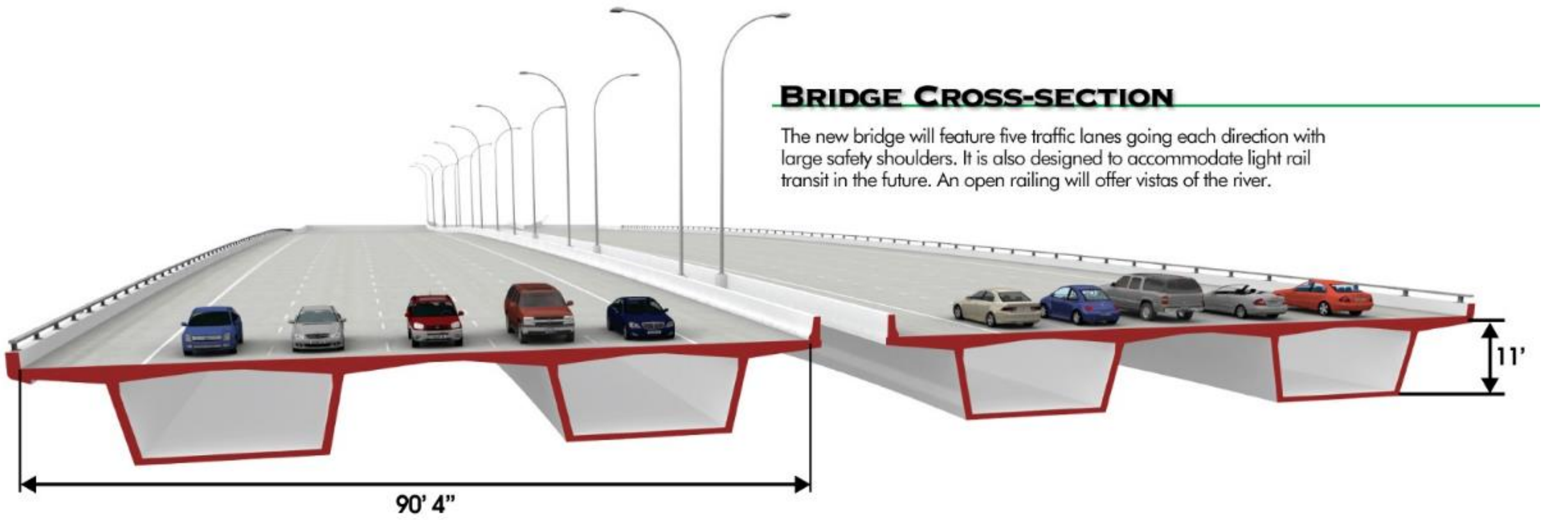
I-35W Bridge – Collapse

I-35W Bridge – Design

- Twin bridge replacement
- 125-year design life
- Overall length of 1,223 feet (373 m)
- Combined width of 176 feet (54 m)
- Foundation
  - Driven H-piles
  - Drilled shafts

