US 301 Section 2A
Construction Phase Downdrag Analysis
DelDOT BDM Approach

Presented to: Mid-Atlantic Quality Assurance Workshop, February 14, 2018
OUTLINE

Project Background
Initial Design/Construction Sequence
Alternate Downdrag Recommendation
Downdrag Analysis
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Acknowledgements
US 301 Section 2
US 301 Section 2
Project Overview

• New Alignment of US 301
• 4 Lane Limited Access Hwy
• Section 2, Approx. 4 miles
• New Castle County
• 3 Interchanges
• 8 Bridge Structures
• 2 Culverts
• 11 Cross Culverts
All of the 8 bridge abutments were founded on either PPC or Steel H-Piles driven piles.

Most structures used 14”x14” PPC piles.

Subsurface for these structures was consistent: Dense to Very Dense Silty Sand (SM, A-2-4)
Initial Design

All foundations for Section 2 bridges were designed prior to DelDOT’s release of their new Bridge Design Manual in 2015.
Due to the sandy foundation soils only elastic settlement needed to be considered for approach embankment fills; however, consideration had to be given to the time that settlement would occur because of the silt compliment and low plasticity.

Estimates were calculated providing that ~ 4-inch settlement magnitude would be developed over a 3-4 week time period.

This amount of settlement, although elastic and in granular soils would develop downdrag (negative skin friction) forces if the piles were driven before the embankment settlement was realized.
Based on the 3-4 week period to develop the settlement and to avoid having to account for downdrag a Construction Sequence of was recommended:

- Construct approach embankment to subgrade elevation.
- Install sleeves to receive the piles during the construction of embankment.
- Monitor the settlement during construction of the embankment and afterward to confirm settlement.
- Then drive piles in sleeves.
- Backfill annular space between pile
Initial Construction Sequence

- Settle 1<sup>st</sup> - Drive 2<sup>nd</sup> construction sequence was specified for each of the 8 bridge’s abutment foundations.
RFI 0033

In March 2016 after award of the Construction Contract to Allan Myers; AECOM received a RFI #0033 asking to amend the Construction Sequence to allow driving of the piles 1\textsuperscript{st} to eliminate the need for the settlement quarantine.

AECOM provided the following response:

- AECOM has accepted the proposed driving sequence to drive production piles prior to placing MSE wall backfill.
- However, pile casings will still be required as indicated in the contract plans.
- Piles are to be re-struck providing a minimum 6” of movement to release negative skin friction.
- Pile re-strikes are to be performed prior to backfilling the annular space between the piles and casings with Fine Aggregates as indicated on the contract plans.
Response

In early April 2016, DelDOT’s Bridge group reached out to each of the US 301 Section Designers and asked that they reconsider prescribing driving of piles post construction of the surrounding embankments. Especially in MSE approaches. DelDOT requested the use of the new BDM Section 210.7.1.6.2 on Downdrag.

210.7.1.6.2 —Downdrag

The following shall supplement A10.7.1.6.2

Downdrag and transient loads such as live loads should not be considered as acting simultaneously on any load combination. For the different load cases, use only the higher of these two factored loads (factored downdrag versus factored transient loads).
Response

5 of 8 Section 2 bridge structures exhibited a factored DD Load Condition in excess of the Factored Resistance of the piles:

- BR1-468
- BR1-470
- BR1-472
- BR1-507
- BR1-477
Downdrag Analysis

AECOM approach:

- Embankment approach fill would be placed on med. dense sandy soil over a dense to v. dense sand.
- Elastic settlement was calculated using the Hough method for granular soils (cons.)
- Extent/limit of DD was est. from settlement calc (neutral axis)
- Magnitude of DD est. from skin friction of pile. (used Driven)
- Factored DD (using 1.05 factor from A3.4.1-2) + DC+DW was compared to factored DC + DW+ LL.
- Where DD + DC exceeded the factored pile resistance mitigation meas. were recommended.
### Bridge 1-472 (BR2-3)

<table>
<thead>
<tr>
<th>Load Type</th>
<th>Unfactored Load</th>
<th>Applicable Load Factor</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DC Load</td>
<td>112.06</td>
<td>1.25</td>
<td>kip/pile</td>
</tr>
<tr>
<td>DW Load</td>
<td>7.79</td>
<td>1.5</td>
<td>kip/pile</td>
</tr>
<tr>
<td>LL</td>
<td>28.89</td>
<td>1.75</td>
<td>kip/pile</td>
</tr>
<tr>
<td>DD</td>
<td>113.5</td>
<td>1.05</td>
<td>kip/pile</td>
</tr>
</tbody>
</table>

