INTERIM REPORT

EVALUATION OF THE INSTALLATION AND INITIAL CONDITION OF HIGH PERFORMANCE CONCRETE OVERLAYS PLACED ON ROUTE 60 OVER LYNNHAVEN INLET IN VIRGINIA

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16. Abstract

Sixteen high performance concrete overlays were placed on two 28-span bridges on Rte. 60 over Lynnhaven Inlet, Virginia Beach, Virginia, in the spring of 1996. 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 condition of the overlays and to prepare this report.

The installation included 13 different concrete mixtures, an overlay with a thickness of only 19 mm (0.75 in), and spans with and without topical treatments of two corrosion inhibitors, for a total of 16 different overlays. The overlay types are 7% silica fume (SF), 5% SF and 35% slag (S), 5% SF and 15% class F fly ash (FA), 15% latex-modified concrete (LMC), 13% SF and 15% FA, 13% SF and 15% FA placed 19 mm thick, 7% SF and Rheocrete corrosion inhibiting admixture (CIA) (RCI), 7% SF and Armatec CIA (ACI) and ACI topical treatment (A), 7% SF and ACI, 7% SF and Darex CIA (DCI) and Postrite (P) topical treatment, 7% SF and DCI, 40% S, 7% SF and shrinkage reducing admixture (CQI), 7% SF and polyolefin fibers (POF), 7% SF and steel fibers (STF), and 7% SF and polypropylene fibers (PPF). With the exception of system F, overlays were required to have a minimum thickness of 32 mm. Also, system E had a variable thickness that ranged from 32 mm to 19 mm to provide good ride quality.

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(A Cooperative Organization Sponsored Jointly by the
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1.0 Project Introduction

1.1 Summary

Sixteen high performance concrete overlays were placed on two 28-span bridges on Rte. 60 over Lynnhaven Inlet, Virginia Beach, Virginia, in the spring of 1996. 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 condition of the overlays and to prepare this report.

A site location map for the two bridges is shown in Figure 1.1. Initially, the westbound bridge (WBL) was overlaid while traffic used the eastbound bridge (EBL). Then, traffic was detoured to the WBL while the EBL was overlayed.

The installation included 13 different concrete mixtures, an overlay with a thickness of only 19 mm (0.75 in), and spans with and without topical treatments of two corrosion inhibitors for a total of 16 different overlays. The overlay types are identified in Figure 1.1 as follows: 7% silica fume (SF), 5% SF and 35% slag (S), 5% SF and 15% class F fly ash (FA), 15% latex-modified concrete (LMC), 13% SF and 15% FA , 13% SF and 15% FA placed 19 mm thick, 7% SF and Rheocrete corrosion-inhibiting admixture (CIA) (RCI), 7% SF and Armatec CIA (ACI) and ACI topical treatment (A), 7% SF and ACI, 7% SF and Darex CIA (DCI) and Postrite (P) topical treatment, 7% SF and DCI, 40% S, 7% SF and shrinkage-reducing admixture (CQI), 7% SF and polyolefin fibers (POF), 7% SF and steel fibers (STF), and 7% SF and polypropylene fibers (PPF). With the exception of system F, overlays were required to have a minimum thickness of 32 mm. Also, system E had a variable thickness that ranged from 32 mm to 19 mm to provide good ride quality.

1.2 Objective

The objective of this research is to demonstrate and evaluate bridge deck overlays placed using ISTEA section 6005 funds.

1.3 Methodology

The objective is to be accomplished by completing tasks as follows for the outside travel lane of at least one deck span with each of the 16 overlays:

- Task 1 Evaluate conditions of each deck prior to placement of the overlays.
- Task 2 Document the specifications used for each installation.
- Task 3 Document the installation of each overlay.
- Task 4 Evaluate the initial condition of each overlay.
- Task 5 Evaluate the condition of each overlay annually.

- Task 6 Evaluate the final condition of each overlay in 1999.
- Task 7 Prepare and submit a draft and final report to FHWA covering tasks 1 through 7. The report will include an estimate of the service life and cost-effectiveness of each installation.

This report covers tasks 1 through 4. When available, information obtained for more than one span and for the inside lane is presented and included in the evaluation of each overlay.

