EXPERIMENTAL BRIDGE DECK MEMBRANE

APPLICATIONS IN VERMONT

REPORT 75-2

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National Experimental & Evaluation Program
Bridge Deck Protective Systems
Work Plans #24 - #32 & #34
Initial Report

VERMONT DEPARTMENT OF HIGHWAYS

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ABSTRACT

This report covers the application of eleven membrane systems on thirteen new bridge decks in 1974. Information includes data on the membrane systems, laboratory test results, condition of the bridge decks, observations made during the membrane applications, cost information, preliminary field test results and discussions on the applications. Summaries of findings on each membrane system are concluded with recommendations on further use. The report also includes summaries of field and laboratory observations on membrane systems applied in the years 1971 through 1973, and includes chloride concentrations detected in the decks after two to four winters of deicing chemical applications.

Vermont currently specifies the use of the three standard preformed sheet membrane systems, namely Heavy Duty Bituthene; Royston #10; and Protecto Wrap M-400, on non-experimental bridges. With the possible exception of Bituthene, experiences obtained with the membrane systems discussed in this report and the latest results of continuous follow-up testing, do not indicate that any major shift should be made away from the standard preformed sheet systems.

The five preformed membrane systems identified by the NCHRP Project 12-11 are not recommended for further use unless follow-up evaluations prove the standard systems are not satisfactory. The negative recommendation is based on the difficulties in applying the materials and due to their high in-place costs. NEA 4000, a thermo-setting PVC polymer membrane, and Chevron's Bridge Deck Membrane system show sufficient promise to warrant further use. Duralseal 3100 and other liquid applied polyurethanes are recommended as curb line sealers and for use on deck repair and widening projects where surfaces are often too rough to apply the preformed sheet membranes.

Most serious problems which occur with the use of membrane systems are directly related to the pavement applications. Agencies calling for the use of membranes are strongly encouraged to design their pavements to fully comply with the recommendations of the membrane's manufacturer. Initial cracking and blistering of 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. Construction traffic should not be allowed to travel over the membrane and first course of pavement.

Chemical analysis of cores taken from bridges treated with experimental membrane systems between 1971 and 1973 indicate that most membrane systems have provided initial protection against the leakage of chlorides, except in areas adjacent to the curb line. The results suggest that simple inexpensive and less than impervious membrane materials may be adequate for protecting properly drained crack free structures, if curb line areas are treated with an impervious membrane material. Further research is required and will continue in this area.

INTRODUCTION

Applications of experimental bridge deck membrane systems have been carried out by the Vermont Department of Highways since 1971. The applications made during the 1971-1973 construction seasons included the use of twenty systems. Materials included two polyurethane and two cold-applied built-up systems; three preformed sheet products; four hot-applied materials; and nine epoxy systems. All applications were closely monitored and recorded in the following reports:

"National Experimental & Evaluation Program - Bridge Deck Protective Systems"
Initial Reports 72-10 & 73-1

"Experimental Bridge Deck Membrane Applications in Vermont"
Report 74-4

Field evaluations of the membrane systems have included an annual series of tests after exposure to two years of traffic and deicing salt applications. The evaluations include resistivity tests; steel potential readings; moisture strip readings; and the recovery of concrete samples for the determination of chloride content. Paved but otherwise unprotected approach slabs of the experimental bridges are used as control sections. Comments on the effectiveness of the systems, based on test results and service life to date, are briefly discussed in the conclusion of this report and in summary tables on pages 98 through 100.

The basic information in this report covers the application of eleven membrane systems on thirteen new bridge decks in 1974. The systems include the five preformed membrane systems selected during the first phase of the NCHRP Project 12-11, Waterproof Membranes for Protection of Concrete Bridge Decks. Other products include Heavy Duty Bituthene, Royston #10, and Protecto Wrap M-400,preformed sheet systems; Duralseal 3100 and Chevron Bridge Deck Membrane,polyurethane systems; and NEA 4000, a hot-applied PVC Polymer membrane.

Surveillance of all bridge decks will continue until valid conclusions can be obtained as to the effectiveness of each protective system.

WORK PLAN - NO. 24

ROYSTON BRIDGE MEMBRANE #10

DESCRIPTION

A 75-mil thick preformed sheet membrane composed of an impregnated fiberglass mesh sandwished between layers of a bituminous mastic and coated with a polyester film. The material is manufactured by Royston Laboratories, Inc., of Pittsburgh, Pennsylvania 15238.

TEST RESULTS

The membrane was not damaged by puncture or heat when subjected to the application of 275°F to 325°F bituminous mixes applied at a load of 200 pounds per square inch. The material displayed good cold temperature flexibility when bent around a 1-inch mandrel at -10°F and satisfactorily bridged cracks in cement mortar slabs when broken over a 3/16-inch anvil at 0°F.

RECOMMENDED APPLICATION PROCEDURE

1. Apply Royston Roybond Primer 713 by roller, brush or squeegee at the rate of approximately 10 square yards per gallon. Allow the primer to dry thoroughly before applying the membrane.
2. Place the membrane sheet with the sticky surface down by removing the release paper as the application progresses. Place the sheets in such a manner that a shingling effect will be achieved and that any water which accumulates will drain toward the curb and the drain pipes. Each strip should be overlapped a minimum of 4 inches. Hand rollers or other satisfactory pressure apparatus shall be used on the applied membrane to assure firm and uniform contact with the primed concrete surface.
3. The membrane should be fused to the curb face by melting the polyester film with a propane torch and by pressing or rolling the heated membrane into intimate contact with the primed curb surface.
4. Any torn or cut areas, or narrow overlaps shall be patched by the heat fusion method, overlapping a minimum of 6 inches.

