INVESTIGATION OF PROTECTIVE MEMBRANES USED ON FOUR VERMONT BRIDGE DECKS

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ABSTRACT

An investigation was made to determine the effectiveness of four different bridge deck protective membranes: asphalt emulsion, tar emulsion, polyester resin, and epoxy resin. The membranes had been exposed to either two or three winters of deicing salt applications.

Membrane performance evaluations were based primarily on whether or not the treatment had protected the bridge deck from the penetration of chlorides. Although visual observations did not reveal significant information on membrane performances, analysis of the concrete cores indicated that only the deck treated with asphalt emulsion appeared to be free of chlorides.

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INTRODUCTION

The accelerated deterioration of concrete bridge decks caused by the increased use of deicing chemicals has prompted the Vermont Department of Highways to enter into active participation in the National Experimental & Evaluation Program - Bridge Deck Protective Systems. The purpose of the program is to apply and evaluate various protective treatments recommended for use on concrete bridge decks to determine which material is most effective in prohibiting the deterioration caused by intrusion of deicing chemicals and moisture. In conjunction with participation in the National Program, it was also suggested that an investigation be made of several special membrane treatments used in the past. The following information is the result of that investigation.

INSPECTION PROCEDURE

All bridges were visually inspected for leakage or efflorescence on the underside of the decks. In addition, two deck cores were taken from each membrane system for visual inspection and testing. This included noting the bond between the membrane and concrete, inspecting the membrane surface for pinholes, cracks or other failures, and testing the bituminous portion of the cores for water permeability and air void content. The top inch of concrete was analyzed for chloride content using ASTM Designation D512-67, Method B. The inspection also included the use of a Steel Corrosion Detection Device, as developed by the California Division of Highways, on selected areas of two of the decks.

DATA

Test Location

Interstate 89 Southbound over Vt Rte 132 in Sharon
Project - Hartford-Sharon I 89-1 (7) C/4 & I 89-1 (25) Stage II

Protective Treatment

Product - Asphalt Emulsion RS-1
Date Applied - September 13, 1968
Weather Log - Clear 75°F
Construction Cost - $3.00 per gallon Total Cost $ 780.00
Test Results - Residue % - 61.0 Sieve Test % - .005
Viscosity @ 77°F - 45 seconds Meets all requirements for RS-1
Construction Operation - 260 gallons applied in one coat for an application of 0.25 gallons per square yard
Wearing Surface - 2" bituminous concrete

Deck Construction Data

Type of Structure - 3 span WF Beam (composite & non composite)
Span Lengths - 44 - 84 - 44 Overall length 172'-0
Curb to Curb Width - 37'-5 Skew - 40° Horizontal curvature 3°-35
Grade - + 0.614% Banking or superelevation - 15/16"/foot
Date Deck Poured - August, 1967 Deck thickness - 7½"
Concrete Cover Over Top Reinforcement - 1½" Surface texture - burlap drag

Traffic Data

Average Daily Traffic	1970 - 1930 vehicles	
	1971 - 2600 vehicles	
Percent Trucks	1970 - 10%	
	1971 - 10%	

Climatic Conditions

Approximate number of freeze-thaw cycles
1968-1969 - 125 cycles
1969-1970 - 107 cycles
1970-1971 - 106 cycles

