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Use of Concrete Pavement Overlays on U.S. 58 in Virginia

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Abstract:

Asphalt overlays are typically used to extend the life of continuously reinforced concrete pavement (CRCP) because they can be placed in one or more layers while traffic uses the adjacent lane and can be opened to traffic in a short time. Hydraulic cement concrete overlays have also been used to extend the life of CRCP but have often not been considered an alternative to asphalt because of the higher cost and longer curing time.

In 2012, the Virginia Department of Transportation rehabilitated a 4.8-mi section of the westbound lanes of a CRCP on U.S. 58 in Southampton County using a 4-in-thick bonded concrete overlay and a 7-in-thick unbonded concrete overlay with a 1-in asphalt separation layer. The four-lane, divided primary highway is an 8-in-thick CRCP placed over a 6-in cement-treated aggregate layer. Saw cutting was used to form joints at 6 ft by 6 ft panels for an unbonded overlay, and tie bars were used along the centerline of the pavement and along both shoulders. A concrete overlay was placed on the shoulders of the unbonded overlay, and asphalt was placed on the shoulders of the bonded overlay.

Two layers of asphalt with a total thickness of 5 in were placed on a 9.75-mi section of the eastbound lane of U.S. 58, which provided cost information that was used to compare the alternatives. Since traffic management was very different for the two projects, definitive conclusions on the total cost of asphalt versus concrete overlays could not be drawn. On the basis of material costs alone, concrete and asphalt can be competitive options for extending the service life of CRCP.

Construction of the concrete overlays was successfully executed on time. The concrete was of high quality with good strength and low permeability. The bonded overlay is well bonded. The ride quality was much better than for the original pavement. Using the initial cost of materials in-place, the cost of the bonded and unbonded overlays was approximately the same, at an average of $36 to $38 per square yard. The unit cost of patching concrete pavements is approximately 6 times the cost of the bonded concrete overlay and approximately 4 times the cost of an unbonded overlay.

VDOT's Materials Division should consider the use of bonded concrete overlays to extend the life of CRCPs that are in good condition and need little patching ($\leq$10%) prior to placement of the overlay and should consider the use of unbonded concrete overlays as an alternative to patching to extend the life of CRCP that needs more than 10 percent patching. Further, the Materials Division should advertise overlay projects allowing alternate designs using stone-matrix asphalt and hydraulic cement concrete to determine if they are competitive alternatives. VDOT's Traffic Engineering Division should explore innovative traffic management plans for pavement rehabilitation to reduce maintenance of traffic costs.

FINAL REPORT

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Virginia Center for Transportation Innovation and Research
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ABSTRACT

Asphalt overlays are typically used to extend the life of continuously reinforced concrete pavement (CRCP) because they can be placed in one or more layers while traffic uses the adjacent lane and can be opened to traffic in a short time. Hydraulic cement concrete overlays have also been used to extend the life of CRCP but have often not been considered an alternative to asphalt because of the higher cost and longer curing time.

In 2012, the Virginia Department of Transportation rehabilitated a 4.8-mi section of the westbound lanes of a CRCP on U.S. 58 in Southampton County using a 4-in-thick bonded concrete overlay and a 7-in-thick unbonded concrete overlay with a 1-in asphalt separation layer. The four-lane, divided primary highway is an 8-in-thick CRCP placed over a 6-in cement-treated aggregate layer. Saw cutting was used to form joints at 6 ft by 6 ft panels for an unbonded overlay, and tie bars were used along the centerline of the pavement and along both shoulders. A concrete overlay was placed on the shoulders of the unbonded overlay, and asphalt was placed on the shoulders of the bonded overlay.

Two layers of asphalt with a total thickness of 5 in were placed on a 9.75-mi section of the eastbound lane of U.S. 58, which provided cost information that was used to compare the alternatives. Since traffic management was very different for the two projects, definitive conclusions on the total cost of asphalt versus concrete overlays could not be drawn. On the basis of material costs alone, concrete and asphalt can be competitive options for extending the service life of CRCP.

Construction of the concrete overlays was successfully executed on time. The concrete was of high quality with good strength and low permeability. The bonded overlay is well bonded. The ride quality was much better than for the original pavement. Using the initial cost of materials in-place, the cost of the bonded and unbonded overlays was approximately the same, at an average of $36 to $38 per square yard. The unit cost of patching concrete pavements is approximately 6 times the cost of the bonded concrete overlay and approximately 4 times the cost of an unbonded overlay.

VDOT's Materials Division should consider the use of bonded concrete overlays to extend the life of CRCPs that are in good condition and need little patching ($\leq$10%) prior to placement of the overlay and should consider the use of unbonded concrete overlays as an alternative to patching to extend the life of CRCP that needs more than 10 percent patching. Further, the Materials Division should advertise overlay projects allowing alternate designs using stone-matrix asphalt and hydraulic cement concrete to determine if they are competitive alternatives. VDOT's Traffic Engineering Division should explore innovative traffic management plans for pavement rehabilitation to reduce maintenance of traffic costs.

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INTRODUCTION

For the construction of new pavements, continuously reinforced concrete pavement (CRCP) is considered to be an alternative to asphalt pavement. Traffic control and concrete curing time are not issues in new construction. Asphalt overlays are typically used to extend the life of CRCP because they can be placed in one or more layers while traffic uses the adjacent lane and can be opened to traffic in a short time.

Hydraulic cement concrete (HCC) overlays have also been used to extend the life of CRCP. Historically, HCC overlays have often not been considered as an alternative to asphalt because of the higher initial cost, greater thickness, and longer curing time. In addition, HCC overlays are considered more challenging to construct with traffic in the adjacent lane because the paving machine requires more width than an asphalt paving machine As the price of liquid asphalt continues to increase, HCC overlays are becoming more competitive on an initial cost basis. Bonded HCC overlays placed in 1995 on I-295 (overlaid with stone matrix asphalt [SMA] after 17 years to match the adjacent pavement overlay, not because the overlay needed to be replaced) and I-85 are still in service after 18 years.[1-3] The pavement sections located immediately before and after the bonded overlays have many patches and need additional repair.

The Colorado Department of Transportation[4] reported the successful use of an unbonded concrete overlay (7¾ in) on a 13-mi section of I-25 during the 1980s. Seven years of performance data showed it to be a viable method of rehabilitating a badly distressed rigid pavement. No meticulous cleaning and repair were needed other than repair of the unstable areas of the existing pavement. A bond breaker or separation layer of 1/4-in chip seal was able to prevent crack reflection, and the tied shoulder performed well.

The Pennsylvania Department of Transportation[5] evaluated the performance of a 23-year-old unbonded concrete overlay on I-80. The original 10-in jointed reinforced concrete pavement built in 1959 was overlaid with a 10-in jointed plain concrete pavement (JPCP) in 1988 with a skewed transverse joint spaced closer than in the original pavement. A 2-in dense-graded asphalt layer was used as a separation layer and proved to be effective in preventing crack reflection. The original pavement was severely distressed with cracks, surface spalling, and joint failure. Although the edge drain was retrofitted during construction of the unbonded overlay to improve the subsurface drainage condition, pumping and loss of support were evident after 10 years in service. This section performed well for 20 years with one diamond grinding at 10 years to improve ride quality, but accelerated deterioration attributable to a subsurface drainage problem was observed and the section needed repair again at 20 years.

In 2012, the Virginia Department of Transportation (VDOT) rehabilitated a 5.1-mi section of the westbound lanes of a CRCP on U.S. 58 in Southampton County using a 4-in-thick bonded concrete overlay over a 2.6-mi section and a 7-in-thick unbonded concrete overlay with a 1-in asphalt separation layer over a 2.2-mi section and reconstruction with JPCP for the remaining 0.3 mi. The four-lane, divided primary highway was built in 1988 with an 8-in-thick CRCP placed over a 6-in cement-treated aggregate layer. Saw cutting was used to form joints at 6 ft by 6 ft panels for an unbonded overlay, and tie bars were used along the centerline of the pavement and along both shoulders. A concrete overlay was placed on the shoulders of the unbonded overlay, and asphalt was placed on the shoulders of the bonded overlay. A nearby project with an asphalt overlay, which is the conventional VDOT practice for extending the life of CRCP, provided cost information that was used to compare the three alternatives. The project included two layers of asphalt with a total thickness of 5 in placed on a 9.75-mi section of the eastbound lane of U.S. 58. For the U.S. 58 project, VDOT participated in the Concrete Overlay Field Application Program administered by the Federal Highway Administration and the National Concrete Pavement Technology Center.

PURPOSE AND SCOPE

This study evaluated bonded and unbonded HCC overlays as options to extend the life of CRCP. The specific objectives were as follows:

- Determine if bonded and unbonded HCC overlays are cost-competitive based on initial cost and practical alternatives to asphalt overlays.