- **Total Factor Load (LL)**: 202.3175 kip/pile
- **Total Factored Load (DD)**: 270.935 kip/pile

Nominal Resistance, per plans = 361 kip/pile

Factored Resistance = 234.65 kip/pile
1. Per the previous RFI 0033 response, “...Piles are to be re-struck providing a minimum 6” of movement to release negative skin friction once approach emb is to subgrade elev. Pile re-strikes are to be performed prior to backfilling the annular space between the piles and casings...”

2. Pre-drill at each of the pile locations to a depth of 10’-0” below existing grade, install casing, drive piles to nominal driving resistance per plan, backfill annular space with fine aggregate, extend casing through MSE approach fill and backfill remaining casing once MSE construction is completed.

3. Apply a friction reducer (bitumen coating or equivalent) to the top 10’-0” of each pile that will be embedded below the existing ground surface in the final driven position (depth), install casing around the pile, construct the MSE approach fill and backfill casing with fine aggregate once MSE construction is completed.

4. Drive the piles deeper to the revised nominal driving resistance to account for DD (see attached calculations). The additional depth of pile would be determined during the test pile operation. If the additional depth can be achieved without over-stressing the piles, then the production piles would be driven to similar revised capacity, casing would be installed around each pile, the MSE approach would be constructed and the casing would be backfilled with fine aggregate. For this alternative revised contract plans would have to be developed by the Designer, along with the pertinent calculations to determine if the additional pile resistance exceeds the structural capacity of the pile. Also, due to the potential for over-stressing the pile as determined by the Design-Phase Test Pile program, August 2010, additional scrutiny would have to be paid to the results of the PDA/CAPWAP analysis. Therefore, this approach would not be a preferred alternative for construction of these structures.
Contractor Preferred Alternative

“Apply a friction reducer (bitumen coating or equivalent) to the top 10’-0” of each pile that will be embedded below the existing ground surface…”
Friction Reducer

- Designer provided spec for Bitumen Coating for Friction Reducer.
- Limits of friction reducer to be provided prior to Test Pile operation.
- Results of test pile operation determine length of production piles and friction reducer limits for production piles.

CONCRETE PILING BITUMEN COATING

This section shall include the following:

The work shall consist of furnishing and applying bitumen coating and primer to Precast, Pre-stressed Concrete (PPC) pile surfaces as required in the plans and as specified herein.

MATERIALS:

A. Bitumen Coating. Canal Liner Bitumen conforming to AASHTO M 239 (ASTM D 2521) shall be used for the bitumen coating and shall have a softening point of 190 to 200 degrees F, a penetration of 56 to 61 at 77°F, and a ductility in excess of 1.4” at 77°F.

B. Primer. Primer shall conform to the requirements of AASHTO M116 (ASTM D 41).
Application of Bitumen

Applying the Primer: 

Applying the Bitumen:
Alternate Friction Reducer

- Due to the Safety and Environmental Hazards associated with applying hot bitumen (~ 300°F) the Contractor requested the use of an alternate friction reducer that could be painted or sprayed on the piles.

- DelDOT gave provisional approval to use Slickcoat™

**Slickcoat™**

A FRICTION REDUCTION SYSTEM FOR COATING PILES, DRILLED SHAFTS AND SHEET PILING PRIOR TO INSTALLATION IN ORDER TO REDUCE FRICTION IN CONSTRUCTION APPLICATIONS WHERE NEGATIVE SKIN FRICTION, DOWNDRAG FORCES, EASE OF INSTALLATION AND EXTRACTION ARE OF CONCERN.