RECOMMENDED APPLICATION PROCEDURE (Con't)

5. The bituminous pavement should be between 300°F and 340°F at the time of application to insure adequate bond between the membrane and the deck.

WORK LOCATION

I 91 northbound bridge over Waits River at station 5190+6.25 - 5192+57.17, 0.1 mile north of the Vermont Route 25 interchage in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth finish, very few projections or holes in surface. Very little laitance.

Cracks - Only very light pattern cracks noted.

Miscellaneous - Cracks were noted between the concrete deck and epoxy mortar along 42 percent (106 lineal feet) of the easterly curb line. The epoxy mortar (Rambond 622) had been placed on July 12, 1973. No cracks were noted between the bottom of the granite curb and the epoxy mortar along the easterly curb line or at any point along the curb line on the high side of the banked curve.

Average Initial Chloride Level - 61 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb face. Loose and cracked epoxy mortar was removed with chisels. Deck was washed clean on May 13, 1974.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	5-14-74		Royston representative on the project. Air temperature recorded in shade. Clear.
9:25	55	51	Began applying Royston Roybond Primer #173 with squeegees.
10:00	58	49	Prime coat complete on half of southerly span. Air bubbles noted in the primer at rates of 100-300 per square foot with maximum size of 3/8-inch.
12:00	63	43	48 gallons of primer applied on 4,924 square feet for application rate of 103 square feet per gallon. Breaking air bubbles in primer with squeegees. Copper foil strips placed 2 feet from curb on southerly end of deck with lead wires extended down drain tubes.
2:20	71	38	Began placing sheet membrane along easterly curb.
2:50			Concrete surface temperature 85°. Obtaining a good bond between membrane sheets at side and end laps due in part to the sun and air temperatures.
3:40	74	34	Seven, 125-foot strips in place. One man cutting membrane to fit around drain scuppers at curb line and four men placing material.
5:10	74	35	Membrane application complete on the 548 square yard southerly span. Using propane torch to heat seal membrane along curb line and following it up with an

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (Con't)

Time	Air Temp.	% Humid.	
	5-14-74		
5:10			application of mastic along the outer edge of the sheets. System complete at 6:30.
	5-15-74		0-60% cloud cover. 15-30 mph wind. Sheets placed previous day are completely free of wrinkles and good bond noted on side laps.
3:15	89	27	Northerly span blown clean with air compressor prior to the application of primer.
3:40	90	27	98° in sun. Approximately the same number of air bubbles are occurring in the primer as the number which resulted on the southerly span even though 29 additional hours have passed since the deck was washed on 5-13-74.
4:30	88	23	Brushing out areas with heavy primer application. Copper foil strips placed 3 feet from the easterly curb at a point 203-208 feet north of the southerly approach slab joint.
4:45	93	24	Began placing sheet membrane.
5:30	86	28	Four men placing sheets and one man fusing membrane at curb face.
6:00	85	33	Six, 125-foot strips in place.
7:30	79	46	Application complete including seal along curb lines.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	1115 s.y.	@ $4.25/s.y.	=	$4,738.75
Bituminous Concrete	247 tons	@ $9.90/ton	=	$2,445.30
Tar Emulsion on Approach Slab	72 gals.	@ $2.00/gal.	=	$ 144.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application", on pages 4 & 5.

The 1115 square yard application was completed by five workmen in eight working hours. The membrane sheets were flexible during the application due to high ambient temperatures. This permitted placement along the 3°-30' curvature of the deck without the necessity of cutting the 50-foot rolls or wasting material by excessive overlapping. The high temperatures also resulted in good bond between sheets at end and side laps prior to rolling. The sheet membrane application extended 3 feet onto the approach slabs with the remainder of the approach

slabs treated with two coats of tar emulsion. This procedure was used on all bridges on the project.

The first one-inch course of asbestos modified pavement was placed on May 22, 1974, seven days after the membrane system had been completed. The mix temperatures in the truck ranged from 345°F to 360°F, with initial in-place readings averaging 313°F. Pavement compaction was obtained with a ten-ton, double axle steel wheeled roller, followed by 80 p.s.i. loading with a rubber tired roller. Final compaction was obtained with the ten-ton steel wheeled roller. There were no blisters or cracks in the pavement upon completion.

Electrical resistance readings were recorded at infinity on the pavement-membrane system seven days after completion. Sections of pavement were also removed for the purpose of inspection. Excellent bond was noted between the pavement and membrane at the first location checked. The in-place mix temperatures had been recorded at 335°F. Approximately 90% of the mylar coating and 25% of the bituminous portion of the membrane on the upper side of the reinforcement remained bonded to the bituminous sample. The bond of the membrane to the primed concrete resulted in 10% of the bottom portion of the membrane remaining on the concrete when the six-inch square sample was removed.