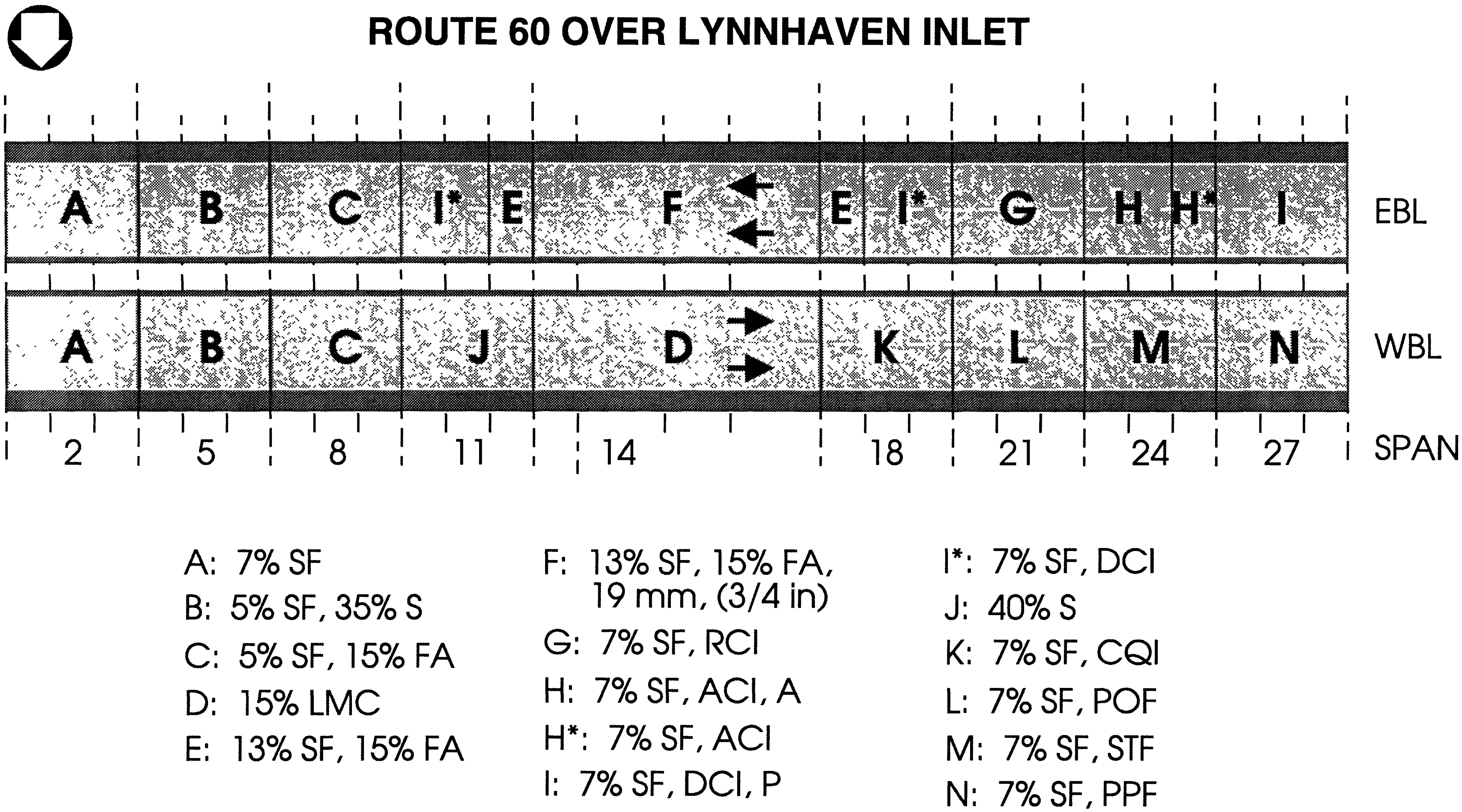


Figure 1.1. The plan view for the overlays on the two 28-span bridges on Rte. 60 over the Lynnhaven Inlet.

2.0 Evaluation of Conditions Prior to Installation

2.1 Electrical Half-Cell Potentials (ASTM C876)

Electrical half-cell potential measurements (ASTM C876) were taken on a 1.2-m grid over the outside shoulder and travel lane prior to placement of the overlays. The electrical half-cell potential data (Table 2.1) show that there is a 90 percent or greater probability that corrosion is occurring in a small percentage of the spans. On the majority of the spans, there is a 90 percent or greater probability that corrosion is not occurring.

Span	Lane	Half-Cell Potential Range (-VCSE) (%)		
		<0.20	0.2-0.35	>0.35
2	EBL	81.32	14.28	4.40
	WBL	96.94	3.06	0.00
5	EBL	100.00	0.00	0.00
	WBL	100.00	0.00	0.00
8	EBL	97.80	2.20	0.00
	WBL	91.84	7.14	1.02
11	EBL	75.82	19.78	4.40
	WBL	97.96	2.04	0.00
14	EBL	43.96	43.96	12.08
	WBL	86.34	11.62	2.04
18	EBL	80.22	15.38	4.40
	WBL	96.91	3.09	0.00
21	EBL	86.81	10.99	2.20
	WBL	98.98	1.02	0.00
24	EBL	100.00	0.00	0.00
	WBL	94.90	4.08	1.02
27	EBL	94.51	5.49	0.00
	WBL	97.94	2.06	0.00

Table 2.1 Electrical half-cell potentials prior to overlay applications (ASTM C 876)

2.2 Chloride Ion Content Profiles

Chloride ion content samples were taken at five depths at three locations on each of the spans.

The data in Table 2.2 show that there is not sufficient chloride (0.77 kg/m^3) at the level of the top mat of reinforcement (approximately 5 cm) to cause corrosion. The chloride data support the half-cell potential data. The EBL is closer to an active state of corrosion than the WBL. The

Depth of Samples from Surface, cm	Chloride Ion Content, kg/m³									
	Span No.									
	2		5		8		11		14	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.64-1.27	2.55	1.36	1.96	1.01	1.35	2.48	1.9	1.79	2.17	2.16
1.27-2.54	1.68	0.49	1.23	<0.18	0.96	0.83	1.1	1.03	1.2	1.12
2.54-3.81	1.5	<0.18	0.67	<0.18	0.27	<0.18	0.61	0.43	0.55	0.21
3.81-5.08	0.94	<0.18	0.21	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18
11.43-12.70	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18

Depth of Samples from Surface, cm	Chloride Ion Content, kg/m³							
	Span No.							
	18		21		24		27	
	EBL	WBL	EBL	WBL	EBL	WBL	EBL	WBL
0.64-1.27	2.65	1.26	2.27	1.45	1.85	1.77	1.92	1.49
1.27-2.54	1.2	0.3	1.86	0.37	1.26	0.92	0.79	0.52
2.54-3.81	0.77	<0.18	1.1	<0.18	0.47	0.23	0.39	<0.18
3.81-5.08	0.5	<0.18	0.72	<0.18	<0.18	<0.18	<0.18	<0.18
11.43-12.70	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18	<0.18

Table 2.2 Chloride ion content data. Values are the average of three samples taken from the outside lane; one taken in the right wheel path at the quarter point of the span; one taken in the center of the outside lane at midspan; and one taken in the left wheel path at the ¾ point.

installation of the overlays should retard the further progress of chlorides and extend the life of the structures.

2.3 Map of Cracks and Patches

Maps of the cracks and patches in the outside lane of each span are on file. With the exception of the center spans, which are on steel beams, the decks were free of cracks and patches. Span 14 in the WBL had 101 m (322 ft) of transverse cracks, and span 14 in the EBL had 21 m (69 ft).

2.4 Permeability to Chloride Ion (AASHTO T277)

Cores 102 mm in diameter by approximately 127 mm long were taken for chloride ion permeability tests (AASHTO T277). One core was taken at midspan in the center of the outside lane of each span. In most cases, the permeability values (Table 2.3) for the spans were in the very low (100-1000 coulombs) to low (1000-2000 coulombs) range. The EBL was constructed in the early 50s, and the WBL in the early 60s. The low permeability of the concrete along with

Span No.	Lane	Permeability, Coulombs
2	EBL	1449
	WBL	918
5	EBL	640
	WBL	850
8	EBL	1070
	WBL	879
11	EBL	2255
	WBL	1169
14	EBL	1725
	WBL	883
18	EBL	561
	WBL	1251
21	EBL	627
	WBL	1281
24	EBL	1936
	WBL	740
27	EBL	656
	WBL	41

Table 2.3 Preinstallation permeability readings

the good cover over the reinforcement was the likely reason the bridge decks were relatively free of corrosion after 35 to 45 years in service.

2.5 Preinstallation Photographic Record

Color slides were used to provide a photographic record of the condition of the decks prior to placement of the overlays. The slides are on file.

3.0 Specifications for Installation

3.1 Site Preparation and Preoverlay Repairs

Traffic control devices and concrete barricades were installed to divert traffic to the EBL prior to preparation of the surface of the WBL. When the overlays on the WBL were complete, traffic was diverted to the WBL and the surface of the EBL was prepared.

The surface was chain dragged to identify delaminated areas. Concrete was removed to one half the deck thickness at several small locations on the EBL because a chain drag of the surface identified delaminations. The total area of concrete removed for patching was approximately 2.9 m^2 (3.5 yd^2). Span 2 had 0.3 m^2; span 11, 0.1 m^2; span 14, 2.3 m^2; and span 21, 0.2 m^2.