I-35W Bridge – Design

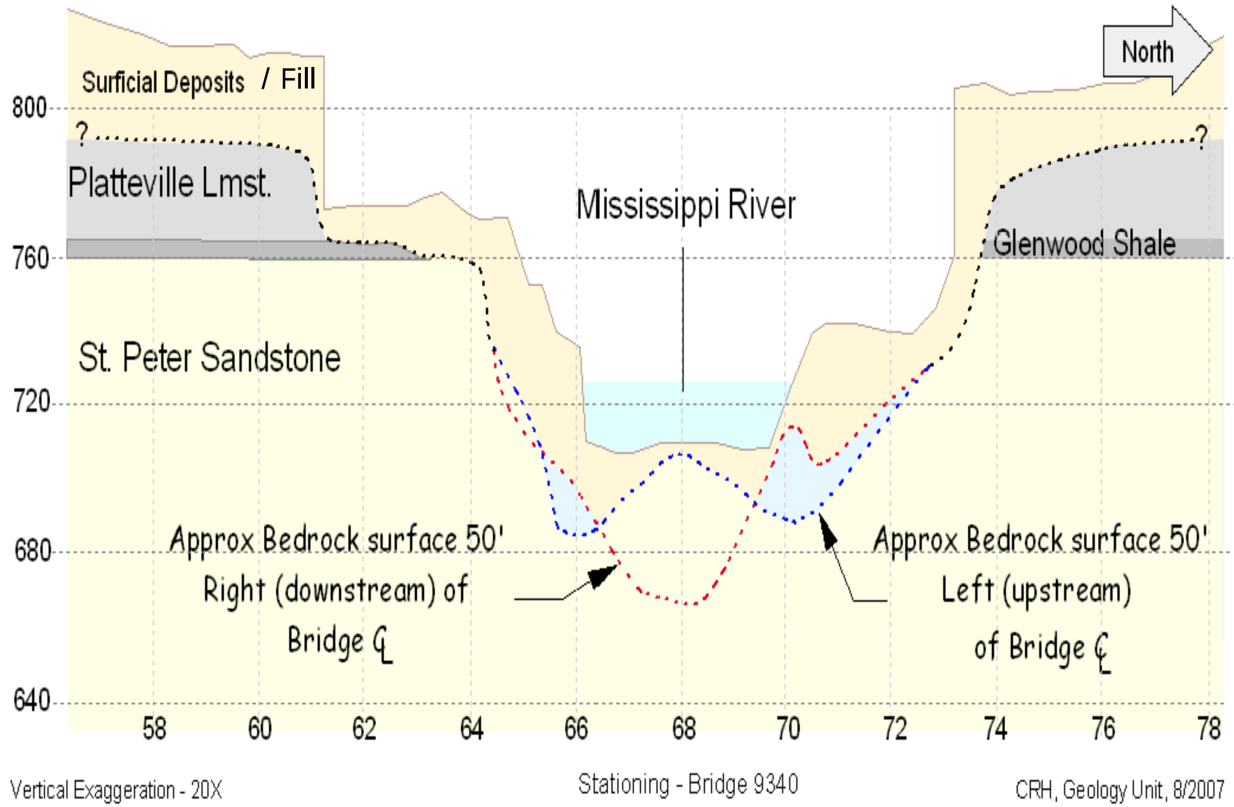




I-35W Bridge – Design

I-35W Bridge – Subsurface Conditions

- Primarily bedrock
- Artesian conditions
- Environmental challenges from previous development



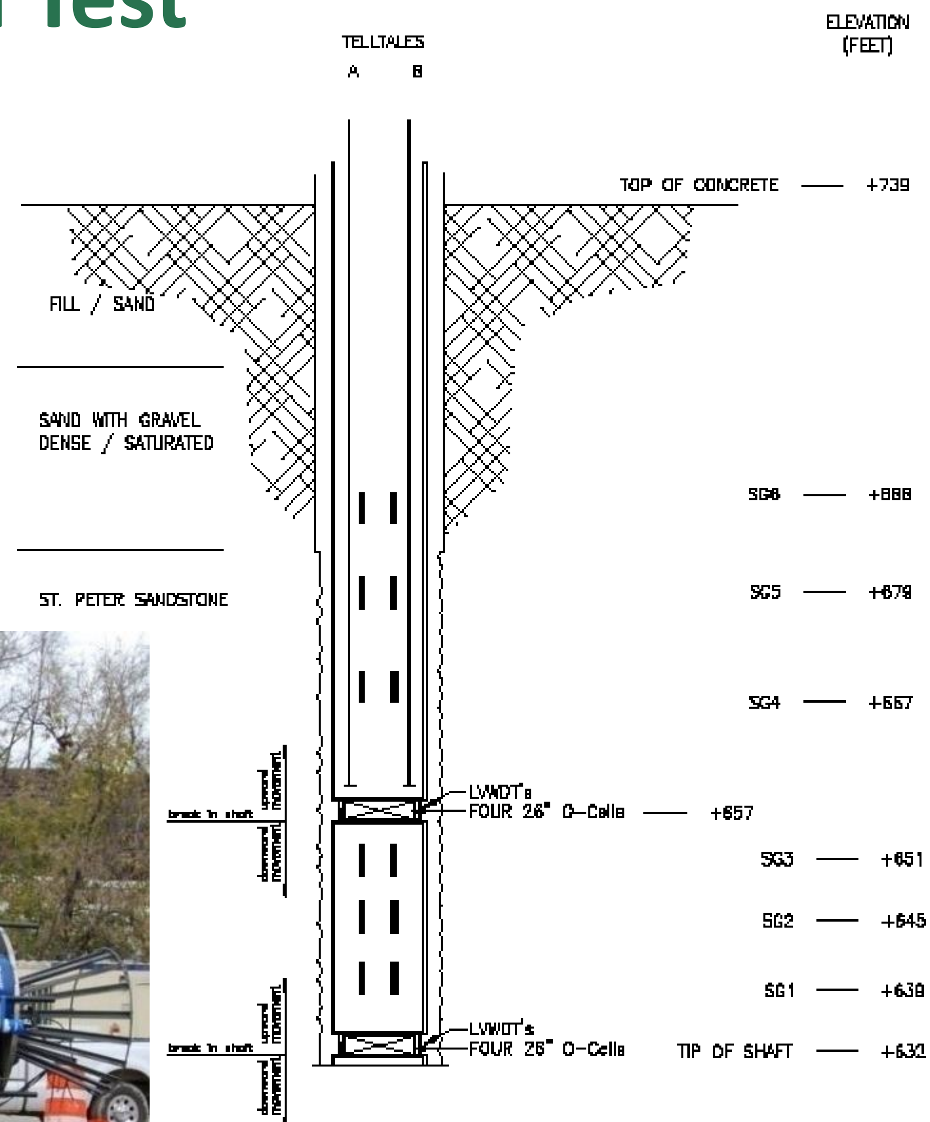
I-35W Bridge – Preliminary Shaft Design

- Rock Quality Designation (RQD) varied from 0% to 97%
- Unconfined compressive strength varied from 40 to 2,100 psi

	Geotechnical Unit Resistance (ksf)		Rock Socket Diameter (inches)
	Side Shear	End Bearing	
2 and 3	0.5 to 10	60 to 150	84
4			96

