FINAL REPORT

EVALUATION OF HYDRAULIC CEMENT CONCRETE OVERLAYS PLACED ON THREE PAVEMENTS IN VIRGINIA

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(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

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ABSTRACT

Three hydraulic cement concrete pavement overlays were placed in the summer of 1995 at three locations in Virginia. Two of the overlays were placed on continuously reinforced concrete pavement to prevent spalling caused by a shy cover over the reinforcement and to enhance the structural integrity. The third overlay was placed to correct a rutted asphalt pavement.

The construction was funded with 20 percent Virginia Department of Transportation maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial conditions of the overlays and to prepare the report. The variables in the study were concrete mix design, overlay thickness, and base material. Mineral admixtures and steel and plastic fibers were used to improve the mechanical properties and durability of the overlay concrete. Overlay thickness and base material were varied to determine their effect on overlay performance.

Overlays that were 51 and 102 mm (2 and 4 in) thick worked well on hydraulic cement concrete pavements. Overlays that were 76 and 102 mm (3 and 4 in) thick worked well on asphalt concrete pavements. These overlays can be used to extend the life of the pavements.

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INTRODUCTION

Hydraulic cement concrete (HCC) pavement overlays were placed in the summer of 1995 at three locations in Virginia: I-295 near Richmond, I-85 near Petersburg, and Rte. 29 near Charlottesville. Overlays were placed on continuously reinforced concrete pavement on the I-295 southbound lane (near mile marker 29) and the I-85 southbound lane (near mile marker 51) to prevent spalling caused by a cover over the reinforcement that was less than it should be and to enhance the structural integrity. An overlay was also placed on the Rte. 29 northbound lane 16 km (10 mi) south of Charlottesville to correct a rutted asphalt pavement.

The construction was funded with 20 percent Virginia Department of Transportation maintenance funds and 80 percent special ISTEA Section 6005 federal funds specifically allocated to demonstrate overlay technologies. ISTEA funds were also used to evaluate the installation and initial conditions of the overlays and to prepare the report.

The variables in this study were concrete mix design, overlay thickness, and base material. Mineral admixtures and steel and plastic fibers were used to improve the mechanical properties and durability of the overlay concretes. Overlay thickness and base material were varied to determine their effect on overlay performance. A summary of these variables is presented in Table 1.

Table 1. Summary of Project Variables

Project	**I-295**	**I-85**	**Rte. 29**
Mineral admixture	Fly ash	Fly ash	Slag
Type of fiber used	Hooked-end steel Fibrillated polypropylene Polyolefin	Hooked-end steel Monofilament polypropylene ---	Hooked-end steel Monofilament polypropylene Polyolefin
Overlay thickness (mm)	51	102	51/76/102
Base material	Continuously reinforced concrete pavement	Continuously reinforced concrete pavement	Asphalt pavement

The symbols in Table 2 are used to designate the types of fiber-reinforced concrete (FRC) used in this project.

Table 2. Symbolic Designation of Overlay FRCs

Symbol	Fiber Amount, kg/m^3	Description
PO-1	11.9	25 mm polyolefin fiber
PO-2	14.8	51 mm polyolefin fiber
FP	1.8	Fibrillated polypropylene fiber, 19 mm
MP-1	0.9, 3.0	Monofilament polypropylene fiber, Brand I
MP-2	3.0	Monofilament polypropylene fiber, Brand II
ST	29.7, 44.5	Hooked end steel fiber, 30 by 0.5 mm

Table 3 lists the construction dates for the three overlays.

Table 3. Placement Dates for Overlays

Lane	I-295	I-85	Rte. 29
Inner lane (passing)	6/7/95-6/8/95	6/13/95-6/14/95	7/20/95-7/21/95
Middle lane	6/15/95	N/A	N/A
Outer lane (travel)	6/26/95	6/23/95	7/6/95-7/7/95

Tables 4, 5, and 6 show the mixture proportions for the three projects. The concrete was truck mixed in accordance with ASTM C 94.

Table 4. Mix Proportioning for I-295 Installation

Overlay Type	Control	PO-2	PO-1	FP	ST	
Fiber length, mm	--	51	25	19	32	32
Fiber amount, kg/m^3	--	15	12	1.8	29.7	44.5
Cement, kg/m^3	320	320	320	320	320	320
Fly ash, kg/m^3	75	75	75	75	75	75
Coarse aggregate, kg/m^3	908	908	908	908	908	908
Fine aggregate, kg/m^3	745	728	728	728	728	728
Water, L/m^3	166	178	174	174-178	178	174
Air entraining, L/m^3	0.21-0.23	0.15	0.15	0.15	0.15	0.15
Water reducer, L/m^3	0.51	0	1.81	0.0-0.33	0.0-3.1	0.77-3.9
Air, %	4.5-6.4	6.5	6.1-6.3	6.5-7.2	6.3-7.1	5.9-6.3
Slump, mm	34-114	64	51-121	38-95	76-108	44-102
W/cm	0.42	0.45	0.44	0.44-0.45	0.45	0.44