**ADVANTAGES**
- Reduces peripheral anomaly activity in drilled shaft construction by creating an excellent plane between the drilled shaft casing and the cast-in-place concrete
- Realize substantial friction reduction
- Reduces uplift
- Prolongs the life of piles, sheets and casings
- Durable abrasion resistance
- Save valuable time
- Improved ease of installation, and an expeditious extraction process
- Reduce maintenance costs
- Reduce tidal friction on submerged piling

**CONSTRUCTION BENEFITS**
- Highly resistant to corrosion and chemicals common to construction
- Surfaces stay clean reducing maintenance costs
- Water based, the environment is protected since toxins, chemicals, and harmful metals are not leached into the ecosystem as with bitumen coatings
- Excellent bond breaking characteristics
- Cleans up with water
- Waterproof in a cured state
- Stays in place even during hot weather conditions
- Bonds to pile or casing
- Provides excellent friction reduction between the earth and piling
- Durable
- Apply with conventional equipment
- Replaces bitumen coatings which are unreliable, hazardous to work with, and difficult to maintain on the pile surface during driving, especially under high temperatures

**Patents:** 5,931,604, 5,234,708, 6,371,466
Designer estimated the extent of the Slickcoat.

Reduced DD forces were considered due to the application of the friction reducer

<table>
<thead>
<tr>
<th>BR 1-470 Slick-Coat Extent</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Note:</strong> all dimensions in feet</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ABUTMENT 1</strong></td>
<td>BPCE NB</td>
<td>BPCE SB</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>80</td>
</tr>
<tr>
<td><strong>ABUTMENT 2</strong></td>
<td>BPCE NB</td>
<td>BPCE SB</td>
</tr>
<tr>
<td></td>
<td>80.25</td>
<td>81.5</td>
</tr>
<tr>
<td><strong>Stick-up</strong></td>
<td>NB Abutment 1</td>
<td>SB Abutment 1</td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>NB Abutment 2</td>
<td>NB Abutment 1</td>
</tr>
<tr>
<td></td>
<td>19.25</td>
<td>20.5</td>
</tr>
<tr>
<td><strong>Pile Embedment in pile cap</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Starting Depth of Slick-coat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td><strong>Downdrag extent</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td><strong>Ending Depth of Slick-coat</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>29</td>
</tr>
</tbody>
</table>
Test Piles

Starting in June 2016, Century Engineering, Inc. (Century) CM/CI for the 301 project started coordinating Test Pile results with AECOM.

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### DELAWARE DEPARTMENT OF TRANSPORTATION
### CONSTRUCTION: T200911303
### DATE: 6-21-2016

<table>
<thead>
<tr>
<th>DESIGNER'S TEST PILE RECORD</th>
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</thead>
<tbody>
<tr>
<td>CONTRACTOR: Allen Meyer, Inc.</td>
</tr>
<tr>
<td>FOOTING DESCRIPTION: Absent 2</td>
</tr>
<tr>
<td>PREL NO: TP 77</td>
</tr>
<tr>
<td>HR/DATE: B 317</td>
</tr>
<tr>
<td>NOMINAL HAMMER MAX HP: 1250</td>
</tr>
<tr>
<td>NOMINAL HAMMER MAX HP: 1250</td>
</tr>
<tr>
<td>NOMINAL HAMMER MAX HP: 1250</td>
</tr>
</tbody>
</table>

**INFORMATION FROM CONTRACTOR’S WAVE EQUATION SUBMITAL**

| PREDICTED BLOW P/B FOOT TO ACHIEVE BEARING: | 34 |
| PREDICTED TIP ELEVATION TO ACHIEVE BEARING: | BL 34 |
| PREDICTED CAPACITY AT FINAL TIP ELEVATION: 400 Kips |
| PREDICTED STROKES HEIGHT TO ACHIEVE BEARING: 7.25 ft |
| MAXIMUM ALLOWABLE STRESS IN THE PILE (TENSION): 1,038 psi |
| PILE CUSHION TYPE: Fypeal and Thickness: 10 in. |
| MAXIMUM ALLOWABLE STRESS IN THE PILE (COMPRESSION): 5,299 psi |

**INFORMATION FROM PDA DURING DRIVING**

| BLOWS PER FOOT AT END OF DRIVING: | 54 |
| CAPACITY AT END OF DRIVING: 525 Kips |
| BLOWS IN LAST 1 INCHES OF DRIVING: |
| STROKE HEIGHT AT END OF DRIVING: 10.7 - 11.2 ft |
| RECORDED MAXIMUM STRESS (TENSION) IN THE PILE: 490 psi |
| RECORDED MAXIMUM STRESS (COMPRESSION) IN THE PILE: 4,130 psi |