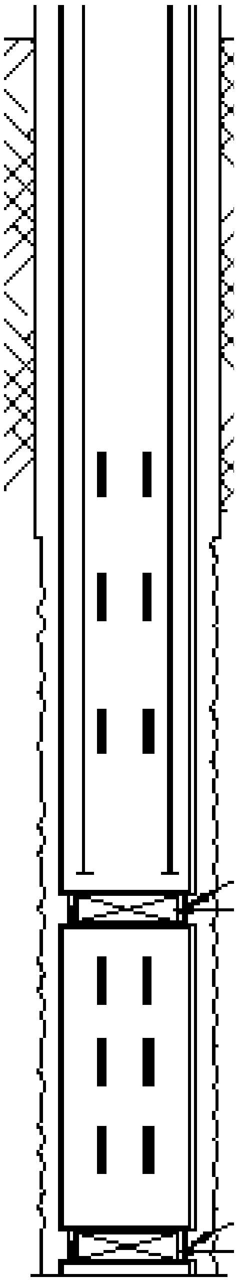
I-35W Bridge – Load Test

- Test and method shaft at Pier 3
- 78-inch-diameter, 39-foot-long, rock socket



I-35W Bridge – Load Test

- Two-level, three-stage, bi-directional load test
    1. Upper assembly closed, lower assembly pressurized
    2. Upper assembly pressurized, lower assembly open
    3. Upper assembly pressurized, lower assembly closed



I-35W Bridge – Load Test

I-35W Bridge – Unit Resistance Summary

Design Stage	Nominal Unit Resistance (ksf)	
	Side Shear	End Bearing
Initial	0.5 to 10 ksf	60 to 150 ksf
Test Shaft Design	2 to 8 ksf	150 ksf
Final (Test Shaft Actual)	2 to 40 ksf	90 ksf

- 400 to 2,500 percent increase in side shear resistance for more-competent sandstone
- End bearing resistance agrees with design estimates

I-35W Bridge – Final Shaft Design

	Pier 2	Pier 3	Pier 4
Initial Design Diameter (inches)	84	84	96
Final Design Diameter (inches)	78	90	90
Initial Design Socket Length (feet), overall / more-competent	136 / 68	124 / 41	215 / 171
Actual Socket Length (feet), overall / more-competent	54 / 22	50 / 23	80 / 16

I-35W Bridge – Final Shaft Design

Less-competent sandstone

More-competent sandstone

I-35W Bridge – Cost Comparison

- Drilling cost of $45 per cubic foot in both soil and rock
- Cost of initial design: $15,162,976
- Cost of final design:
  - Testing: $583,000
  - Construction: $7,726,612
  - Total: $8,309,612
- Net savings resulting from testing: $6,853,364

I-35W Bridge – Foundation Support Cost

A Con

$$Cap\ Support\ Cost = \frac{Cap\ Construction\ Cost}{Factored\ Load\ on\ Cap}$$

$$= \frac{}{\sum Factored\ Loads\ Under\ Construction\ Control}$$

$$\boldsymbol{Total\ Support\ Cost = \frac{Total\ Foundation\ Cost}{\sum Structure\ Factored\ Loads}}$$

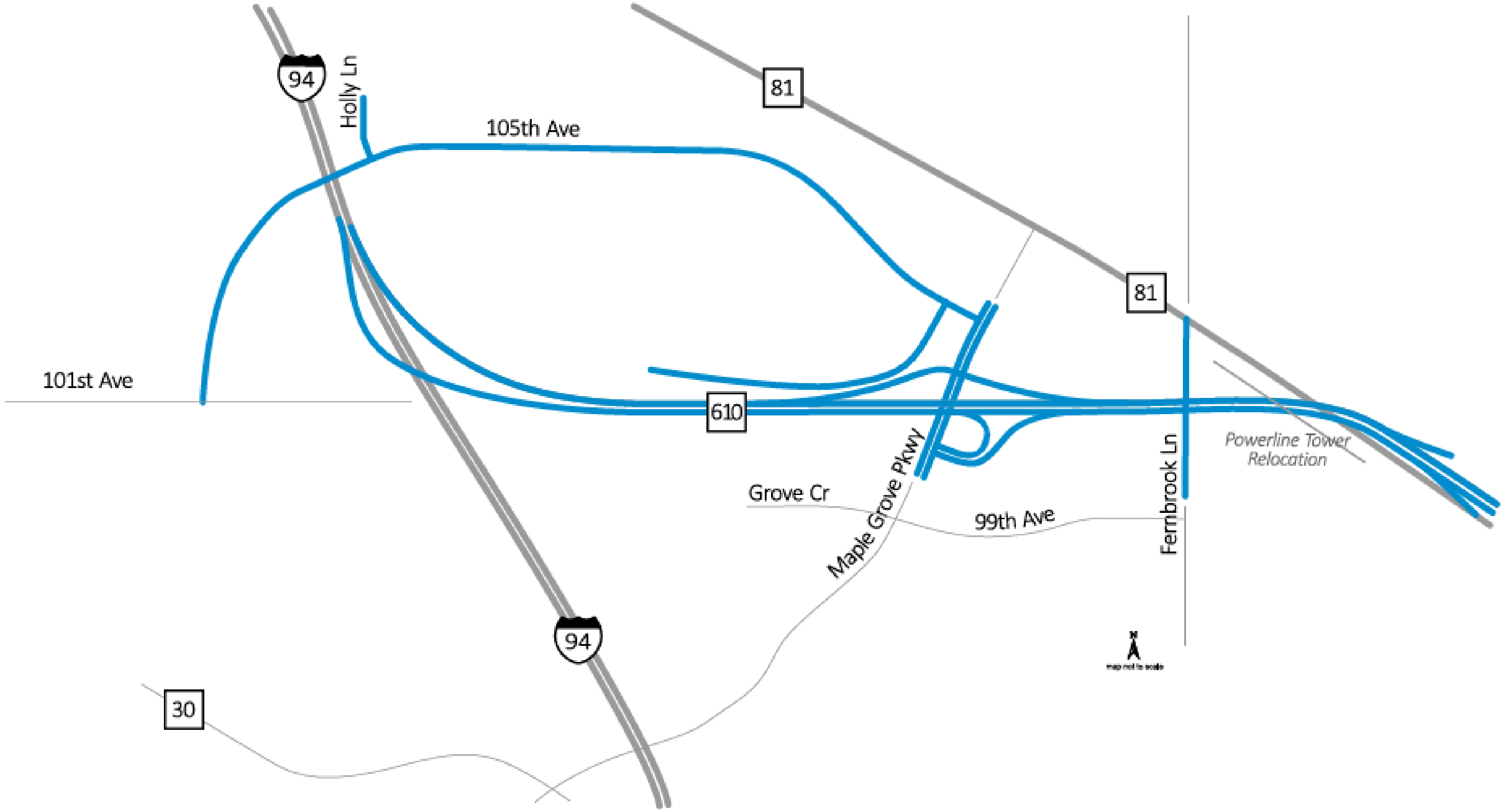
			Construction	
Final	$16.70/kip	$20.09/kip	$1.52/kip	$21.61/kip

