US 301 Section 2A

Construction Phase Downdrag Analysis
DelDOT BDM Approach

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

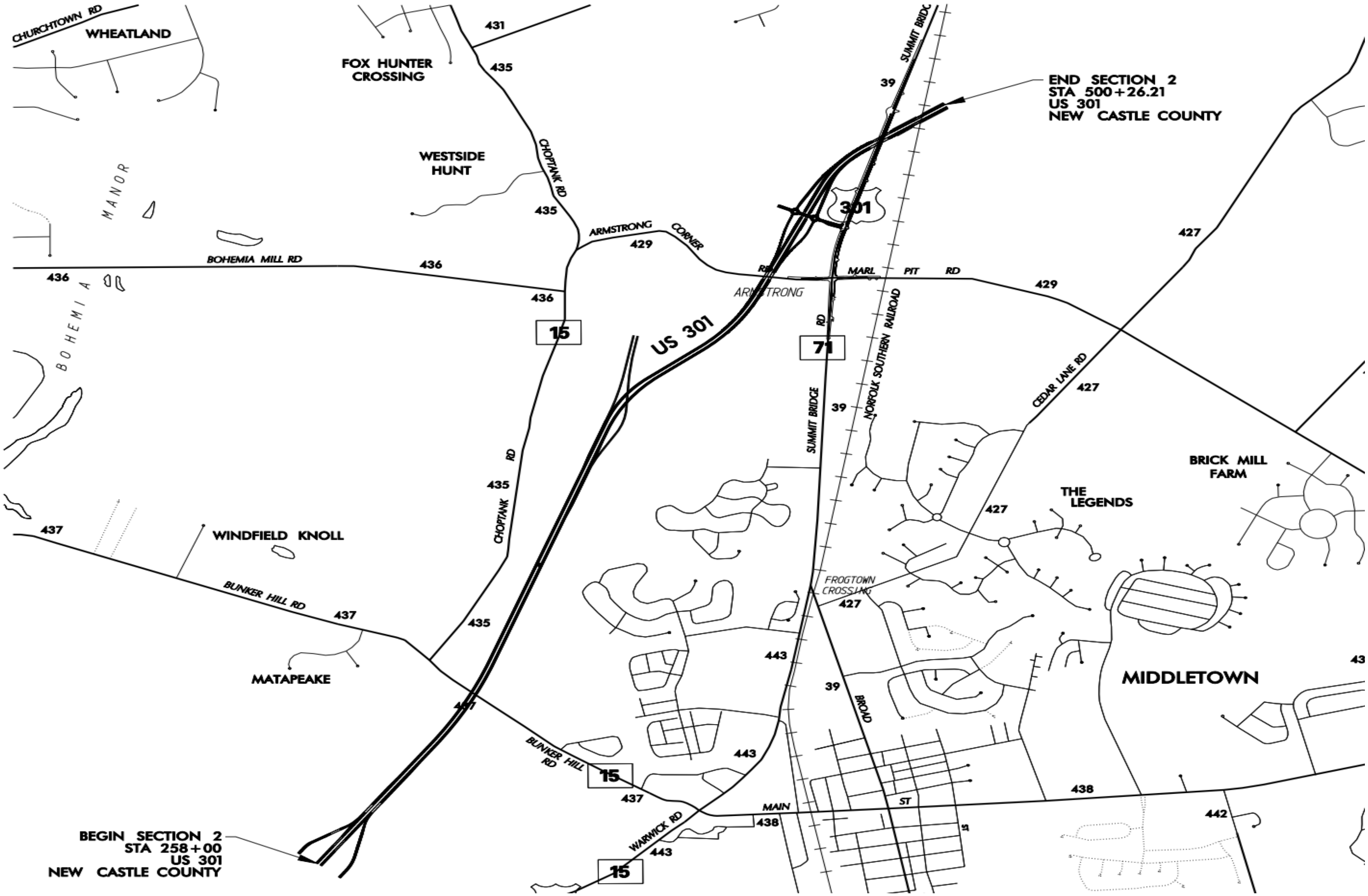
DelDOT

AECOM

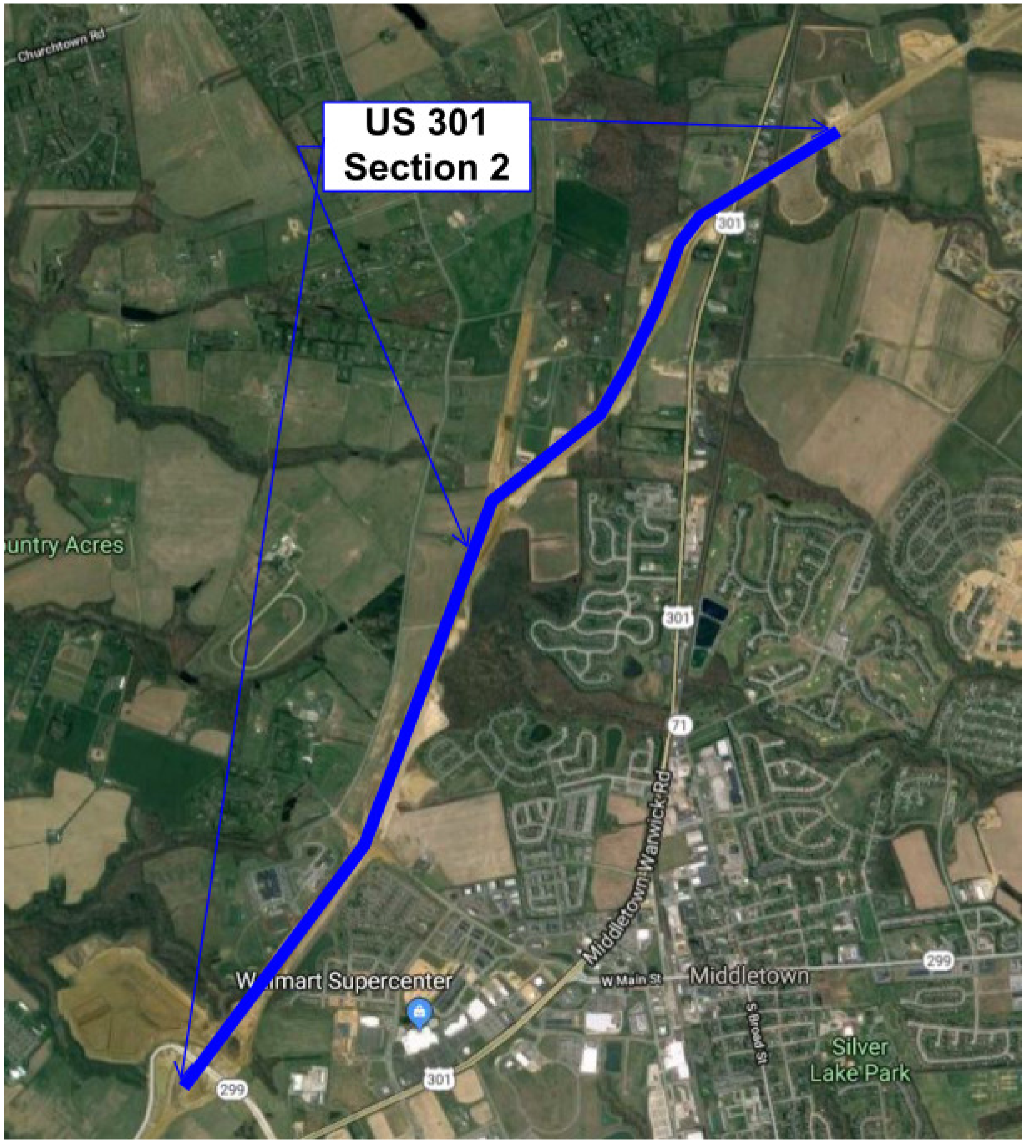
OUTLINE

- Project Background
- Initial Design/Construction Sequence
- Alternate Downdrag Recommendation
- Downdrag Analysis
- Conclusions
- 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

