FINANCIAL AND SCHEDULE BENEFITS OF PROJECT-SPECIFIC LOAD TESTING

109th Annual TEAM Conference
Matthew R. Glisson, PE
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
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
The new bridge will feature five traffic lanes going each direction with large safety shoulders. It is also designed to accommodate light rail transit in the future. An open railing will offer vistas of the river.
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

<table>
<thead>
<tr>
<th>Side Shear</th>
<th>End Bearing</th>
<th>Rock Socket Diameter (inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 and 3</td>
<td>0.5 to 10</td>
<td>84</td>
</tr>
<tr>
<td>4</td>
<td>60 to 150</td>
<td>96</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Design Stage</th>
<th>Nominal Unit Resistance (ksf)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Side Shear</td>
</tr>
<tr>
<td>Initial</td>
<td>0.5 to 10 ksf</td>
</tr>
<tr>
<td>Test Shaft Design</td>
<td>2 to 8 ksf</td>
</tr>
<tr>
<td>Final (Test Shaft Actual)</td>
<td>2 to 40 ksf</td>
</tr>
</tbody>
</table>

- 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

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

\[ \text{Cap Support Cost} = \frac{\text{Cap Construction Cost}}{\text{Factored Load on Cap}} \]

\[ \sum \text{Factored Loads Under Construction Control} \]

**Total Support Cost**

\[ \frac{\text{Total Foundation Cost}}{\sum \text{Structure Factored Loads}} \]

<table>
<thead>
<tr>
<th>Construction</th>
<th>Final</th>
<th>$16.70/kip</th>
<th>$20.09/kip</th>
<th>$1.52/kip</th>
<th>$21.61/kip</th>
</tr>
</thead>
</table>

- 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**

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

*Classification based on ASTM D2487 (2011).

- Beta method, modified by experience
TH 610 – Pile Testing

- Closed-end pipe (CEP) piles
  - Diameter: 12 \(\frac{3}{4}\) -inch
  - Wall thickness: \(\frac{1}{4}\) -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 – Costs
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 an 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
Questions and Thank You!