- Testing resulted in total support cost savings of $17.81 per utilized kip of support

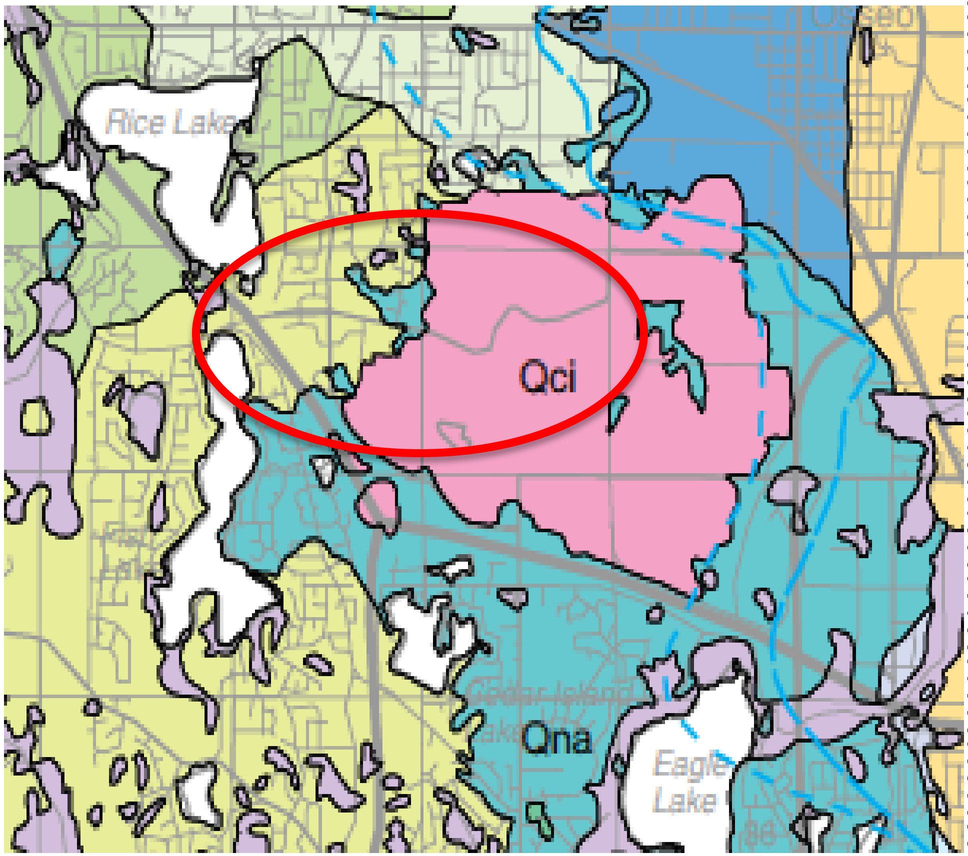
I-35W Bridge – Time Savings

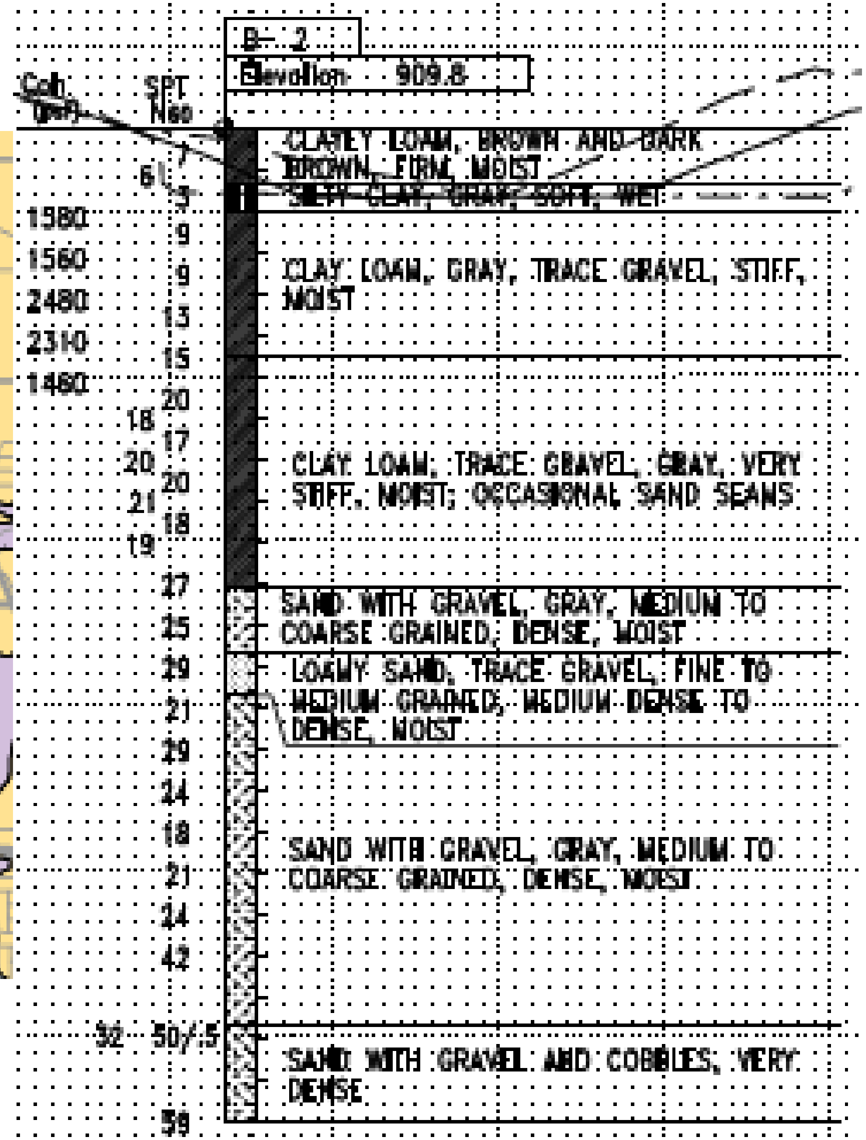
- Initial design length (3,114 ft) – actual length (836 ft) = 2,278 feet of less drilling in more-competent rock
- Observed drilling rate of 1 to 4 feet/hour in more-competent rock means initial design would have required an additional 570 to 2,278 hours (23 to 95 days) of drilling

TH 610 Design



TH 610 – Subsurface Conditions





TH 610 – Foundation Design

Soil Type	Consistency	Blow Count, N_{60} (bpf)	Friction Angle, f (deg.)	Cohesion, c (psf)	β	N_t
Lean Clay (CL*)	Soft	2 - 4	-	250 - 500	0.15	3
	Firm	5 - 8	-	750 - 1,200	0.19	8
	Stiff	9 - 15	-	1,500 - 2,500	0.20 - 0.29	14 - 19
	Very Stiff	16 - 30	-	2,500 - 4,500	0.30 - 0.35	25 - 30
	Hard	31 - 60	-	4,500 - 9,000	0.36 - 0.40	30 - 33
	Very Hard	61+	-	10,000	0.41 - 0.50	37 - 40
Poorly Graded Sand (SP/SP-SM*)	Very Loose	0 - 4	28 - 29	-	0.15 - 0.20	15 - 20
	Loose	5 - 10	30 - 31	-	0.21 - 0.25	20 - 30
	Medium Dense	11 - 17	32 - 33	-	0.26 - 0.39	30 - 45
	Medium Dense	18 - 24	33 - 34	-	0.40 - 0.52	45 - 60
	Dense	25 - 30	35	-	0.53 - 0.59	60 - 75
	Dense	31 - 50	36 - 38	-	0.60 - 0.75	75 - 120
	Very Dense	51+	38 - 40	-	0.76 - 0.90	120 - 150

*Classification based on ASTM D2487 (2011).