Project Overview

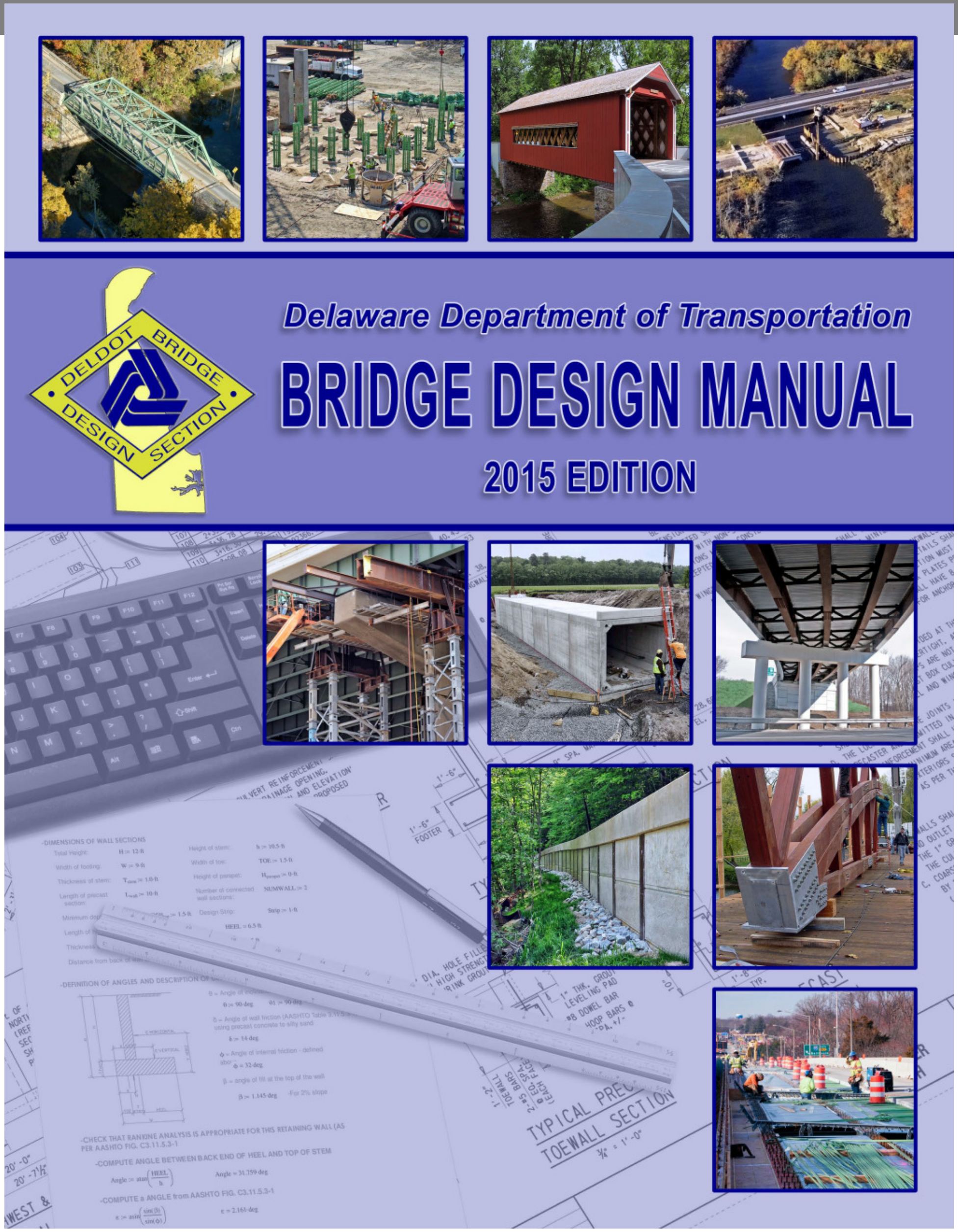
All of the 8 bridge abutments were founded on either PPC or Steel H-Piles driven piles.

