IMPLEMENTATION OF COMPOSITE PAVEMENT SYSTEMS

VDOT SMA/CRCP Composite Pavement Construction Project: U.S. 60 WB

Prepared By:

Applied Pavement Technology, Inc.
115 West Main Street, Suite 400
Urbana, IL 61801
217-398-3977
www.appliedpavement.com

applied pavement TECHNOLOGY

March 2019

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Arturo Espinoza-Luque & Kurt D. Smith
Applied Pavement Technology, Inc.
115 West Main Street, Suite 400
Urbana, Illinois 61801

Shabbir Hossain
Virginia Transportation Research Council
Virginia Department of Transportation
530 Edgemont Road
Charlottesville, VA 22903

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Applied Pavement Technology, Inc.
115 West Main Street, Suite 400
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VDOT SMA/CRCP COMPOSITE PAVEMENT CONSTRUCTION PROJECT: U.S. 60 WB

Introduction

The Strategic Highway Research Program 2 (SHRP2) R21 project, *Composite Pavement Systems*, focused on the design and construction of renewable composite pavements using either a hot-mix asphalt (HMA) wearing course or a portland cement concrete (PCC) surface over an underlying structural concrete layer (i.e., either HMA/PCC or PCC/PCC designs). These composite pavement systems are promising technologies for providing sustainable, long-lasting roadways that can be rehabilitated with minimal disruption to the traveling public.

Under the SHRP2 Implementation Assistance Program (IAP), the Federal Highway Administration (FHWA), working in collaboration with the American Association of State Highway and Transportation Officials (AASHTO), administered a series of activities aimed at fostering the implementation of composite pavement systems:

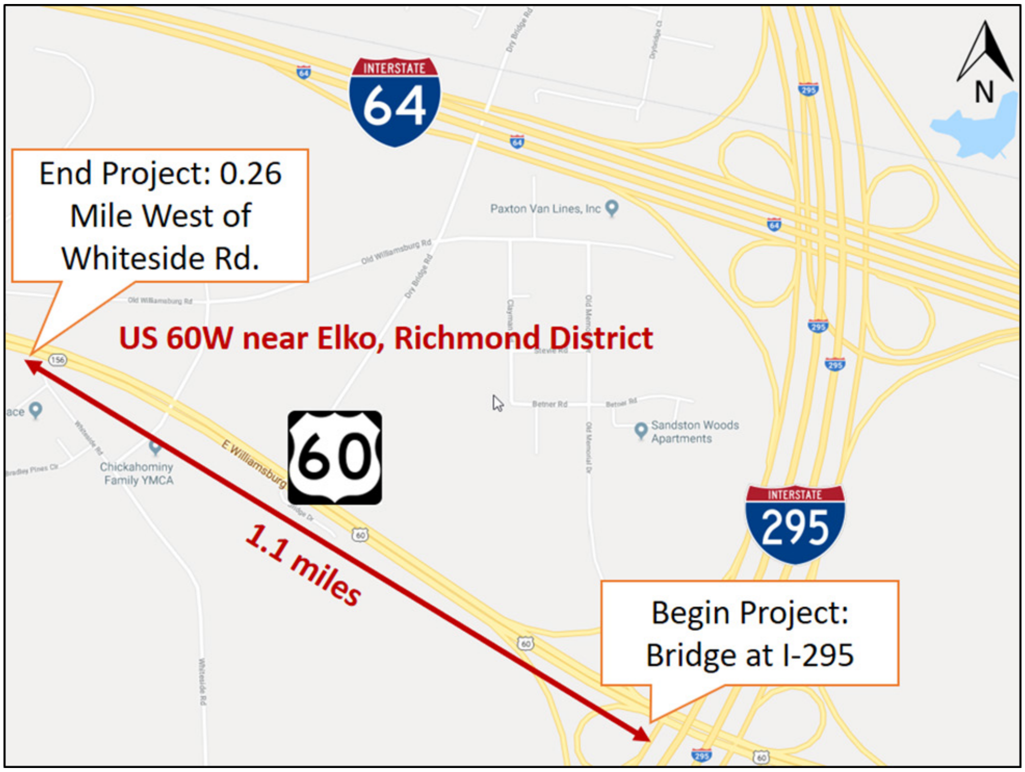
- Provision of technical assistance and support to State Highway Agencies (SHAs) in the planning, design, and construction of new composite pavement systems.
- Development of a workshop on the design and construction of new composite pavement systems and delivery of that workshop to interested SHAs.
- Sponsorship of a multi-state showcase event promoting new composite pavement systems and featuring a visit to a nearby project.
- Conduct of a multi-state peer exchange providing a forum for SHAs to share their knowledge of and experience with new composite pavement systems.
- Provision of technical outreach through technical presentations on new composite pavement systems at national conferences and events.

As part of this implementation effort, the Virginia Department of Transportation (VDOT) proposed the construction of a new composite pavement structure featuring a stone matrix asphalt (SMA) surface on a new continuously reinforced concrete pavement (CRCP). Based on its exceptional experience with SMA overlays of existing CRCP, VDOT was interested in assessing the long-term performance and overall cost-effectiveness of this new composite pavement, with the expectation that the pavement will require only periodic surface maintenance and renewal to achieve its 30-year design life.

This report documents the design and construction of the new composite pavement as it occurred over a period from July to October 2017.

Project Overview

The composite pavement was constructed in the westbound lanes of U.S. 60 just east of Richmond as part of a larger rehabilitation project. The composite pavement section is about 1.1 mi (1.8 km) long and begins at the west end of the bridge intersecting I-295 and ends just west of Whiteside Road (see figure 1). There are two lanes of traffic in each direction, and the roadway carries an annual two-way average daily traffic (ADT) of 14,000 vehicles, including 6 percent heavy trucks.



Map data ©2017 Google (see Acknowledgments on last page)

Figure 1. Location of U.S. 60 composite pavement section.

The existing section was constructed in 1979, and consisted of an 8-inch (203-mm) CRCP over a 6-inch (152-mm) cement-treated aggregate (CTA) base. The prevailing subgrade soil is an AASHTO classification A-7-6. A pavement evaluation conducted in 2015 revealed significant longitudinal and transverse crack deterioration and indicated the need for reconstruction.

The construction of the composite pavement required the demolition of the old concrete pavement, stabilization of the underlying base, the addition of underdrains, and the placement of the CRCP and SMA surface. The total treated area was approximately 15,600 yd^2 (12,540 m^2).

Pavement Design Considerations

The structural design of the composite pavement section was performed using the AASHTO 1993 design guide (AASHTO 1993). Table 1 presents the inputs by VDOT in the AASHTO 1993 procedure, which are based on VDOT's *Manual of Instructions* (MOI), chapter VI. Using the stated design inputs, a total concrete slab thickness of 8.42 inches (214 mm) was determined.

To obtain the thicknesses for the individual layers of the new composite pavement section, the "AC overlay of JPCP, JRCP, and CRCP" module within the AASHTO Guide was used. The thickness of the CRCP layer was fixed at 8 inches (203 mm) and, since it was new, was assumed to have no damage. The concrete thickness deficiency of 0.42 inches (11 mm) was converted into an equivalent thickness of asphalt concrete using the conversion equation in the AASHTO Guide, yielding an SMA thickness of 2 inches (51 mm). Figure 2 shows a schematic of the final structure, with selected construction plans and design details provided in Appendix A. No special provisions were used in the construction of this project.