Annual Application of Deicing Chemicals in tons per two lane mile

1968-1969 not open to traffic
1969-1970 25 tons (estimated)
1970-1971 22.5 tons

cont'd

DATA

Precipitation and Temperatures as recorded at Chelsea, Vermont

Date	Average Temperature	Average Minimum Temperature	Total Precipitation		Snowfall
Oct 1968	48° F	34° F	2.5"		Trace
Nov 1968	32	23	5.5		17"
Dec 1968	17	6	4.3		26
Jan 1969	14	- 1	2.1		18
Feb 1969	19	5	2.5		31
Mar 1969	25	12	1.8		7
Apr 1969	40	27	3.3		1
				Total	100"
Oct 1969	44° F	29° F	1.6"		3"
Nov 1969	36	26	6.9		6
Dec 1969	20	11	5.6		40
Jan 1970	4	-12	0.5		6
Feb 1970	15	- 1	2.1		14
Mar 1970	26	14	1.9		15
Apr 1970	40	26	4.0		7
				Total	91"
Oct 1970	50° F	38° F	2.0"		1"
Nov 1970	37	27	1.9		2
Dec 1970	16	5	3.5		38
Jan 1971	7	- 9	1.4		19
Feb 1971	17	3	3.5		27
Mar 1971	23	9	3.9		46
Apr 1971	36	23	1.4		7
				Total	140"

DATA

Test Location

I 89 Northbound over Vt Rte 132 in Sharon
Project - Hartford-Sharon I 89-1 (7) C/4 & I 89-1 (25) Stage II

Protective Treatment

Product - Cybond 2501 Polyester Resin
Date Applied - August 29 & 30, 1968
Weather Log - August 29 Clear 70°F August 30 Clear 75°F
Test Results - None
Construction Operation -

The deck was washed first with water, then with acetone and then washed a third time using water. The first coat of the treatment consisted of Cybond part I which was applied with street brooms. Upon completion of curing, which took less than one hour, an application of Cybond part II was applied with squeegees. A total of 385 gallons of the material was placed on the 1035 square yard deck for an application of 0.372 gallons per square yard. 5250 pounds of washed sand was spread on the top coat prior to its curing, for an application rate of five pounds per sq. yd.

Construction Cost - No information available
Wearing Surface - 2" bituminous concrete

Deck Construction Data

Type of Structure - 3 span WF Beam (composite & non-composite)
Span Lengths - 44 - 84 - 44 Overall Length - 172'-0
Curb to Curb Width - 37'-5 Skew - 38° Horizontal Curvature - 3°25
Grade - +0.614% Banking or Superelevation - 15/16"/foot
Date Deck Poured - August 1967 Deck Thickness - 7½"
Concrete Cover Over Top Reinforcement - 1½" Surface Texture - Burlap Drag

Traffic Data

Average Daily Traffic	1970	-	1930 vehicles
	1971	-	2600 vehicles
Percent Trucks	1970	-	10%
	1971	-	10%

Climatic Conditions

Approximate Number of Freeze-Thaw Cycles

1968-1969	-	125 cycles
1969-1970	-	107 cycles
1970-1971	-	106 cycles

Annual Application of Deicing Chemicals in tons per two lane mile.

1968-1969	-	not open to traffic
1969-1970	-	25 tons (estimated)
1970-1971	-	22.5 tons

Precipitation and Temperatures - see page 5

DATA

Test Location

I 89 Northbound over State Aid Hwy #3 & Central Vermont Railroad in Sharon
Project - Sharon-Royalton I 89-1 (37) & I 89-1 (26) Stage II

Protective Treatment

Product - Tar Emulsion
Date Applied - April 28 & 29, 1969
Weather Log - April 28 Cloudy - Humid 70° F April 29 Cloudy 52° F
Test Results - Water % - 50.5 Non-volatile % - 47.8
Solubility of Non-volatile % - 47.8
Meets all requirements for Item 318 Tar Emulsion
Construction Operation - 280 gallons applied in two coats on a 990 square yard area for an application of 0.283 gallons per square yard
Construction Cost - $3.00 per gallon Total cost - $840.00
Wearing Surface - 1½" Bituminous Concrete

Deck Construction Data

Type of Structure - 4 span composite WF Beams
Span Lengths - 49-69-59-59 Overall length - 236'-0
Curb to Curb Width - 30'-0 Skew - 44° Horizontal Curvature - 2°-0
Grade - -1.000% Banking or Superelevation - 5/8"/foot
Date Deck Poured - May 10 & 16, 1968 Deck thickness - 8"
Concrete Cover Over Top Reinforcement - 2" Surface Texture - light broom finish

