"VERMONT'S EXPERIENCE WITH BRIDGE DECK PROTECTIVE SYSTEMS"

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Abstract

Vermont's search for an effective waterproofing system has resulted in the application and evaluation of 29 different membrane systems since 1971. A number of the protective membranes have been in service for sufficient time to draw conclusions on their effectiveness. The results of follow up evaluations show that several systems have provided complete protection to the bridge decks while a number of other materials have prevented chloride intrusion except in areas where deicing chemicals are often trapped due to the ponding effect of curb lines and expansion dams. Such results suggest that the simple and inexpensive materials could be specified for sealing the major portion of a deck surface if a compatible and impervious membrane material is placed over poorly drained areas. Difficulties encountered with the application of sophisticated and expensive membrane systems have resulted in a theory that the search for the most effective waterproofing system should concentrate on uncomplicated and less costly materials which could be applied without difficulty.

The results of laboratory tests indicate that liquid-applied membranes offer substantial protection even when pinholes and bubbles occur in the coatings, when contrasted with the chloride intrusion which occurs in untreated concrete. The tests also show the relationship between resistivity readings and chloride penetrations and suggest that readings well below the generally accepted standard of 500,000 ohms may be acceptable.

Introduction

The problem of bridge deck deterioration has generated a concentrated effort to design, construct and protect both new and old structures with a variety of different protective systems. The methods currently in use or under study include two course bonded construction utilizing low slump concrete, latex, polymer impregnation or wax beads, epoxy coated and galvanized reinforced steel, cathodic protection, neutralization or removal of chlorides, penetrating sealers, mastic asphalt and waterproofing membranes. Many reports have been written covering nearly all of the varied protective systems.

Of the many techniques being tried bridge deck waterproofing has had the most wide-spread use. Vermont is one of many states which have concentrated on the installation and evaluation of membrane systems under the Federal Highway Administration's National Experimental and Evaluation Program #12 Bridge Deck Protection Systems. Vermont's experiences have included the use of 29 different systems on 70 new bridge decks since 1971. The materials have included ten preformed sheet products, seven epoxy systems, five hot-applied materials, five polyurethanes, and two cold-applied built-up membrane systems. Fifty-five of the protective systems were closely monitored during the applications, and detailed initial reports were issued. Yearly field evaluations are being conducted on the individual systems after the structures have been exposed to two years of traffic and deicing salt applications. The field applications have included resistivity tests, steel potential readings, moisture strip readings, and the recovery of concrete samples for chloride analysis. Paved but otherwise untreated approach slabs of the experimental bridges are being used as control sections for comparing chloride penetration through the pavements and membranes.

Table I

Relationship Between Resistivity Results and Chloride Penetration through Liquid Applied Membranes

Membrane Treatment	No. of test slabs	Holes or bubbles per ft^2	lbs Cl at 0-1/2" depth after 730 days	Ohms Resistance High	Ohms Resistance Low	Ohms Resistance Average
Polyurethane (1 coat)	5	232	3.5	30,000	550	9,800
Polyurethane (2 coat)	5	47	1.2	380,000	2,800	98,300
Polyurethane (3 coat)	5	31	2.0	5,000,000	37,000	802,000
Polyurethane (4 coat)	1	5	0.6	7,000,000	95,000	3,365,000
Epoxy (1 coat)	3	132	2.8	10,000	1,800	6,000
Epoxy (2 coat)	3	33	3.7	28,000	1,200	11,700
Epoxy (3 coat)	3	8	0.9	400,000	1,400	82,500
Epoxy (4 coat)	2	1	2.4	160,000	5,000	45,000

			Lbs. Cl at specified depths 0-1/2"	1/2"-1	1"-1 1/2"	1 1/2"-2'
No Treatment	4 test slabs	440 days	22.7	18.5	13.5	11.2
No Treatment	4 test slabs	730 days	21.5	22.2	21.0	18.7