- Collect and analyze data regarding the condition of the existing pavement.
- Document the overlay pavement designs.
- Monitor the construction of the overlays, and document the challenges for future projects.
- Evaluate the initial condition of the overlays.

METHODS

Overview

The following tasks were performed to achieve the study objectives:

1. A site was selected based on preliminary investigations of four sites.
2. Pavement designs were prepared for the bonded and unbonded overlays.
3. The condition of the existing pavement was determined before construction.
4. Construction steps were monitored and documented.
5. The materials properties of the concrete were measured in the fresh and hardened states as part of a quality control and quality assurance (QC/QA) program.
6. Ride quality was measured immediately after construction before opening of the overlays to traffic.
7. Visual surveys of the condition of the pavement were conducted after 4 months of traffic and a winter season.
8. Construction costs were compared.

Site Selection

A team of experts from the Federal Highway Administration, the National Concrete Pavement Technology Center, the Virginia Center for Transportation Innovation and Research (VCTIR), and VDOT's Materials Division and districts visited four pavement sites in July 2010. U.S. 58 Westbound in Southampton County (Milepost [MP] 15.8 to MP 20.9) was selected as the candidate for the concrete overlay application. This 5.1-mi section is a four-lane divided primary highway. A preliminary structural evaluation using the falling weight deflectometer

(FWD) and pavement coring was conducted by VDOT's Materials Division and Hampton Roads District to facilitate the proper pavement design for the overlays.

Pavement Design

The American Association of State Highway and Transportation Officials (AASHTO) 1993 *Guide for Design of Pavement Structures*[6] was used to design bonded and unbonded overlays using a 30-year design life. About 2.6 mi were designed as bonded and 2.2 mi as unbonded overlays. Although the National Concrete Pavement Technology Center recommended using an unbonded overlay on the entire 4.8 mi, VDOT believed that after patching the deteriorated areas, the easternmost 2.6 mi would be in good enough condition to use a bonded overlay. Patching is typically not needed when an unbonded overlay is used. The remaining 0.3 mi was designed as a complete replacement with JPCP to facilitate matching the elevation with that of adjoining pavements at the termini of the project.

Construction Documentation

The researchers visited the construction site during the construction of the bonded and unbonded overlays to document construction steps. Highlights of the visits were observation of surface distresses before overlay, surface preparation, paving operations, concrete production including QC/QA, finishing, saw cutting, and sealing. Discussion with the field personnel for both VDOT and the contractor resulted in many lessons learned.

Surface preparation for the bonded section was verified using the sand patch test (ASTM E965[7]) and tensile bond tests (ASTM C1583[8]).

Performance Evaluation

The pavement was evaluated for ride quality by VDOT's Materials Division using a high-speed inertial profiler right after construction and curing but before opening to traffic. An International Roughness Index (IRI) was obtained for every 0.01-mi section. Both wheel paths were measured on a single pass of this vehicle-mounted device, which ran at or near highway operating speeds. The device uses a narrow laser beam, and it is assumed not to be affected by the transverse tining.

As the success of a bonded section depends on the bond strength between the new overlay and the old existing pavement surface, several cores were taken from random locations and tested in the laboratory using a procedure similar to that used in ASTM C1583,[8] which is typically done on site.

The pavement was visually surveyed for distresses after 4 months of traffic, which included one moderate winter season.

Construction Costs

Construction costs for the bonded and unbonded overlay sections were compared to costs for a nearby asphalt overlay.

RESULTS AND DISCUSSION

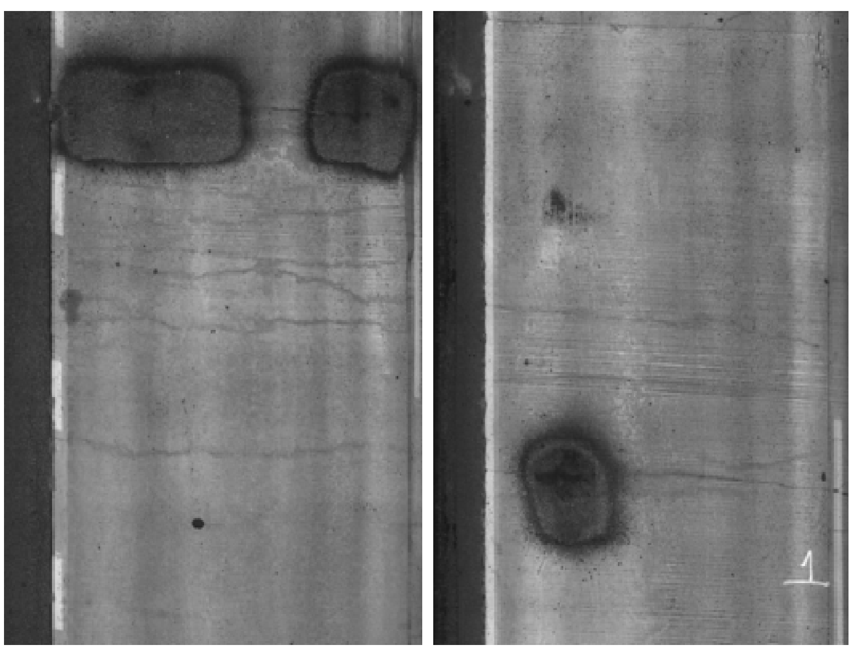
Test Site and Existing Condition

A portion of the westbound lanes of U.S. 58 in Southampton County was selected for the concrete overlay application. Three repair options were applied between MP 15.8 and MP 20.9:

1. *Reconstruction with JPCP:* 0.3 mi (MP 15.8 to MP 16.1)
2. *Unbonded overlay:* 2.2 mi (MP 16.1 to MP 18.3)
3. *Bonded overlay:* 2.6 mi (MP 18.3 to MP 20.9).

Within the project limits, 4.8 mi of the existing pavement is an 8-in CRCP sitting on a 6-in layer of a cement-treated aggregate layer and 0.3 mi is JPCP sitting on existing subgrade.

A visual distress survey and video imaging were used to collect the pavement distress information along with the GPS location. Figure 1 shows the video image of distresses on a portion of the section where bonded overlay was used. The distresses shown in Figure 2 were observed visually before the unbonded overlay was placed. Distressed areas must be patched prior to placement of the bonded overlay. Distressed areas should be filled in with asphalt prior to placing the asphalt separation layer, but full-depth concrete patching is not required.



Photos courtesy of Virginia Department of Transportation

Figure 1. Video Images of Bonded Section Before Construction

Photos courtesy of Virginia Department of Transportation

Figure 2. Visual Distress Observed on Unbonded Section Before Construction

The structural condition of the pavement was evaluated with FWD data for the entire section during the design phase in 2010. A few points were measured again right before the construction in 2012. The deflection under the load for this existing CRCP section, which is presented in Figure 3, provides the overall condition of the pavement. It is important to note that two different vendors conducted the test in 2012 and in 2010.

The IRI was measured before construction, and the average IRIs for the bonded and unbonded sections are provided in Figure 4. The average IRI ranged from 110 to 163 in 2012 for the section to receive the concrete overlays. The average IRI for the asphalt section ranged from 101 to 131 in 2005 (most recent data). The CRCP had a variable transverse cross slope and variable longitudinal profile, which contributed to high IRI values. To correct these deficiencies as per the contractor's suggestion, VDOT approved placing thicker pavement (up to an additional 1 in) to ensure that a uniform cross slope and longitudinal profile be achieved and the minimum required thicknesses (7 in for unbonded and 4 in for bonded) of the sections be maintained.