Traffic Date

Average Daily Traffic	1970	1930 vehicles
	1971	2600 vehicles
Percent Trucks	1970	10%
	1971	10%

Climatic Conditions

Approximate Number of Freeze-Thaw Cycles
1969-1970 - 107 cycles
1970-1971 - 106 cycles

Annual Application of Deicing Chemicals in tons per two lane mile

1968-1969 - not open to traffic
1969-1970 - 35 tons (estimated)
1970-1971 - 32.3 tons

Precipitation and temperatures - see page 5

DATA

Test Location

I 89 Northbound over Vt Rte 104 In Fairfax
Project - Georgia-Fairfax-St. Albans I 89-3 (35) C/2 & I 89-3 (41) Stage II

Protective Treatments

Product - Tar Emulsion (Used on End Spans Only)
Date Applied - May 15, 1968
Weather Log - Fair 65°F
Test Results - Water % - 45.8 Non-volatile % - 51.7
Solubility of Non-volatile % - 48.7
Specific Gravity - 1.20
Meets all requirements for Tar Emulsion, Vt. Spec. 318
Construction Operation - 240 gallons applied in two coats on a 675 square yard area for an application of 0.36 gallons per square yard
Construction Cost - $3.00/gal Total Cost - $720.00
Wearing Surface - 1½" Bituminous Concrete

Product - Rambond 223 Epoxy (Used on Center Span Only)
Date Applied - August 8, 1967
Weather Log - Clear 55°- 75°
Test Results - None
Construction Operation - The treatment consisted of a single coat of trowel spread 100% solids epoxy topped with an application of stone grits. Application rate unknown.
Construction Cost - Cost of treatment borne by bridge contractor. Added protection considered necessary due to low air in center span deck concrete.
Wearing Surface - 1½" Bituminous Concrete

Deck Construction Data

Type of Structure - 3 span composite WF Beam
Span Lengths - 44 - 74 - 59 Overall Length - 177'-0
Curb to Curb Width - 37'-3 Skew - 7° Horizontal Curvature - 0°-48'-08"
Grade - +1.850% Banking or Superelevation - ¼"/foot
Date Deck Poured - May 25 & 31, 1967 Deck Thickness - 7½"
Concrete Cover Over Top Reinforcement - 1½" Surface Texture - broomed

Traffic Data

Average Daily Traffic	1969	2295
	1970	2560
	1971	2760
Percent Trucks	1969	8%
	1970	10%
	1971	10%

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Climatic Conditions

Approximate Number of Freeze-Thaw Cycles
1968-1969 - 76 cycles
1969-1970 - 75 cycles
1970-1971 - 83 cycles

Annual Application of Deicing Chemicals in tons per two lane mile
1968-1969 - 45 tons (estimated)
1969-1970 - 45 tons (estimated)
1970-1971 - 43.6 tons

Precipitation and Temperatures as Recorded at Burlington, Vermont

Date	Average Temperature	Average Minimum Temperature	Total Precipitation	Snowfall
Oct 1967 - Apr 1968	Information not available			
Oct 1968	50° F	41° F	2.7"	Trace
Nov 1968	32	27	4.4	19"
Dec 1968	18	10	3.1	29
Jan 1969	17	7	2.4	16
Feb 1969	19	11	0.9	17
Mar 1969	24	16	1.9	12
Apr 1969	41	31	2.9	4
			Total	97"
Oct 1969	46° F	36° F	1.6"	5"
Nov 1969	36	30	5.0	11
Dec 1969	19	12	4.6	51
Jan 1970	4	- 8	0.7	11
Feb 1970	17	6	2.0	14
Mar 1970	26	18	2.0	11
Apr 1970	43	32	2.8	2
			Total	105"
Oct 1970	51° F	42° F	2.7"	Trace
Nov 1970	39	32	2.4	3"
Dec 1970	14	6	3.8	57
Jan 1971	10	0	1.2	17
Feb 1971	20	11	3.0	23
Mar 1971	24	16	2.7	33
Apr 1971	37	28	2.7	13
			Total	146"

DISCUSSION

ASPHALT EMULSION

I 89 southbound over Vt Rte 132 Membrane applied September 1968

Visual inspection of the bridge deck treated with asphalt emulsion disclosed that the underside of the deck was free of all but a very few minor temperature or shrinkage cracks, and there were no signs of leakage or efflorescence.