Table II

PRODUCT EVALUATION SUMMARY

OBSERVATIONS	Hot Asphalt & Glass Fabric	Mastic Asphalt & Gussasphalt	Standard Preformed Membranes (3 Products)	NCHRP Project 12-11 Preformed Membranes (5 products)
Surface Preparation Required	Wash & Sweep	Wash & Sweep	Wash & Sweep	Wash & Sweep Sand blast (1)
Mositure Sensitive	Yes	Yes	Yes	Yes
Ease of Application	Difficult	Difficult	Easy to Average	Difficult
Flexibility & Crack Bridging Properties	Poor	Poor	Good	Excellent
Bond & Seal at Curb	Fair/Poor	Poor	Fair/Good	Fair/Good
Bubbles and/or Pinholes in Membrane	Yes	Yes/No	No	No
Resistivity Reading Prior to Paving	46,000 to 71,000	Infinity	Infinity	14,000 to infinity (some materials conductive)
Bond Between Membrane and Concrete	Good	System included bond breaker	Fair to Good	Fair to Good
Bond Between Pavement and Membrane	Good	N-A	Good	Good
Protection System Req. over Membrane	No	N-A	No/Possible	Yes to promote adhesion between pave. & Membrane
Pavement subject to blistering or cracking during installation due to Membrane	No	N-A	Yes	Yes
Post Construction Problems with Pavement & Membrane	No	No	Yes/No	Yes/No
Cost per s.y. not including Pavement	$1.32 $3.50 with fabric	$62.35	$4.50	$10.65
Performance Based on followup evaluations	Fair to Good	Unsatisfactory	Fair to Good	Insufficient Service life to draw conclusions
Recommendations	Await continued followup evaluations	Not recommended for further use.	Continue use of 2 systems with liquid curb line sealant. Await followup on third system	Not recommended for further use unless other systems prove to be unsatisfactory

Table II

PRODUCT EVALUATION SUMMARY

OBSERVATIONS	Tar Emulsion With & Without Glass Fabric	Hot Applied PVC Polymer	Epoxies (Solvent Cut Coal Tar Mod. 100% Solids)	Polyurethanes Modified & 100% Solids
Surface Preparation Required	Wash & Sweep	Wash & Sweep	Sand blast or Acid Etch	Sweep and/or Acid Etch
Moisture Sensitive	No	Yes	Most Cases	Yes
Ease of Application	Very Easy	Average	Average	Average
Flexibility & Crack Bridging Properties	Poor	Good	Poor	Good
Bond & Seal at Curb	Good/Poor	Good	Good/Poor	Good
Bubbles and/or Pinholes in Membrane	No	Yes	Yes	Yes
Resistivity Reading Prior to Paving	500 to 6000	Infinity on Protection system	1100 to 1,200,000	480,000 to 2,600,000
Bond Between Membrane and Concrete	Excellent	Good	Good	Good
Bond Between Pavement and Membrane	Good	Fair to Good	Fair to Poor	Poor unless roofing sheet or prot boards used
Protection System Req. over Membrane	No	Yes	No	Yes (most cases)
Pavement subject to blistering or cracking during installation due to Membrane	No	Slight	No	No
Post Construction Problems with Pavement & Membrane	No	Slight	No	No
Cost per s.y. not including Pavement	$3.50 with Fabric	$4.00	$9.42	$5.19
Performance Based on followup evaluations	Good w/o Fabric except along curb lines and dams	Insufficient service life to draw conclusions	Poor to Fair	Fair to Good
Recommendations	Use in combination with compatible curb line sealant on structures not subject to severe cracking delete use of fabric	Recommend further experimental use	Restrict use, await continued followup evaluations	1 of 4 systems recommended limit other materials to use on repair projects or as curb line sealant