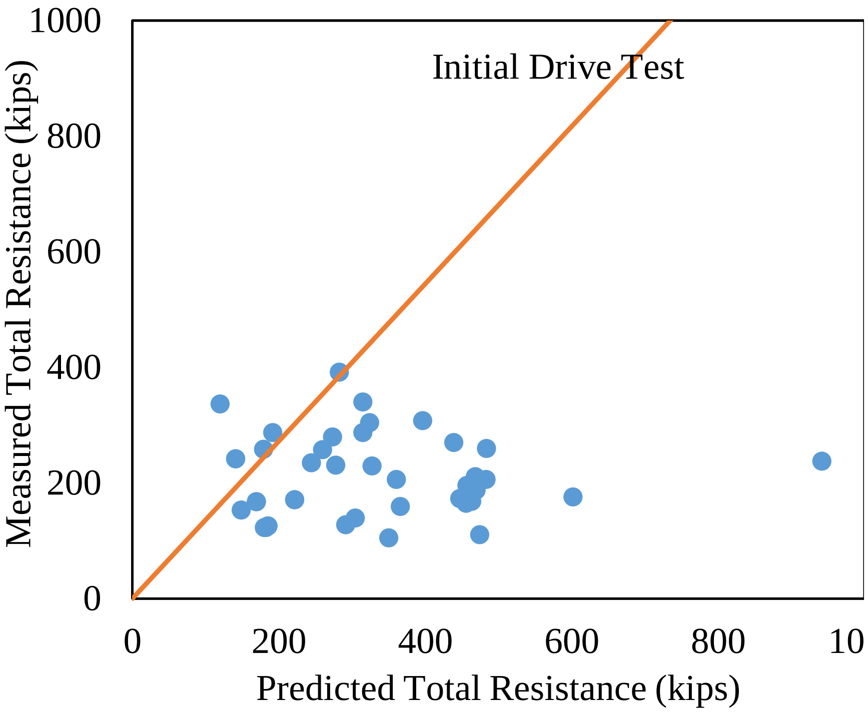
- Beta method, modified by experience

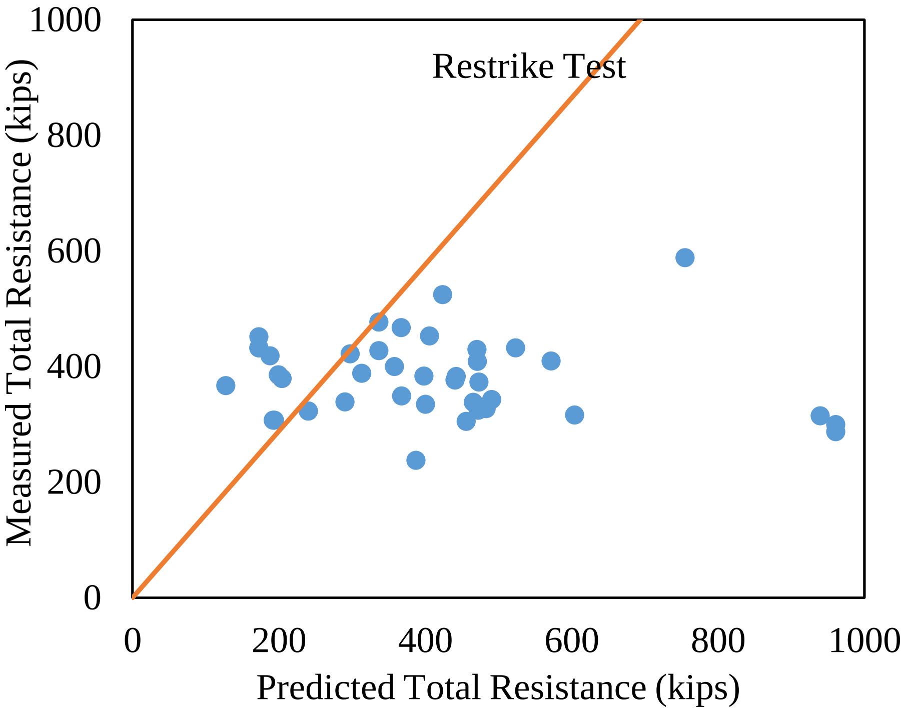
TH 610 – Pile Testing

- Closed-end pipe (CEP) piles
  - Diameter: 12 ¾-inch
  - Wall thickness: ¼-inch
- High-strain dynamic testing
  - Initial drive and restrike
  - Case method and wave matching using CAPWAP