Two-4 inch cores were taken from the northerly and middle spans adjacent to the expansion dams on the low side of the deck. The bond between the bituminous pavement, membrane and concrete was such that a hammer and wedge were required to loosen the core prior to removal from the deck. Inspection of the core upon separation revealed that most of the asphalt emulsion was retained on the bituminous portion of the core with only a light coating remaining on the concrete. There was no indication of any cracks or holes in the membrane surface.

A permeability test performed on the bituminous portion of one core using a twenty-four inch head of water (0.865 lbs/in^2 pressure) demonstrated that water was able to penetrate through the core in three hours and fifty minutes. (See Table I) The penetration time could be considered quite lengthy when compared against the readings of from one to twenty-two minutes recorded on six other cores tested in the same manner. The 9.4% air void content of the core would not appear to be the reason for the resistance to water penetration since it was higher than the 8.9% average air void content of the other cores checked. (The air void content of all the initial bridge deck cores averaged 6.8%). The presence of asphalt emulsion on the bottom of the core could have been partially responsible for the extended penetration time.

A chloride analysis made on the top inch of concrete indicated that there were no chlorides present in the cores. (See Table II) Although only two cores were taken, the absence of chlorides is a good indication of the membrane's effectiveness since the cores were taken adjacent to the expansion dams in an area where ponding would increase the likelihood of chloride intrusion. For deicing chemical applications, see data on page 4.

Cybond 2501 Polyester Resin

I 89 northbound over Vt Rte 132 Membrane applied August 1968

Visual inspection of the bridge deck treated with a polyester resin system disclosed efflorescence on the underside of the deck in two small areas at opposite ends of the deck. Temperature or shrinkage cracks of similar magnitude at other locations in adjacent areas were free of any leakage.

Cores taken adjacent to the expansion dams on the center and northerly spans displayed very little bond between the bituminous pavement and the polyester resin. However, the bond between the polyester membrane and concrete appeared to be satisfactory on both cores. The membrane surface on the core taken from the center span appeared to be free of any cracks or holes, while the core taken from the northerly span revealed a thin membrane coating with several holes visible when viewed under a thirty power microscope.

Permeability tests performed on the bituminous portion of the cores demonstrated that water could pass through the samples in one minute. The air void contents of the two samples were 8.6% and 8.9%.

An analysis of the top inch of concrete taken from the center span revealed an average sodium chloride content of 33 parts per million, while the core taken from the northerly span contained 45 parts per million of sodium chloride.

Readings were taken with a steel corrosion detection device which is used to measure voltage produced by the active corrosion of reinforcing steel. The readings, taken within 15 foot by 70 foot section of the right hand lane, center span, on the high side of the deck, revealed two areas of active corrosion registering 0.35 and 0.40 volts. Potential readings over 0.30 volts indicate active corrosion.

Tar Emulsion

I 89 northbound over State Aid Hwy #3 & Central Vermont Railroad in Sharon

Membrane applied April 1969

I 89 northbound over Vt Rte 104 in Fairfax (end spans)

Membrane applied May 1968

Visual inspection of areas treated with tar emulsion revealed no wet areas or signs of leakage on the underside of the decks.

There were no cracks or openings detected on the membrane coatings recovered on cores taken from the deck in Sharon and the southerly span in Fairfax. Inspection of the core taken from the northerly span in Fairfax disclosed numerous long fine cracks. The application of hydrochloric acid on the membrane produced effervescence confirming that the cracks were open to the concrete surface.