Table 5. Mix Proportioning for I-85 Installation

Overlay Type	Control	MP-1		ST	
Fiber length, mm	--	19	19	32	32
Fiber amount, kg/m^3	---	0.9	3	29.7	44.5
Cement, kg/m^3	344	344	344	344	344
Fly ash, kg/m^3	81	81	81	81	81
Coarse aggregate, kg/m^3	893-1084	1078 -1084	1078-1084	1078-1084	1078-1084
Fine aggregate, kg/m^3	627-847	627-637	627-637	627-637	627-637
Water, L/m^3	137.6-148	141-148	141-144	176-179	171-179
Air entraining, L/m^3	0.14-.35	0.14-0.31	0.14-0.31	0.14-0.31	0.14-0.31
WR + R, L/m^3	0.55-0.88	0.69-0.88	0.69-0.88	0.69-0.88	0.69-0.88
Air, %	4.2-7.5	5.4-6.9	4.2-7.3	4.8-7.3	5.4-7.5
Slump, mm	32-83	51-83	44-76	44-76	51-76
W/cm	0.40-0.43	0.41-0.43	0.41 -0.42	0.41-0.42	0.41-0.42

Note: WR + R = water reducing and retarding admixture.

Table 6. Mix Proportioning for Rte. 29 Installation

Overlay Type	Control, 51 mm	Control, 76 & 102 mm	PO-1	MP-2	ST	
Fiber length, mm	--	--	25	19	32	32
Fiber amount, kg/m^3	--	--	12	3	29.7	44.5
Cement, kg/m^3	251	226	251	251	251	251
Slag, kg/m^3	167	151	167	167	167	167
Coarse aggregate, kg/m^3	922	1051	922	922	922	922
Fine aggregate, kg/m^3	752	745-758	752	752	752	752
Water, L/m^3	167-192	143-181	180	180-184	176-179	171-179
Air entraining, L/m^3	0.3	0.3	0.48	0.44-0.48	0.48	0.48
WR + R, L/m^3	0.77-1.08	0.77-0.97	0.85-1.08	0.85-1.08	0.85-1.08	0.85-1.08
Air, %	4.3-8.0	4.0-6.0	5.6-7.4	6.6-6.8	5.6-10.3	4.4-6.0
Slump, mm	44-95	44-83	44	38.1-44	83-114.3	51-76.2
W/cm	0.40-0.46	0.38-0.48	0.43	0.43-0.44	0.42-0.43	0.41-0.43

Note: WR + R = Water reducing and retarding admixture

Site location maps for the three overlay projects are shown in Figures 1, 2, and 3.

PURPOSE AND SCOPE

The objective of this research was to evaluate hydraulic cement concrete pavement overlays with pozzolans and slag and with and without fibers constructed using ISTEA Section 6005 funds. The overlays were placed to correct for shy cover over the reinforcement or rutting and to enhance the structural integrity of the pavements.