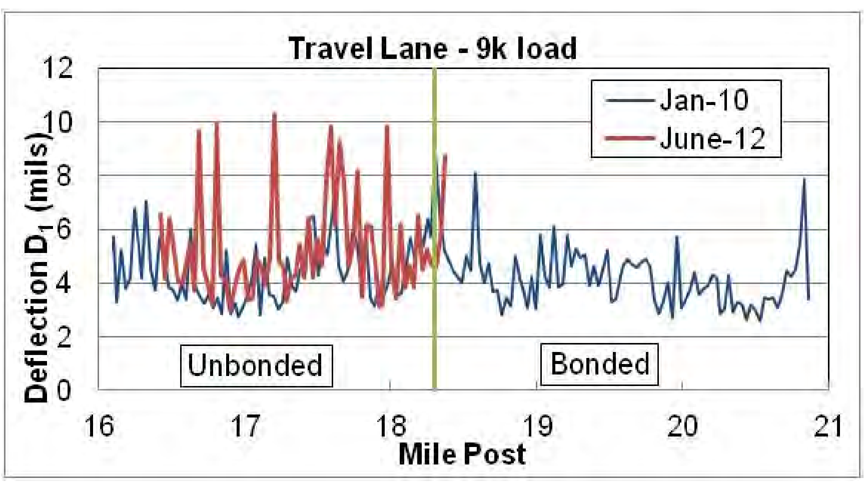


Figure 3. Falling Weight Deflectometer Deflection Under 9,000-lb Load

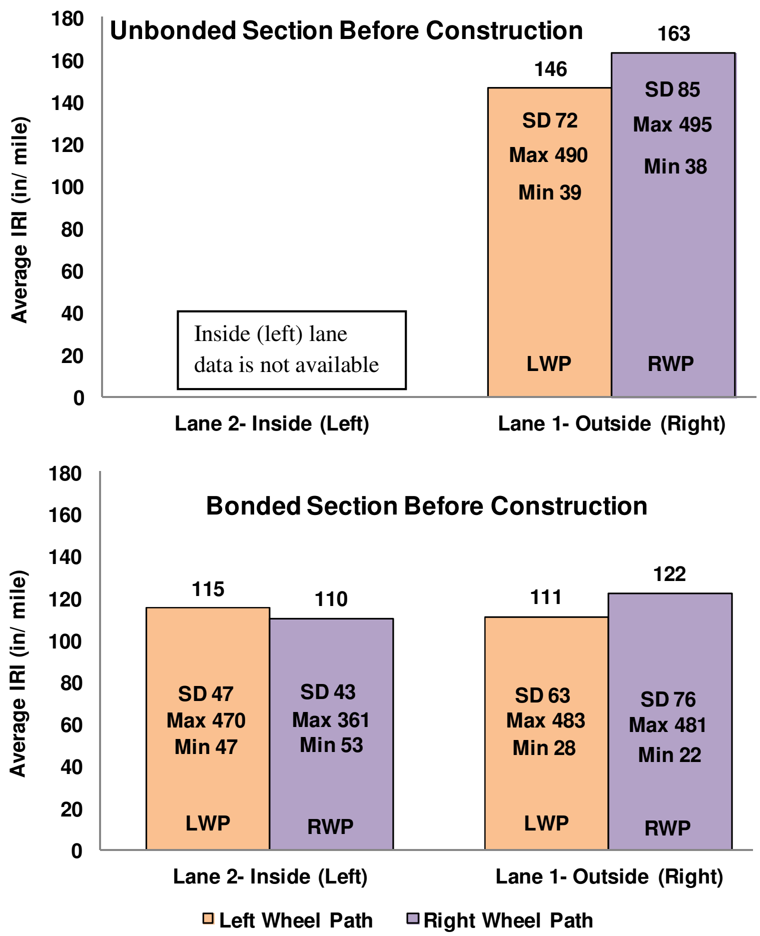
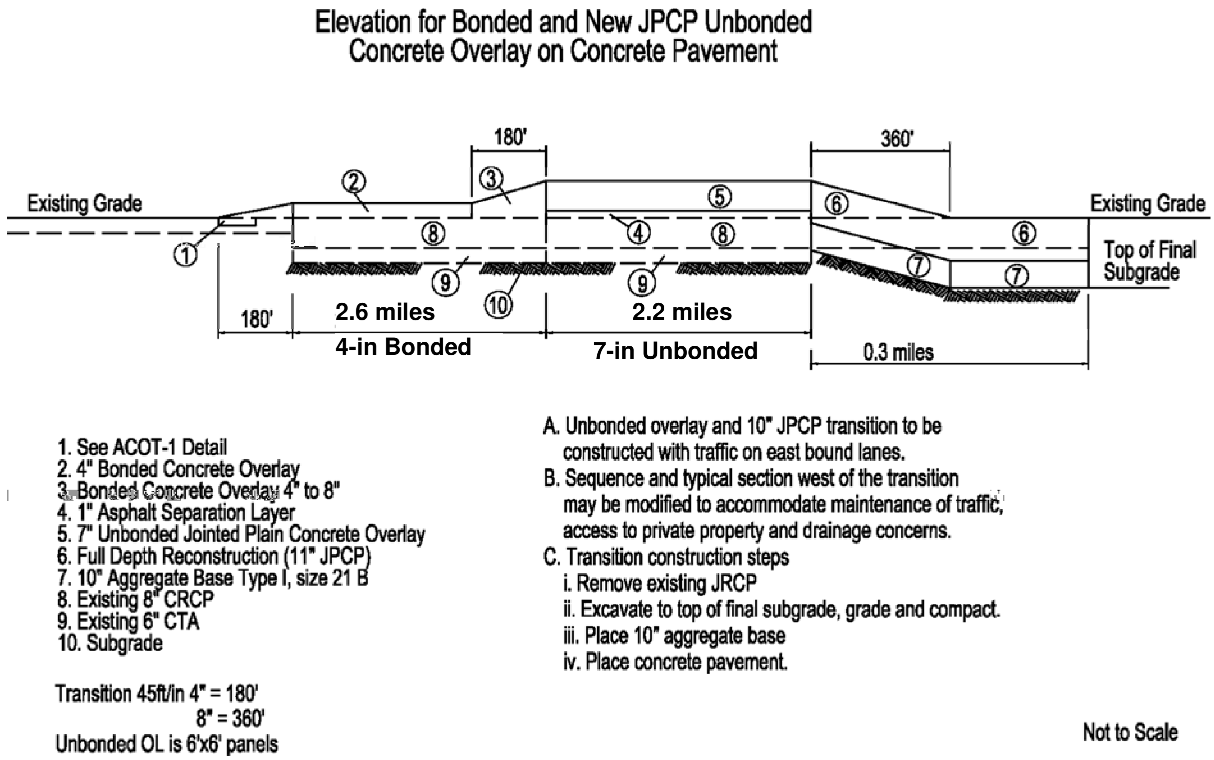


Figure 4. Summary International Roughness Index (IRI) Values Before Overlay

Pavement Design

Chapter VI of the VDOT *Manual of Instructions,* (MOI)-Materials Division,[9] and the AASHTO 1993 pavement design guide[6] were used to design the bonded and unbonded overlays and new JPCP. Traffic data used in the design were obtained from the 2009 VDOT Traffic Engineering Division traffic estimates reports,[10] and growth rate was calculated based on historical traffic data and the compound growth rate. A back-calculated average modulus of subgrade reaction (K) value was used. Existing portland cement concrete (PCC) design distress parameters were assumed from field evaluations using distress rating data from the VDOT Pavement Management System (PMS). The existing PCC thickness of 8 in was used based on measurements obtained from cores (which varied from 7.25 to 9.5 in) and the original design sheet. The eastern end of the pavement was in good enough condition to be upgraded with a bonded concrete overlay. The existing CRCP surface was shot blasted and wetted before the placement of the 4-in bonded overlay. The western part of the pavement was more distressed than the eastern part, and a 7-in-thick unbonded overlay was needed for best performance. Figure 5 shows the bonded and unbonded and new JPCP sections. The inside shoulder was trench widened by 1 ft the entire length of the project.



Drawing courtesy of Virginia Department of Transportation

Figure 5. Sketch of Proposed Overlay Thickness on U.S. 58

The 7-in-thick unbonded overlay has a 6-ft joint spacing without any dowels, tie bars along the centerline and shoulder, and a 1-in-thick asphalt separation layer. Although dowels are not used with thinner unbonded overlays, dowels are recommended[11] for pavements that are 8 in thick and thicker and when the joint spacing is 12 ft or more. An open-graded mixture was selected because it can provide for drainage as long as the voids are not filled with concrete paste when the overlay is placed. A mockup indicated the HCC does not fill the voids in the porous friction course (PFC). A slice from the mockup is shown in Figure 6.

The unbonded section used a tied concrete shoulder, whereas the bonded section used an asphalt shoulder. According to the design, the bonded section provides enough thickness for adequate edge support, so a tied concrete shoulder or wider lane was not necessary. At the time of the design, it was thought that an asphalt shoulder 4 in thick would be less expensive. Moreover, the existing shoulder was asphalt. Therefore, an asphalt shoulder was selected over white topping for a concrete shoulder.

Figure 6. Slice From Mockup of a Hydraulic Cement Concrete Overlay Placed on a Porous Friction Course

Construction Documentation and Lessons Learned

This overlay project demonstrated three repair options and was constructed in three phases, as shown in Figure 7. Phase 1 involved constructing the unbonded section; Phase 2 involved constructing the bonded section; and Phase 3 involved reconstructing a small portion of JPCP with JPCP. A detailed traffic management plan was developed to execute the construction operation safely considering the increase in grade: 4 in for the bonded and 8 in for the unbonded. The traffic management plan allowed the contractor to pave both lanes at the same time but forced head-to-head traffic to go through the project on the eastbound lanes. To provide a construction zone speed limit of 50 mph with head-to-head traffic, it became necessary to use concrete barriers and crossovers for the safe passage of traffic, as shown in Figures 8 and 9. The use of crossovers and concrete barriers presented an additional significant cost to the project on the order of 26 percent of the total project cost and added considerable time to the project. Later on, during construction, the contractor indicated that this project could have been constructed one lane at a time, which would have saved the cost of very extensive traffic management. The asphalt overlay was constructed one lane at a time with live traffic on the adjacent lane. At least one lane of traffic was maintained at all times during the construction, which eliminated the cost of traffic diversion.