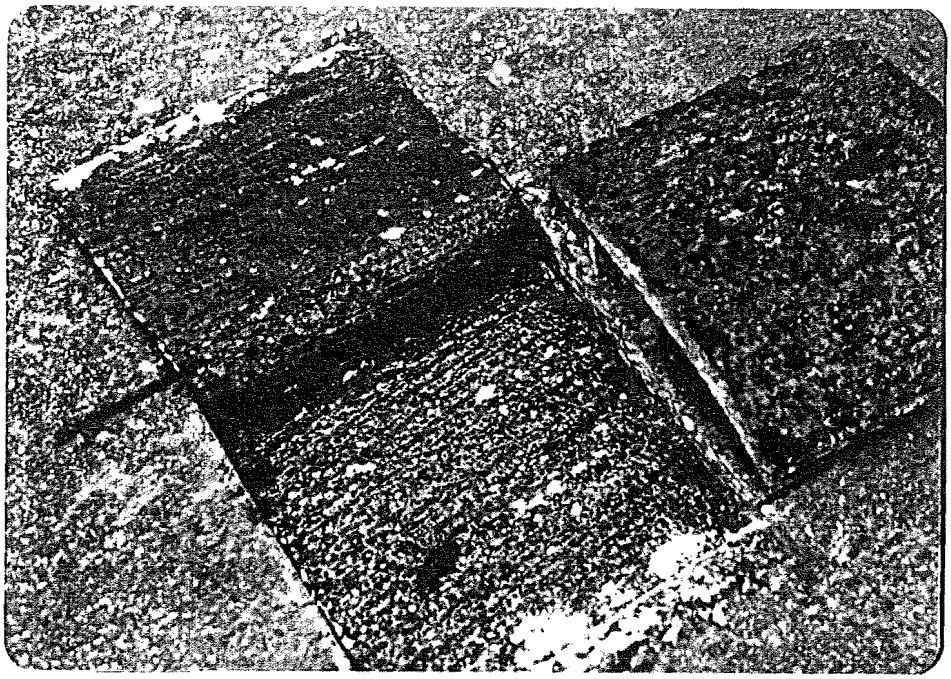
Only slight indentations were noted in the surface of the membrane inspected in an area where the pavement temperature had been recorded at 315°F-320°F. The mylar coating was bonded to the pavement and although the bond to the concrete appeared to be satisfactory, only about 2% of the bottom of the membrane had many indentations at the third location checked. The indentations in the membrane were believed due to the visible lack of fines in the bottom of the bituminous course rather than the 325°F temperatures or compactive effort noted in the inspected area. The membrane had not lost its waterproofing ability, since maximum penetration of the mix was confined to the bituminous portion of the membrane above the reinforcement. Bond to the concrete was excellent, with 25% of the bottom of the membrane remaining on the concrete when the sample was removed.

DISCUSSION (Con't)

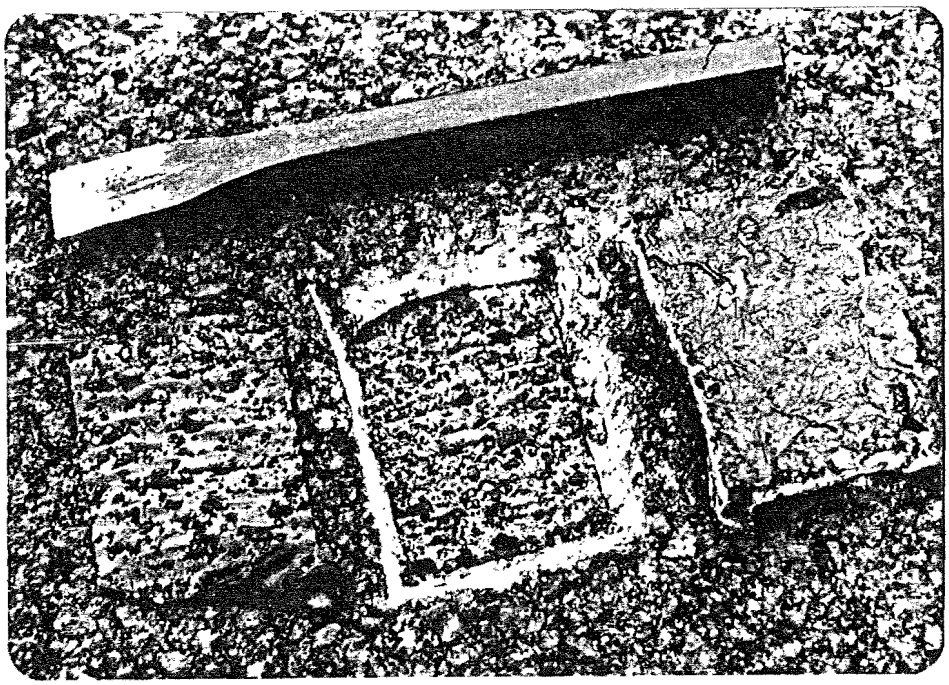
Light vehicle traffic was allowed over the bridge for approximately 3-1/2 months prior to placing the final inch of bituminous pavement. During the latter part of the period, periodic inspection disclosed the formation of numerous short cracks in the pavement. A total of 172 cracks were logged on September 4, 1974, with all but 21 confined to the southerly span. Nine of the cracks exceeded ten inches in length with the remainder averaging five inches. Twenty-two of the cracks were curved or transverse in nature, while eighteen consisted of three or four short cracks radiating out from a single point as is common when minor air blisters form beneath the pavement. The remaining cracks were longitudinal with a significant number occurring at equal offsets from the curb line. The condition suggested that the cracks were caused by a combination of air or vapor pressures and occasional reflections of edges of the membrane sheets. Such findings were confirmed when pressures were noted beneath the membrane when the pavement was removed from several cracked areas approximately 3 feet from the curb line. The system remained waterproof as indicated by infinite electrical resistance readings taken over cracked areas. It is suspected that the cracks would not have occurred if both pavement courses had been applied initially, thereby providing additional dead weight over the membrane. The final course of bituminous pavement was placed without difficulty and has remained free of any reflective cracks or blisters.