Permeability tests performed on the two bituminous cores taken in Sharon disclosed that the water was able to pass through one sample in two and one-half minutes, and a second one in nine minutes. Air void contents were recorded at 9.8% and 10.3% with the latter reading from the core which took the longer penetration time. Air void contents of the cores taken in Fairfax were 6.4% and 7.8%, with water permeation reading of 22 minutes on the latter.

An analysis of the concrete cores taken in Sharon showed average sodium chloride contents of 46 parts per million. The readings were much higher than the average count of 19 parts per million detected in cores taken from Fairfax where the deck has been exposed to greater applications of deicing chemicals over a longer period of time. Refer to pages 7 and 9 for deicing chemical applications.

Readings taken with a steel corrosion detection device in Fairfax on a 20 foot by 45 foot section of the right hand lane, southerly span, revealed no active corrosion. Electrical resistance readings taken over the same area also indicated there were no openings in the tar emulsion membrane.

RAMBOND 223 EPOXY RESIN

I 89 northbound over Vt Rte 104 in Fairfax (center span)

Membrane applied August 1967

Visual inspection of the span treated with epoxy resin disclosed no signs of leakage or wet areas on the underside of the deck.

Inspection of the cores revealed that the epoxy membrane surface was free of pinholes or other types of distress. The bond between the epoxy resin and the concrete appeared to be very strong; although cracks or separations were detected between the two materials with the aid of a microscope. The existence of the cracks could be due to stresses caused by the higher coefficient of thermal expansion of the epoxy, in comparison to that of the concrete; or it may have been due, at least in part, to handling during core recovery and testing.

A permeability test performed on the bituminous portion of one core disclosed that water could penetrate through the sample in six and one-half minutes. The air void content of the sample was 10.2%.

An analysis of the concrete core taken four feet north of the expansion dam revealed an average sodium chloride content of 66 parts per million. The second core, which was taken 32 feet north of the expansion dam, contained sodium chloride at the rate of five parts per million. The difference in chloride content may have been due to the core locations, since the second core was taken from an area which was less susceptible to ponding and subsequent leakage.

An August 1971 report issued by the Federal Highway Administration, Eastern Highway Projects Office, Region 15, stated that steel corrosion readings taken on the deck revealed no active corrosion of the reinforcing steel. High electrical resistance readings taken in the same area indicated that the membrane system was impermeable. The information was incorrect with regard to the membrane system since the area tested was on the southerly span of the bridge deck which had been treated with tar emulsion rather than epoxy resin as stated in the report.

TABLE I

Structure	Membrane	Visual Inspection of Bridge Deck	Permeability of Bituminous Cores Under 24" Head of Water	Steel Corrosion Readings
I 89 SB over Vt Rte 132	Asphalt Emulsion	Underside of deck revealed no wet areas, efflorescence or other signs of leakage	9.4% air voids Water penetration 3 hrs 50 min	No readings taken
I 89 SB over Vt Rte 132	"		Not checked	
I 89 NB over Vt Rte 132	Polyester Resin (Cybond 2501)	Underside of deck revealed two small areas with efflorescence leaking from fine cracks	8.6% air voids Water penetration 1 minute	Two areas of active corrosion were detected within a 15'x 70' section of the right hand lane, center span with readings of 0.35 and 0.40 volts recorded.
I 89 NB over Vt Rte 132	"		8.9% air voids Water penetration 1 minute	
I 89 NB over SA #3 & CVRR	Tar Emulsion	Underside of deck revealed no wet areas, efflorescence or other signs of leakage	9.8% air voids Water penetration 2½ minutes	No readings taken
I 89 NB over SA #3 & CVRR	"		10.3% air voids Water penetration 9 minutes	
I 89 NB over Vt Rte 104	Epoxy Resin (Rambond 223)	Underside of deck revealed no wet areas, efflorescence or other signs of leakage	9.1% air voids	No readings taken
I 89 NB over Vt Rte 104	"		10.2% air voids Water penetration 6½ minutes	
I 89 NB over Vt Rte 104	Tar Emulsion (southerly span)	Underside of deck revealed no wet areas, efflorescence or other signs of leakage	6.4% air voids	No active corrosion detected on a 20'x 45' section of the right hand lane, southerly span. High electrical resistance readings indicated that the membrane should be impermeable.
I 89 NB over Vt Rte 104	Tar Emulsion (northerly span)		7.8% air voids Water penetration 22 minutes	