Table 1. Inputs used in design of U.S. 60 composite pavement.

Design Variable	Value
No. of lanes (1 direction)	2
Design life	30 years
Lane distribution factor	90%
Directional factor	50%
Design 18-kip (80-kN) ESALs	5,306,300
Initial serviceability	4.5
Terminal serviceability	2.9
PCC modulus of rupture (S'c)	650 lb/in^2
PCC elastic modulus	4,000,000 lb/in^2
Mean effective k-value	196 lb/in^2/in
Reliability level	90%
Overall standard deviation	0.39
Load transfer coefficient (J)	2.6
Drainage coefficient (C_d)	1

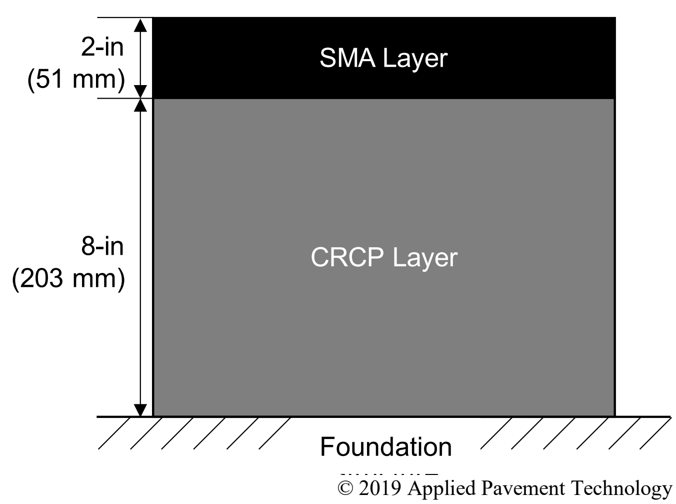


Figure 2. Schematic of the SMA/CRC composite section on U.S. 60 WB.

Concrete Mix Design

The concrete mix design for the CRCP layer is shown in table 2. The design modulus of rupture for the concrete mix was 650 lb/in^2 (4.5 MPa).

Table 2. Concrete mixture design used in new CRCP.

Material	Quantity
Cement (lb/yd^3)	451 (Type II)*
Fly Ash, Type F (lb/yd^3)	113*
#57 Stone (lb/yd^3)	1780
Sand (lb/yd^3)	1244
Water (lb/yd^3)	246
Air Entrainment (Sika AEA-14)	Varies
Theoretical unit weight (lb/ft^3)	142
Design w/c	0.44
Design air content (%)	4 – 8
Target slump (inches)	0 – 3

* Total cementitious content was later increased to 658 lb/yd^3 as strengths were not being achieved.

SMA Mix Design

Important properties for the SMA layer of the composite pavement are shown in table 3. The mix design includes 10 percent reclaimed asphalt pavement (RAP).

Table 3. Properties of SMA used in surface layer.

Property	Value
Nominal Maximum Aggregate Size, NMAS (mm)	12.5
PG Grade	64E-22
Binder Content (%)	7.0%
Voids in Mineral Aggregate, VMA (%)	18.0%
Voids Total Mix, VTM (%)	3.3%
Voids in Coarse Aggregate, VCA (%)	42.1% (dry rodded)
RAP (%)	10
Cellulose Fiber (%)	0.30
Moisture resistance additive (%)	0.30 (Zycotherm)
Passing #200 sieve (%)	9.2

Construction Process

The construction of the composite pavement project on U.S. 60 is presented in the following sections. The construction activities included the demolition of old concrete pavement, treatment of the foundation material, placement of the CRCP, and the laydown of the SMA layer. The project construction took place between June and October 2017.

Concrete Demolition

The first step in the construction process involved the demolition and removal of the existing 8-inch (203 mm) CRCP. A guillotine breaker was used to fracture the concrete and then the steel was recovered before the material was hauled from the project site. Figure 3 shows the concrete broken up on grade.

Figure 3. Broken up PCC on grade.

Foundation Preparation

After removal of the old concrete, the underlying CTA exhibited some pumping issues, particularly at the east end near the bridge. As a result, a series of undercuts were made in this area to various depths of up to 15 inches (381 mm) and replaced with a combination of No. 3 and No. 21A materials, with some use of geogrids. Further west, an area received 12 inches (305 mm) of lime stabilization. Overall, only three areas of the CTA were left in place.

After removal of the old concrete, the underlying CTA exhibited pumping issues over most of the project area. As a result, a series of undercuts were made in these areas to various depths of up to 15 inches (381 mm) and replaced with No. 21A aggregate materials over a tri-axial geogrid. Overall, only a few areas of the CTA were left in place. Because of heavy rain and continuous pumping, these new 21A fills and old CTA were stabilized in-place with 4 percent cement using a full-depth reclamation process. Further west, an area of about 1000 ft^2 (93 m^2) received 12 inches (305 mm) of lime stabilization and 15-inches (381 mm) of 21A aggregate.

Steel Reinforcement Placement

The two-lane project was placed one lane at a time. This included the layout of the steel reinforcement, which allowed for improved lateral access during the paving operations. The CRCP contained longitudinal reinforcement consisting of Grade 60 No. 5 steel bars placed on 6-inch (152 mm) centers. The bars were placed longitudinally in a skewed pattern such that they did not terminate on the same plane (see figure 4), with the coupling bars overlapping a minimum of 16 inches (406 mm). Transverse reinforcement consisted of Grade 60 No. 4 steel bars spaced on 36-inch (914 mm) centers. The steel was supported by longitudinal chairs and placed such that the mid-point of the longitudinal steel was 4 inches (102 mm) above the grade.

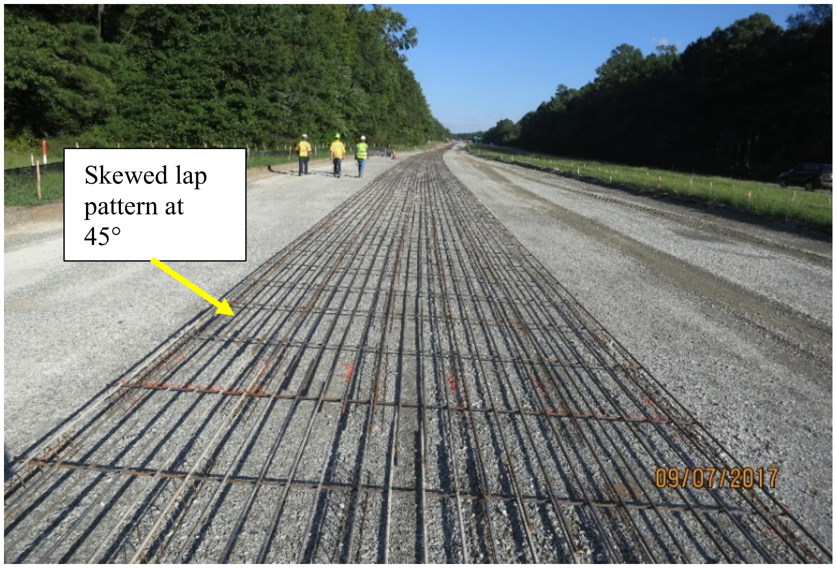


Figure 4. Layout of reinforcing steel, single lane.