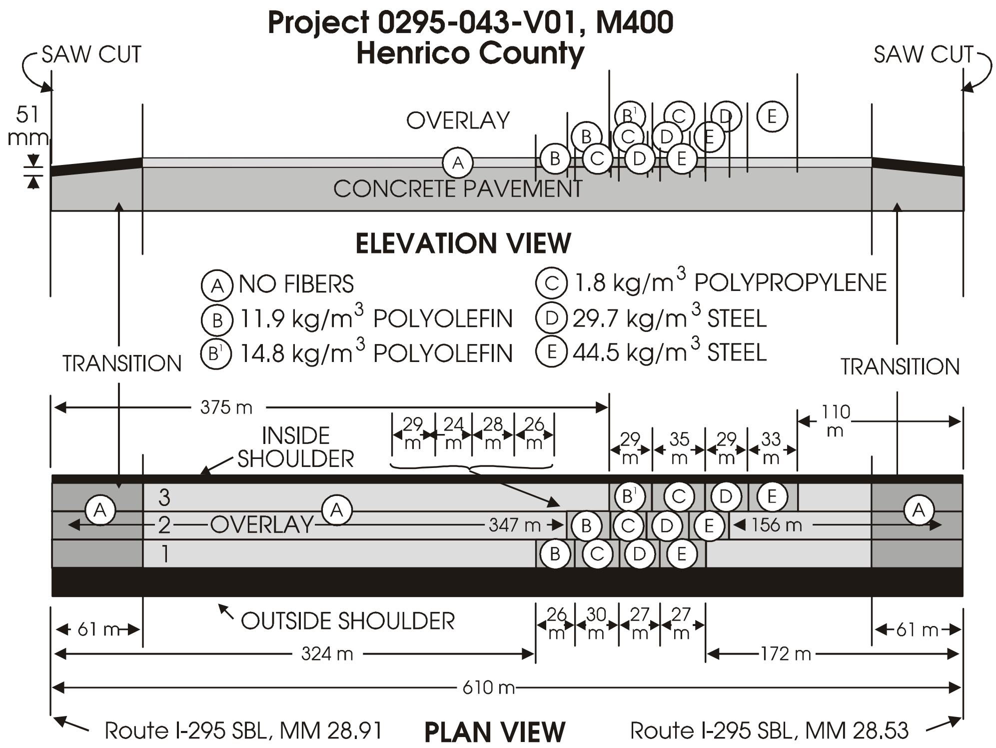

Figure 1. Site Map for I-295

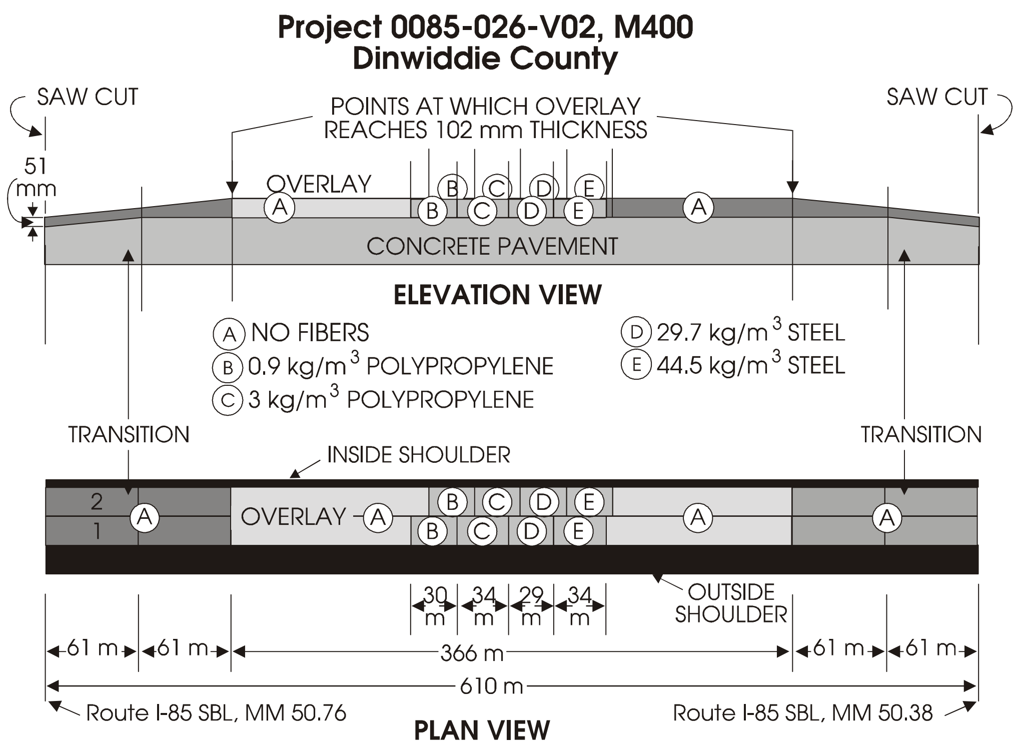

Figure 2. Site Map for I-85

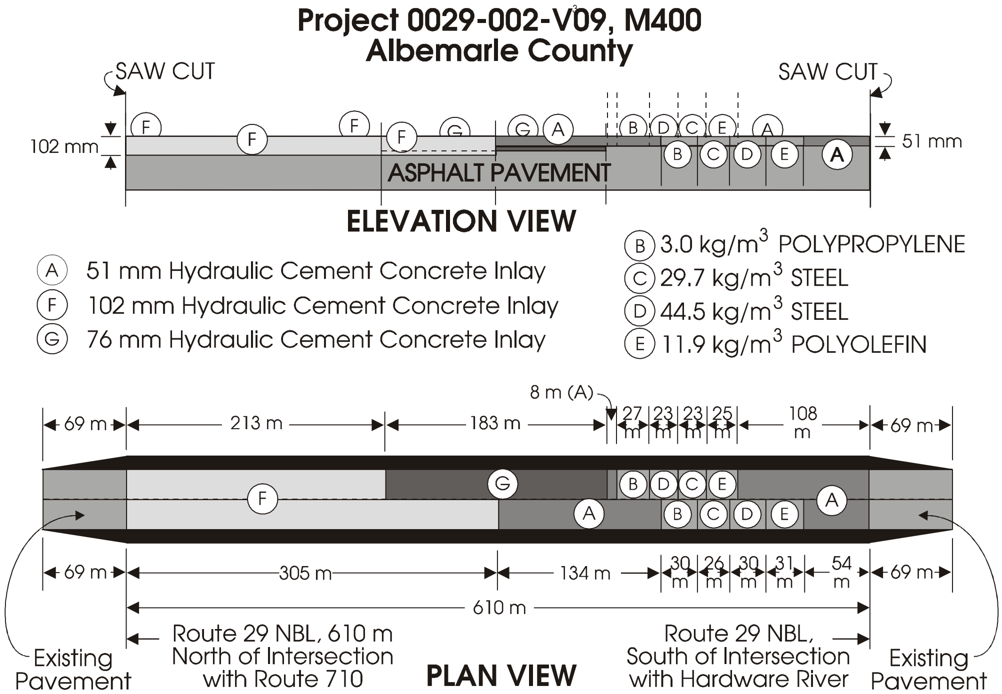

Figure 3. Site Map for Rte. 29

METHODOLOGY

The study objective was to be accomplished by completing the following tasks:

1. Evaluate conditions of each pavement before overlay is placed.
2. Document the specifications used for each installation.
3. Record results of quality assurance testing for each overlay.
4. Evaluate initial conditions of each installation.
5. Evaluate the condition of each installation annually.
6. Evaluate final condition of installation in 1999.
7. Submit final report to the Federal Highway Administration.