**TEST PILE RESEARCH INFORMATION**

| RESTRICT STROKE HEIGHT OF HAMMER: N/A |
| PILE MOVEMENT AFTER RESTRICTOR IN INCHES: N/A |

**INFORMATION FROM COPWAP ANALYSIS**

| CAPACITY ESTIMATE: BLOW AT THE END OF DRIVING: 510 Kips |
| CAPACITY ESTIMATE: BLOW AT THE END OF DRIVING: 510 Kips |

**RECOMMENDATIONS FOR PRODUCTION PILES REPRODUCED BY THIS TEST PILE**

| PRODUCTION PILE ORDER LENGTH: 51.0 ft |
| BLOWS PER FOOT REQUIRED TO ACHIEVE BEARING: 54 blows/ft |
| MINIMUM STROKE HEIGHT REQUIRED: 9.5 ft |

**ADDITIONAL COMMENTS / RECOMMENDATIONS**

- Recommended production pile order length is 51 feet for both plank and batter piles.
- Minimum tip consist is designed at BL 11.0. The tip is critical and should be achieved before the pile reaches refusal.
- Operate the hammer at final setting 3 for all piles in this footing.
- Use same 10 inch thick pile cushion for every pile. Replace the cushion if 1,000 blows are reached on an individual pile, or if excessive detonations are unwitnessed.
- Achieve a minimum of 54 blows per foot in the last foot of driving with minimum hammer stroke height of 9.5 feet. Minimum stroke height should be limited to 11.0 feet so that the pile is not overstretched.
- Refusal is defined at 120 blows/ft or 10 blows/10
c
- Note that if refusal is reached during driving, the operation should be stopped even if the minimum tip has not been reached in order to avoid damage to the pile and/or hammer.
- Slick top cutting shall be applied to only the plank piles, starting 1 foot below the top of the pile for a length of 10 feet, stopping 3 feet below the top of the pile.

- Approx. Grade FL: 42.00
- Projected Final plank pile length: 51 ft
- Test Pile Driven Length: 56 ft
- Test Pile Tips: achieved: 31.0 ft
- Recommend 56.0 ft for production pile order length to account for variability

- Based upon adding 50% of the skin friction estimated from the PDA results between BL 37 and BL 17 to the strength load to account for driving, the required Nominal Capacity is 526 kips for Abschnitt 2.3. Based upon the dynamic test results for Abschnitt 3.3, the planks and batter piles should be installed to estimated tip elevations of -33 with a minimum final penetration resistance of 54 blows/ft using a minimum stroke of 9.5 feet.
Test Piles/Production Piles

Test Pile in Leads on BR 1-477
Test Piles/Production Piles

Test Pile being driven on BR 1-477
Completed Test Pile w/ Template BR 1-477
Test Piles/Production Piles

Slickcoat on H-piles at BR1-507
Test Piles/Production Piles

Test Piles being driven BR 1-507
Test Piles/Production Piles

Abutment Production Piles at BR 1-507
Test Piles/Production Piles

Abutment 2 BR 1-475
Test Piles/Production Piles

Abutment 2 BR 1-475
Test Piles/Production Piles

Abutment 2 BR 1-475
Test Piles/Production Piles

Abutment 2 BR 1-475
Conclusions

- Total Bid for the project was ~ $94MM
- Cost for Slickcoat material/application = $53K
- Total cost savings for elimination of settlement monitoring/abutment for 5 bridges = - $40K
- Net savings of only $13K for the project; however…
Conclusions

- By allowing the Contractor to drive the piles 1st and eliminate the quarantine/settlement monitoring period per abutment provided a schedule savings of ~30 days/abutment.

- For 10 abutments on 5 bridges that equates to 300 days of schedule savings.

- This construction sequence also allowed the Contractor to keep the Bridge Crews working continuously without delay adding to the overall efficiency of the project.
Acknowlegdements

• **DelDOT**
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  – Ziaul Hader, PE
  – Bruce Shelly, PE
  – Curt Krhounek, PE
  – Ray Kirchner, PE

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  – Tate Cantwell, Res. Eng.

• **R K & K, Inc.**
  – Scott Berkheimer, PE
  – Drew Pavlick, Office Mgr.

• **Allan Myers, Inc.**
  – Travis Kirchner, Proj. Mgr.
Drone Video Footage

https://www.youtube.com/watch?v=rHahgUVpQ9g