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.



Initial Design

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.

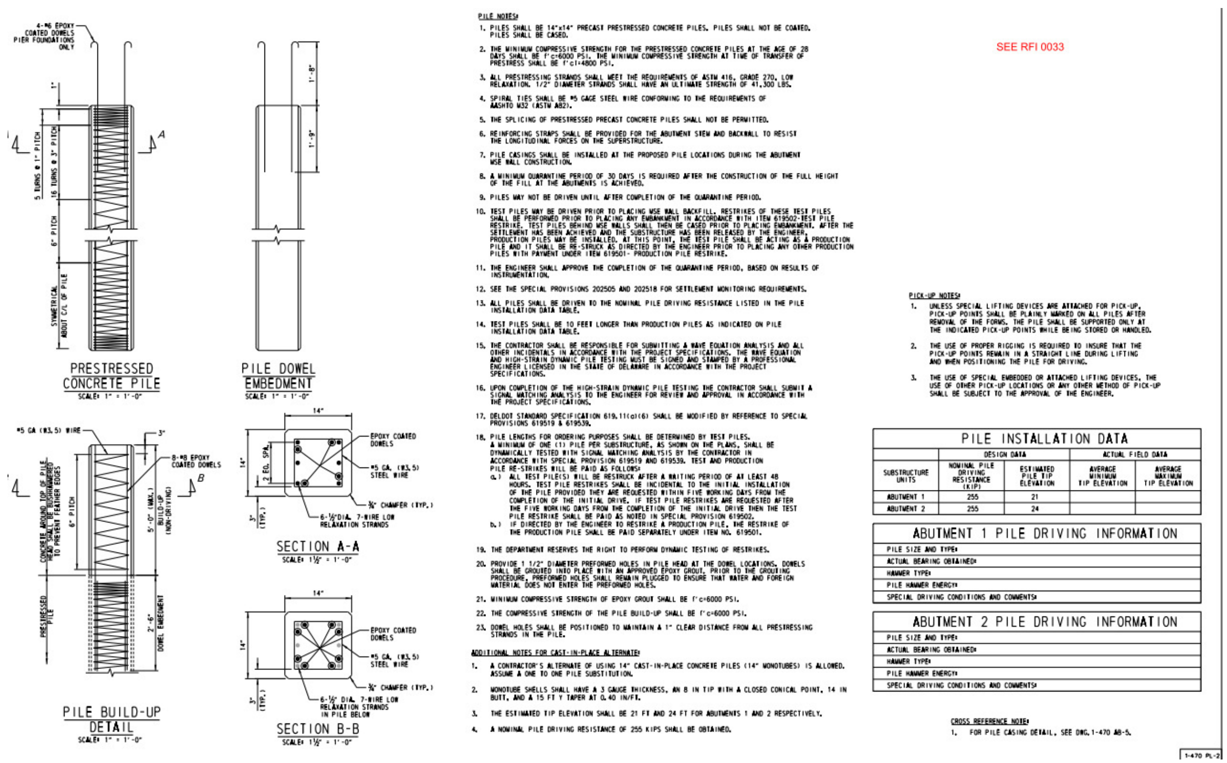
Initial Construction Sequence

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 1st - Drive 2nd 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 1st 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