Tasks 6 and 7 are covered by this report. Tasks 1 through 5 were covered by an interim report.[1]

Evaluations of the overlays were based on an assessment of how well the overlays are bonded to the base concrete, how well they increase the stiffness of the pavement, how well they are protecting the pavement from the infiltration of chloride ion and corrosion, how well they are providing a skid-resistant surface, and their cost-effectiveness.

A modified version of VTM 92 was used to indicate how well the overlays are bonded to the base concrete. Typically, three cores, 57.2 mm (2.25 in) in diameter and approximately

102 mm (4 in) long, were tested to evaluate each overlay. The cores were drilled through the overlay and the base concrete and taken to the laboratory for testing. In the laboratory, the cores were saw cut parallel with and approximately 25 mm (1 in) above and below the plane of the bond interface. The machined surfaces of two pipe caps were bonded to the saw cut surfaces of each core with an epoxy. Two hooks were connected to the threaded pipe caps, and the hooks and core are pulled in tension using a universal testing machine. Cores were loaded at the rate of 5340 N (1,200 lb) per minute. The failure load and failure location were recorded.

Failures can occur in the base concrete, the bond interface, the overlay, the epoxy used to bond the caps to the core, and a combination of these locations. A 100% failure in the bond interface provides a true indication of bond strength. Failures at other locations indicate that the bond strength is greater than the failure load. However, for practical purposes, failures in the base concrete or overlay indicate the degree to which the overlay is anchored and are considered to indicate bond strength. When a failure occurs in the epoxy, the result may be discarded if it is lower than the average of the other results or included if it is the same or higher. An epoxy failure should be a rare occurrence.

Bond strength test results may be qualified as follows:

≥ 2.1 MPa (300 psi), excellent
1.7 to 2.1 MPa (250 to 299 psi), very good
1.4 to 1.7 MPa (200 to 249 psi), good
0.7 to 1.4 MPa (100 to 199 psi), fair
0 to 0.7 MPa (0 to 99 psi), poor.

A chain drag of the overlay was used to indicate areas that were delaminated (0 bond strength). A survey of the overlay for spalled and patched areas indicated bond strengths that were not high enough to prevent failure because of stress caused by shrinkage, traffic, temperature change, moisture, and freeze-thaw action.

The stiffness of the pavements was determined by a falling weight deflectometer (FWD) before and after placement of the overlays. An FWD imparts a series of impact loads transversely across a lane of pavement at 300-mm (12-in) longitudinal intervals and measures the deflection at each impact point. An average deflection is obtained for each interval, and the composite stiffness at each interval is then calculated from pavement deflection equations.

Protection against the infiltration of chloride ion WAS evaluated based on pavement surveys and mapping cracks and tests of two or three cores for permeability to chloride ion (AASHTO T 277). Permeability test results are based on tests of the top 51 mm (2 in) of cores 102 mm (4 in) in diameter and are typically the average of tests on two or three cores. Results are expressed as follows:

> 4000, high
2000-4000, moderate
1000-2000, low

100-1000, very low
< 100, negligible.

Skid resistance is typically measured with a skid test trailer that is pulled at 64 km/h (40 mph). Tests are done with a treaded tire (ASTM E501) or a bald tire (ASTM E524). Results are reported based on the average of three tests. The treaded tire provides a good indication of microtexture, and the bald tire, macrotexture. State departments of transportation do not publish standards for numbers, but asphalt and concrete pavements and bridge decks typically have numbers between 30 and 50. Cost-effectiveness is typically based on life cycle costs. Unfortunately, it is difficult to get representative costs for demonstration projects because of the unique nature and small size of typical projects. Relative comparisons of the costs of traffic control, construction, materials, and mobilization for various overlay systems can provide an indication of relative cost-effectiveness.

RESULTS

Cracks, Delaminations, and Patches

Sketches of the cracks before and after placement of the overlays are on file. Cracks on I-295 and I-85 were in the transverse direction. Cracks on Rte. 29 were predominately corner cracks (45° to corner). Cracking on Rte. 29 was so extensive that length, spacing, and width could not be used. The majority of the cracking on Rte. 29 occurred when the lanes were opened to traffic. No delaminations were found based on a chain drag of the overlays approximately 1 month and 4 years after they were constructed. On Rte. 29, some cracked corners sounded delaminated, but the sound may have been attributable to the crack. No patching was done on the I-295 and I-85 overlays after 4 years.

When evaluated in 1999, the Rte. 29 “white topping” was patched. Tables 7 and 8 show the crack spacing width on I-295 and I-85. Table 9 shows the intensity of cracking and patching on Rte. 29. The crack intensity is given in percentage of cracks per total number of corners.