TH 610 – Pile Testing

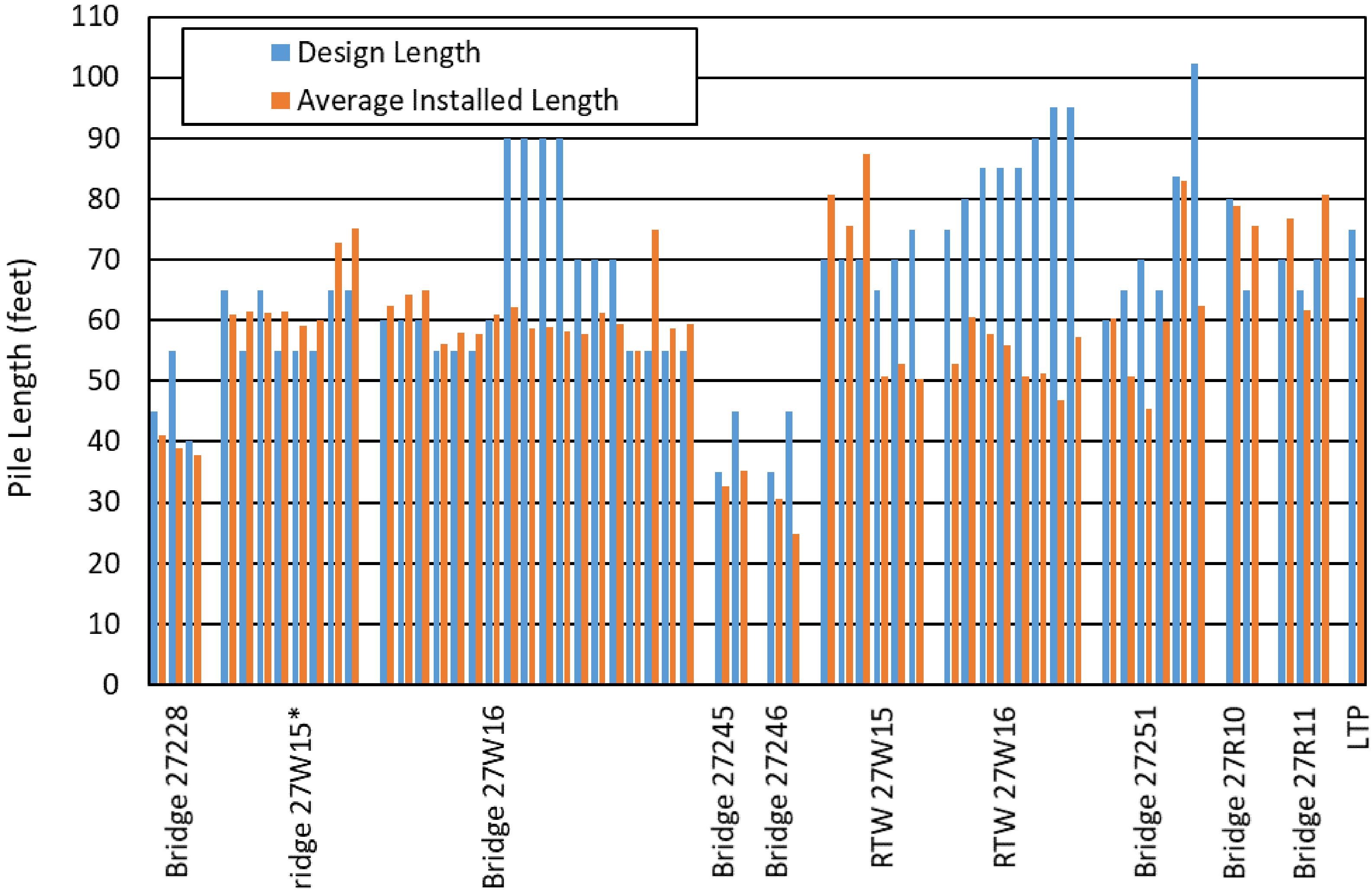
- Test results versus prediction