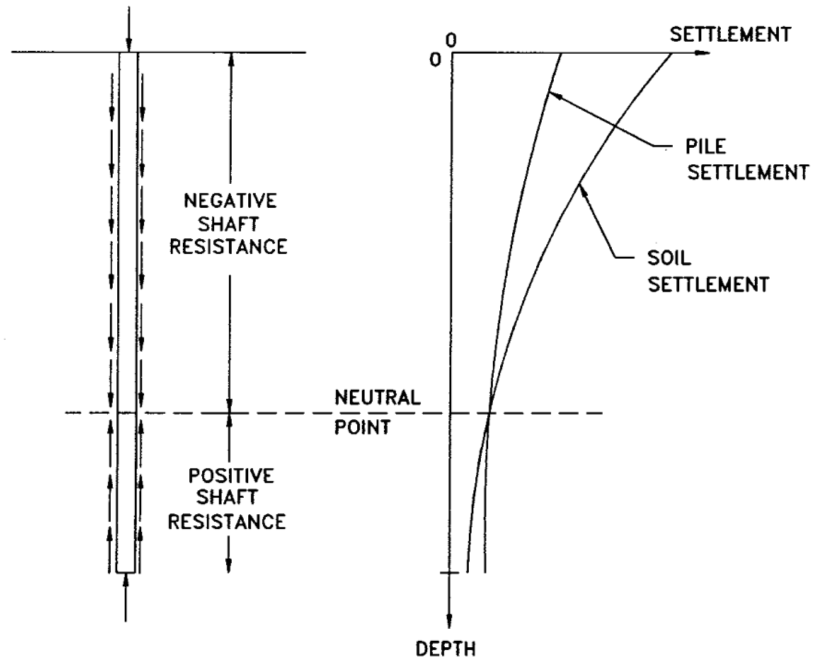
5 of 8 Section 2 bridge structures exhibited a factored DD Load Condition in excess of the Factored Resistance of the piles:

- 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 settlment 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.



Downdrag Analysis

Bridge 1-472 (BR2-3)			
Load Type	Unfactored Load	Applicable Load Factor	
DC Load	112.06	1.25	kip/pile
DW Load	7.79	1.5	kip/pile
LL	28.89	1.75	kip/pile
DD	113.5	1.05	kip/pile
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

Downdrag Mitigation Alternatives

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 <u>can be achieved without over-stressing the piles</u>, 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 252l) shall be used for the bitumen coating and shall have a softening point of l90 to 200 degrees F, a penetration of 56 to 6l at 77^{o}F, and a ductility in excess of 1.4” at 77^{o}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^{o}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*
6,234,720 BI P
6,471,446

Driven Piles

Shaft Casings

Sheet Piling

Friction Reducer

Designer estimated the extent of the Slickcoat.

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

BR 1-470 Slick-Coat Extent			
Note: all dimensions in feet			
ABUTMENT 1	BPCE NB	BPCE SB	TLPE
	78	80	62
ABUTMENT 2	BPCE NB	BPCE SB	TLPE
	80.25	81.5	61
Stick-up	NB Abutment 1	SB Abutment 1	
	16	18	
	NB Abutment 2	NB Abutment 1	
	19.25	20.5	
	Northbound	Southbound	
Pile Embedment in pile cap	1	1	
Starting Depth of Slick-coat	17	19	
Downdrag extent	10	10	
Ending Depth of Slick-coat	27	29	

Friction Reducer

Test Piles

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

DELAWARE DEPARTMENT OF TRANSPORTATION

CONTRACT: T200911303	F.A.P. No. NH-2015(23)	DATE 6-21-2016

DESIGNER'S TEST PILE RECORD

FOUNDATION FOR BR. # 1-477

CONTRACTOR Allan Myers, Inc.	TYPE OF PILE: Precast Concrete
FOOTING DESCRIPTION Abutment 2; Southbound	TIP DIAM. 14 inch BUTT DIAM. 14 inch
PILE NO. TP 77	PROPOSED TEST PILE LENGTH 64 FT RATE OF PILE BATTER IF APPLICABLE N/A
PILE HAMMER MAKE ICE ; MODEL I-30v2	BOTTOM OF FOOTING ELEVATION EL 37 (+1.0 ft embedment)
NOMINAL BEARING 400 Kips	MINIMUM PILE TIP ELEVATION REQUIRED EL -11.0
	TIP ELEVATION ACHIEVED (REMEMBER TO CORRECT IF BATTERED) EL -12