Table III CHLORIDE CONCENTRATIONS RECORDED IN

BRIDGE DECKS PROTECTED WITH EXPERIMENTAL MEMBRANE SYSTEMS

BRIDGE NUMBER & PRODUCT	DATE APPLIED	WINTERS SALTED	CHLORIDE CONTENT IN PARTS PER MILLION OFFSET FROM CURB & SAMPLE DEPTH: 1 Foot		5 or 10 Feet		15 Feet	
			0-1"	1-2"	0-1"	1-2"	0-1"	1-2"
1 Tar Emulsion	7-20-71	4	138	67	37	35	43	44
2 Hot Rubberized Asphalt	8-18-71	4	52	56	82	50	63	51
3 Tar Emulsion	7-20-71	4	164	136	36	33	35	34
4 Hot Rubberized Asphalt	8-18-71	4	60	51	35	32	46	37
6 Tar Emulsion & G.F.	7-14-72	3	86	67	42	35	46	35
7 Tar Mod. Polyurethane	7-31-72	3	63	52	46	45	45	52
8 Tar Emulsion & G.F.	7-27-72	3	48	35	118	66	61	45
9 Solvent Cut Epoxy	7-12-72	3	296	89	101	56		
10 Cold Tar Epoxy	7-29-72	3	117	64	82	84		
11 65 Mil preformed sheet	8-14-72	3	53	40	44	43	157	95
12 Tar Emulsion & G.F.	5-25-72	3	56	48	52	45	46	29
14 Tar Emulsion & G.F.	7-24-72	3	183	85	38	40	45	45
15 Asp. Mod. Polyurethane	5-13-72	3	53	40	32	37	31	38
16 100% Solids Epoxy	7-20-72	2	50	31	55	36	22	41
17 Asp. Mod. Polyurethane	8-23-72	2	29	24	36	32	30	24
18 Hot Asphalt & G.F.	5-16-73	2	57	43	24	32	42	29
19 100% Solids Epoxy	4-20-73	2	78	58	45	39	43	29
20 Hot Asphalt & G.F.	5-23-73	2	26	31	21	27	32	33
21 Tar Emulsion & G.F.	5-7-73	2	42	44	37	43	41	45
22 Solvent Cut Epoxy	5-7-73	2	127	69	38	34	55	39
23 Cold Tar Epoxy	4-21-73	2	30	29	40	35	39	32
24 75 Mil preformed sheet	5-2-73	2	37	39	40	46		
25 70 Mil preformed sheet	4-16-73	2	32	46	44	21		
Approach Slabs (9)	No Treatment	3			88	58		
Approach Slabs (9)		2			60	32		

Underlining indicates areas with chloride concentrations over base levels of 18 to 46 PPM. Divide PPM by 250 to obtain chloride concentrations in lbs./c.y. of concrete.

Laboratory Evaluation of Membrane Materials

Experimental membrane installations generally are preceded by a series of laboratory tests developed to determine if the materials merit field trials. The tests include flexibility, crack-bridging ability, resistance to pinholing, resistance to puncture, bond to concrete substrate, and adhesion of bituminous pavement to membrane. Of the many laboratory tests performed, none appear capable of predicting the service life of a membrane system. The tests often do disclose that many of the materials previously and currently proposed for use as membrane systems do not possess all of the properties required to satisfactorily seal off all areas of a bridge deck and retain complete impermeability.

Although the value of conducting basic laboratory tests can not be disputed, it should be pointed out that some of the tests are too severe and thus result in the elimination of potentially satisfactory membrane materials. An example is the cold temperature flexibility test where a material is generally required to resist cracking when bent around a one-inch mandril at $0^{o}F$ or lower. Although such flexibility characteristics would be of value, somewhat less flexible materials may well be completely adequate for sealing off even those structures where some cracking and flexing may be anticipated.

The current methods of using the resistivity test (1) in both laboratory and field evaluations could also be subject to additional study. The test usually is accepted as a standard for determining membrane performance with regard to porosity. Readings in excess of 100,000 ohms, and generally, 500,000 ohms are considered necessary for a system to be acceptable. Although high ohm readings would be preferred, low readings on a membrane system would not necessarily mean the material would allow significant quantities of chlorides to penetrate into the concrete. This theory is based on test results obtained on 32 polyurethane and epoxy coated test slabs which have received nearly continous ponding applications of a three percent chloride solution since October, 1973. An example, five slabs were treated with a single 50 mil polyurethane coating. Low initial and followup resistivity readings were recorded on all test areas due to pinholes, craters and bubbles which were present in the coatings at an average rate of 232 per square foot (Table I). Yet, although the average resistivity reading was less than 10,000 ohms, only 3.5 pounds of chloride was detected in the top 1/2 inch of the concrete specimens after 770 days. Similar findings were obtained on slabs treated with single epoxy coatings which resulted in holes or bubbles at the rate of 132 per square foot. Although the resistivity readings averaged only 6,000 ohms, chloride concentrations in the top 1/2 inch of concrete were found to be only 1.9 pounds and 2.8 pounds respectively after 440 days and 730 days of ponding.