Tie bars were used in the longitudinal construction joint between the two adjacent paving lanes but the tie bars were installed post-paving by drilling them into the hardened concrete of the first lane prior to the paving of the second lane. The tie bars were Grade 40 No. 5 bars that were 30 inches (762 mm) long and placed at 30-inch (762-mm) intervals along the length of the longitudinal construction joint.

At the east end of the project and just west of the bridge over I-295, an existing anchor lug terminal joint system was salvaged and used in the construction of the new CRCP. The new concrete was doweled into the bridge approach slab and then two heavily reinforced jointed panels with dowel bars were constructed before leading into the anchor lug system (see figure 5). At the west end of the project, the new CRCP transitions to an existing CRCP. The steel in the existing CRCP was exposed and the new CRCP tied into it.

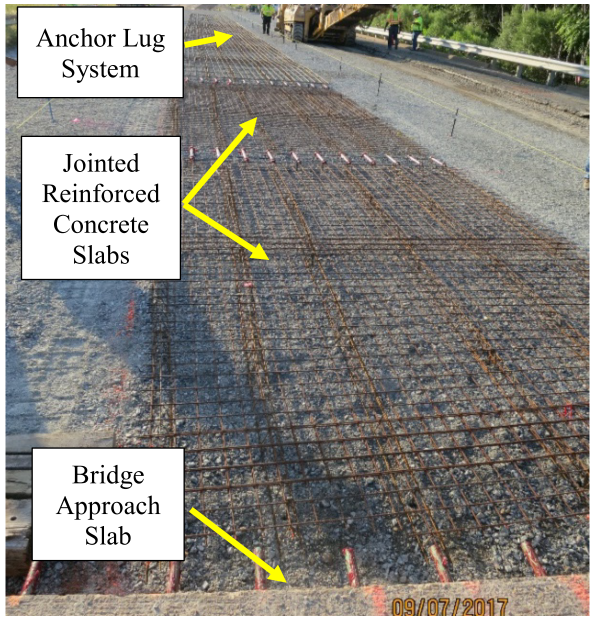


Figure 5. Transition slabs between bridge and new CRCP at project east end.

Concrete Paving

Concrete was produced at the Powhatan Ready Mix Plant (see figure 6) in the Bryan Park area of Richmond, a distance of approximately 17 miles from the project site. The concrete was transported to the project via end-dump trucks, and a Gomaco RTP-500 belt placer for delivery on grade. A Wirtgen SP25i slipform paver was used to place the concrete and also provided surface texturing with a burlap drag affixed at the aft of the machine. The concrete was cured with a Dayton-Superior white cure at a rate of 100 to 150 ft^2 per gallon (2.5 to 3.7 m^2 per liter). The driving (right) lane was paved between September 7 and September 15, and the passing (left) lane was paved between September 21 and September 28. Figure 7 shows different aspects of the concrete paving process, with additional photos provided in Appendix B.

Figure 6. Powhatan Ready Mix plant.

a. Mix delivery.

b. Paving operation.

c. Finishing work.

d. Final paved lane.

Figure 7. Placement of CRCP.

SMA Paving

Before the asphalt paving commenced, a test strip was first constructed on October 5 to establish the roller pattern. After that was determined, the SMA was placed in two separate paving events, with the passing (left) lane paved on October 13 and the driving (right) lane paved on October 18. The material was hauled by end-dump trucks and delivered into a Roadtec material transfer vehicle and then transferred to a Caterpillar asphalt paver. A total of 2,550 tons of SMA were placed.

Laydown temperature was specified to be between 200 to 335 °F (93 to 168 °C). The compaction process involved using two smooth drum tandem roller compactors. The vibratory function of the rollers was not used to avoid particle breakage of the SMA aggregate. The specified density target range was between 94 and 98 percent. A tack coat was applied at a nominal rate of 0.05 to 0.06 gallons per yd^2 (0.22 to 0.27 liters per m^2) to ensure bonding between the concrete and asphalt layers. Figure 8 shows photos of the SMA placement operations.

a. SMA paving in driving lane.

b. Compaction with smooth rollers in passing lane.

c. Final pavement surface from east end looking west.

Figure 8. Paving of SMA overlay.

Testing

VDOT performed testing on both the concrete and asphalt paving layers to confirm that the specified properties were being achieved. Table 4 presents some of the testing results that were collected by VDOT.

After the construction of the PCC, but before the placement of the SMA, the concrete surface was visually examined to evaluate the emerging crack pattern. Tight cracks ranging from 0.004 to 0.02 inches (0.1 to 0.6 mm) wide were confirmed at intervals of about 3 to 8 ft (0.9 to 2.4 m), with most of the cracks less than 0.008 inches (0.2 mm) wide.

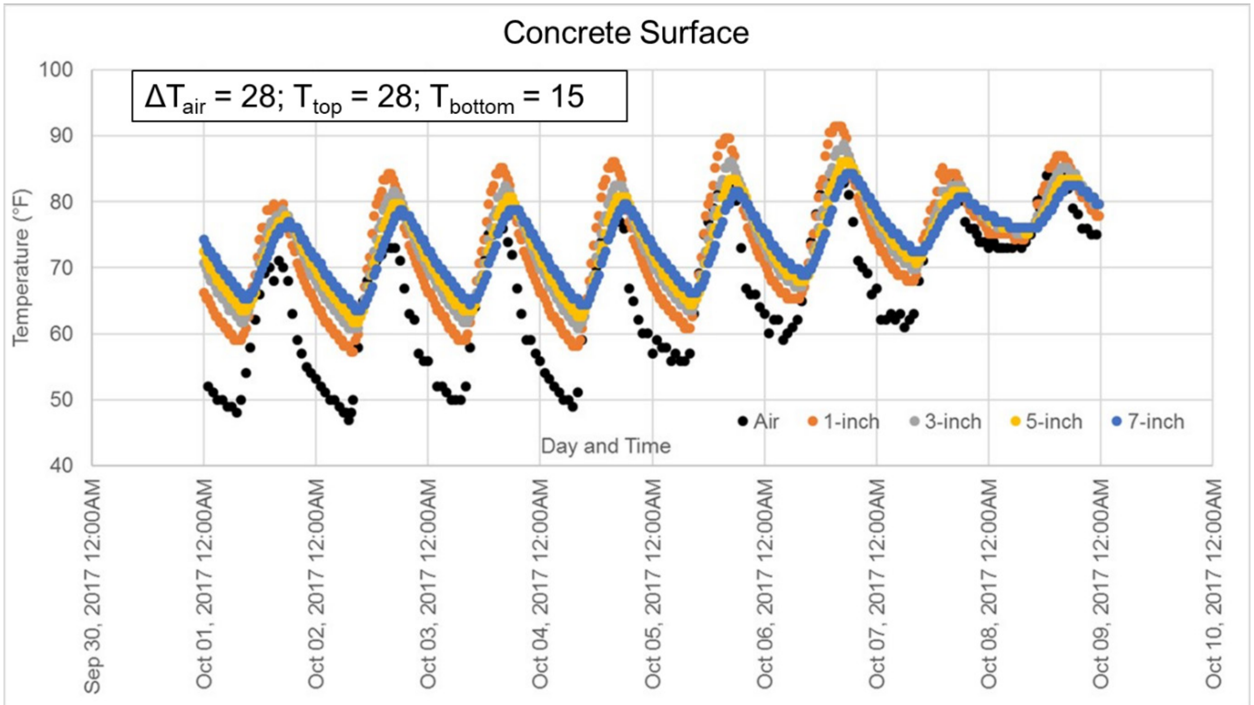
Table 4. VDOT testing results for PCC and SMA.