ROYSTON BRIDGE MEMBRANE #10

I 91 NB over Waits River



The membrane appeared undamaged at the above location where bituminous lay-down temperatures were recorded at 335°F. Bond between membrane and pavement resulted in adhesion of 90% of the mylar coating and 25% of the membrane surface to the bituminous mix. Membrane bond to the concrete appeared adequate with 10% of the membrane remaining on the deck.



Bituminous lay-down temperatures of 315°F to 320°F also appeared to promote adequate adhesion between substrate, membrane, and pavement.

WORK PLAN - NO. 25

HEAVY DUTY BITUTHENE

DESCRIPTION

A 65-mil thick preformed sheet membrane system composed of a woven polyproplene mesh coated on one side with a layer of rubberized asphalt. The material is manufactured by W. R. Grace & Company.

TEST RESULTS

The membrane was not damaged by puncture or heat when subjected to the application of 275°F to 300°F bituminous mixes applied at a load of 200 pounds per square inch. The material did not crack when bent around a 1-inch mandril at -10°F and satisfactorily bridged cracks in cement mortar slabs when broken over a 3/16-inch anvil at 0°F.

RECOMMENDED APPLICATION PROCEDURE

1. Apply Bituthene primer by brush or roller at the rate of 200 to 400 square feet per gallon and allow the primer to dry tack free before applying the membrane.
2. Place 8 to 9-inch wide strips of the membrane along the base of the curb so that the material extends up the curb face to the height of the proposed bituminous overlay. On rough faces, place a bead of Bituthene Mastic on the vertical face before flashing strips are applied.
3. Place the membrane sheet with the sticky surface down by removing the release paper as the application progresses. Place the sheets in such a manner that a shingling effect will be achieved and that any water which accumulates will drain toward the curb and the drain pipes. Each strip should be overlapped a minimum of 2-1/2 inches.
4. All termination points at curbs, expansion joints or end of the deck should be sealed with a bead of Bituthene Mastic, applied after the membrane has been placed.

RECOMMENDED APPLICATION PROCEDURE (con't)

5. Repair any torn or cut areas by overlapping a minimum of 6 inches with a patch of the membrane.

6. The bituminous pavement should be between 275°F and 325°F at the time of application.

WORK LOCATION #1

I 91 southbound bridge over Waits River at station 5190 + 08.50 - 5192 + 79.42, 0.1 mile north of the Vermont Route 25 exit in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Southern span has smooth surface; northerly span somewhat rougher with slightly pitted surface due to rain.

Cracks - None visible.

Average Initial Chloride Level - 44 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb faces the day before the membrane application began.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	4-17-74		Air temperature recorded in shade. Clear. 10-20 m.p.h. breeze.
11:15	50	47	Began applying primer with long handled paint rollers.
11:45	53	45	500 square feet covered. First area treated is dry to the touch.
12:20	53	37	8.5 gallons of primer applied on 23,190 square feet for application rate of 273 square feet per gallon.
1:45	57	33	Began placing 6-inch wide membrane strips approximately 1-1/4 inch up the 45° epoxy mortar filled face along the southeasterly curb. Would not be able to seal area where epoxy mortar contacts granite curb due to roughness.
2:00	58	30	Placing first 59.5-foot by 3-foot roll. Lot No. 03-183-1-E and -W.
3:00	62	27	Some attempts to correct roll alignment result in longitudinal wrinkles in the membrane. Smoothing and pressing the membrane by hand from the middle to the edges when it first makes contact with the concrete eliminates most of the wrinkles. Occasional wrinkle due to manufacturing process.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
4:00	64	27	Eight full rolls in place (1440 s.f.). One man cutting membrane to fit around drain scuppers.
4:45	64	25	Two men placing the 60-foot rolls in 5-15 minutes. Operation is slowed considerably when difficulties occur with release paper tearing and sticking to bottom of the membrane on about 20% of the rolls. Eleven rolls placed in 2 hours and 50 minutes.
5:25	63	27	Full width rolls complete. Placing 6-inch strip along westerly curb.
7:00	58	33	Finished applying mastic along edge of membrane at curb line.
	4-18-74		Clear a.m. 75-100% cloud cover p.m. 5-20 m.p.h. breeze.
9:00	52	46	Priming remainder of southerly span. Placed 5-foot copper foil strips on primed concrete 2 feet from easterly curb at a point 193-198 feet south of northerly approach slab joint.
9:50	55	45	Placing membrane sheets. 18 gallons of primer applied on southerly span at an average rate of 297 square feet per gallon.
10:45	58	39	Having occasional difficulty obtaining proper alignment. Necessary to cut and restart rolls when it occurs.
12:10	60	41	8 full rolls in place.
1:45	54	48	Placing 20-foot strips up to expansion dam. 6-inch membrane strip placed transversely along 45° concrete fillet on both sides of the expansion dam.
3:15	56	51	Priming northerly span and placing mastic along curb face on southerly span.
5:00	53	50	Placing first roll along easterly curb.
7:15	51	51	Placed eighth roll along westerly curb.
	4-19-74		
10:00	42	49	Began priming remainder of northerly span. Two men on project.
1:10	46	35	Placing 15-inch wide strip along easterly curb.
4:20	48	31	3930 square feet covered. Beginning 20-foot strips on northerly end of deck.
5:45	47	31	Placing 2-inch wide by 1/4-inch thick application of mastic along top edge of membrane and adjoining granite curb.
6:50	46	34	Rolling membrane with a pick-up truck. Procedure successful in removing wrinkles or bubbles in the recently placed membrane, but only partially successful in bonding areas where air had built up beneath the membrane over a 24 to 48-hour period.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	1202 s.y.	@	$4.50/s.y.	= $ 5,409.00
Bituminous Concrete	267 tons	@	$9.90/ton	= $ 2,643.30
Tar Emulsion on Approach Slabs	71 gals.	@	$2.00/gal.	= $ 142.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application", on pages 10 and 11.