Table 7. Average Spacing and Width of Crack in Overlay on I-295

Type	Lane	Length (m)	No. Cracks	Avg. Spacing (m)	Avg. Width (mm)
51 mm HCC	Outside	30.5	19	1.6	0.53
15 kg/m^3 PO 1	Outside	25.6	17	1.5	0.43
2 kg/m^3 PP	Outside	30.2	20	1.5	0.55
30 kg/m^3 ST	Outside	26.2	16	1.6	0.43
75 kg/m^3 ST	Outside	31.1	13	2.4	0.65
51 mm HCC	Inside	30.5	20	1.5	0.37
15 kg/m^3 PO 2	Inside	29.0	21	1.4	0.25
2 kg/m^3 FP	Inside	33.8	20	1.7	0.28
30 kg/m^3 ST	Inside	29.9	18	1.7	0.40
45 kg/m^3 ST	Inside	31.4	11	2.9	0.38

Table 8. Average Spacing and Width of Crack in Overlay on I-85

Type	Lane	Length (m)	No. Cracks	Avg. Spacing (m)	Avg. Width (mm)
102 mm HCC	Outside	30.5	30	1.0	0.43
1 kg/m^3 MP-1	Outside	29.0	20	1.4	0.42
3 kg/m^3 MP-1	Outside	33.2	21	1.6	0.41
30 kg/m^3 ST	Outside	29.3	21	1.4	0.41
45 kg/m^3 ST	Outside	33.5	10	3.4	0.46

Table 9. Crack Intensity and Area Patched in Overlay on Rte. 29

Type	Crack Intensity (%)	Patches (% of area)
51 mm HCC	11.3	1.2
76 mm HCC	0.2	0.0
102 mm HCC	3.8	0.0
3 kg/m^3 MP-2	22.3	17.9
30 kg/m^3 ST	52.4	14.9
45 kg/m^3 ST	24.6	2.3
12 kg/m^3 PO-1	66.3	1.0

Data from the Rte. 29 project indicated the following:

- No patches on 76 and 102 mm (3 and 4 in) test sections.

- Highest percentage of patching for polypropylene fibers because fibers do not hold cracked sections together.

- Lowest percentage of patching for polyolefin fibers because polyolefin fibers hold cracked sections together.

- Steel fibers at 30 kg/m^3 (lb/yd^3) had a high percentage of patching because fibers do not hold cracked sections together. The percentage of patching was less for steel fibers at 45 kg/m^3 (75 lb/yd^3), possibly because there were enough fibers to hold the sections together even with cracking fibers.

Stiffness

The composite stiffness of the pavements is shown in Figures 4, 5, and 6. The stiffness was improved with the placement of the overlay. However, the overall stiffness of the Rte. 29 pavement with asphalt and concrete was low because of the presence of the asphalt layer. Figure 7 shows the stiffness of the Rte. 29 inside lane in 1999 with the 6 mm (3 in) white topping. After 4 years, the stiffness of the section with the 51 mm (2 in) white topping was about the same as that initially.