Property	PCC		SMA	
	Average	Range	Average	Range
Compressive strength (psi) Right lane Left lane	 4,840 4,534	 4,460 - 5,580 4,180 - 4,800	-	-
Slump (in)	1.74	1-2	-	-
Air content (%)	6.26	4-7.9	-	-
Permeability (coulombs)	1,337	1,155 - 1,614	-	-
Asphalt Content (%)	-	-	6.97	6.87 - 7.25
Rice Density	-	-	2.416	2.411 - 2.421
VTM (%)	-	-	3.7	3.6 - 3.8
VMA (%)	-	-	18.2	17.8 - 18.8
VCA_{mix} (%)	-	-	39.3	38.7 - 39.8
Field Density (% of max. density)	-	-	-	95.0 - 97.1
Core Thickness (inches)	8.58	8.00 – 9.125	2.21	2-2.5

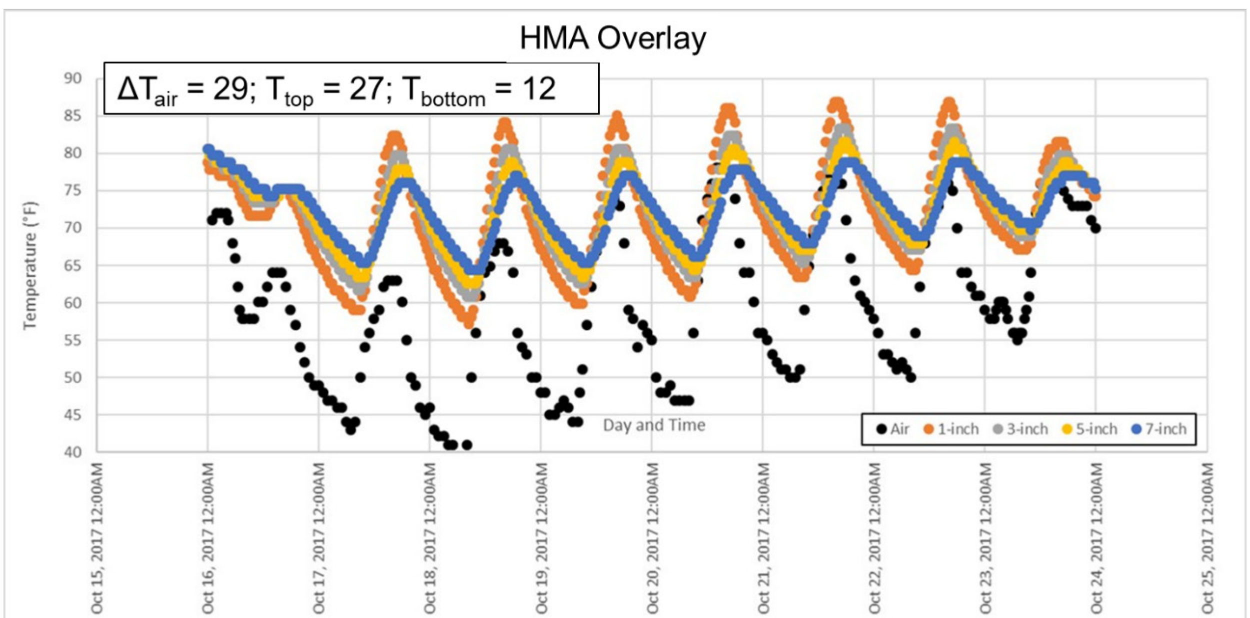
VDOT monitored the air and slab temperatures versus depth and time for the project after paving, as shown in figure 9 (Hossain 2017). Prior to the asphalt placement (top graph), the top of the concrete slab (1 inch [25 mm] below the concrete surface) experienced a temperature swing of up to 28 °F (16 °C) while the bottom of the slab (7 inches [178 mm] below the concrete surface) experienced a temperature swing of up to 15 °F (8 °C). Following the placement of the HMA surface layer, the top of the concrete slab showed a temperature swing of up to 27 °F (15 °C) but the bottom of the concrete slab only experienced a swing of up to 12 °F (7 °C), indicating the insulation capability of the HMA. This lower temperature gradient significantly reduces slab curling and associated stresses.

VDOT collects smoothness data as an incentive/disincentive pay item. The overall roadway received a bonus, with average roughness readings (expressed in terms of the International Roughness Index, IRI) of 55 and 58 inches/mi (0.87 and 0.92 m/km) in the driving and passing lanes, respectively. Most 0.01-mi (0.16-km) sections received a bonus of either 10 percent (for IRI values IRI between 55.1 and 65 in/mi [0.87 and 1.03 m/km]) or 15 percent (for IRI values of 55 in/mi [0.87 m/km]) or less. Only a few sections received a disincentive, mostly in the range of 80.1 to 90 in/mi (1.26 to 1.42 m/km), although one section exhibited an IRI value of 122 in/mi (1.93 m/km).

To assess the long-term performance of the composite pavement, the VDOT plans to carry out periodic evaluations including visual inspections to monitor distress development, falling weight deflectometer (FWD) to test the structural integrity, and assessment of the temperature profile in the pavement by monitoring the sensors embedded in the concrete layer.



a) Bare CRCP



b) After HMA overlay placement

Figure 9. Temperature differentials in HMA/PCC composite pavement (Hossain 2017).

Summary

The rehabilitation project on the westbound section of US 60 included the construction of new composite pavement that featured an underlying 8-inch (203-mm) CRCP topped with a 2-inch (51-mm) SMA surface. Based on its exceptional experience with SMA overlays of existing CRCP, VDOT was interested in assessing the long-term performance and overall cost-effectiveness of this new composite pavement, with the expectation that the pavement will require only periodic surface maintenance and renewal to achieve its 30-year design life. Table 5 provides a brief summary of key project information.

Table 5. U.S. 60 composite pavement project information.