INFORMATION FROM CONTRACTOR'S WAVE EQUATION SUBMITTAL

PREDICTED BLOWS PER FOOT TO ACHIEVE BEARING 34	PREDICTED TIP ELEVATION TO ACHIEVE BEARING EL -16
PREDICTED CAPACITY AT FINAL TIP ELEVATION 400 Kips	PREDICTED STROKE HEIGHT TO ACHIEVE BEARING 7.25 ft
MAXIMUM ALLOWABLE STRESSES IN THE PILE (TENSION) 1,038 psi	PILE CUSHION TYPE: Plywood AND THICKNESS: 10 inch
MAXIMUM ALLOWABLE STRESSES IN THE PILE (COMPRESSION) 4,290 psi	

INFORMATION FROM PDA DURING DRIVING

BLOWS PER FOOT AT END OF DRIVING 54	CAPACITY AT END OF DRIVING 525 Kips
BLOWS IN LAST 4 INCHES OF DRIVING ________	STROKE HEIGHT AT END OF DRIVING 10.7 - 11.2 ft.
RECORDED MAXIMUM STRESSES (TENSION) IN THE PILE 490 psi	
RECORDED MAXIMUM STRESSES (COMPRESSION) IN THE PILE 4,190 psi	

TEST PILE RESTRIKE INFORMATION

RESTRIKE STROKE HEIGHT OF HAMMER N/A	PILE MOVEMENT AFTER RESTRIKE IN INCHES N/A

INFORMATION FROM CAPWAP ANALYSIS

CAPACITY ESTIMATE FROM REP. BLOW AT THE END OF INITIAL DRIVE: 510 Kips	CAPACITY ESTIMATE FROM RESTRIKE REP. BLOWS: N/A Kips

RECOMMENDATIONS FOR PRODUCTION PILES REPRESENTED BY THIS TEST PILE

PRODUCTION PILE ORDER LENGTH 58 LF	MINIMUM STROKE HEIGHT REQUIRED 9.5 ft
BLOWS PER FOOT REQUIRED TO ACHIEVE BEARING 54 blows/ft	MAXIMUM STROKE HEIGHT 11.0 ft

ADDITIONAL COMMENTS / RECOMMENDATIONS

- Recommended production pile order length is 58 feet for both plumb and batter piles
- Minimum tip remains as designed at EL -11.0. The tip is critical and should be achieved unless the pile reaches refusal.
- Operate the hammer at fuel setting 2 for all piles in this footing
- Use a new 10 inch thick pile cushion for every pile. Replace the cushion if 1,000 blows are reached on an individual pile, or if excessive deterioration is witnessed.
- Achieve a minimum of 54 blows per foot in the last foot of driving with a minimum hammer stroke height of 9.5 feet. Maximum stroke height should be limited to 11.0 feet so that the pile is not overstressed
- Refusal is defined as 120 blows/foot or 10 blows/inch should that occur during driving. 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.
- Slickcoat coating shall be applied to only the plumb piles, starting 5 feet below the top of the pile for a length of 20 feet, stopping 25 feet below the top of the pile.

Approx. Ground EL 42.00	Projected Final plumb pile length: (EL 38) - (EL -13.0) = 51 ft
Test Pile Driven Length: 56 ft	Projected batter pile length: 52.6 ft
Test Pile Tip EL achieved: EL -12	Recommend 58 ft. for production pile order length to account for variability

Based upon adding 50% of the skin friction estimated from the PDA results between EL. 37 and EL. 17 to the strength load to account for downdrag, the required Nominal Capacity is 526 kips for Abutment 2 SB. Based upon the dynamic test results for Abutment 2 SB, the plumb and battered piles should be installed to estimated tip elevation of -13 with a minimum final penetration resistance of 54 blows/foot 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

Test Piles/Production Piles

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 continously without delay adding to the overall efficiency of the project.**

Acknowledgements

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  - Scott Berkheimer, PE
  - Drew Pavlick, Office Mgr.

- **Allan Myers, Inc.**
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QUESTIONS?

Drone Video Footage

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