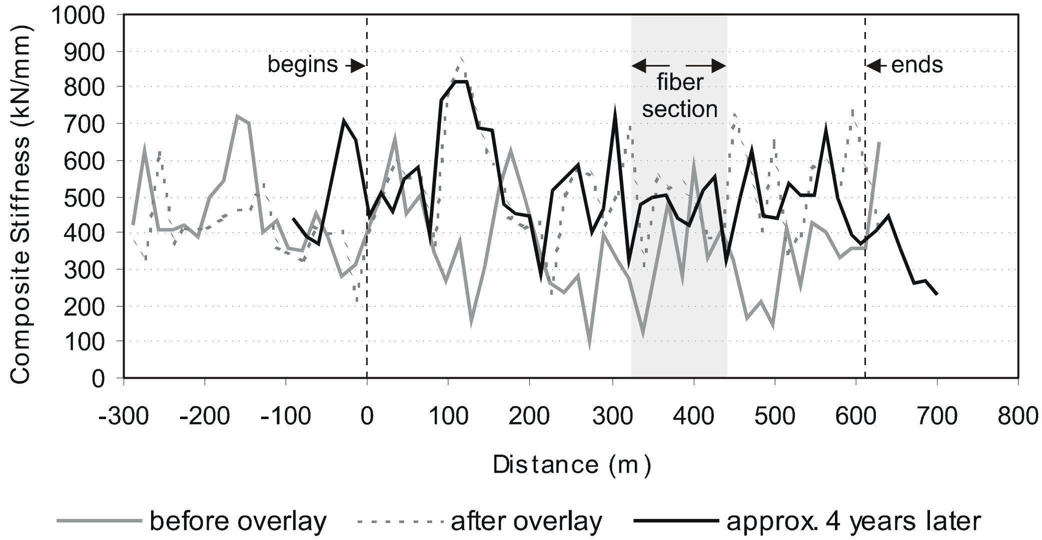

Figure 4. FWD Data of Overlay on I-295 Outside Lane

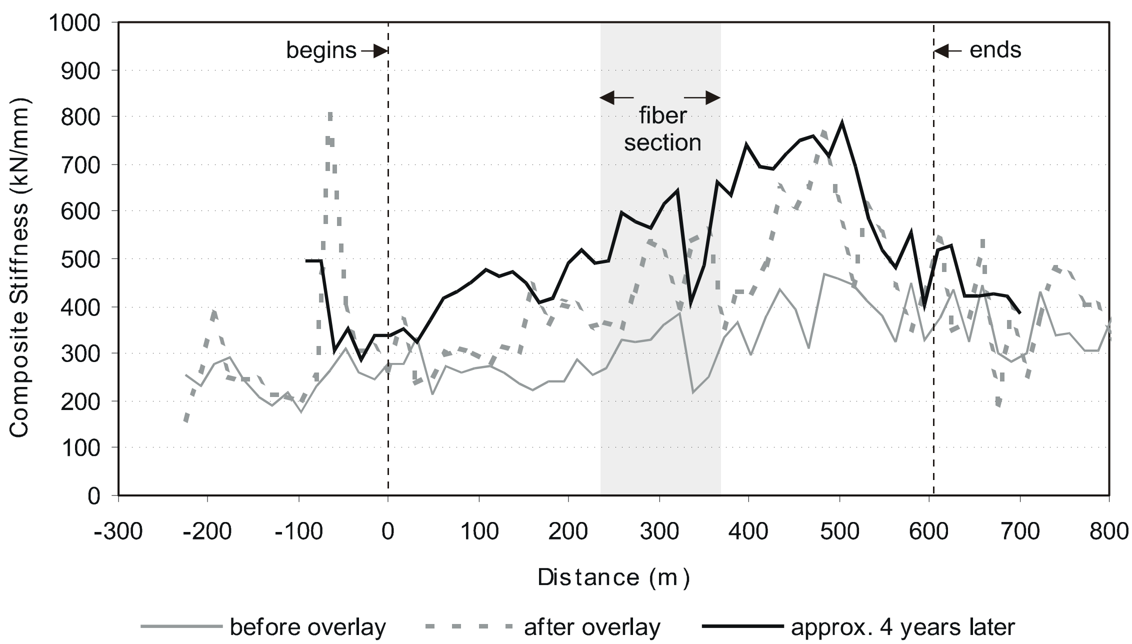

Figure 5. FWD Data of Overlay on I-85 Outside Lane

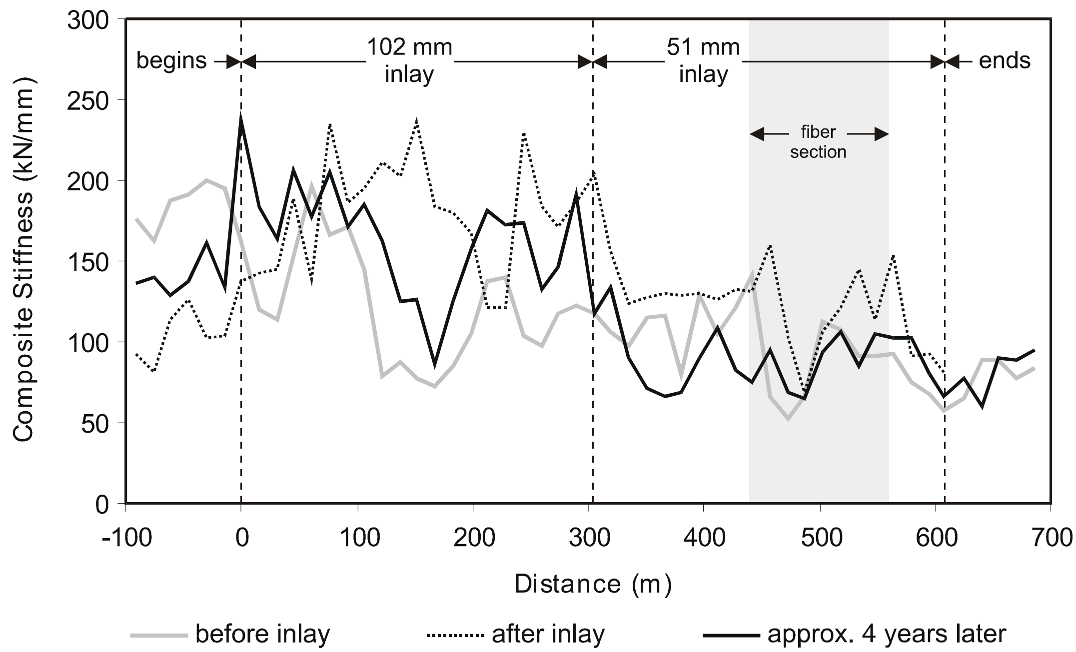

Figure 6. FWD Data of Overlay on Rte. 29 Outside Lane

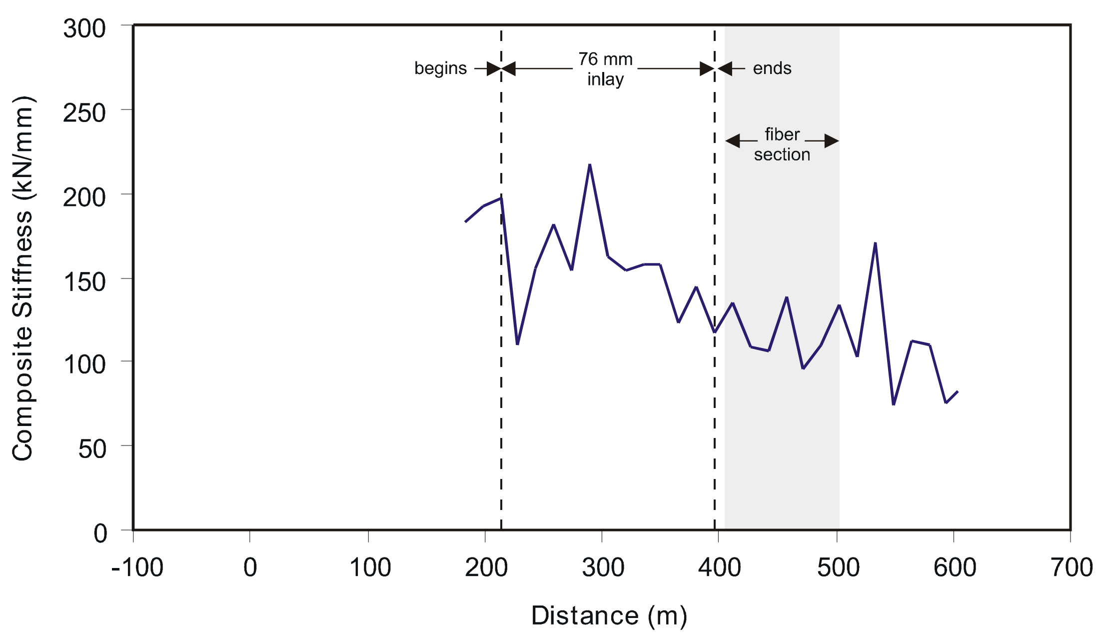

Figure 7. FWD Data of Overlay on Rte. 29 Inside Lane

Skid Resistance

The bald tire skid numbers at 3 months and at 4 years are provided in Table 10. This test uses a skid trailer that travels at a constant speed. VDOT considers skid numbers above 40 to be very good. Values for all overlays were above 40 except for the outer lane of I-85 after 4 years. Placement of the I-85 overlay led to large improvements in skid numbers; the road previously had skid numbers in the 20 to 40 range. Unfortunately skid resistance in the outer lane of I-85 declined after 4 years but was still higher than the before and after sections. I-295 had high skid numbers prior to placement of the overlay, and the high numbers were maintained with the placement of the overlay. The overlay on Rte. 29 had higher values than the 30 to 40 that are typical for asphalt.

Table 10. Skid Test Results From Overlay Placements

Job	Lane	1995 Before Test Section	1995 Test Section	1999 Test Section	1995 After Test Section
I-295	Inner lane	58	49	51	51
	Middle lane	52	48	47	46
	Outer lane	52	53	47	49
I-85	Inner lane	35	54	52	41
	Outer lane	22	48	34	29
Rte. 29	Inner lane	---	52	51	---
	Outer lane	---	42	41	---

Note: The bald tire test was used for all lanes.

Tensile Adhesion