Item	Details
General Project Information	• SMA over CRC composite pavement. • Location: US 60 WB, between bridge overpass of I-295 and Whiteside Road. • Length: 1.15 miles
Pavement Design and Materials Information	• Design Life: 30 years • 8-in CRCP − Longitudinal reinforcement: 24 Grade 60 # steel bars, per lane − Transverse reinforcement: #4 steel bars spaced 30-in • 2-in 12.5 mm SMA overlay • Base: lime-stabilized CTB, with estimated k-value of 196 psi/in
Construction Information	• Construction Dates: June-October 2017 • Average AADT: 14,140 vpd (with 6% trucks) • Required activities: removal of old-CRCP, stabilization treatment, concrete paving, and asphalt overlay

Some of the key takeaways from the construction of this composite pavement project are as follows:

- The existing concrete pavement, built in 1979, exhibited a significant amount of deterioration, including transverse and longitudinal cracking, punchouts, and patching. The section exhibited significant roughness levels in excess of 200 in/mi (3.16 m/km).
- The VDOT had experienced good performance using an SMA overlay on existing CRCP designs. By placing an SMA surface on a newly constructed CRCP section, VDOT anticipates that the concrete will never deteriorate to the point of needing repair, leaving the maintenance requirements contained to the top asphalt layer.
- The existing CRCP pavement was demolished and removed. Portions of the underlying foundation were in poor condition and required undercutting, while other portions required lime stabilization.
- The CRCP was constructed one lane at a time to facilitate construction access. The construction of each lane of CRC took approximately 1 week.

- At the east end of the project, an existing anchor lug terminal joint system from the original CRCP was integrated into the new CRCP to avoid pushing against the bridge.
- The final profile of the section showed positive results, with an average IRI of 55 and 58 in/mi (0.87 and 0.92 m/km) in the right lane and left lane, respectively.
- VDOT plans to periodically monitor the performance of the composite pavement in terms of distresses condition, structural soundness, and climatic loading.
- The initial construction cost of the proposed composite pavement is expected to be higher than that of a traditional asphalt over concrete overlay. However, a complete life-cycle cost analysis is needed in order to fully evaluate the cost savings that could be realized from this design approach.

References

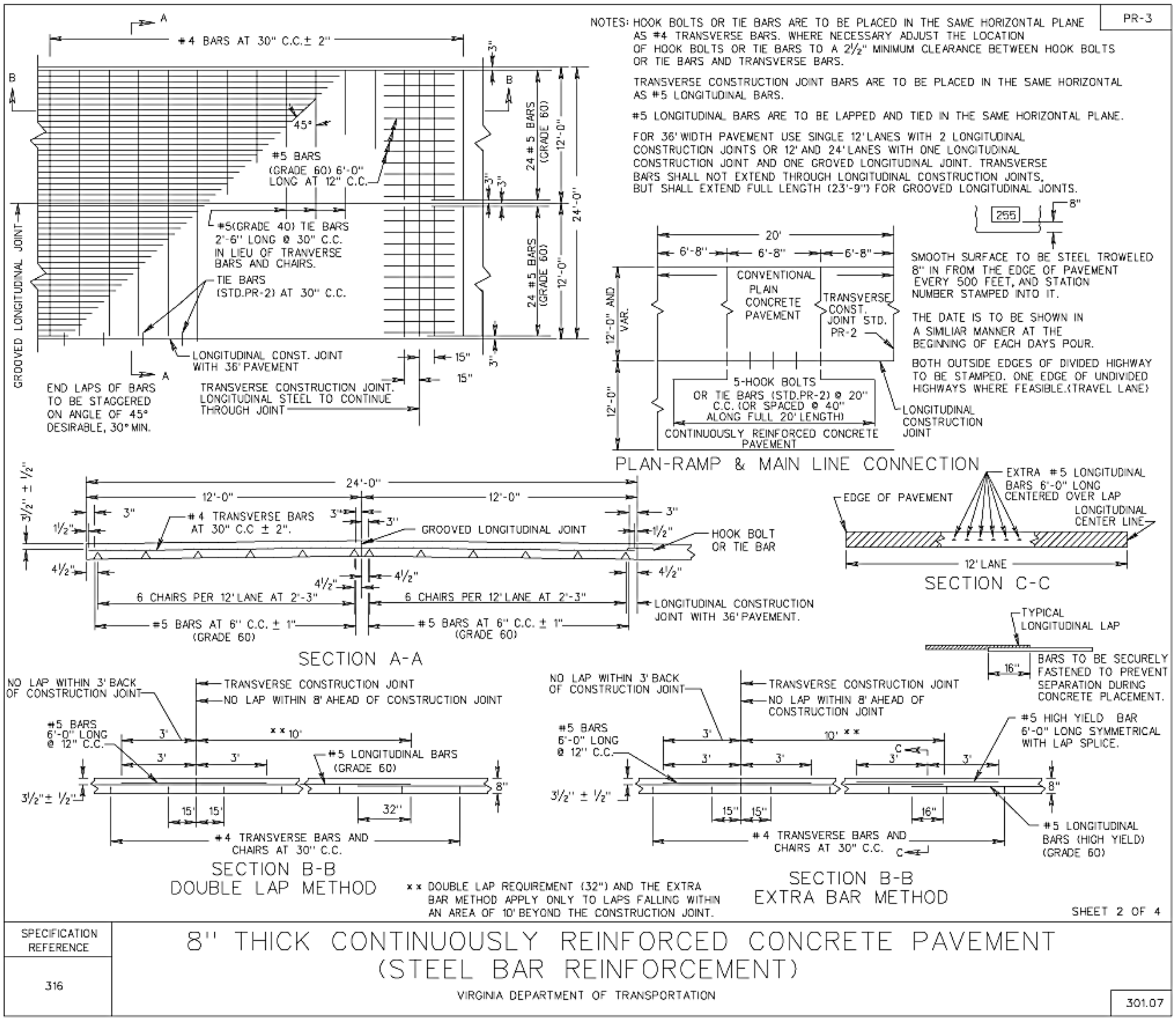
American Association of State Highway and Transportation Officials (AASHTO). 1993. *AASHTO Guide for Design of Pavement Structures*. American Association of State Highway and Transportation Officials, Washington, DC.