TABLE II

Structure	Membrane	Salt Application	Core Location	Condition of Membrane	Sodium Chloride in (PPM)	Average Sodium Chloride
I 89 SB over Vt Rte 132	Asphalt Emulsion	2 winters	Northerly span 5'6" north of exp dam 12" from curb	Good bond no apparent breaks	none detected	
						none detected
I 89 SB over Vt Rte 132	"	"	Middle span 4' north of exp dam 12" from curb	"	none detected	
I 89 NB over Vt Rte 132	Polyester Resin (Cybond 2501)	2 winters	Center span 5" north of exp dam 12" from curb	Bonded to concrete no apparent breaks	33	
						39
I 89 NB over Vt Rte 132	"	"	Northerly span 3'10" north of exp dam 14" from curb	Coating thin several holes visible	45	
I 89 NB over SA #3 & CVRR	Tar Emulsion	2 winters	Southerly span 6'3" south of exp dam 14" from curb	Bonded to concrete no apparent breaks	62	
						46
I 89 NB over SA #3 & CVRR	"	"	Center span 8'7" south of exp dam 12" from curb	"	30	
I 89 NB over Vt Rte 104	Epoxy Resin (Rambond 223)	3 winters	Center span 4' north of exp dam 18" from curb	Bonded to concrete no apparent breaks	66	
						36
I 89 NB over Vt Rte 104	"	"	Center span 32' north of exp dam 18" from curb	"	5	
I 89 NB over Vt Rte 104	Tar Emulsion	3 winters	Southerly span 9' north of app. slab 15" from curb	Bonded to concrete no apparent breaks	14	
						19
I 89 NB over Vt Rte 104	"	"	Northerly span 22" north of exp dam 19" from curb	Many long fine cracks	24	

SUMMARY & CONCLUSIONS

Results of the investigation of the protective membranes are as follows:

(1) Field inspection of the deck treated with the polyester resin system revealed two areas of leakage on the underside of the deck. There were no wet areas or other signs of leakage detected on the other decks. The overall absence of leakage is due in part to the fact that the simple span structures were free of all but minor temperature or shrinkage cracks.

(2) Permeability tests indicated that water was able to flow through all of the bituminous concrete cores when tested under a 24 inch head.

(3) Visual inspection of the cores disclosed that one out of four areas treated with tar emulsion and one out of two areas treated with polyester resin had cracks or holes in the membrane surface. The epoxy resin membrane surface was free of distress, but cracks or separations were detected between the concrete and the epoxy membrane with the aid of a microscope.

(4) Chlorides were found in concrete cores taken from the bridge decks treated with tar emulsion, polyester resin, and epoxy resin, but chlorides were not detected in cores taken from the deck treated with asphalt emulsion.

The results of the investigation suggest that the polyester resin and tar emulsion systems placed in Sharon were not satisfactory and do not warrant further evaluation. Because epoxy membrane systems are currently being used, yearly evaluations will be continued on the epoxy membrane placed in Fairfax, with special emphasis placed on attempting to determine how the chlorides have penetrated through the membrane. The study of the bridge deck treated with asphalt emulsion will also be continued and expanded to include at least one more deck treated with the same material.

This report is not meant to be a blanket endorsement or condemnation of any of the membrane systems due to the limited number of decks surveyed. An investigation covering a larger number of bridge decks with complete monitoring of the membrane applications would be required for that purpose.