Three cores, 57 mm (2.25 in) in diameter and 102 to 152 mm (4 to 6 in) long, were taken from each overlay test section at 1 month and at 4 years after the overlay was placed. The cores were saw cut parallel with, 25 mm (1 in) above, and 25 mm (1 in) below the bond line, and metal caps were epoxied onto the sawn surfaces. The specimens were pulled in direct tension to provide an indication of tensile bond strength and failure mode. The tensile bond strengths are given in Table 11.

The results were good to excellent for the I-295 and I-85 test sections except for the PO-2 section of I-295. The lower values for Rte. 29 were caused by the lower strength of the asphalt base relative to the concrete bases. Failures were predominately in the base on all three pavements, indicating that the surface preparation prior to placement of the overlays was excellent.

Table 11. Tensile Bond Strengths

Job	Fiber Type	Amount (kg/m^3)	Overlay Thickness (cm)		Bond Strength (kPa)		Failure Area (%)					
							Overlay		Bond		Base	
			1995	1999	1995	1999	1995	1999	1995	1999	1995	1999
I-295	Control (51 mm)	0	6.05	5.99	1731	1961	19	40	2	2	79	58
	PO-1	11.9	5.95	5.67	2162	2680	88	82	2	0	10	18
	PO-2	14.8	5.72	5.40	1029	1171	7	17	5	5	88	78
	FP	1.8	5.83	5.60	1765	1791	50	29	1	5	49	66
	ST	29.7	5.81	5.76	2017	1833	60	7	2	4	38	89
	ST	44.5	5.69	5.78	1834	2119	39	12	1	0	60	88
I-85	Control (102 mm)	0	10.48	10.16	1646	1564	0	0	0	0	100	100
	MP-1	0.9	10.68	10.80	1573	1509	17	0	0	0	83	100
	MP-1	3	10.99	10.80	1909	1385	17	0	0	0	83	100
	ST	29.7	10.72	10.74	1479	1736	0	0	0	0	100	100
	ST	44.5	10.68	10.69	1847	2170	0	0	0	0	100	100
Rte. 29	Control (51 mm)	0	6.03	5.40	794	737	15	0	0	12	85	88
	Control (76 mm)	-	-	9.29	-	558	-	5	-	10	-	85
	Control (102 mm)	0	10.24	11.23	744	379	13	0	5	2	82	98
	PO-1	11.9	5.89	4.76	657	820	28	25	40	38	32	37
	MP-2	3	5.79	5.27	798	151	13	0	15	0	72	100
	ST	29.7	5.77	5.72	815	579	14	0	25	0	61	100
	ST	44.5	5.72	4.97	531	526	20	16	36	7	44	77