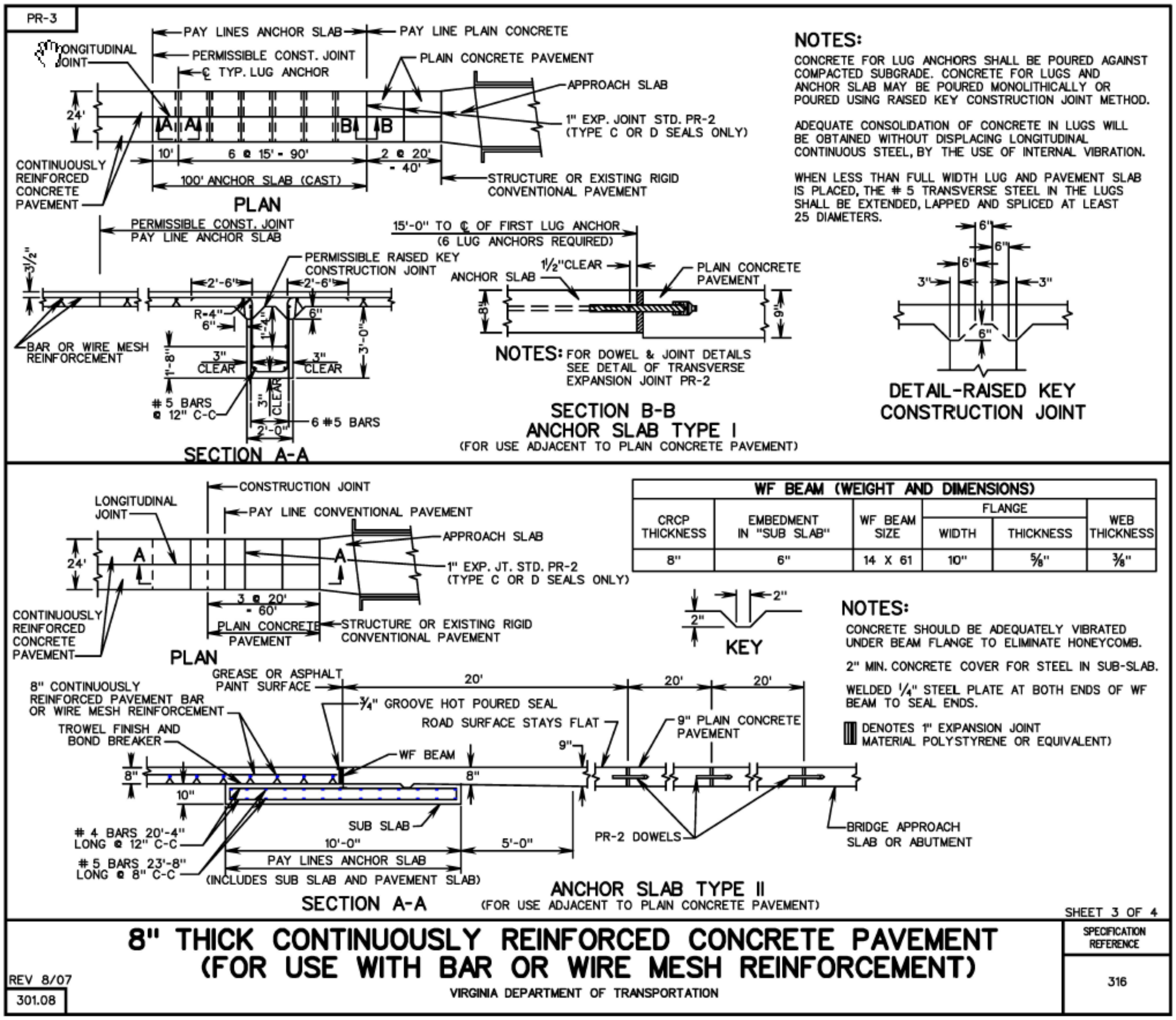
Hossain, S. 2017. "US 60 Composite Pavement Overview." *Technical Presentation*, SHRP2 Project R21 Peer Exchange, Richmond, VA.

Schinkel, T. 2017. "Construction of US 60 Project." *Technical Presentation*, SHRP2 Project R21 Peer Exchange, Richmond, VA.

APPENDIX A – PROJECT PLAN DOCUMENTS

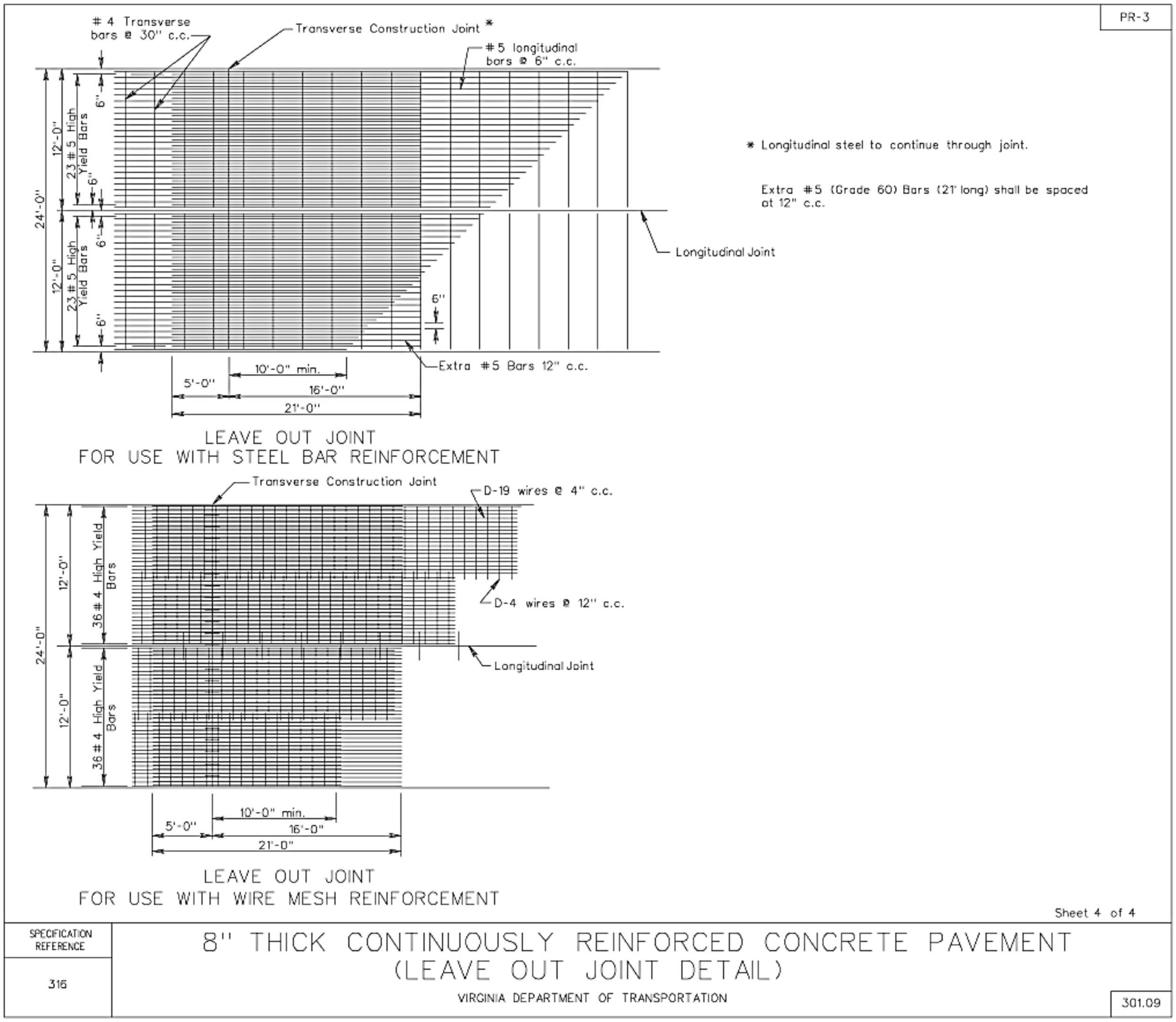
Appendix A plans: © Virginia Department of Transportation