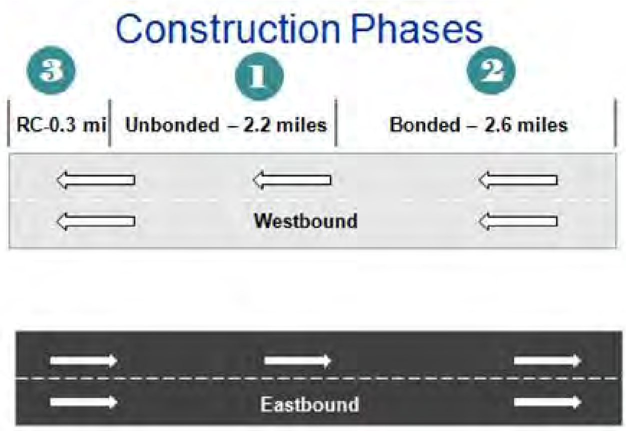


Figure 7. Construction Phases. RC = reconstruction; Unbonded = unbonded hydraulic cement concrete; bonded = bonded hydraulic cement concrete.

Figure 8. Phase 1 Crossovers. Unbonded = unbonded hydraulic cement concrete.

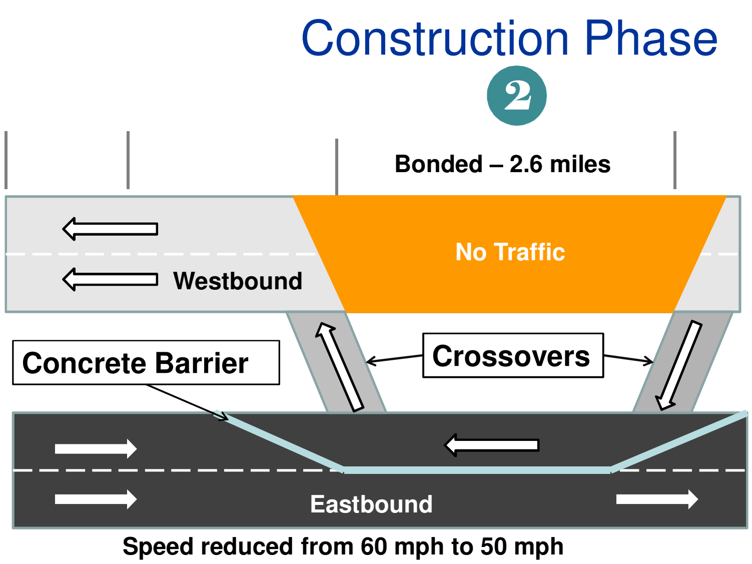


Figure 9. Phase 2 Crossovers. Bonded = bonded hydraulic cement concrete.

Surface Preparation

The bonded and unbonded sections required specific surface preparation before concrete overlay placement. The unbonded section did not need any repair of distresses, as a separation layer was used before 7 in of concrete was placed. A PFC 1 in thick was paved for the entire width including the shoulder as shown in Figure 10. Prior to placement of the PFC, old patches were milled to get a level surface and cracks were sealed with hot pour asphalt. A few large distressed areas were filled with the PFC mixture as it was placed.

Photo courtesy of Virginia Department of Transportation

Figure 10. Porous Friction Course As Separation Layer for Unbonded Section

The bonded section was prepared by patching failed sections with full-depth concrete prior to shot blasting (Figure 11) and pre-wetting. Sand patch and bond tests were performed to ensure proper cleaning and surface preparation, as the success of this section depended on bonding with the old concrete. A water truck ran ahead of the paver to keep the surface wet; the truck driver was careful about not contaminating the surface and drove on the surface only when necessary.

Photos courtesy of Virginia Department of Transportation

Figure 11. Surface Preparation for Bonded Section: a) shot blasting; b) sand patch test

The VDOT special provision[12] for the bonded overlay required the surface to be cleaned and textured by shot blasting to achieve a minimum macrotexture depth (ASTM E965[7]) of 0.06 in. The contractor was not able to achieve the minimum texture with up to four passes of the shot blast equipment. Initially it was speculated that the shot blast equipment was not powerful enough to achieve the texture. So surface tensile strength tests (ASTM C1583[8]) were conducted on a section of the pavement that had been textured with zero to four passes of the shot blaster. The results of the tests are shown in Table 1. Although there was no relationship between the number of passes and the surface tensile strength, the surface tensile strengths were higher than the 175 psi minimum believed to provide good bond strength.[13] Because of the high surface tensile strengths, the surface cleaning was approved and the contractor was allowed to place the overlay. The average surface tensile strength of 501 psi was considered to be reasonable considering that compression tests on cores from the original pavement indicated strengths of approximately 7,000 psi for sections in good condition.

Several weeks later, additional surface tensile tests were conducted on a section of pavement that was patched and the adjacent section of pavement upstream of the patch. Prior to the tests, the macrotexture of the surface was measured. The results of the macrotexture tests and tensile strength tests performed on the surface are shown in Table 2. The results indicate some relation between the surface condition based on a visual inspection and the surface texture. Surfaces that appear to have a heavy texture have a higher texture in inches as measured in accordance with ASTM E965.[7] However, there was no good relation between the surface texture and the surface tensile strength. The average surface tensile strength was much lower than the 501 psi found in earlier tests. The average result of 232 psi is reasonable, considering the compressive strength of the patch was approximately 3,500 psi, and it is believed that the average compressive strength of the pavement adjacent to the patch was similar because this pavement was likely in much worse condition than the pavement section tested earlier. In addition, the tensile strengths shown in Table 2 are typical for a pavement with a compressive strength of approximately 3,300 psi.

Table 1. Number of Shot Blast Passes Versus Surface Tensile Strength (ASTM C1583)

No. Shot Blast Passes	Tensile Strength (psi)
0	501
1	608
2	565
3	594
4	544
4	193
Average of shot blasted surfaces	501
Milled surface	308
Average of all	473

Table 2. Surface Texture (ASTM E965) Versus Surface Tensile Strength (ASTM C1583)

Location	Surface Condition	Surface Texture (in)	Tensile Strength (psi)
1	Patch, clean, heavy texture	0.034	14[a]
2	Patch, not clean, heavy tined texture	0.021	272
3	Pavement, light clean, tined texture	0.025	186
4	Pavement, light clean, light tined texture	0.024	150
5	Pavement, clean, little texture	0.018	36
6	Pavement, clean, little texture	0.015	351
7	Pavement, clean, heavy texture	0.093	351
8	Pavement, clean, heavy texture	0.035	21
9	Patch, not clean, light texture	0.019	301
10	Pavement, clean, little texture	0.023	422
Average	-	0.031	232

[a] Epoxy adhesive failed.

Concrete Plant

Concrete was batched at a central mixture plant about 4 mi from the job site, as shown in Figure 12. The aggregates were stored on concrete slabs to prevent contamination with the soil. The aggregate stockpiles are also shown in Figure 12. The stockpiles were wetted with sprinklers to cool the material and to keep it at the desired moisture content: free moisture in the coarse aggregate was about 2.5 percent and in the fine aggregate about 3.5 percent. The moisture condition of the aggregates was determined at the beginning of each day and then whenever needed throughout the day to maintain uniformity. The weather was hot, and the mixture water was cooled using a chiller shown in Figure 12.

Photos courtesy of Virginia Department of Transportation

Figure 12. Concrete Plant: a) plant setup; b) chiller to cool the water; c) aggregate stockpile

Concrete Mixture

VDOT specifications[14] required a 4,000 psi concrete with 0 to 3 in of slump to build all three sections. The cementitious material in the designed mixture was Type I/II cement with 25 percent Class F fly ash for a total of 596 lb/yd^3. The coarse aggregate was VDOT No. 57 that has a nominal maximum size of 1 in. It was a crushed granite with a specific gravity of 2.67 and absorption of 0.3 percent. The dry-rodded unit weight was 98.1 lb/ft^3. The fine aggregate was natural sand (ASTM C33[15]) with a specific gravity of 2.62, a fineness modulus of 2.80, and absorption of 0.7 percent. The uncompacted void content of the fine aggregate was 43.8 percent, indicating a good (rounded) particle shape with a low void content. Mixtures with a water–cementitious materials ratio (w/cm) of 0.43 and 0.45 were used to provide the desired properties in the concrete. When the lower w/cm was used, the sand content was increased by 31 lb/yd^3 to compensate for the volume decrease attributable to lowering the water content by 12 lb/yd^3. The mixture design is summarized in Table 3.