In contrast to the treated slabs, chloride concentrations averaging 22.7 pounds were detected after 440 days in the top 1/2 inch of four test slabs which received no protective coating. The nearly continuous ponding applications of three percent chloride solution for two years is believed to be similar to 20 years exposure in Vermont's typical roadway environment where deicing chemicals are annually applied at the approximate rate of 30 tons per two lane mile.

A two year study has also been undertaken in an attempt to determine the limitations of the field conducted resistivity test. Initial results on 22 bridges indicate the non-destructive test is 70 percent reliable when compared with the chemical analysis of concrete samples taken from resistivity test locations.

Experimental Membrane Applications

To date 46 of the 55 experimental membrane applications made in Vermont have been reported out in detail (2). The information has covered deck construction data and surface condition, membrane product information, laboratory test results, observations made during the applications, weather conditions, resistivity readings, and discussions on the applications including tentative recommendations with regard to continued use of each system. As followup evaluations and related laboratory tests have been completed, the information and any new recommendations have been included in new reports.

Generally the initial conclusions drawn after placement of the materials have remained valid. However, as our overall experience with membrane systems has broadened, some changes in theory have occurred. Following are summaries on each general membrane type based upon experiences and evaluation results to date.

Tar Emulsion with and without Glass Fabric

Tar emulsion was placed on nearly all new bridges constructed in Vermont from 1960 to 1971. The necessity of repairing deteriorated concrete adjacent to curb lines and expansion dams within 10 years of construction has proven that the material is not capable of protecting concrete in areas where poor drainage or ponding occurs. However, field evaluations of four to seven year old decks treated with two coats of tar emulsion has disclosed no evidence of chloride intrusion in areas where proper drainage occurs due to roadway grade, superelevation, or parabolic. Such areas often comprise approximately 85 percent of a deck surface. This suggests that tar emulsion could be used in combination with a three foot wide application of a satisfactory, compatible sealant along curb lines and expansion dams. A major advantage of tar emulsion is that the deck surface should be wet down immediately prior to the application whereas nearly all other membrane systems are moisture sensitive and require dry conditions. Other advantages include ease of application, low cost and the ability to resist damage if and when the bituminous overlay must be replaced. Weak points include poor flexibility as well as inability to seal poorly drained areas as stated earlier.

The use of glass fabric with tar emulsion is not recommended at this time based on chloride concentrations found in curb line areas and at 5, 10, and 15 foot offsets on experimental applications made in 1972 and 1973. Such findings suggest that the glass fabric encourages moisture penetration by producing a wicking action.

<u>Epoxy Systems</u>

The application and evaluation of seven epoxy systems has resulted in a general lack of confidence in such materials. Those which have been exposed to three winters of deicing chemical applications have disclosed slight to moderate chloride intrusion in all areas. Applications exposed to two winters have generally disclosed chloride penetration only along curb lines. Disadvantages of epoxy materials include the requirement for special preparation of the deck surface, the tendency of such materials to pinhole or blister, their general lack of flexibility, age hardening characteristics and high in place cost. The single advantage of epoxies is the stability they provide both on steep grades and by not creating difficulties with the pavement applications.

Polyurethane Membranes

As a group, the liquid applied polyurethanes offer the greatest potential of any system for sealing curb line areas. Other features include excellent flexibility plus resistance to the type of blistering which might result in difficulties with the pavement applications. The material is subject to moisture vapor pressures outgassing from the concrete which often results in the formation of holes and bubbles in the coating. The rate of pinholing or bubbling can be expected to vary with the density and moisture content of the concrete and with changes in the air temperature. The size and shape of any holes or bubbles which remain in the cured membrane, thus affecting the coating porsity, will often vary with the viscosity and cure rate of each material and with individual applications. Many of the polyurethane systems currently available do not develop sufficient toughness to resist puncture damage and therefore require the use of protection boards or roll roofing for protective purposes. The protection system also serves as a means of promoting adhesion between the membrane and the bituminous overlay.