3.2 Surface Preparation

Prior to placement of the concrete overlay, the entire deck surface was cleaned and roughened by shotblasting (Figure 3.1) to remove asphaltic material, oils, dirt, rubber, curing compounds, paint, carbonation, laitance, weak surface mortar, and other potentially detrimental materials that may have interfered with the bonding or curing of the overlay and to provide a macrotexture depth of at least 1.5 mm (0.06 in) in accordance with ASTM E965. Hydroblasting was an acceptable alternative to shotblasting, but Class A scarification was not permitted.

After the surface was cleaned and roughened, a vacuum cleaner system was used to remove dust and other loose material. Brooms were not used and were not permitted. Any contamination of the deck after initial cleaning was removed. The prepared surface was water soaked and covered with polyethylene within 24 hours of the final pass of the shotblasting equipment. The prepared surface was maintained in the wet and covered condition for at least 8 hours and until the polyethylene cover was removed just ahead of the overlay placement.

3.3 Joint Preparation

The specification required that existing expansion joint material be removed and the existing joint be filled with a material to prevent overlay material from infiltrating the joint. The temporary filler material should extend to the top of the proposed overlay and should provide a true edge for forming the joint in the overlay.

The specification required that as soon as practicable after the overlay was placed, the temporary expansion joint filler material be removed; the joint be saw cut, cleaned, and prepared; and the preformed elastomeric joint sealer be installed.

Figure 3.1 Shotblast equipment with six side-by-side blasting heads used to shotblast large areas of the deck.

3.4 Surface Finish

After proper curing, all overlays were required to be given a Class 6 finish in accordance with Section 404 of VDOT's *Road and Bridge Specifications,* which is saw cut grooves 3.2 mm (0.13 in) wide by 3.2 mm (0.13 in) deep spaced 19 mm (0.75 in) apart.

3.5 Overlay Technology

Table 3.1 shows the span numbers and installation dates for the 16 overlays.

Mix	Cast	Span	Variable		Mix	Cast	Span	Variable
WBLs					**EBLs**			
K1	3-26-96	18	SF7+CQI		C19	5-9-96	8	SF5+FA15
K2	3-26-96	19	SF7+CQI		C20	5-9-96	7	SF5+FA15
L3	4-3-96	21	SF7+POF		B21	5-10-96	5	SF5+Slag35
L4	4-3-96	22	SF7+POF		B22	5-10-96	4	SF5+Slag35
M5	4-3-96	24	SF7+STF		A23	5-10-96	2	SF7
M6	4-3-96	25	SF7+STF		A24	5-10-96	1	SF7
N7	4-4-96	27	SF7+PPF		F25	5-15-96	14	SF13 + FA15, W/CM=0.25
N8	4-4-96	28	SF7+PPF		F26	5-15-96	15	SF13 + FA15, W/CM=0.25
J9	4-11-96	11	A-4 P&R – 40% Slag		G27	5-18-96	21	SF7 + RCI
J10	4-11-96	10	A-4 P&R – 40% Slag		G28	5-18-96	22	SF7 + RCI
C11	4-11-96	8	SF5+FA15		H29	5-18-96	24	SF7 + ACI
C12	4-11-96	7	SF5+FA15		H30	5-18-96	25	SF7 + ACI
B13	4-13-96	5	SF5+Slag35		I31	5-21-96	18	SF7 + DCI
B14	4-13-96	4	SF5+Slag35		I32	5-21-96	19	SF7 + DCI
A15	4-13-96	2	SF7		I33	5-22-96	27	SF7 + DCI + Postrite
A16	4-13-96	1	SF7		I34	5-22-96	28	SF7 + DCI + Postrite
D17	4-18-96	14	Latex Mix 15%		I35	5-22-96	11	SF7 + DCI
D18	4-18-96	15	Latex Mix 15%		I36	5-22-96	10	SF7 + DCI

Table 3.1 Overlay technology description

3.6 Overlay Design Thickness

All overlays except systems E and F were designed to have a thickness of 30 mm (1.25 in) or greater.

3.7 Overlay Design Life

All overlays were designed to have a service life of 20 years of more.

3.8 Design Mixture Proportions

Table 3.2 shows the design mixture proportions for the 16 overlays.

	Test Sections						
Material	**A**	**B**	**C**	**D**	**E**	**F**	**G**
Cement, kg/m^3	363	371	371	390	412	412	363
Silica Fume, kg/m^3	27	20	20	0	62	62	27
Latex, kg/m^3	-	-	-	134	-	-	-
CA, kg/m^3	899	899	899	726	950	950	899
FA, kg/m^3	820	815	804	924	761	761	820
Water, kg/m^3	156	156	156	86	119	119	148
AE Admixture mL/m^3	194-310	194-310	194-310	0	194	194	194-310
HRWA, L/m^3	5	5	5	0	13	13	5
Air, %	4-8	4-8	4-8	5	4-8	4-8	4-8
Slump, cm	10-18	10-18	10-18	10-15	10-18	10-18	10-18
w/c**	0.4	0.4	0.4	0.4	0.25	0.25	0.4

	Test Sections						
Material	**H, H***	**I, I***	**J**	**K**	**L**	**M**	**N**
Cement, kg/m^3	363	363	377	363	363	363	363
Silica Fume, kg/m^3	27	27	-	27	27	27	27
Latex, kg/m^3	-	-	-	-	-	-	-
CA, kg/m^3	899	899	908	899	899	899	899
FA, kg/m^3	820	820	763	820	820	820	820
Water, kg/m^3	156	139	170	147	156	156	156
AE Admixture mL/m^3	194-310	291-310	194-310	970	194-310	194-310	194-310
HRWA, L/m^3	5	5	0.5	5	5	5	5
Air, %	4-8	4-8	4-8	4-8	4-8	4-8	4-8
Slump, cm	10-18	10-18	5-13	10-18	INV***	INV***	10-18
w/c**	0.4	0.4	0.45	0.4	0.4	0.4	0.4

**Water-cementitious material ratio.

***Slump determined using inverted slump cone and internal vibrator.

Table 3.2 Design mixture proportions

3.9 Aggregate Gradation Specification

Table 3.3 shows the design aggregate gradation specification.

Type of Aggregate	Sieve Analysis of Aggregates									
	19 mm (3/4 in)	13 mm (1/2 in)	10 mm (3/8 in)	No 4	No 8	No 16	No 30	No 50	No 100	No 200
CA-No.78	Min. 100	95±5	60±20	Max. 20	Max. 8	Max.5	-	-	-	-
FA-Grading A	-	-	Min. 100	97±3	90±10	67±18	42±17	17±9	Max. 10	-

Table 3.3 Design sieve analysis for aggregates (Virginia Department of Transportation *Road and Bridge Specifications,* January 1994)

3.10 Characteristics of Ingredients

Table 3.4 shows other characteristics of the concrete ingredients.