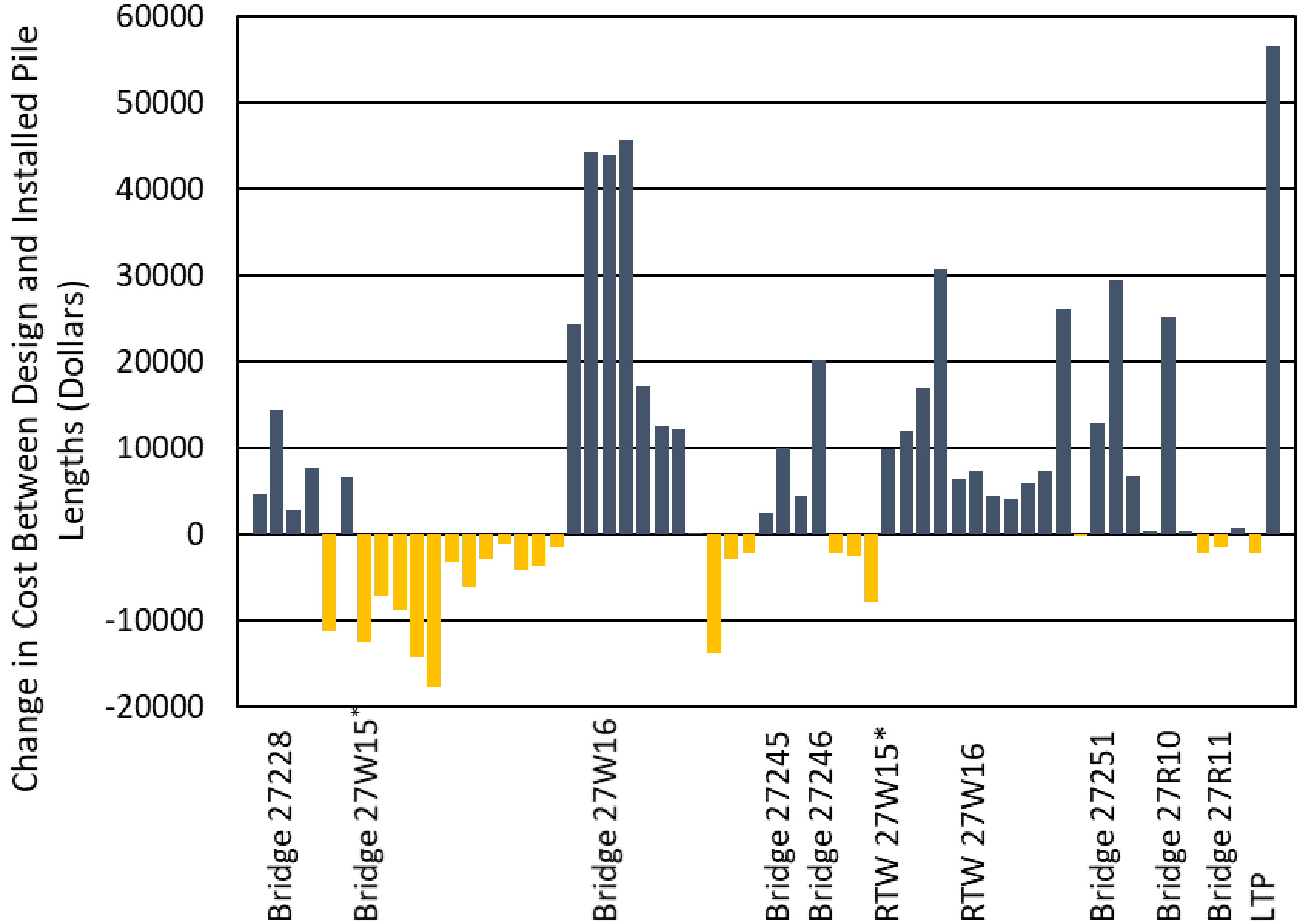


- Total bias of 0.81 for initial and 1.22 for restrike
- Side resistance bias of 0.83 and 1.56