Only one polyurethane system is currently recommended for further use in Vermont following satisfactory initial results on three applications. The system reduces the effects of outgassing by requiring that the concrete be painted black to prematurely raise the surface temperature of the deck and by restricting the 100 mil polyurethane application to the time of day when the air and deck temperatures level off or begin declining. The system also features greater resistance to puncture than similar products and includes the use of an asphalt cement tack coat for promoting adhesion between the membrane and bituminous overlay. The system has not been in service for sufficient time to determine performance based on a chloride analysis of concrete cores.

Hot Asphalt and Glass Fabric

A three coat application of hot asphalt combined with two layers of glass fabric has been used with varying sucess in a number of New England states for approximately 20 years. Vermont's experience has been limited to two applications which have provided nearly complete protection against chloride intrusion through two winter's installation. Further use is being withheld until long term performance can be determined.

The system features low in place cost, good adhesion to the primed concrete, and does not create stability problems with the bituminous overlay. The poorest feature of the roofing grade asphalt is it's complete lack of flexibility at cold temperatures and it's potential for leakage at the curb face due to shrinkage of the asphalt and bituminous pavement during periods of cold temperature.

A hot-applied rubberized-asphalt membrane which was placed on five decks is not recommended for future use due to followup test results which indicate chloride intrusion after three and four winters. The material also was affected by outgassing pressures and created a pavement stability problem under traffic when placed on moderate grades.

Mastic Asphalt and Gussasphalt

A mastic asphalt and Gussasphalt overlay was placed on a single bridge deck during the 1974 construction season. Initial observations and test results over an 18 month period indicated the production and application of the materials were successful, considering the experimental nature of the application. However, the system resulted in failure during the second winter when the seal along the curb lines was lost and approximately 400 lineal feet of random cracks occurred in both the membrane and Gussasphalt. The cause of the failure has not been determined, but it is suspected that it was due to a combination of very low temperatures and rapid temperature changes.

Preformed Sheet Membranes

Vermont currently specifies the three "standard" preformed sheet membrane systems on non-experimental bridges, and allows the contractor to select the preferred system. The desirable characteristics of the three systems include minimum surface preparation, ease of application with improper installation easily visible to the engineer, controlled membrane thickness, not subject to pinholing, good flexibility, and a low in-place cost averaging $4.50 per square yard.

A potential weak point with the sheet materials involves obtaining a complete and lasting seal along the deck-curb joint and lower portion of the curb section which consists of a rough granite face on most bridges. Although all three systems have the potential for waterproofing such areas, the end result depends to a great extent on the care and expertise of the workmen making the installation. For that reason, a compatible liquid polyurethane sealant is specified for use along the membrane perimeter and vertical curb face on two of the three systems. A second problem area concerns the occasional formation of blisters during or after the pavement application. Those which occur during paving are believed to be caused by solvents trapped in the primer or by small concentrations of moisture which collect beneath the membrane and consequently turn to a vapor or gas when exposed to the high temperatures of the bituminous overlay. A reduction in bituminous laydown temperatures will eliminate most initial blistering and also lessen the potential for damaging the materials during placement and compaction of the pavement. The blisters which occur after the pavement has been placed are caused by concrete outgassing pressures which lift the membrane off the deck at areas where adhesion to the concrete is poor. Field test results to date indicate that two of the standard sheet membranes are providing the desired protection. Cores taken from a bridge treated with the third system disclosed chloride contamination in wheelpath areas and adjacent to the curb line. If similar results are noted on other structures, further use of the material would not be recommended.

Other preformed systems which have been applied include an uncured EPDM membrane and a 45 mil vinyl-neoprene system. Both materials were bothered by blister formations but otherwise appeared satisfactory. Neither system has been in service long enough to obtain valid performance data.