The work crew varied from three to five men during the installation, with a total of 76 manhours of labor required to complete the 1202 square yard application.

Although no serious problems were encountered, some lost time occurred due to difficulties with sheet alignment and when the release paper tore and stuck to the bottom of the membrane sheet on a number of the rolls.

The first 1-inch course of asbestos modified pavement was placed on May 2, 1974, 13 days after the membrane system had been completed. Although a number of large bubbles and wrinkles containing air under pressure were noted in the membrane on May 1, they were not apparent the following morning due to low air temperatures and consequently did not require puncturing prior to paving.

The initial in-place mix temperatures ranged from 260°F to 290°F, with an average temperature of 272°F. Cracks appeared in the bituminous mix 2 to 3 minutes after the material was placed. All were over the edges and ends of individual sheets and comprised about 20% of the total sheet perimeters. The cracks were believed due to contraction of the woven polyproplene mesh, which was caused by the heat of the bituminous mix. The cracks ranged up to 1/2-inch in width prior to compaction. Approximately 50% were eliminated during compaction with a 6 to 8 ton double axle steel wheeled roller. The compacted mix varied from 7/8-inch to 1-5/16-inch in thickness. Part of the variation may have been due to unevenness in the surface of the concrete deck. The overall appearance of the pavement was poor, due in part to a number of porous surface areas.

The membrane did not appear to be damaged when a portion of the pavement was

DISCUSSION (con't)

removed for visual inspection. Electrical resistance readings on the membrane and pavement were recorded at infinity at all but one location, with the exception being a 660,000 ohm reading.

WORK LOCATION #2

I 91 northbound bridge over State Aid Highway No. 5 at station 5612 + 19 - 5613 + 17, approximately 8 miles north of the Vermont Route 25 interchange in Bradford. (Material was substituted for Royston #10, due to material supply and scheduling problems).

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Gritty texture due to abrasive action of 4-inch sand blanket maintained on deck during 3-month period of construction traffic.

Cracks - 30-inch diagonal cracks extending from south-westerly and north-easterly corners of deck.

Average Initial Chloride Level - 61 parts per million.

Preparation - A 4-inch layer of sand was removed from the deck on July 19, and the concrete was sandblasted 3 feet out from the curb faces 3 days before the membrane system was placed.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	7-25-74		Air temperatures recorded in shade. 80% cloud cover a.m. 25% cloud cover p.m.
8:50	67	43	Applying Bituthene primer with paint rollers.
9:35	68	38	Copper foil strips placed 2 feet from easterly curb at a point 4 feet north of the southerly approach slab joint.
10:10	69	39	Placing 3-foot wide sheets along westerly curb with outer edge approximately 1-1/2 inches or half-way up epoxy mortar fillet.
11:30	73	34	5 strips complete. No problem with release paper tearing and sticking to the bottom of the membrane as had happened previously.
1:00	76	33	Placing 6-inch wide strips of membrane and mastic along easterly curb.
3:20	77	35	6 strips complete on easterly half of deck.
4:50	80	34	System complete. The 461-square yard installation took 27 manhours to complete.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	461 s.y.	@	$4.50/s.y.	= $ 2,074.50
Bituminous Concrete	90.8 tons	@	$9.90/ton	= $ 898.92
Tar Emulsion on Approach Slab	34 gals.	@	$2.00/gal.	= $ 68.00

DISCUSSION

For more detailed information on the application, refer to "Observations Made During Membrane Application", on page 13.

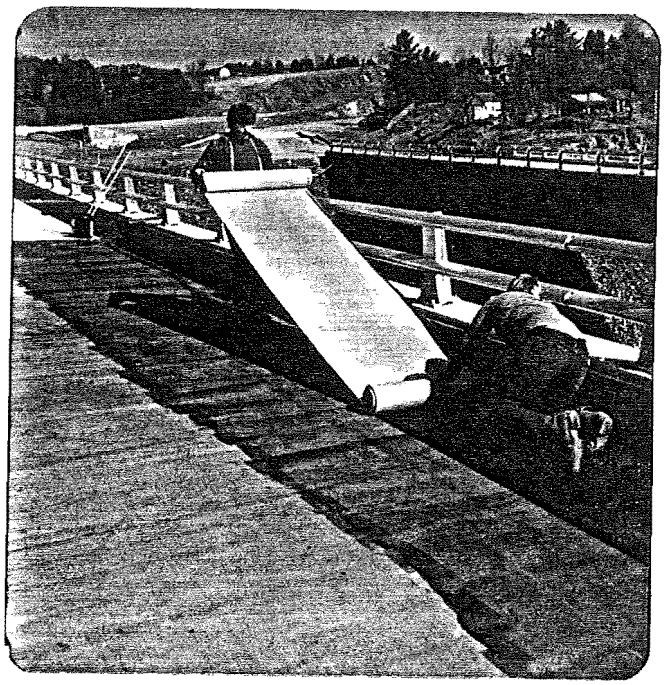
A four man crew completed the 461-square yard installation in 27 manhours.