Table 3. Mixture Proportions for One Cubic Yard of Concrete

Ingredient	Type	Specific Gravity and Absorption	Mass in (lb/yd^3)	
			Mix 1	Mix 2
Portland cement	Type I		447	447
Fly ash	Class F		149	149
Coarse aggregate	No. 57 Crushed Granite (Dry rodded unit weight 98.1 lb/ft^3)	Specific gravity: 2.67 Absorption: 0.3%	1,775	1,775
Fine aggregate	Natural Sand Fineness Modulus: 2.80; Uncompacted void = 43.8%	Specific gravity: 2.62 Absorption: 0.7%	1,149	1,180
Water			268	256
w/cm			0.45	0.43

w/cm = water–cementitious materials ratio.

Concrete Properties

Fresh and hardened concretes were tested for quality assurance. VDOT has been developing an end result special provision,[12] and this project provided an opportunity to test it in a paving project. Each sublot was about 0.1 mi for two-lane width. Initial samples were taken from trucks that agitated because it was difficult to obtain a sample from dump trucks: either it was difficult to climb up to get the sample or it was difficult to close the back gate once opened for sampling because of heavy pressure from the flowing concrete. The sample was tested at the fresh state for slump, air content, density, and temperature, and cylinders were cast for the strength and permeability tests at the hardened state. One sample was taken from each sublot, which was equivalent to about 30 truckloads of approximately 9.5 yd^3 of concrete each. Sampling at the site was too difficult, so samples were collected at the plant after the first six samples were collected at the job site. The results are summarized in Table 4.

Table 4. Fresh and Hardened Concrete Properties

Concrete Property	No. of Samples	Maximum	Minimum	Average	Standard Deviation
Density (lb/ft^3)	50	142.9	137.9	139.8	1.3
Air (%)	71	8.0	4.0	6.5	0.9
Slump (in)	71	5.0	1.0	2.0	0.6
Compressive strength (psi) (28 days)	71	5,750	3,790	4,878	418
Permeability (coulombs)	70	1,239	325	596	189

Paving Operation

Concrete paving was done in two phases (unbonded overlay first followed by the bonded overlay) without major difficulties other than delays because of rain. Paving for the bonded section had many stop-and-go events because of rain.

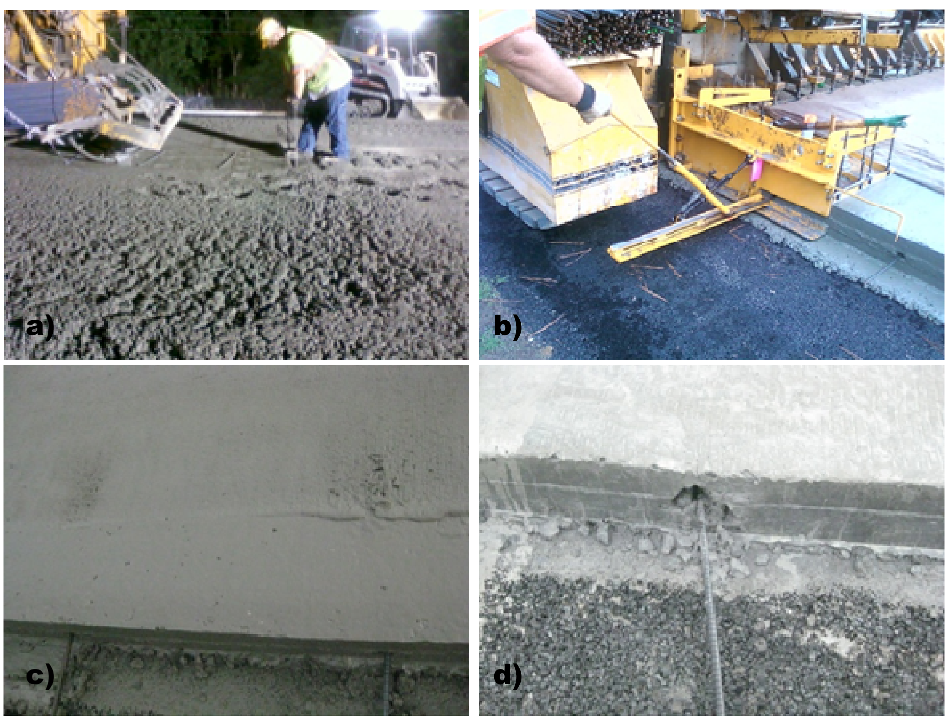
Concrete was batched at the plant using the stationary mixer and delivered to the job site about 4 mi away using dump trucks (Figure 13). Two agitating trucks were also used to facilitate sampling, but the agitators and were not used and the loads were carried as with the dump trucks. Each load was 9.5 yd^3 of concrete. Mixing time was 65 sec and total time to load, mix, and discharge into the truck was 1.5 to 2.5 min. The trucks traveled from the plant and dumped the concrete in front of the spreader in 15 to 20 min. A two-track paver just behind the spreader was used. The paving operation was stringless but used a GPS-enabled laser guidance system, as shown in Figure 13.

Photos courtesy of Virginia Department of Transportation

Figure 13. Paving Operation: a) trucks dumping concrete in front of spreader; b) side discharge; c) two-track paver; d) GPS-enabled laser guidance system

The unbonded section used tie bars at the center of the road along the longitudinal joint and along both edges to tie the shoulders. Behind the spreader, there was a wheel to insert the tie bars; however, because of a problem, many of them did not get inserted (pushed), so they were inserted manually as shown in Figure 14. The tie bars at the edges connecting the shoulders were pushed into concrete at the edge behind the paver, as shown in Figure 14. Figure 14 also shows the wavy edge rather than a straight vertical edge. Figure 14 shows the disturbance on the surface and the hole created on the side because of the insertion of the tie bars. These tie bars disturbed the edge and made it difficult to have a straight vertical edge/face. Considerable hand finishing was needed to provide the vertical edge. This in turn may have impacted the ride quality.

Behind the paver, a float and straightedge were used to maintain the surface smoothness. The pavement was textured with transverse tines. A white pigmented curing compound was sprayed. There was a problem in getting the white pigment to stay in suspension. Therefore, the surface did not look white as desired. The unbonded overlay was cut in 6-ft squares as soon as possible without causing raveling. The width of the cuts was about 1/8 in. These 1/8-in joints were filled with hot pour asphalt.



Photos courtesy of Virginia Department of Transportation

Figure 14. Tie Bar Placement in Unbonded Section: a) insertion in middle of lanes; b) insertion at edges; c) surface disturbance; d) hole at edge

Ride Quality

The initial as-constructed IRI was measured before the overlays were opened to traffic. Both sections achieved a good ride quality, as shown in Figure 15. The contractor had implemented an adjustment in the longitudinal profile by incorporating variable overlay thicknesses to improve the ride quality in addition to stringless laser-controlled grading;

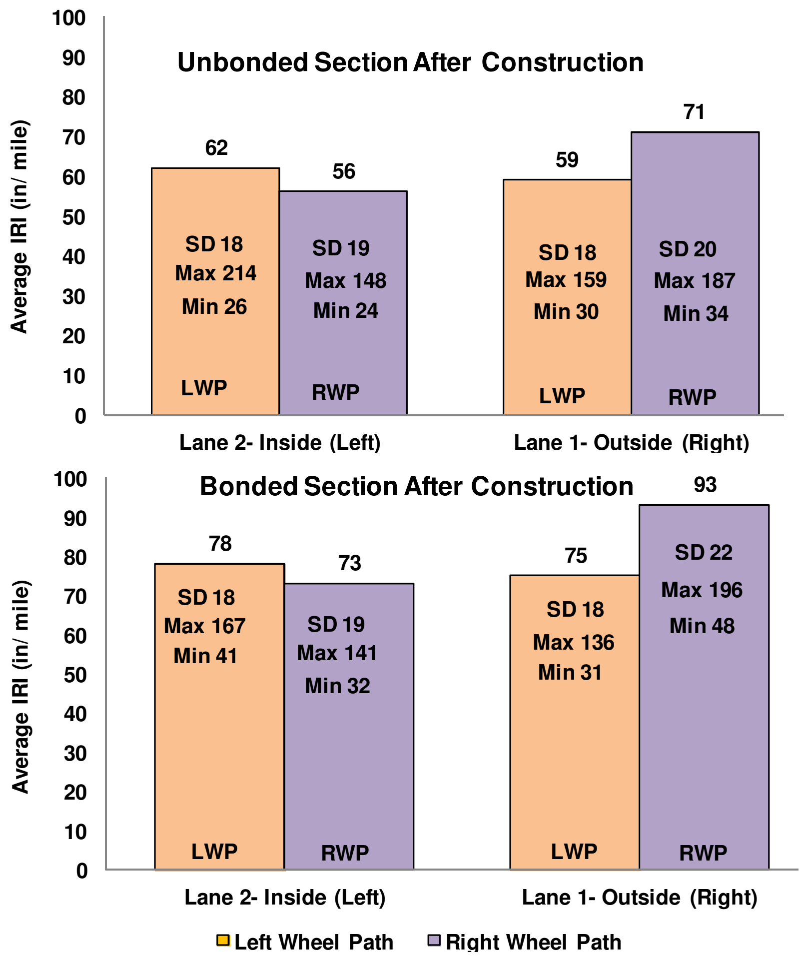


Figure 15. Ride Quality As Measured by International Roughness Index (IRI) Values: a) average IRI for unbonded section; b) average IRI for bonded section. SD = standard deviation.

a significant improvement was observed after overlay construction. This resulted in a variable thickness of the pavement: the bonded thickness varied from 4 to 4.5 in, and the unbonded thickness varied from 6.8 to 8.1 in. The variation in thickness was allowed without pay adjustment other than for the additional concrete. The unbonded section had a better ride than the bonded section because the paver track was riding on a smoother surface, i.e., the PFC separation layer. Figure 16 shows that the ride quality of both overlays was much better than that of the original CRCP.