Hot Applied PVC Polymer

Two applications of a single component, hot applied PVC Polymer membrane have resulted in a recommendation for continued experimental use. The system can be applied without difficulty using the proper heater-field extruder and features a good seal along the curb line plus low basic material cost. Bubbles and pinholes do occur in the coating but their effect is difficult to determine since the material is covered with a roll roofing protection course. The pavement may be subject to stability problems during application due to the thermoplastic characteristics of the membrane. All problems were averted on the second installation by reducing pavement mix temperatures and by obtaining initial compaction with a light-duty roller.

NCHRP Project 12-11 Systems

The five preformed sheet systems selected as most promising in the National Cooperative Highway Research Program Project 12-11 were placed in Vermont as part of the Phase II study. All five systems were well designed and displayed excellent physical characteristics. However, their applications were difficult thus making it appear doubtful that the systems could be placed properly under typical field conditions when an application specialist might not be present. Actual or potential problems included critical air curing requirements, difficulties in obtaining complete coverage with bonding adhesives, inadequate provisions for sealing rough granite curb lines and difficulties in adhering protection systems. Blisters or cracks occurred in the initial pavements placed over all five systems, but it is theorized that most of the problems would not have occurred if a thicker initial course of pavement had been placed and lower pavement temperatures had been maintained.

As a group, the four cured rubber sheet systems and the single PVC polymer membrane are not recommended for further use because of their difficulty in application and high in-place costs. However, use of several of the systems would be reconsidered if the membrane systems now being specified prove to be unsatisfactory.

Summary

Evaluations have been conducted on 14 membrane systems which have been in service for periods of two to four years. The results of the field tests including chemical chloride analysis of concrete samples (Table III) indicate that several systems have provided complete waterproofing protection to the bridge decks. In addition, a number of other materials have prevented chloride intrusion in all areas except where proper drainage is prevented due to the ponding effect of curb lines and expansion dams. Such results suggest that the simple and inexpensive materials could be specified for sealing the major portion of a deck surface if a compatible and impervious membrane material is placed over poorly drained areas.

Field tests are now being rerun on the 14 membrane systems and annual evaluations are beginning on 12 additional products which have now been in service through two winters of deicing chemical applications. Based upon laboratory performance and observations made during the applications, a number of the materials are expected to prove satisfactory. The materials include two of the three standard preformed membranes plus a polyurethane and a PVC Polymer system. Other sophisticated systems may also prove to be satisfactory but due to the difficulties with their application and potential for improper placement, the use of less complicated materials is recommended.

Laboratory tests and field applications have disclosed that air and vapor pressures which outgas from the concrete often result in the formation of holes or bubbles in liquid applied coatings. The rate of pinholing or bubbling can be expected to vary with the density and moisture content of the concrete and with changes in the air temperature. The size and shape of any holes or bubbles which remain in a cured membrane will often vary with the viscosity and cure rate of each material and with individual applications. Although pinholes and bubbles may be present in a membrane, the results of laboratory tests (Table I) indicate that substantial protection is still obtained when contrasted with the chloride intrusion which occurs in unprotected concrete. The test results also show the relationship between resistivity readings and chloride penetrations and suggest that readings well below the generally accepted standard of 500,000 ohms may be acceptable in many cases.

Experience has shown that most serious problems which occur with membrane applications are directly related to the pavement applications, or more specifically, the paving procedures and pavement design. Agencies contemplating the use of preformed membranes or thermo-plastic liquid applied systems are strongly encouraged to alter their normal procedures to fully comply with the recommendations of the membrane's manufacturer. Initial cracking and blistering of such pavement-membrane systems could be eliminated, in many cases, by reducing bituminous mix temperatures to 275 F or lower, by placing thicker pavement courses, and by applying initial compaction effort with light-weight rollers. Wearing courses over membrane systems should be a minimum of two inches thick, with three inches preferred. If placed in more than one lift, the first course should be 1-1/2 inches thick.

Overall experiences indicate that a number of membrane systems are capable of providing the desired protection. However, the potential for improper placement and other related problems with individual applications of even the simplest materials should be sufficient to discourage membrane usage in areas where a lack of sufficient care and attention might be anticipated.

References

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