The first course of asbestos modified pavement was placed on July 29, 1974, 4 days after the membrane system was completed. The mix temperatures ranged from 280 to 320°F, with initial in-place temperatures averaging 270°F. Cracks ranging up to 3/4-inch in width appeared in the bituminous mix prior to compaction, as had occurred on the earlier installation. Compactive effort sealed a portion of the cracks although many remained visible upon completion. No blisters or other difficulties were encountered with the paving operation until the paver was backed up the 4.8 percent grade to complete the final pass. At that point, the pavers tires sunk into the edge of the bituminous mat placed during the third pass of the paver. Spinning of the tires on the mix resulted in an undetermined amount of damage to the membrane at points approximately 11 feet from the easterly curb and 20-23 feet, 25-28 feet and 30-55 feet from the southerly approach slab joint. No problems occurred prior to or following placement of the final inch of bituminous pavement.

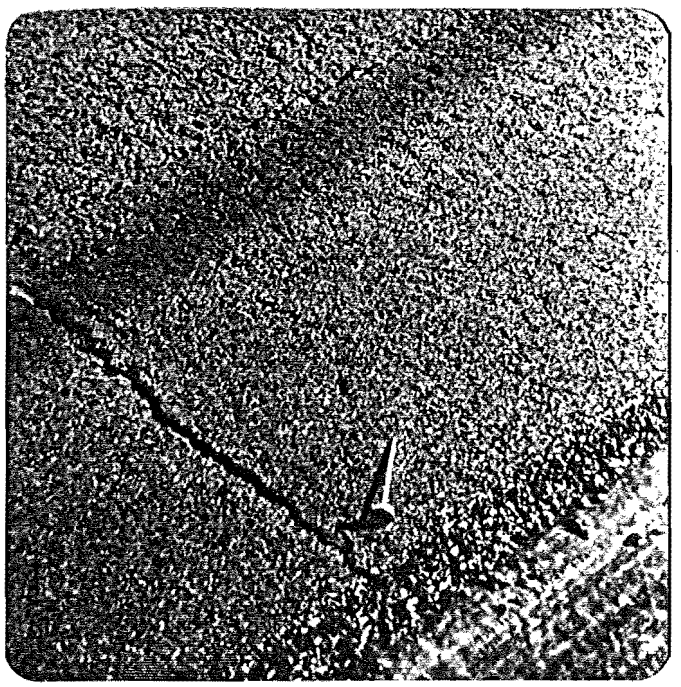
HEAVY DUTY BITUTHENE

I 91 SB over Waits River

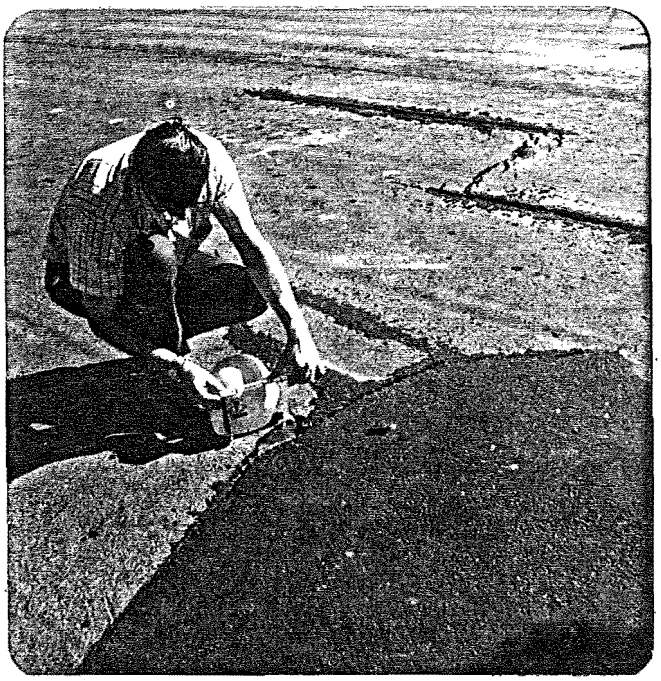
Applying Bituthene primer with paint roller



Placing first sheet along curb line.



Initial cracks in pavement over ends and edges of membrane sheets due to shrinkage of polypropylene reinforcement.



Pavement repair required on first course due to combination of initial cracks, thin pavement, and construction traffic.

WORK PLAN - NO. 26

DURALSEAL 3100 DECK COATING

DESCRIPTION

A 2-component, 100 percent solids polyurethane system which includes an epoxy primer application. The material is manufactured by Dural International Corp., 95 Brook Avenue, Deer Park, N. Y. 11729.

TEST RESULTS

The membrane was not damaged by puncture or heat when subjected to the application of bituminous mixes at temperatures up to 300°F. Samples passed the 1-inch mandril flexibility and crack bridging tests at 0°F. Adhesion to concrete was good before and after submersion of samples in water.

RECOMMENDED APPLICATION PROCEDURE

1. Apply Duralseal 3100 primer by spray or roller at the rate of approximately 300 square feet per gallon.
2. After primer has dried, apply Duralseal 3100 by airless spray, squeegee, trowel or roller at the desired thickness.

WORK LOCATION

I 91 northbound bridge over Vermont Route 25B at station 5195+47 - 5196+83, approximately 0.1 mile north of the Vermont Route 25 interchange in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth finish.

Cracks - Occasional fine shrinkage cracks visible.

Miscellaneous - Scattered cracks noted between the concrete deck and epoxy mortar along the easterly curb line.

Average Initial Chloride Level - 81 parts per million - 44 parts per million chloride recorded in samples taken before deck was acid etched.