Material	Type	Source	S.G.	Absorption	F.M.	Other
Cement	Type II	Kamari, Greece	3.15			
SF	-----	Master Builders	2.2			
Fly ash	F	Monex, Belews Creek, NC	2.3			
Slag	Grade 120	NewCem, Blue Circle	2.95			
CA	No. 7 gravel	Kingsland Reach, VA	2.62	0.6		
CA*	No.8 crushed stone	Jack Quarry, VA	2.68	0.6		
FA	Sand	Petersburg, VA	2.62	0.6	2.8	
Latex	Styrene Butadiene	BASF				48% solids
AEA	Vinsol resin	MBVR, Master Builders				
Retarder	Type D	Rheobuild 997, Master Builders				
WR	Type A	220-N, Master Builders				
HRWR	Type F	Rheobuild 1000, Master Builders				
CQI	------	Eclipse, W.R. Grace				0.93 kg/L
CIA	Calcium nitrite	DCI-S, W.R. Grace				30% solids
	------	Armatec 2000, Sika				
	------	Rheocrete 222, Master Builders				
Fibers	Polyolefin	3M				
	Steel Fibers	Dramix, Bekaert				
	Polypropylene	Fibermesh				

* Aggregate used for LMC

Table 3.4 Overlay concrete ingredient characteristics

3.11 Curing Method and Time

Table 3.5 shows the curing methods and times.

Overlay Type	Description of Curing Method and Time
All overlays except LMC	Wet burlap and white plastic sheeting for 3 days followed by liquid membrane curing compound
LMC	Wet burlap and white plastic sheeting for 48 hours

Table 3.5 Overlay concrete curing methods and times

3.12 Bond Strength (VTM-92)

The specification for the overlays did not require this test.

3.13 Compressive Strength (ASTM C39)

The minimum laboratory design compressive strength at 28 days for the overlays placed for the project were:

- 24.1 MPa (3500 psi) for the LMC
- 34.5 MPa (5000 psi) for the other concretes.

3.14 Grout

For each bridge, the mortar fraction of the overlay concrete was first broomed into the prepared substrate. Coarse aggregate was discarded. A separate grout was not used.

4.0 Results of Quality Assurance Testing

4.1 Mixture Proportions

Table 4.1 shows the mixture proportions that were used. Characteristics of ingredients can be found in Sections 3.9 and 3.10 of this report.

	Test Sections						
Material	**A**	**B**	**C**	**D****	**E**	**F**	**G**
Cement, kg/m^3	363	371	371	390	412	412	363
Silica Fume, kg/m^3	27	20	20	0	62	62	27
Latex, kg/m^3	-	-	-	133	-	-	-
CA, kg/m^3	899	899	899	726	949	949	899
FA, kg/m^3	819	815	804	924	761	761	819
Water, kg/m^3	151	151	151	87	113	113	135
AE Admixture mL/m^3	290	270	290-350	0	190	190	310-350
HRWA, L/m^3	5.1	5.1-5.2	4.8-5.1	0	13.9-51.7	13.9-51.7	5.1
Air, %	6.4-8	4.8-7	5.4-9	5.00	6.8-8.2	6.8-8.2	4-7.2
Slump, mm	130-180	160-180	130-180	100-150	170-200	170-200	130-200
w/c	0.39	0.39	0.39	0.4	0.24	0.24	0.35

	Test Sections						
Material	**H, H***	**I, I***	**J**	**K**	**L**	**M**	**N**
Cement, kg/m^3	363	363	377	363	363	363	361
Silica Fume, kg/m^3	27	27	-	27	27	27	27
Latex, kg/m^3	-	-	-	-	-	-	-
CA, kg/m^3	899	899	908	899	899	899	899
FA, kg/m^3	819	819	762	819	819	819	819
Water, kg/m^3	151	167	164	144	151	151	151
AE Admixture mL/m^3	309	503	309	967	348	387	348
HRWA, L/m^3	3.8	5.1	0.5	3.8	4.3	4.7	4.4
Air, %	6-8	4	7.8-9	5-6.25	4.8-7.8	6.2-8	8.8-9.8
Slump, mm	200-220	150-200	130	130-170	4.7-13.8***	0-7.2***	180
w/c	0.39	0.43	0.44	0.37	0.39	0.39	0.39

**For mobile mixed concrete the design mixture proportions are used because the mixer is calibrated based on those proportions.
***Seconds by inverted slump cone method.

Table 4.1 Overlay mixture proportions used

4.2 Aggregate Moisture Content

Table 4.2 shows the moisture content of the aggregates.

	Test Sections																
Materials	**A**		**B**		**C**		**D**	**E**	**F**	**G**	**H**	**I**	**J**	**K**	**L**	**M**	**N**
Coarse Aggregate (No. 78 Stone)	**2.0**	**0.5**	**0.5**	**0.5**	**2.2**	**0.5**	*	**0.5**	**0.5**	**0.9**	**2.0**	**2.0**	**0.5**	**0.5**	**0.5**	**0.5**	**0.7**
Fine Aggregate (Sand)	**7.0**	**7.5**	**7.0**	**7.5**	**6.8**	**8.0**	*	**6.5**	**6.5**	**7.5**	**7.7**	**7.7**	**8.0**	**7.5**	**8.0**	**8.0**	**4.0**

* Mobile mixer calibration sheets were not available.

Table 4.2 Fine and coarse aggregate moisture contents

4.3 Comparison of Actual Mixture Properties and Design Specifications

A comparison of the data in Tables 3.2 and 4.1 shows that in general the design mixture proportions were used. In some cases the aggregate batch weights were slightly different than the design weights, the amount of water used was less than the maximum, and the admixture dosages were different from the design ranges. The mixtures satisfied the specification.

4.4 Summary of Placement Conditions

Span No.	Overlay Type	Lane	Climatic Conditions	Rate of Evaporation, $kg/m^2/h$	Concrete Temp, C	Air Temp, C	Relative Humidity	Avg Wind Speed, km/h
2	A	EBL	Morning, cool, still	0.1	21	14-18	83-95	2.4
	A	WBL	Morning; warm, windy	0.4	18-19	22-26	33-37	11.3
5	B	EBL	Early morning; cool, raining	0.1	21	13-16	77-96	1.6
	B	WBL	Morning; cool	0.2	17	16-19	42-45	4.0
8	C	EBL	Early morning; cool, raining	0.15	19-20	13-14	96-99	3.2
	C	WBL	Day; cool, windy	0.35	14	16-18	23	10.5
11	I*	EBL	Morning; cool, still	0.1	27	20-21	92	0.0
	J	WBL	Morning; cool	0.2	11-13	10-14	20-29	7.2
14	F	EBL	Morning; chilly	0.3	19-209	8-11	74-79	6.4
	D	WBL	Night; cool, still	0.15	14-16	9-15	28-65	3.2
18	I*	EBL	Early morning; cool, windy	0.35	24-27	19-21	94-95	14.5
	K	WBL	Day; cool, windy, and rainy	0.25	16-22	15-18	41-67	9.7
21	G	EBL	Night; cool, still	0.1	22-23	17-18	83-97	1.6
	L	WBL	Day; warm	0.25	17	24-28	19-21	6.4
24	H	EBL	Early morning; cool, still	0.1	21-25	16-17	97	1.6
	M	WBL	Late day	0.25	13-17	19-26	19-22	6.4
27	I	EBL	Early morning	0.2	26-27	20-22	74-95	4.0
	N	WBL	Late day; warm	0.3	18-20	24-25	24-29	6.4