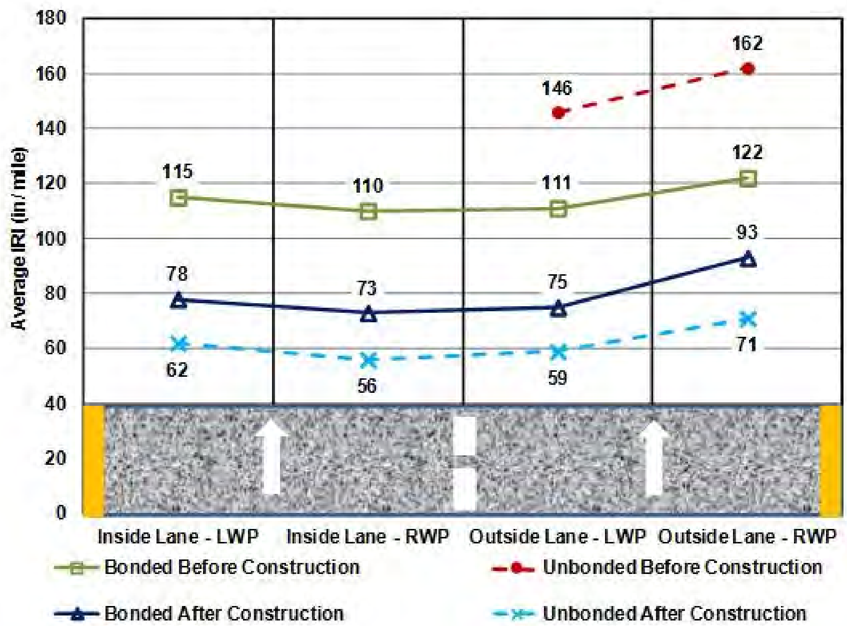


Figure 16. Improvements in Ride Quality As Measured by International Roughness Index (IRI) Values. LWP = left wheel path; RWP = right wheel path.

Bond Strength

The success of a bonded overlay depends on good bonding between the new overlay and the existing old pavement surface. On January 16, 2013, 14 randomly selected areas were cored to check the bond strength of the newly paved bonded overlay on U.S. 58. These 2-in cores, shown in Figure 17, were also used to verify the overlay thickness. Bond strength was measured in the VCTIR laboratory in accordance with a procedure similar to that in ASTM C1583.[7] The results were as follows:

- Seven cores failed at the bond interface when they were being drilled (Cores 1, 5, 6, 9, 14A, and 14B over the old concrete surface and Core 12 over a new patch). This is a high failure rate.

- Four cores failed within 0.4 in of the top surface of the overlay (Cores 2, 4, 7, and 11). The average tensile rupture strength was very good at 275 psi.

- Two cores failed in the old concrete within 0.4 in of the bottom of the core (Cores 3 and 10). The average tensile rupture strength was very good at 270 psi.

- One core failed over a patch. The bond strength was poor at 75 psi. At least two more cores over a patch are needed to evaluate the bond strength.

- The average bond strength for the six cores (Cores 2, 3, 4, 7, 10, and 11) over the old pavement was very good at 273 psi.

Figure 17. Cores to Verify Bond Strength and Thickness of Bonded Overlay

Initial bond strength results for I-85 (4-in overlay) and I-295 (2-in overlay) in 1995 were 239 and 251 psi, respectively.[2, 3] It is assumed that the cores failed on U.S. 58 during drilling and extraction because of the stresses caused by the drilling and extraction operation (the core barrel rotated with some wobble). The bond tests clearly showed that the U.S. 58 bonded overlay was bonded, as were the overlays on I-85 and I-295 (overlaid with SMA after 17 years to match the adjacent pavement overlay), which are still performing well after 18 years.

Visual Observation

The overlaid pavement was visually inspected for distress after 4 months of traffic. As expected, many transverse shrinkage cracks were observed in the bonded overlay. Figure 18 shows some of the cracked section on newly bonded overlay, and Figure 19 shows a typical crack on the I-85 bonded overlay, which is still performing well after 18 years. Most cracks on the U.S. 58 bonded overlay were tight and typical of a bonded overlay that contains cracks that have reflected from the pavement. A few of the cracks were wider than normal (as wide as ¾ in), and further investigation revealed the pavement was moving with changes in temperature in the vicinity of the wide cracks. Cores revealed the movement was accommodated by the loss of bond between the concrete and the steel. Either the steel that was cut during the patching was not spliced adequately and early age movement caused a loss in bond or the steel in the pavement had lost bond and should have been patched prior to placement of the overlay. Plans have been developed to patch areas with wide cracks. The unbonded overlay shown in Figure 20 did not have cracks reflected from the pavement.

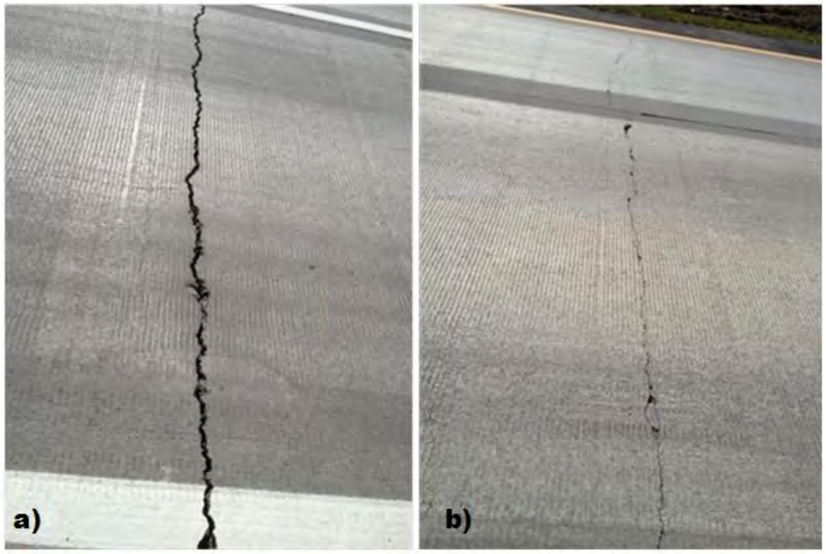


Figure 18. Cracks on Bonded Overlay: a) a wide crack; b) regular shrinkage crack


Figure 19. Cracks on 4-in Bonded Overlay on I-85

Figure 20. Unbonded Overlay With Concrete Shoulder

Cost Comparison

Construction costs for the bonded and unbonded overlay sections were compared to costs for a nearby asphalt overlay. Although concrete overlays were used on the westbound lane of U.S. 58 near Courtland, the CRCP on the nearby eastbound lane was being repaired using 5 in of asphalt overlay. SMA was used to repair this 9.75-mi section. SMA is a premium asphalt mixture that provides enhanced rut resistance and durability compared to regular hot-mix asphalt through a special stone-on-stone contact of crushed coarse aggregate and a high binder content. This section also needed extensive concrete patching before placement of the asphalt overlay. The construction of this section was completed a few months after the construction of the concrete overlays.

The final paid costs of comparable items for the two projects are shown in Table 5. Because VDOT chose to use methods of traffic management that are fundamentally different and significantly different in cost, the concrete overlay project cost more per lane-mile than the asphalt project. Constructing crossovers and placing and bolting down concrete barriers are construction activities related to the traffic management plan that affected the total project cost. In order to compare the initial materials cost of the two overlay systems, the Maintenance of Traffic (MOT) cost was removed from both projects. Table 6 provides the detailed information needed for the reader to compare the costs of unbonded and bonded HCC overlays as well as asphalt overlays. In addition, Table 6 provides comparisons with and without patching costs. The reader can see that concrete and asphalt can be competitive with or without patching when the cost of traffic control is excluded from the comparison.