Preparation - The deck surface was acid etched on May 6, 1974 and was blown clean with a compressor just prior to the membrane application on May 14, 1974.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	5-14-74		Air temperatures recorded in shade. Clear.
8:00	50°	59	Dural representative on project. Blowing off deck with air compressor. Some stains from acid etching noted on the concrete even though the surface was thoroughly flushed as the etching proceeded.
11:30	59°	44	Began placing 2-component epoxy primer along south westerly curb with long handled paint rollers. Switched application to squeegee after 300 square feet covered, in an attempt to increase the coverage per gallon of material. Reworking coating with paint rollers 3 to 5 minutes after application, in an attempt to eliminate holidays and break air bubbles.
12:30	65°	41	Placed primer on 18-inch square test slab. Vapor pressures from test slab resulted in approximately 25 pinholes and a few bubbles before reworking the material. Similar conditions noted on deck with most of the pinholes and air bubbles reappearing a short time after the material was reworked.
1:00			28 gallons applied on 3420 square feet for application rate of 122 square feet per gallon.
2:25	71°	38	30 gallons of primer applied. 1/2 pint of xylol solvent added per gallon of primer, on last 10 gallons used.
5:20	74°	36	Began applying Duralseal 3100 polyurethane with squeegee. Aiming for an application rate of 27 square feet per gallon which would produce a wet film thickness of 60 mils.
6:30	73°	41	Noting air bubbles and pinholes in the coating at approximately the same rate as that which occurred in the prime coat.
6:55	73°	43	120 gallons of material applied. Slight flow of coating noted in thick areas.
7:30	69°	49	Applying final batch of available material. 170 gallons applied on 3970 square feet for application rate of 23.4 square feet per gallon. Approximately 1410 square feet of deck area remaining to be treated.
	5-18-74		Clear.
7:45	52°	59	Using air compressor to remove dirt from remaining area to be treated.
8:40	53°	58	Priming remainder of deck and repriming area treated on 5-14-74. Electrical resistance readings on the primer ranged from 3000 to 11,000 ohms per square foot.
9:10	54°	54	Prime coat complete. 6 gallons applied on 1410 square feet.
9:30			0 - 5 air bubbles per square foot noted in area given first coat of primer but very few bubbles visible in area given second coat.
11:00	63°	45	Began applying urethane.
12:40	68°	40	Application complete. Vapor pressures outgassing from the concrete are resulting in 100-200 pinholes and 25-75 air bubbles per square foot at many locations.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION
(Con't)

Time	Air Temp.	% Humid.	
	5-21-74		75% average cloud cover. 3-8 mph breeze.
2:50	66°	28	Applying a second coat of the polyurethane over areas treated on 5-18-74, in an attempt to seal off some of the pinholes and bubbles.
3:20	65°	29	Reworking material with paint rollers.
3:35	65°	31	20 gallons applied. Area given heavy coat appears good while some pinholes still visible in area given light second coat.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	616	s.y.	@ $7.25/s.y.	=	$ 4,466.00
Bituminous Concrete	137.8	tons	@ $9.90/ton	=	$ 1,364.22
Tar Emulsion on Approach Slab	76	gals.	@ $2.00/gal.	=	$ 152.00

TABLE I

RESISTANCE READINGS, PINHOLES AND BUBBLES IN DURALSEAL 3100

All locations checked were 6 inches square in area opposite the specified guard rail posts along the easterly curb line. Posts were numbered in a northerly direction.

Guard Rail Post #	Offset	Pinhole or Crater Size 1/8"-1/4"	1/16"-1/8"	1/32"-1/16"	*1/32"	Bubbles	Holes and Bubbles/sf	Ohms/sf Resistance
3	2'							420,000
3	6'							295,000
3	12'	1	7	16	7	0	124	170,000
9	5.5'							455,000
9	9'							1,000,000
9	12'							1,200,000
10	7'	8	12	4	15	3	168	230,500
10	12'	0	0	5	2	2	36	5,000,000
10	18'	0	0	4	0	0	16	7,000,000
10	24'	8	4	0	32	0	176	190,000
10	30'	4	4	0	8	0	64	200,000
17.5	10'	3	6	8	4	13	136	
17.5	15'	0	7	12	5	0	96	
17.5	20'	0	2	2	4	0	32	
17.5	25'	0	5	4	5	0	56	
17.5	30'	0	0	2	3	0	20	
17.5	35'	4	12	12	4	4	144	
						Average	89	1,453,636

*Holes in 1/32"- range appeared as dimples in the membrane surface, but offered little resistance to penetration when probed with a pencil point.

DISCUSSION

For more detailed information on the application, refer to "Observations Made During Membrane Application", on page 17.

The installation began with the application of Duralseal 3100 epoxy primer. When bubbles and pinholes were noted in the coating shortly after application, the material was reworked with paint rollers. Although this procedure eliminated many of the bubbles and pinholes, most reappeared a short time later. Insufficient material prevented the completion of the prime coat. The 40 gallons on hand covered 4800 square feet, for an application rate of 120 square feet per gallon.

The squeegee application of Duralseal 3100 polyurethane began approximately 3 hours after the prime coat was completed. The application rate was maintained at approximately 27 square feet per gallon by marking off sections of the deck for each 10 gallon batch of material mixed. Numerous bubbles and pinholes appeared in the material at approximately the same rate as that which occurred in the prime coat. This was surprising, since the finish coat was applied during the late afternoon hours when air and moisture outgassing from the concrete would not be expected to be as much of a problem.

The primer and polyurethane membrane were completed on the morning of May 18, 1974, when additional material was received. Rising air temperatures which occurred during the morning application resulted in from 100 to 200 holes and 25 to 75 air bubbles per square foot of area treated. Since the condition of the membrane was not considered satisfactory, a second coat was applied 3 days later over the 1410 square foot area, using material donated by the manufacturer.