Table 4.3 Summary of placement conditions

Table 4.3 provides a summary of the placement conditions. It is generally accepted that plastic shrinkage cracking is likely in overlays when the evaporation rate exceeds 0.5 $kg/m^2/h$. The data show that this rate was not exceeded and no cracking occurred.

4.5 Thermal Coefficients of Deck and Overlay Concrete

Specimens were not tested for the coefficient of thermal expansion. Specimens of LMC and SF concretes made for another ISTEA-funded overlay project were tested, and values ranged from 14.2 to 21.2 mm/mm/°C x 10^{-6} (1). It is believed that these values are representative of the concretes used in this project.

Compressive modulus of elasticity measurements were determined for the overlay concretes (Table 4.4).

Overlay	Modulus of Elasticity (GPa) at 28 d
A	31.1
B	30.9
C	31.4
D	26.1
E, F	27.7
G	30.8
H, H*	33.9
I, I*	31.1
J	26.2
K	28.5
L	29.4
M	30.2
N	27.2

Table 4.4 Compressive modulus of elasticity

The old base concrete was assumed to have a modulus of elasticity of 28.9 GPa and a coefficient of thermal expansion of 10.3 x 10^{-6} mm/mm/°Cx10^{-6} (2). Using these values for the base concrete, the modulus values in Table 4.4, and the coefficient of thermal expansion values from the earlier report (1), theoretical shear stresses attributable to temperature change can be computed. Assuming a 40°C maximum temperature change, theoretical shear stresses would range from a low of 2.2 MPa (320 psi) for overlay N to a high of 6.0 MPa (870 psi) for overlay D. In general, the higher the modulus of elasticity of the overlay, the higher the stress and the higher the coefficient of thermal expansion the higher the stress, with the coefficient of thermal expansion having a much greater effect on theoretical shear stress than the modulus of elasticity.

Based on these stresses, the overlay could delaminate because of thermal stress at times of extremely low temperatures. Thermal failures rarely occur because of creep and shrinkage and because the overlay is in tension relative to the base.

4.6 Drying Shrinkage of Overlay Concrete

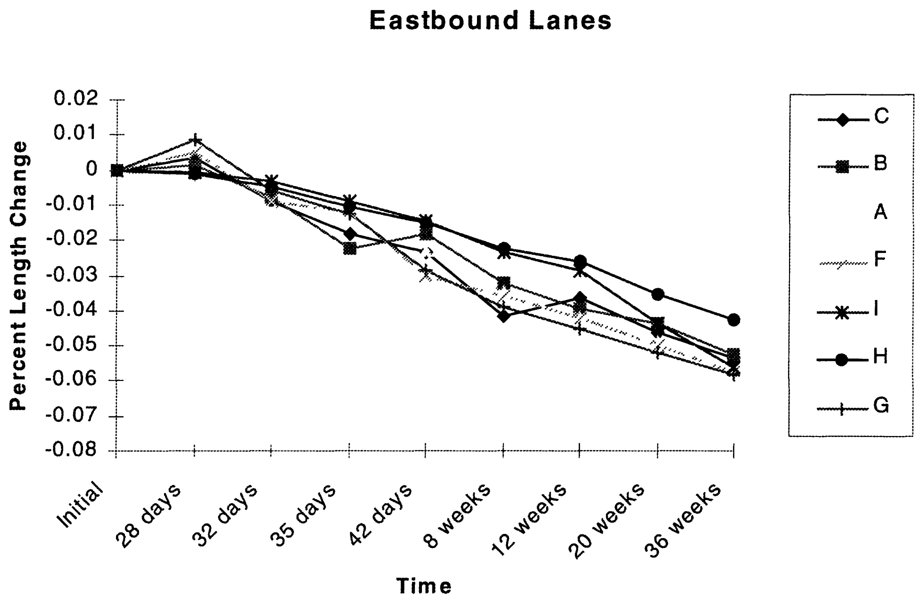
Three length change specimens were prepared from each of two samples of concrete taken during the overlay placements. The specimens were cured next to the bridge for approximately 20 hours, transported to the laboratory over the next 3 hours, and removed from their molds between 23 and 24 hours of age. The initial length was measured at 24 hours of age, and the specimens were placed in a moist curing room. Once the moist curing period was complete, specimens were moved to the laboratory and stored on racks at approximately 50% relative humidity. The length as a function of age is plotted in Figure 4-1. In general, the concrete batches displayed similar trends during the drying period. Exceptions to this included the LMC (D), which showed less shrinkage than the others in the first few weeks but more toward the end of testing, and the CQI (K) mix, which displayed less shrinkage throughout the testing. ACI (H) also showed low shrinkage.

4.7 Compressive Strength, MPa

Table 4.5 shows the compressive strength of the overlay concretes. The LMC (D) and low water-cementitious ratio SF and FA (F) showed the greatest strengths at 1 year.

Span No.	Overlay Type	Lane	24 h	7 d	28 d	1 yr
2	A	EBL	21.3	34.3	46.9	54
	A	WBL	19.8	34.3	45.5	54.6
5	B	EBL	32.1	42.1	50.5	56.9
	B	WBL	14.8	31.4	48.5	55.2
8	C	EBL	24.4	36.8	48.7	61.4
	C	WBL	18.3	32.8	45.4	56.7
11	I*	EBL	23.9	31.1	39.3	45.3
	J	WBL	5.3	18	31.4	40.5
14	F	EBL	18.3	43.3	62.4	72.4
	D	WBL	24	43	54.7	71.8
18	I*	EBL	20	37.3	49.2	56.4
	K	WBL	10.7	30.8	40.1	48.6
21	G	EBL	28.3	39.4	49.3	54.2
	L	WBL	14.4	28.5	41.9	48.3
24	H	EBL	34.8	44.9	53.2	59.6
	M	WBL	14.4	31.3	41.6	49.5
27	I	EBL	25.4	43.9	56.7	63.3
	N	WBL	11.9	24.5	36.6	43.7

Table 4.5 Compressive strength based on the average of three specimens from each of two batches