Detailed cost information is provided in the Appendix.

Table 5. Actual Costs of Selected Items for Concrete and Asphalt Overlays

Item	HCC Project: 5.1 mi ($)	Asphalt Project: 9.75 mi ($)
Mobilization	400,000	425,225
Field Office	25,000	60,000
Traffic Maintenance Plan[a]	1,932,375	242,678
Crossover, drainage, and reconstruction[b]	1,684,709	None
Pavement and Shoulder Repair	4,402,194	8,726,425
Guardrail, Re-vegetation, and Erosion Control	280,013	429,173
Total Paid Cost	8,724,293	9,883,501
Bid Price	7,885,334	8,653,586
Paid cost per mile ($ millions)	1.711	1.014
Paid cost per mile for pavement and shoulder only ($ millions)	0.863	0.895

[a] Use of rigid concrete barrier for the hydraulic cement concrete (HCC) project added $1.287 million for traffic control.
[b] Construction and removal of four crossovers added another $1.346 million to the HCC project.

Materials In-Place Costs

The unit (bid) prices of materials in-place on the traffic lanes only for the bonded and unbonded concrete sections and the asphalt section are also compared and presented in Table 6. Unit costs for the bonded and unbonded sections were almost the same, although the thickness of the bonded section was about one-half that of the unbonded section. A bonded section is supposed to be used when the overall CRCP section is in good condition and does not require significant patching. The main reason for distresses in the section where the bonded overlay was applied was the shallow cover depth for the reinforcement because of the tube feeding system used in the construction of the original CRCP. The distresses related to steel corrosion were predominant mostly in one-half of the slabs. Therefore, it was advisable to use half-width patches; however, full-width patching was used, resulting in an increase in patching quantities for the bonded section. In this case, almost 10.6 percent of the area was patched before application of the bonded overlay. This added significant cost to the system, causing the overall unit cost to be nearly equal to that of the unbonded section. According to Table 6, it would take

Table 6. Bid Prices of Materials In-Place for Asphalt and Concrete Overlays

HCC Unbonded Overlay	HCC Bonded Overlay	Asphalt Overlay
Length: 2.2 mi	Length: 2.6 mi	Length: 9.75 mi
1-in PFC: $155/ton Cost/$yd^2$: $8.53 (110 lb/in/$yd^2$)	Concrete Patch: $130/$yd^2$ Actual patched area: 10.6% Cost/ yd^2[b]: $13.74	Concrete patch: $155.5/$yd^2$ Actual patched area: 12.4% Cost/ yd^2[b]: $19.28
7-in HCC: $27/$yd^2$	4-in HCC: $19/$yd^2$	3-in SMA-19.0: $100/ton Cost/$yd^2$: $16.6 (110 lb/in/$yd^2$)
HCC for profile correction up to 1 in: $2.61	HCC for profile correction up to 1 in: $3.38	2-in SMA-12.5: $105/ton Cost/$yd^2$: $11.54 (110 lb/in/SY)
Total[a]: $38.14/$yd^2$	Total[a]: $36.12/$yd^2$	Total[a]: $47.42/$yd^2$

HCC = hydraulic cement concrete; PFC = porous friction coarse; SMA = stone matrix asphalt.
[a] The cost for the maintenance of traffic is not included in the total.
[b] The cost for the entire surface area of the overlay.

about 12.1 percent of the area to be patched at the rate of $\$130/yd^2$ concrete to make the bonded cost similar to that of the unbonded cost (bonded cost = $22.38 + 130 * 0.121 = $38.14). This case clearly shows that the cost of the unbonded overlay will be comparable to that of the bonded overlay when more than about 10 percent of the pavement must be patched. The initial unit cost of patching is 6.5 times the cost of the bonded overlay.

Although the unit bid price of the materials in-place for the asphalt overlay was higher than that of the concrete overlays, a few other points such as the design life of each system and costs for traffic maintenance and construction staging need to be considered in a life cycle cost analysis to make appropriate comparisons. One of the major items that added to the cost of the concrete systems was the elaborate traffic control.

Traffic Control Cost

The construction and removal of crossovers and the rental, installation, and removal of concrete barriers added approximately 26 percent to the total cost of the concrete overlays and added more than 1 month time to the construction. The cost of the traffic maintenance plan for the concrete overlay mentioned in Table 5 includes $1.287 million for only rigid barriers and another $1.346 million for crossovers. The bonded concrete overlay could have been constructed with traffic in the adjacent lanes using Type II barricades, as was done in 1995 on I-85 and I-295. The unbonded concrete overlay could have been constructed with traffic in the adjacent lane using Type II barricades, as was done in 2011 for the I-81 full-depth reclamation project.[16] Other concrete overlays have been constructed with traffic in the adjacent lane.[17, 18] The National Concrete Pavement Technology Center has written a guide that describes and illustrates how to construct concrete overlays with traffic in the adjacent lane.[11] Tables 5 and 6 indicate that when the cost of traffic control is not considered, the concrete overlays are competitive with the asphalt overlay. The cost for traffic control would have been similar for the concrete and asphalt overlays if they had been constructed with traffic in the adjacent lanes.

CONCLUSIONS

- *Construction of the concrete overlays was successfully executed on time.* The concrete was of high quality with good strength and low permeability. The bonded overlay is well bonded.

- *As constructed, ride quality was good for the unbonded section (IRI = 56 to 71 in/mi) and fair for the bonded section (IRI = 73 to 93 in/mi), but the ride quality for both was much better than for the original pavement.*

- *Using the initial cost of materials in-place, the cost of the bonded and unbonded overlays was approximately same at an average of $36 to $38 per square yard.*

- *The unit cost of patching concrete pavements is approximately 6 times the cost of the bonded concrete overlay and approximately 4 times the cost of an unbonded overlay.*

- *Unbonded concrete overlays should be used when more than approximately 10 percent of the CRCP must be patched. Bonded concrete overlays should be considered when the CRCP is in good condition.*

RECOMMENDATIONS

1. *VDOT's Materials Division should consider the use of bonded concrete overlays to extend the life of CRCPs that are in good condition and need little patching ($\leq$10%) prior to placement of the overlay.*

2. *VDOT's Materials Division should consider the use of unbonded concrete overlays as an alternative to patching to extend the life of CRCP that needs more than 10 percent patching.*

3. *VDOT's Materials Division should advertise overlay projects allowing alternate designs using SMA and HCC to determine if they are competitive alternatives.*

4. *VDOT's Traffic Engineering Division should explore innovative traffic management plans for pavement rehabilitation in order to reduce maintenance of traffic costs.*

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APPENDIX

DETAILED COST INFORMATION

Table A1. Itemized Cost for Traffic Control and Pavement Markings

Description	Unit	Concrete Overlay			Asphalt Overlay		
		Unit Price ($)	Quantity	Actual Cost ($)	Unit Price ($)	Quantity	Actual Cost ($)
Traffic Barrier Service Double Face Concrete	LF	40.00	32184.00	**1,287,360.00**			
Type III Barricade	EA	395.00	5.00	1,975.00			
Construction Signs	SF	35.00	2024.75	70,866.25	12.00	459.00	5,508.00
Truck Mounted Attenuator	HR	1.00	1321.00	1,321.00	10.00	1679.50	16,795.00
Group 2 Devices	DAY	0.70	69300.00	48,510.00	0.50	27632.00	13,816.00
Portable Changeable Sign	HR	2.25	6408.00	14,418.00	5.00	2114.00	10,570.00
Electronic Arrow	HR	1.00	7380.00	7,380.00	1.50	3436.00	5,154.00
Pave. Mess. Mark. Elongated Arrow Single	EA	75.00	18.00	1,350.00	100.00	26	2,600.00
Impact Attenuator Ser. Ty. 1 (TL-3> 45mph)	EA	8500.00	13.00	110,500.00			
Flagger	HR						
Subtotal: Traffic Control Items				**256,320.25**			**54,443.00**
Median Strip MS-2	LF	90	115.00	10,350.00	80.00	94.00	7,520.00
Remove Existing MS-2	LF	25	100	2,500.00			
Temp. Pave. Marker 1 Way	EA	5.00	597.00	2,985.00			
Temp. Pave. Marker 2 Way	EA	5.00	519.00	2,595.00			
Constr. Pave. Mark. 4 in (class II), Type D	LF	1.45	53449.00	77,501.05			
Type B Class I Pavement Line Marking 4 in	LF	0.33	60091.00	19,830.03	1.00	548.00	548.00
Type B Class I Pavement Line Marking 6 in	LF				0.66	122113.00	80,594.58
Type B Class I Pavement Line Marking 24 in	LF				4.00	112.00	448.00
Type B Class III Pavement Line Marking 6 in	LF	2.40	64286.00	154,286.40			
Yield Bar Triangles	EA				30.00	5.00	150.00
Eradication of Exist. Pavement Marking	LF	0.30	149440.00	44,832.00	0.38	128043.00	48,656.34
Eradication of Exist. Nonlinear Pave. Mark.	SF	0.65	60.00	39.00	2.00	465.00	930.00
Snow Plow. Raised Pave Marker	EA	32.00	382.00	12,224.00	22.00	806.00	17,732.00
Constr. Pave. Mark. 4 in (Class I or II), Type F	LF	0.14	108452.00	15,183.28	0.15	211040.00	31,656.00
Replace Snow Plow. Raised Pave Marker	EA	18.50	388.00	7,178.00			
Flex. Post delineator	EA	50	10.00	500.00			
Subtotal: Pavement Markings				**350,003.76**			**188,234.92**
Sign Panel	SF	25.00	433.01	10,825.25			
Sign Post STP 1-2 in	LF	21.00	227.50	4,777.50			
Sign Post STP 1-2 3/16 in	LF	23.00	162.00	3,726.00			
Sign Post STP 1-2 1/2 in	LF	26.00	276.50	7,189.00			
Concrete Foundation	EA	136.00	54.00	7,344.00			
Remove and dispose sign Str Ty WP-1	EA	104.00	36.00	3,744.00			
Remove and dispose sign Str Ty STP-1	EA	155.00	7.00	1,085.00			
Subtotal: Signs				38,690.75			
Total				**1,932,374.76**			**242,677.92**
Cost per mile				**378,897.01**			**24,890.04**