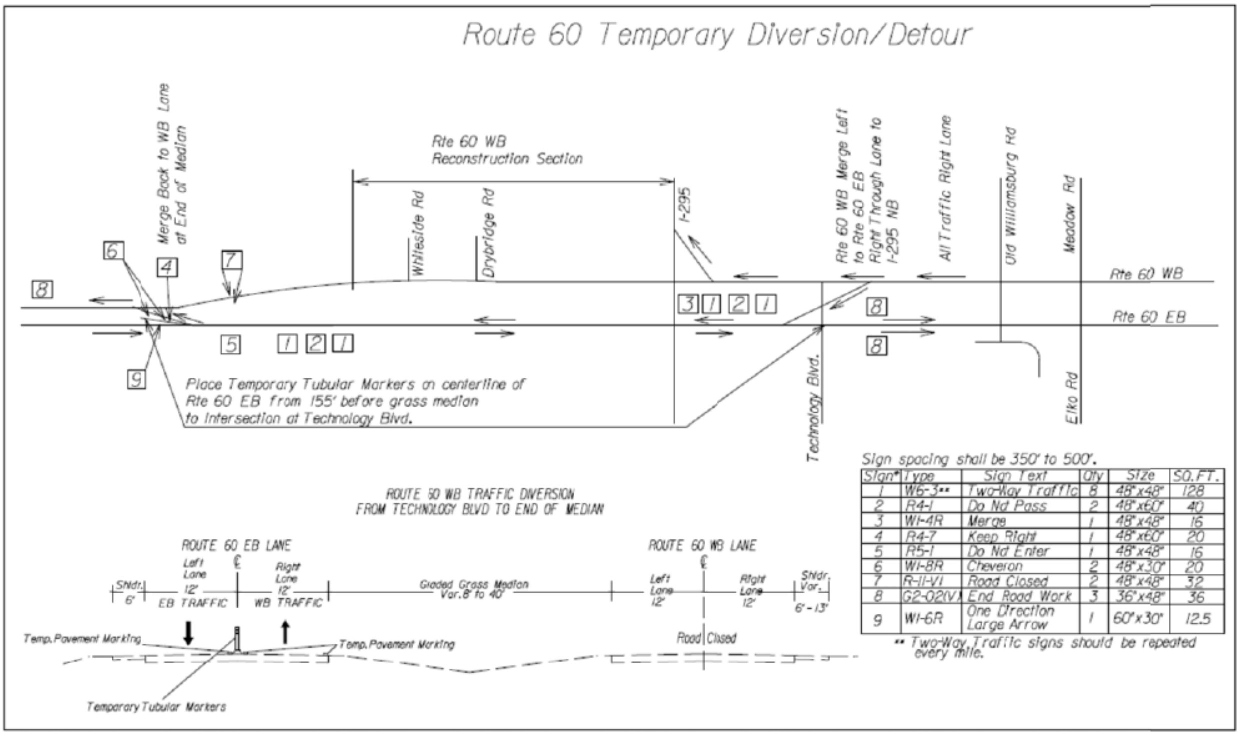




WF BEAM (WEIGHT AND DIMENSIONS)

CRCP THICKNESS	EMBEDMENT IN "SUB SLAB"	WF BEAM SIZE	FLANGE WIDTH	FLANGE THICKNESS	WEB THICKNESS
8"	6"	14 X 61	10"	⅝"	⅜"

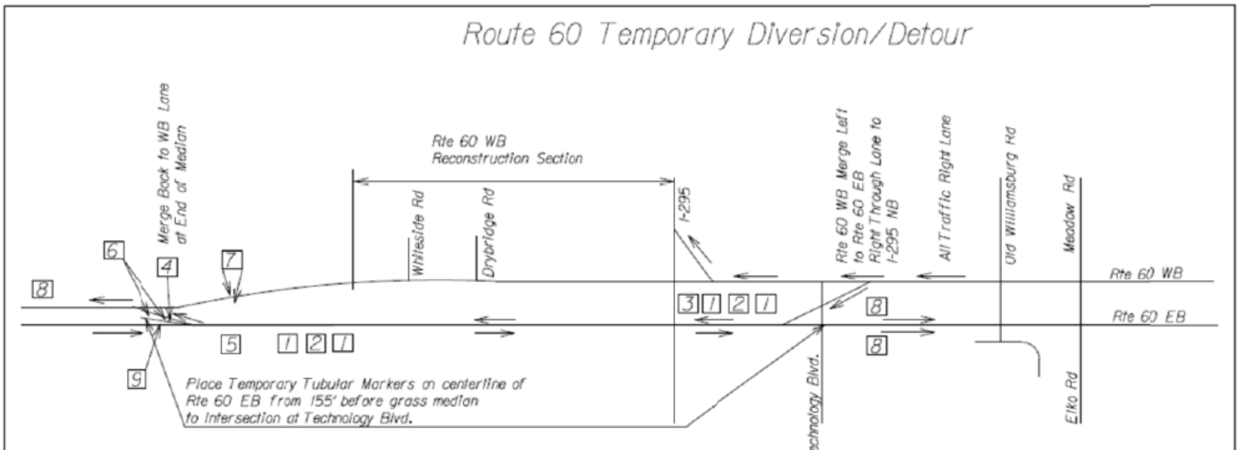

PR-3
4 Transverse bars @ 30" c.c.
Transverse Construction Joint *
5 longitudinal bars @ 6" c.c.
* Longitudinal steel to continue through joint.
Extra #5 (Grade 60) Bars (21' long) shall be spaced at 12" c.c.
Longitudinal Joint
24'-0"
12'-0"
23 # 5 High Yield Bars
6"
Extra #5 Bars 12" c.c.
10'-0" min.
5'-0"
16'-0"
21'-0"
LEAVE OUT JOINT
FOR USE WITH STEEL BAR REINFORCEMENT
Transverse Construction Joint
D-19 wires @ 4" c.c.
D-4 wires @ 12" c.c.
Longitudinal Joint
36 # 4 High Yield Bars
LEAVE OUT JOINT
FOR USE WITH WIRE MESH REINFORCEMENT
Sheet 4 of 4
SPECIFICATION REFERENCE
316
8" THICK CONTINUOUSLY REINFORCED CONCRETE PAVEMENT
(LEAVE OUT JOINT DETAIL)
VIRGINIA DEPARTMENT OF TRANSPORTATION
301.09



Sign spacing shall be 350' to 500'.

Sign*	Type	Sign Text	Qty	Size	SQ.FT.
1	W6-3**	Two-Way Traffic	8	48"x48"	128
2	R4-1	Do Not Pass	2	48"x60"	40
3	W1-4R	Merge	1	48"x48"	16
4	R4-7	Keep Right	1	48"x60"	20
5	R5-1	Do Not Enter	1	48"x48"	16
6	W1-8R	Cheveron	2	48"x30"	20
7	R-11-V1	Road Closed	2	48"x48"	32
8	G2-02(V)	End Road Work	3	36"x48"	36
9	W1-6R	One Direction Large Arrow	1	60"x30"	12.5