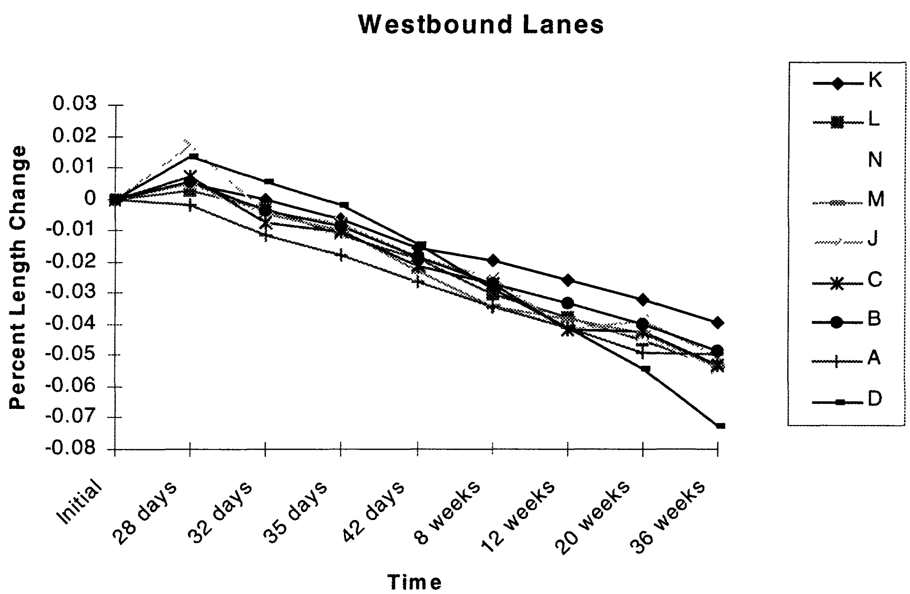


Figure 4.1 Graph of length change versus age of concrete

4.8 Shear Bond Strength

Table 4.6 shows the guillotine shear bond strength test results for specimens prepared at the job site during the placement of the concretes in the outside lane. The base concretes were 5 cm (2 in) thick sawn slices of the typical A4 bridge deck concrete batched in the laboratory. The slices are placed in the bottom of 102-mm-high molds and overlayed with concrete at the bridge site. The results show the bond strength potential of the overlay concretes. In general, the shear bond strengths tend to be proportional to the compressive strengths.

Span No.	Overlay Type	Lane	Avg. Bond Strength (KPa)
2	A	EBL	4380
	A	WBL	4230
5	B	EBL	3040
	B	WBL	4330
8	C	EBL	5450
	C	WBL	3740
11	I*	EBL	4280
	J	WBL	4310
14	F	EBL	5000
	D	WBL	4360
18	I*	EBL	6120
	K	WBL	3880
21	G	EBL	4780
	L	WBL	4120
24	H	EBL	4230
	M	WBL	3310
27	I	EBL	6110
	N	WBL	4280

Table 4.6 Shear bond strength. Values are average of two specimens. All specimens are 102 mm (4 in) in diameter.

4.9 Permeability to Chloride Ion (AASHTO T277), Coulombs

Table 4.7 shows the results of the test on specimens diameter of overlay concretes 51 mm thick by 102 mm. With the exception of the mixtures with DCI (I, I*) and the 40% S mixture (J), all values at 1 year are in the very low range.

Span No.	Overlay Type	Lane	28 d, 73F	28 d, 100F	3 mo	1 yr
2	A	EBL	1280	698	691	589
	A	WBL	1375	708	799	788
5	B	EBL	1041	666	675	819
	B	WBL	1385	579	600	570
8	C	EBL	1001	417	536	294
	C	WBL	1157	567	511	300
11	I*	EBL	5924	3850	4098	3115
	J	WBL	4213	2396	1847	1900
14	F	EBL	505	125	258	160
	D	WBL	1487	836	-----	210
18	I*	EBL	2853	1558	1468	1360
	K	WBL	1666	828	1259	986
21	G	EBL	1294	857	913	1010
	L	WBL	1649	873	1083	980
24	H	EBL	574	422	420	420
	M	WBL	-----	-----	-----	-----
27	I	EBL	3105	1916	1624	1584
	N	WBL	1563	738	967	883

Table 4.7 Rapid permeability test data. All values are averages of two samples.

4.10 Susceptibility to Freeze-Thaw Cycles

Table 4.8 shows the results of tests conducted in accordance with ASTM C666, Procedure A, modified by the addition of 2% NaCl to the test water.

A variety of results were obtained. Many of the mixtures failed on durability factors because of internal cracking (DF<60%). Mixtures failing on this criteria included 7% SF and POF, 7% SF, LMC, 7% SF and RCI, 7% SF and ACI, 7% SF and DCI. Mixtures failing on weight loss (WL>7%) included 7% SF and POF, 7% SF, LMC, 7% SF and RCI, 7% SF and DCI. Mixtures failing on surface rating (SR>3) included 7% SF and POF, 7% SF, 7% SF and RCI, 7% SF and ACI, 7% SF and DCI. The only mixtures passing all three criteria of the freeze taw test include 7% SF and CQI, 7% SF and STF, 7% SF and PPF, 40% S, 5% SF and 15% FA, 5% SF and 35% S, and 13% SF and 15% FA. The test is not considered realistic for overlays because LMC overlays more than 25 years old have not shown freeze-thaw damage.