Table A2. Itemized Cost for Crossover, Temporary Access Road, Drainage, and Reconstruction

Description	Unit	Concrete Overlay			Asphalt Overlay		
		Unit Price ($)	Quantity	Actual Cost ($)	Unit Price ($)	Quantity	Actual Cost ($)
Construction Surveying[a, c]	LS	80000	0.9	**72,000.00**			
Grading [a, c]	LS	500000	0.9	**450,000.00**			
Borrow Excavation [a, c]	CY	12	6441.96	**69,573.17**			
15 in Pipe	LF	85	1380	117,300.00			
Storm Sewer Pipe 18 in	LF	65	720	46,800.00			
Aggr. Base Matl. Ty1 No. 21A (6 in)	TON	40	3486.02	139,440.80			
Asphalt Concrete BM-25D (6 in)	TON	110	1867.4	205,414.00			
Asphalt Concrete BM-25A (CO tie-in)[b]	TON	100	2109.31	210,931.00			
Flexible Pavement Planing	SY	2	9662.47	19,324.94			
Allaying Dust	HR	125	86	10,750.00			
Misc. Concrete A-3	CY	1500	3	4,500.00			
Subtotal: Crossover, Temp Acc., and Drainage[c]				**754,460.74**			
Reconstruction of Base for 0.3-mi Jointed Plain Concrete Pavement Section							
Outlet Pipe	LF	20	812	16,240.00			
Endwall EW-12	EA	600	6	3,600.00			
Underdrain UD-7	LF	20	3287	65,740.00			
Drop Inlet Grates	EA	1250	2	2,500.00			
Aggregate Base 10 in (21B)	TON	40	4136.68	165,467.20			
Demolition of Rigid Pavement	SY	15	4442.50	66,637.50			
Extra Excavation	CY	15	1232.82	18,492.30			
Subtotal: Base Reconstruction				**338,677.00**			
Total				**1,684,710.91**			
Cost per mile				**330,335.47**			

[a] 90% cost is considered for crossovers, temporary access roads, drainage structures, and reconstruction.
[b] 50% cost is considered for crossovers and temporary access roads.
[c] Cost for installation and removal of crossovers and temporary access is $1.346 million.

Table A3. Itemized Cost for Pavement and Shoulder Repair

Description	Unit	Concrete Overlay			Asphalt Overlay		
		Unit Price ($)	Quantity	Actual Cost ($)	Unit Price ($)	Quantity	Actual Cost ($)
Bonded Concrete (4 in)	SY	19.00	36480.01	693,120.19			
Add. Concrete for bonded profile correction	LS		1	123,272.24			
Concrete Patching on bonded section	SY	130.00	3853.94	501,012.20			
Unbonded Concrete (7 in)	SY	27.00	46482.00	1,255,014.00			
Add. Conc. for unbonded profile correction	LS		1	121,231.50			
Porous Friction Course	TON	155.00	2637.93	408,879.15			
New JPCP 11 in PCC (reconstruction)	SY	52.00	4393.33	228,453.16			
Construction Surveying (estimated)[a]	LS	80,000	0.1	8,000.00			
Grading (estimated)[1]	LS	500,0000	0.1	50,000.00			
Borrow Excavation (estimated)[a]	CY	12	644.196	7,730.35			
Flexible Pavement Tie-in Planing	SY	10.00	796.83	7,968.30			
AC BM 25.0A (Trench widening and Transition)[b]	TON	100.00	2109.31	210,931.00			
AC IM 19A (Bonded: 4 in shoulder)	TON	120.96	3106.37	375,746.52			
AC SM 12.5D (Bonded: 4 in shoulder)	TON	114.00	3603.82	410,835.48			
2 in Stone Matrix Asphalt 12.5	TON				104.87	18663.20	1,957,209.78
3 in Stone Matrix Asphalt 19	TON				100.62	23918.71	2,406,700.60
Patching Cement Conc. Pave	TON				155.50	17021.30	2,646,812.15
Grading	LS				68000.00	1.00	68,000.00
Borrow Excavation	CY				22.00	1615.48	35,540.56
Rumble Strip	LF				0.26	87113.00	22,649.38
Liquid Coating Rumble Strip	SY				1.25	14518.83	18,148.54
Std. Curb and Gutter	LF				40.00	207.00	8,280.00
Aggregate VDOT No. 25 & 26	TON				42.00	132.90	5,581.80
Asphalt Concrete BM 25.0A	TON				78.00	2429.48	189,499.44
Asphalt Concrete SM 12.5D	TON				83.11	7308.38	607,399.46
Asphalt Concrete IM 19D	TON				77.97	9377.42	731,157.44
Flexible Pavement Tie-in Planing	SY				9.14	2040.00	18,645.60
Rigid Pavement Tie-in Planing	SY				15.00	720.00	10,800.00
Total				**4,402,194.09**			**8,726,424.75**
Cost per mile				**863,175.31**			**895,017.92**

[a] 10% cost is considered for regular pavement and shoulder repair.
[b] 50% cost is considered for trench widening for shoulder and transition.

Table A4. Itemized Cost for Guardrail, Re-vegetation, and Erosion Control

Description	Unit	Concrete Overlay			Asphalt Overlay		
		Unit Price ($)	Quantity	Actual Cost ($)	Unit Price ($)	Quantity	Actual Cost ($)
Guardrail Terminal GR-6 (NCHRP)	LF	80	12.5	1,000.00	65	37.5	2,437.50
Guardrail Terminal GR-11	EA	750	6	4,500.00	850	18	15,300.00
Guardrail GR-2	LF	15.5	3037.5	47,081.25	16.05	10850	174,142.50
Atl. Breakaway Cable Terminal GR-9	EA	2200	5	11,000.00	2175	14	30,450.00
Guardrail GR-10	LF				20	25	500.00
Fixed Object Attach GR-FOA-3 Ty I	EA				1600	2	3,200.00
Fixed Object Attach GR-FOA-3 Ty II	EA				1200	1	1,200.00
Remove Existing GR Terminal					100	38	3,800.00
Remove Existing Guardrail GR-8					1.1	8437.5	9,281.25
Remove Existing GR-7 & GR-8 Type I	EA	200	8	1,600.00			
Remove Existing Guardrail	LF	1	1940	1,940.00			
Subtotal: Guardrail				67,121.25			240,311.25
Topsoil	ACRE	6000	15.3	91,800.00	8100	10.17	82,377.00
Regular Seed	LB	6.5	3575	23,237.50	12	3383.4	40,600.80
Legume Seed	LB	18	400	7,200.00			
Fertilizer	TON	1275	4.95	6,311.25	12	3.26	39.12
Lime	TON	260	33	8,580.00	300	21.39	6,417.00
Subtotal: Re-vegetation							
Check Dam(rock) Ty II	EA	600	41	24,600.00	200	169	33,800.00
Siltation Control Excavation	CY	13	10	130.00			
Inlet Protection Type A	EA	350	26	9,100.00	250	55.27	13,817.50
Temp. Silt/ Filter Barrier	LF	4	2799	11,196.00	1.85	6384	11,810.40
Soil Stabilization Mat EC-3 Ty C	SY	3.75	11	41.25			
Super Silt Fence	LF	6	5116	30,696.00			
Subtotal: Erosion Control							
Total				**280,013.25**			**429,173.07**
Cost Per Mile				**54,904.56**			**44,017.75**