** Two-Way Traffic signs should be repeated every mile.



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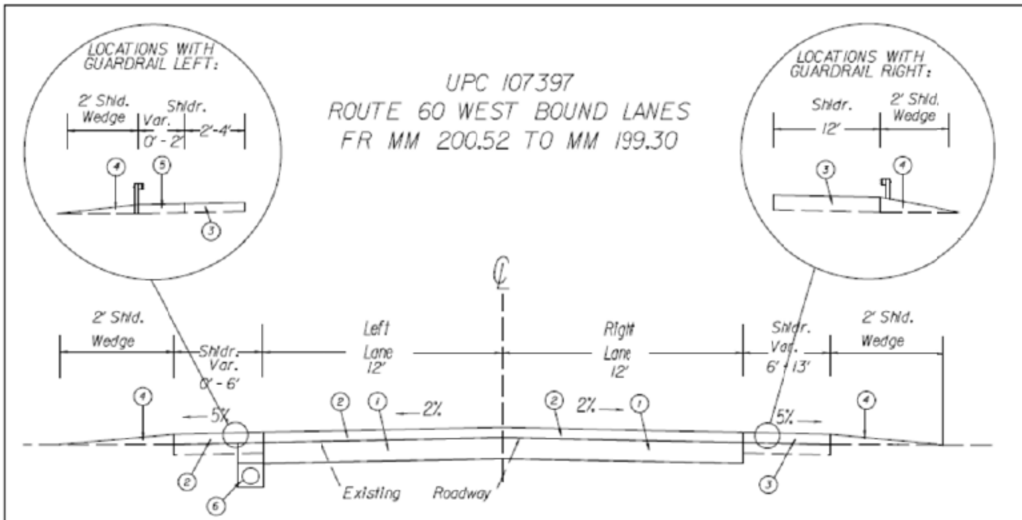

1. REMOVE EXISTING CONCRETE PAVEMENT AND REPLACE WITH 8" CONT.REINF.HYDRAULIC CONC. PAVEMENT. USE AGGREGATE 21A OR 21B TO FILL VOIDS WITHIN EXISTING CTA CREATED BY REMOVAL OF EXISTING CONCRETE (4" FOR ESTIMATING PURPOSES)
2. 2" ASPHALT CONC TY SMA-12.5 (76-22 OR 64E) @ 220 lbs/SY.
3. 2" ASPHALT CONC TY SM-12.5A @ 220 lbs/SY.
4. TIE IN SHOULDERS WITH AGGR.BASE TY 21A or 21B STONE SHOULDER WEDGE (12:1 SLOPE MAX)
5. 2" AGGR.BASE TY 21A or 21B STONE ON GRADED SHOULDER TO FACE OF GUARDRAIL
6. PLACE UNDERDRAINS UD-7s AND OUTLET PIPES, AND ENDWALLS EW-12s. SEE UNDERDRAIN UD-7 DETAIL FOR PROPOSED UNDERDRAIN PLACEMENT.

**FOR PAVEMENT APPROACH SLAB LOCATIONS, SEE TYPICAL DETAIL FOR PAVEMENT APPROACH SLAB.
**FOR TURN LANES AT DRYBREAD ROAD AND WHITESIDE ROAD, PATCH AS DIRECTED BY THE ENGINEER AND OVERLAY WITH 2" ASPHALT CONC.TY.SMA-12.5 (76-22 OR 64E) @ 220 LBS/SY.
**RESEAL JOINTS ALLONG ALL JOINTED CONCRETE PAVEMENT LOCATIONS WITH TYPE B CRACK SEALANT/FILLER.

Not To Scale

APPENDIX B – CONSTRUCTION PHOTOS

Photo B-1. Condition of old pavement.

Photo B-2. Demolition process.

Photo B-3. Transverse reinforcement spacing.

Photo B-4. Longitudinal reinforcement spacing.

Photo B-5. Layout of steel reinforcement.

Photo B-6. Reinforcement depth.

Photo B-7. West end of the project.

Photo B-8. East end of the project looking west.

Photo B-9. Temperature logging sensors installed in slab.

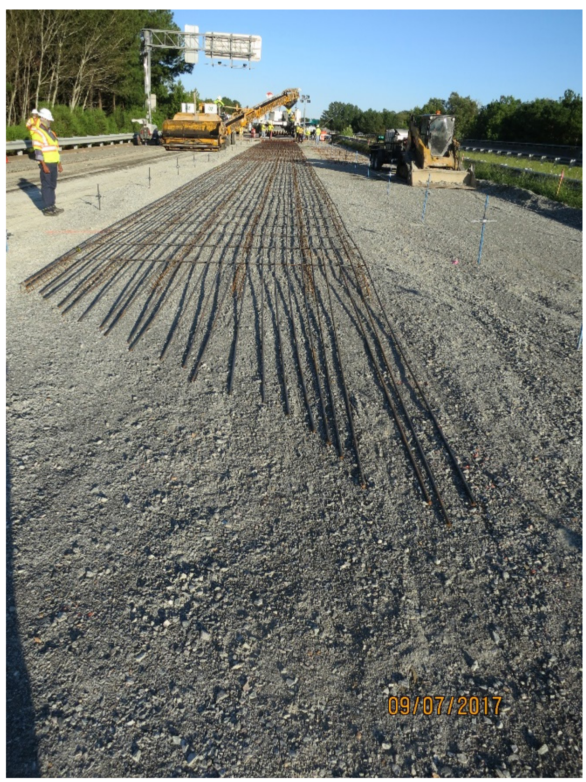

Photo B-10. Steel leave-out area to provide access.

Photo B-11. Concrete paver.

Photo B-12. Existing anchor lugs.

Photo B-13. Anchor lug close-up.

Photo B-14. Dowel bar placement in transition slabs near east end of project.

Photo B-15. Initial concrete delivery.

Photo B-16. East end of project at bridge approach slab.

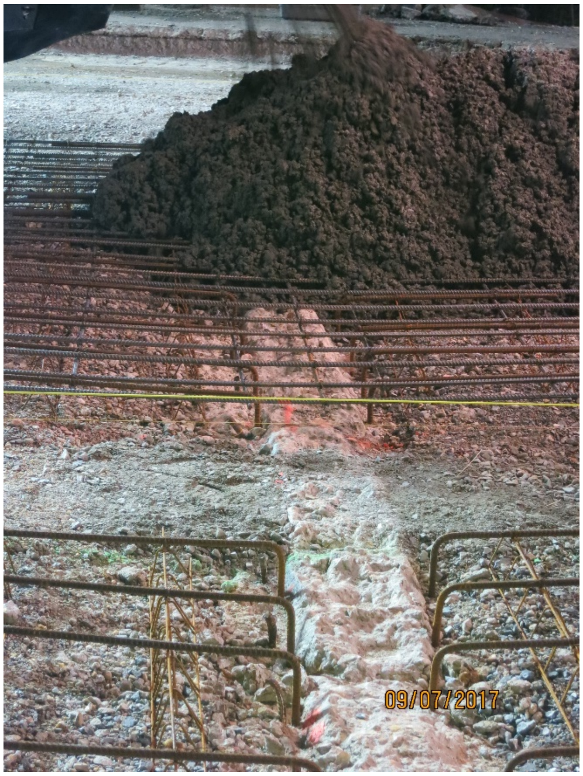

Photo B-17. Material delivery at existing anchor lug.

Photo B-18. Burlap drag finishing.

Photo B-19. Finished concrete surface.

Photo B-20. Asphalt paving operation.

Photo B-21. Asphalt compaction operation.

Photo B-22. Final surface view of the composite pavement.

ACKNOWLEDGMENTS

The original map on page 2 is the copyright property of Google and can be accessed from https://www.google.com/maps/. The map overlays were developed as a result of this research project. The map overlays include lines showing the project location with a line along Highway 60 pointing to the beginning and end as well as text box inserts with details on the location.