Batch No.	Mix	WL (%)	DF	SS	P/F
1	7% SF w/ CQI Span No.18 System K	2.17	102	1.96	P
2	7% SF w/ CQI Span No.19 System K	1.65	104	1.63	P
3	SF w/ POF Span No.21 System L	3.18 (50)	-	1.85 (50)	F
4	SF w/ POF Span No.22 System L	5.54 (50)	-	2.81 (50)	F
5	7% SF w/ Steel Fibers Span No.24 System M	2.81	115	1.69	P
6	7% SF w/ Steel Fibers Span No.25 System M	1.44	115	1.23	P
7	7% SF w/ Polypro Fibers Span No.27 System N	4.77	110	1.94	P
8	7% SF w/ Polypro Fibers Span No.28 System N	4.38	111	1.89	P
9	A-4 Post and Rail Mix 40% Slag Span No.11 System J	4.91	115	2.01	P
10	A-4 Post and Rail Mix 40% Slag Span No.10 System J	2.41	112	1.55	P
11	5% SF 15% FA Span No.8 System C	2.21	114	1.41	P
12	5% SF 15% FA Span No.7 System C	2.49	107	1.30	P
13	5% SF 35% Slag Span No.5 System B	3.59	106	1.75	P
14	5% SF 35% Slag Span No.4 System B	6.28	98 (250)	2.59	P
15	7% SF Span No.2 System A	4.59	115	1.90	P
16	7% SF Span No.1 System A	8.41 (250)	No Reading (250)	1.29 (250)	F
17	15% Latex Span No.14 System D	7.59 (150)	No Reading (150)	1.5 (150)	F
18	15% Latex Span No.15 System D	1.17 (100)	No Reading (100)	0.46 (100)	F
19	5% SF 15% FA Span No.8 System C	1.78	111	1.55	P
20	5% SF 15% FA Span No.7 System C	0.58	111	1.23	P
21	5% SF 35% Slag Span No.5 System B	1.70	115	1.94	P
22	5% SF 35% Slag Span No.4 System B	0.76	111	1.08	P
23	7% SF Span No.2 System A	6.07 (150)	78 (150)	3.01 (150)	F
24	7% SF Span No.1 System A	2.44 (50)	61 (50)	1.36 (50)	F
25	13% SF 15% FA W/CM = 0.25 Span No.14 System F	1.76	113	0.68	P
26	13% SF 15% FA W/CM = 0.25 Span No.15 System F	0.89	111	1.00	P
27	7% SF w/ Rheocrete Span No.21 System G	31.55 (50)	-	5.00 (50)	F
28	7% SF w/ Rheocrete Span No.22 System G	7.24 (50)	-	1.79 (50)	F
29	7% SF w/ Armatec 2000 Span No.24 System H, Armatec 3020	1.85 (50)	78 (50)	0.86 (50)	F
30	7% SF w/ Armatec 2000 Span No.25 System H*	1.11	106	0.69	P
31	7% SF w/ DCI Span No.18 System I*	14.85 (50)	-	-	F
32	7% SF w/ DCI Span No.19 System I*	4.9 (50)	-	1.71 (50)	F
33	7% SF w/ DCI Span No.27 System I, Postrite	11.71 (50)	-	2.96 (50)	F
34	7% SF w/ DCI Span No.28 System I, Postrite	9.18 (50)	-	2.64 (50)	F
35	7% SF w/ DCI Span No.11 System I*	5.06 (50)	-	2.24 (50)	F
36	7% SF w/ DCI Span No.10 System I*	3.98 (50)	-	2.11 (50)	F

- No value at the first reading (50 cycles).

Number of cycles in parentheses.

Table 4.8 Weight loss, durability, and surface scaling performance

4.11 Flexural Strength

Table 4.9 shows the average results of flexural tests conducted on three specimens at 28 days (ASTM C 1018). The beams were 102 x 102 x 356 mm.

WBLs	Flexure (GPa)	EBLs	Flexure (GPa)
Mix		Mix	
K1	4.96	C19	5.44
K2	4.65	C20	5.99
AVG	4.81	**AVG**	5.72
L3	4.96	B21	6.44
L4	5.20	B22	6.10
AVG	5.08	**AVG**	6.27
M5	5.03	A23	6.27
M6	5.51	A24	6.03
AVG	5.27	**AVG**	6.15
N7	4.75	F25	6.75
N8	4.82	F26	6.79
AVG	4.79	**AVG**	6.77
J9	4.72	G27	5.44
J10	5.03	G28	5.82
AVG	4.87	**AVG**	5.63
C11	5.37	H29	6.51
C12	5.82	H30	6.13
AVG	5.60	**AVG**	6.32
B13	5.79	I*31	2.82
B14	5.51	I*32	4.44
AVG	5.65	**AVG**	3.63
A15	5.65	I33	5.27
A16	6.03	I34	5.13
AVG	5.84	**AVG**	5.20
D17	6.03	I*35	4.65
D18	5.37	I*36	5.27
AVG	5.70	**AVG**	4.96

Table 4.9 Flexural strengths

5.0 Evaluation of Conditions After Installation

5.1 Location of Delaminations

A chain drag of the overlays found no delaminations except adjacent to the joints. Areas of delamination adjacent to the joints ranged from 0 to 4.5 m^2.

Joints on the WBL were not properly prepared. No filler material was placed in the joint, and the finisher placed a notch in the surface of the freshly placed overlay to control contraction cracking. Unfortunately, when the spans expanded, the overlay delaminated within 0.6 m (2 ft) on each side of the joint because no expansion material was in the joint area. The overlay had to be removed in the vicinity of most joints, formed properly, and placed again.

The overlay delaminated on each side of most of the joints on the EBL because the form material was not compressible and because it was not removed in a timely fashion. The overlay was recast one or more times in the vicinity of most joints on both bridges because incorrect forming and form removal techniques were used. The 7% SF mixture (A) was used for the overlay repairs. A silicone joint material was placed in each joint following the saw cutting operation.

5.2 Skid Tests

The results of the skid tests conducted on December 11, 1996, with a skid trailer are shown in Table 5.1. The tests were conducted on the outside lane of the overlays. All the overlay concretes provide excellent skid resistance. Saw cut grooves 3.2 mm (0.13 in) wide by 3.2 mm (0.13 in) deep spaced 19 mm (0.75 in) apart yielded the excellent skid numbers.

Overlay Type	WBL Bald Tire	WBL Treaded Tire	Overlay Type	EBL Bald Tire	EBL Treaded Tire
A	48	47	I	45	46
B	49	50	H	33	34
C	48	47	G	38	39
J	54	53	I*	43	43
D	42	43	F	37	39
K	39	42	I*	38	42
L	36	38	C	37	42
M	41	43	B	41	43
N	40	39	A	46	44

Table 5.1 Skid testing on outside lane

5.3 Electrical Half-Cell Potential Results

Tests were not done following completion of the overlays. Tests will be done in 1999 when the final evaluation of the overlays is done.

5.4 Tensile Bond Strength Results

Table 5.2 shows the results of the tensile adhesion tests conducted on the outside travel in accordance with a modified version of ACI 503R and VTM 92. The modification is that cores are removed from the deck and saw cut in the laboratory to provide a specimen 102 mm high with 51 mm on each side of the bond line, a pipe cap is bonded to both sawn surfaces, and the specimen is subjected to tension using a universal testing machine in the laboratory. The bond strengths are fair to good. The majority of the failures were at the bond interface and in the base concrete close to the bond interface, which indicates that surface preparation could have been better. Spans that received topical treatments of corrosion inhibiting admixtures had the lowest bond strengths.