TH 610 – Length Comparison



TH 610 – Costs



Change in Cost Between Design and Installed Pile Lengths (Dollars)
60000
50000
40000
30000
20000
10000
0
-10000
-20000
Bridge 27228
Bridge 27W15*
Bridge 27W16
Bridge 27245
Bridge 27246
RTW 27W15*
RTW 27W16
Bridge 27251
Bridge 27R10
Bridge 27R11
LTP

TH 610 – Costs

- Total design length less installed length is 13,548 ft
- Assume $30/ft for savings of $406,440
- High-strain dynamic testing fee $51,584
- Estimated total savings of $354,856
- For average pile length, saved approximately 28 days of driving

TH 610 – What does it mean?

- High-strain dynamic testing is more accurate than static analysis – maybe
  - Experience in static models
  - Over-estimate length for bidding
- Can’t compare with lengths for formula or static load test

TH 610 – Conclusions

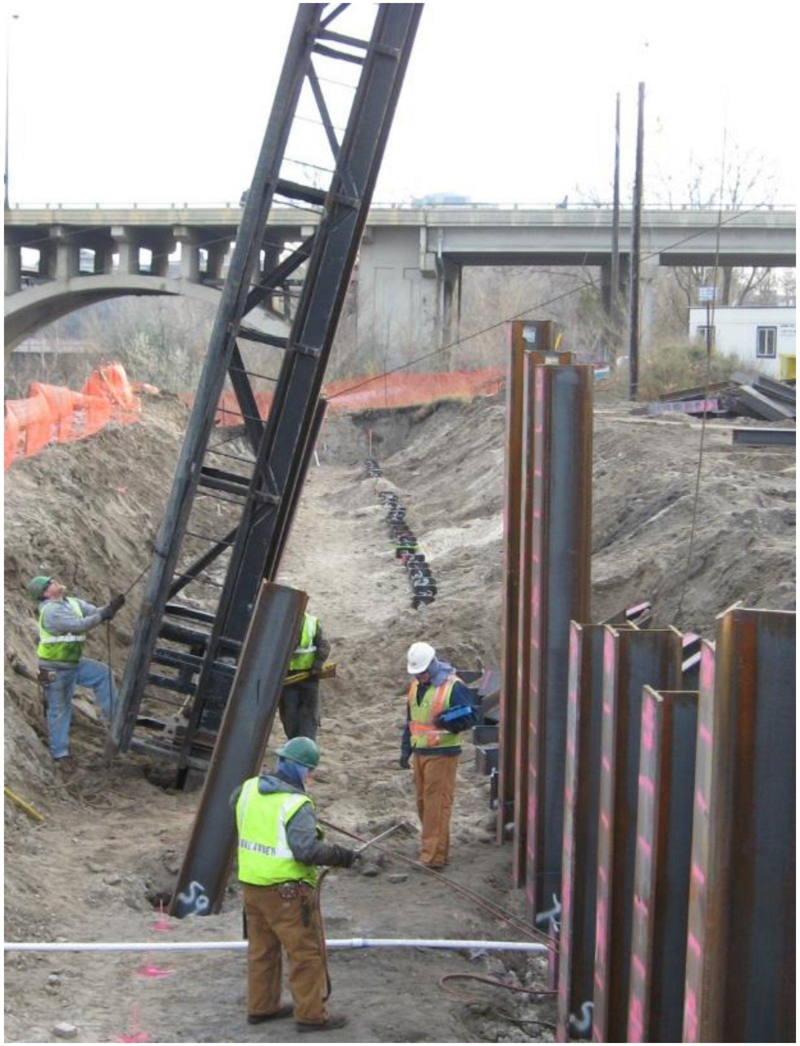
- Empirical methods are inaccurate, even with experience
- Restrike testing results in higher nominal resistance than initial-drive testing
- Foundation support cost analysis during design won't have all the information
- Foundation support cost analysis post-construction is also difficult with driven piles

I-35W Bridge – Summary

- Load testing cost \$1.52 per kip of utilized support
- Increased side shear resistance by 400 to 2,500 percent
- Testing saved \$17.81 per kip of utilized support and between 23 and 95 days of drilling

Both Projects – Conclusions

- Initial designs based on empirical values can be conservative
- Construction control with testing can be expensive, which can lead to easy dismissal
- Support cost provides a method of perspective



Both Projects – Conclusions

- Time-savings is important consideration that is not part of support cost
- Savings from test can be many times the total of testing cost

Acknowledgements

Based on papers published and presented at IBC 2017 and GeoCongress 2017

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Questions and Thank You!