Permeability

Cores 102 mm (1 in) in diameter were taken through the overlays approximately 1 month after and 4 years after the overlays were placed. The top 51 mm (2 in) was tested for permeability to chloride ion (AASHTO T 277). This test measures the amount of electrical charge that passes through a concrete sample during a 6-hour period. Steel FRC was not tested for permeability because of the significant increase in conductivity of the concrete by the metal. The results are shown in Table 12. The results indicate that after 6 weeks of curing, the permeability ranged from medium to high, as expected; when tests were done at 4 years when the pozzolans and slag were more completely cured, all values were very low.

These results demonstrate the effectiveness of pozzolans or slag in reducing the permeability of concretes. In conventional paving concretes without a pozzolan or slag at 28 days, high permeability values are expected, which decrease to a moderate range with time.

Table 12. Permeability of Cores Taken After Overlay Installation

Fiber Type	Amount (kg/m^3)	1995			1999		
		I-295	I-85	Rte. 29	I-295	I-85	Rte. 29
Control	0	2051	4462	3136	398	396	483
PO-2	14.8	-	-	-	532	-	-
PO-1	11.9	2847	-	3328	523	-	698
FP	1.8	5115	-	-	579	-	-
MP-1	0.9	-	4481	-	-	590	-
MP-1	3.0	-	2609	-	-	345	-
MP-2	3.0	-	-	4067	-	-	473

Overlay Design Life

Overlays were designed to have a service life of 20 years or more.

Cost of Overlay

Table 13 provides the costs for the overlays. The I-295 costs are less than those for I-85 because the overlay placed in I-295 was 51 mm (2 in) thick and required less material than the 102 mm (4 in) overlay placed in I-85. In this study, steel FRC was more expensive than polypropylene or polyolefin FRC. However, the cost does not reflect the market price of polyolefin FRC. Because of bidding and contractual stipulations, polyolefin fiber was acquired at the cost of polypropylene fiber. The order from highest cost to lowest was polyolefin FRC, steel FRC, and polypropylene FRC. Therefore, the actual cost of the polyolefin FRC would be higher than what is shown in Table 13.

The cost data show that a 102 mm (4 in) overlay can be a much better buy than a 51 mm (2 in) overlay. Especially for white topping, as represented by Rte. 29, the cost of the 102 mm (4 in) overlay is only 8% more than that of the 51 mm (2 in) overlay, but the thickness is double and the modulus is four times greater.

An asphalt overlay 51 mm (2 in) thick would cost approximately $\$3/m^2$ ($\$2.50/yd^2$). A 51 mm (2 in) concrete overlay would have to last 10 times longer to be competitive. Consequently, white topping would not typically be economical compared to asphalt on asphalt. Its use could be justified at selected locations, such as intersections where rutting of asphalt is severe and the asphalt must be replaced frequently, resulting in severe disruption of traffic.

Similarly, the use of HCC overlays on continuously reinforced concrete pavements would not typically be economical compared to the use of asphalt, but it might be justified in special situations.

Table 13. Comparison of Cost for FRC Versus Regular Concrete Overlays ($/m^2)

Overlay	Control, 51 mm	Control, 102 mm	FP, MP-1,2		ST		Mobilization	Traffic Control and Misc.
Fiber amount, kg/m^3	0	0	0.9	3.0	29.7	44.5	3.81	10.26
I-295	21.53	---	25.48	27.15	29.07	31.28	3.81	8.42
I-85	---	28.41	32.06	34.51	43.24	49.34	5.38	26.85
Rte. 29	24.64	26.56	25.90	27.87	33.73	38.10		

CONCLUSIONS

- High performance concrete overlays can be successfully placed on continuously reinforced concrete pavements and on asphalt pavements.
- Strong and low-permeability concretes can be obtained.
- The stiffness of the pavements increases with the addition of overlays. However, the increase obtained with the 51 mm (2 in) white topping is lost after 4 years.
- Satisfactory skid resistance can be achieved.
- The 51 mm (2 in) thick overlays placed on asphalt crack badly as soon as traffic is applied and are not likely to last long.
- Compared to asphalt, HCC overlays are not typically economical.
- Because of the high cost of fibers, their use is not typically economical.

RECOMMENDATIONS

1. HCC overlays 51 to 102 mm (2 to 4 in) thick may be used to increase the cover over reinforcement and increase the stiffness of continuously reinforced concrete pavements when these benefits justify the cost.
2. HCC overlays 76 to 102 mm (3 to 4 in) thick may be placed on asphalt to prevent rutting when economically justified.
3. HCC overlays 51 mm (2 in) thick should not be used on asphalt.

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