	WBL at 10 mo of age					**EBL at 6 wk of age**				
Span	**Overlay Thickness, cm**	**Bond Strength, KPa**	**Failure Area, %**			**Overlay Thickness, cm**	**Bond Strength, KPa**	**Failure Area, %**		
			Overlay	**Bond**	**Base**			**Overlay**	**Bond**	**Base**
2	4.0	2.1	3	29	68	3.8	1.6	3	40	57
5	4.0	2.2	3	32	65	3.6	1.4	5	38	57
8	4.0	1.8	0	0	100	3.8	1.7	2	30	68
11	3.5	1.8	20	33	47	4.4	1.6	3	34	63
14	4.3	1.8	0	25	75	2.8	1.7	0	35	65
18	4.0	1.9	10	40	50	4.6	1.9	5	40	55
21	4.0	1.8	18	58	24	3.7	1.5	3	17	80
24	4.7	2.1	20	27	53	4.2	0.9	0	28	72
25	-	-	-	-	-	5.0	1.5	2	27	71
27	3.8	2.1	0	17	83	3.9	1.0	0	57	43

Table 5.2 Tensile bond strength test results

5.5 Permeability Test Results

Table 5.3 shows the results of permeability tests (AASHTO T 277) conducted on cores 102 mm in diameter removed from the outside lane of the decks and tested at an age of 6 to 7 months (November 1996). Tests were conducted on the top 51 mm of two cores from each span on the WBL and one core on the EBL. The STF on span 24 of the WBL could not be tested. The results for the specimens are in the low to very low range, indicating that all of the overlays are providing good protection. Systems in the low range are the 40% S, POF, and DCI.

	WBL		EBL	
Span	Overlay Thickness, cm	Permeability, Coulombs	Overlay Thickness, cm	Permeability, Coulombs
2	4.2	1082	4.0	527
5	3.5	522	3.8	422
8	4.1	349	3.3	369
11	3.6	1309	4.8	1418
14	4.1	703	3.0	193
18	3.9	581	4.3	1614
21	4.0	1249	4.3	1031
24	-	-	4.3	393
25	-	-	-	327
27	3.5	923	3.8	1695

Table 5.3 Postinstallation rapid permeability test data

5.6 Post-Installation Photographic Record

Color slides showing the overlays are on file.

5.7 Cracks, Patches, and Surface Scaling

Table 5.5 provides a summary of the cracks and surface scaling in the outside lane on 4/16/98. Inspections were done on 11/18/96 and 4/16/98. Almost all overlays are patched adjacent to joints. No other patching has been done. Most of the spans showed significant scaling that exposes the coarse aggregate. The least scaling occurred for LMC and the most for DCI and POF.

Span	WBL Cracks, m	Scaling	EBL Cracks, m	Scaling
2	0	2	0	2
5	0	2	0	1
8	0.2	1	0	2
11	0.1	2.5	0	2
14	0.3	1.5	5.5	1
18	0	2.5	0	2
21	0	3	0	2
24	0	1.5	0	2
27	0	1.5	0	2

Table 5.7 Summary of cracks and scaling rating (1 = light, 2 = moderate, 3 = medium, 4 = heavy) after overlay placements

5.8 Cost of Overlay

The contractor bid $1435/m^3 ($1200/yd^3) for all overlay systems. Therefore, it was not possible to get an indication of relative cost from this project. The cost was approximately 50% greater than we typically pay for LMC and SF concrete overlays probably because of the experimental nature of the project. Based on relative cost of the ingredients, we believe that the overlays would rank as follows from highest to lowest cost:

1. 7% SF and STF, 7% SF and POF
2. 7% SF and PPF, LMC, 7% SF and CQI
3. 7% SF and DCI, 7% SF and RCI, 7% SF and ACI
4. 13% SF and 15% FA
5. 7% SF
6. 5% SF and 35% Slag, 5% SF and 15% FA
7. 40% S.

The majority of the cost of an overlay is for labor, equipment, mobilization, and traffic control. The material is often less than 10% of the cost, and, therefore, differences in material costs are minor when the total cost of the overlay is considered.

6.0 Conclusions

6.1 Estimate of Remaining Service Life of Overlays

Data obtained during the evaluation indicate the overlays have many properties that are similar to those of overlays that have lasted 20 years. Some areas adjacent to the joints may have to be patched in less than 20 years because of less than satisfactory construction practices.

6.2 Evaluation of Cost-Effectiveness

The concretes differ slightly with respect to cost because of the differences between the cost of the ingredients and the equipment and procedures required for the installation. The contractor bid all overlays at $1435/m^3 ($1200/yd^3), and, therefore, comparative costs for the different systems could not be determined for this project.

Because of the relatively higher costs of the ingredients, the overlays with steel fibers, polyolefin fibers, and latex would be slightly more expensive and overlays with 40% S, 5% SF and 35% slag, and 5% SF and 15% FA would cost the least.

6.3 Assessment of Project's Objectives Using Section 6005 (e) 7

In the spirit of the ISTEA funding, this project has demonstrated the viability of high performance concrete overlays and identified areas for improvement.

6.4 Specific Conclusions

1. High performance concrete overlays that have low permeability to chloride ion penetration and high bond strength can be constructed with a variety of combinations of silica fume, fly ash, slag, latex, corrosion-inhibiting admixtures, a shrinkage-reducing admixture, and fibers.

2. Polyolefin fibers with a length of 51 mm should not be used in an overlay that is less than 51 mm thick.

3. Topical applications of corrosion inhibitors may reduce bond strength.

4. Joints in overlays must be properly formed and the forms removed in a timely fashion to prevent damage to the bond interface of the overlay adjacent to the joint and subsequent spalling in a short time.

5. Removal of concrete to a depth below the top reinforcement adjacent to joints and placement of the overlay concrete around the reinforcement will reduce the incidence of spalling adjacent to joints caused by improper forming and form removal.

7.0 Recommendation

High performance concrete overlays as described in this report should be used to extend the life of bridge decks.

8.0 Acknowledgments

This research and 80% of the construction was done with ISTEA 6005 thin bonded overlay funds provide by FHWA. Thanks to Vasant Mistry and Roger Larson of FHWA for administering the funds.

9.0 References

1. Sprinkel, Michael M., and Christopher Moen. *Evaluation of the Installation and Initial Condition of Latex-Modified and Silica Fume Concrete Overlays Placed on Six Bridges in Virginia.* VTRC 99-IR2. Virginia Transportation Research Council, Charlottesville, 1999.

2. Sprinkel, Michael M. *Polymer Concrete Overlay on Beulah Road Bridge.* VHTRC 83-R28. Virginia Transportation Research Council, Charlottesville, 1982.

FINAL APPROVAL FORM FOR FINAL REPORT

DATE: April ~~9~~ 8, 1999

TO: Michael Sprinkel

FROM: Linda Evans

SUBJECT: Interim Report: Lynnhaven Inlet

Please read the attached copy of your final report very carefully. If there are any corrections to be made, note the number of the pages(s) on which they occur in the space provided. Initial the appropriate box below and then pass it on to your Research Manager for his or her review and approval.

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TO: Gary Allen

FROM: Linda Evans

DATE: April 9, 1999

DOCUMENT: Interim Report: Overlays on Lynnhaven Inlet

DOCUMENT EDITED AND PROOFED BY LINDA EVANS

This document is ready for your comments or approval.

Thank you.

Gary Allen, Director

Gary, the "strange" format is per FHWA for this project.