The number of holes and bubbles in the completed membrane was recorded at 12 locations. The number ranged from a low of 16 to a high of 176 per square foot. The size of the holes and bubbles ranged up to 1/4-inch in diameter, although most were in the range of 1/16-inch or less. Individual small pinholes were visible in the center of some of the larger crater-type depressions. Many of the holes in the minus 1/32-inch range appeared as dimples in the membrane surface, but offered little resis-

tance to penetration when probed with a pencil point. (See Table I on page 18, for size and number of holes and bubbles). Differences in the color of the cured membrane were also noted with variations ranging from greenish-yellow to blue-gray.

Electrical resistance readings taken on the completed membrane system ranged from 170,000 to 7 million ohms per square foot. As would be expected, the lower resistance readings were recorded in areas with the greatest number of holes and bubbles. (See Table I on page 18).

The first 1-inch course of asbestos modified pavement was placed the day after the membrane system was completed. The initial in-place temperatures of the mix ranged from 250°F to 290°F, with most averaging 262°F. Pavement compaction was obtained with 10-ton steel and 80-psi rubber tired rollers.

Removal of the compacted pavement from an area which received the highest bituminous temperatures disclosed no visible signs of damage to the membrane system. As expected, there was very little bond between the polyurethane membrane and the bituminous pavement.

Electrical resistance readings on the completed membrane-pavement system averaged 4.5 million ohms.

I 91 NB over Rte. 25B

Applying 2-component polyurethane over epoxy prime coat.

Air and/or moisture vapor outgassing from the concrete resulted in an average of 89 pinholes, craters, and bubbles per square foot.

WORK PLAN - NO. 27

PROTECTO WRAP M-400

DESCRIPTION

A 70 mil thick preformed sheet membrane composed of aromatic tars modified with synthetic resins and reinforced with a synthetic non-woven fabric. The membrane is manufactured by the Protecto Wrap Company, 2255 South Delaware Street, Denver, Colorado 80223.

TEST RESULTS

The membrane was not damaged by puncture or heat when subjected to the application of 275°F to 300°F bituminous mixes applied at a load of 200 pounds per square inch. The membrane displayed sufficient flexibility to resist cracking when bent around a 5-inch diameter mandril at -10°F; however, cracks occurred in the material when it was bent around mandrils of a smaller diameter. The membrane bridged cracks in cement mortar slabs when broken over a 3/16-inch anvil on 75 percent of the samples tested at 0°F.

RECOMMENDED APPLICATION PROCEDURE

1. Apply Protecto Wrap Number 80 Primer by roller, brush or squeegee at a rate not exceeding 150 square feet per gallon. Allow the primer to dry to a tack free condition prior to applying the membrane. Reprime areas not covered within 24 hours.
2. Place the membrane wrinkle free with a minimum of 3-inch overlaps in a manner that will provide a shingling effect toward the low side of the deck. Apply a bead of mastic along the upper outside edge of the membrane along the curb to form a seal.
3. Remove the polyethylene release film from the surface of the membrane prior to placing the bituminous overlay. The temperature of the bituminous mix should not exceed 280°F at the time of application.

WORK LOCATION #1

I 91 southbound bridge over Vermont Route 25B at station 5196 + 34 - 5147 + 94, approximately 0.1 mile north of the Vermont Route 25 interchange in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Varies from smooth to moderately pitted.

Laitance - Moderate in pitted areas.

Average Initial Chloride Level - 26 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb faces and the deck was washed the day before the membrane application began.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	5-1-74		Air temperature recorded in shade. 45% average cloud cover. Winds 15-45 m.p.h.
9:30	55	50	Began primer application. Necessary to heat material with a torch to liquify it as per directions of Protecto Wrap representative on project. Partial solidification
10:30	57	46	of material supplied in 55 gallon drums may have been due to possible freezing during storage.
11:00	59	42	Placing 30-inch roll of membrane along lower easterly curb.
12:00	62	39	Completed primer application with 65 gallons placed on 6489 square feet for application rate of 100 square feet per gallon. Air bubbles in the prime coat vary greatly in number and size (max. 1/2 - 3/4"). The variation in the number of bubbles may be due to the temperature range the material attained during heating, since readings ranged from 80°F to 110°F.
12:30	62	38	Attempting to seal membrane along curb face by pressing it into an application of CA 1200 mastic and then coating the edge of the membrane and adjacent areas with a second coat of the mastic. Necessary to lower membrane along curb face, due to roughness along upper edge of epoxy mortar fillet.
1:30	63	37	Placing 60-inch wide rolls with the aid of a pickup truck. Roll supported by 1-inch diameter pipe and upright posts at tail gate. End of sheet placed on concrete or preceding strip of membrane and held in place as truck moves ahead and membrane unrolls.
2:25	62	37	Third strip complete. Strong winds making it difficult to hold the material in place as it is unrolled.
3:15	63	35	5 strips complete. Wrinkles in sheets placed earlier are becoming more evident as air pressure from the deck builds up beneath the sheets.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
4:00	59	37	Rolling membrane with a car to eliminate bubbles and wrinkles. Necessary to puncture large blisters with a pick and then force air out.
4:35	56	45	Rain shower. Upper edge of membrane sealed with mastic to prevent seepage of water beneath sheets.
	5-2-74		Clear. 5-10 m.p.h. breeze
8:00	34	44	Almost no air visible beneath wrinkles in membrane due to low air and deck temperatures. Repriming area along westerly curb where sand was blown into the first coat of primer. Technical representative ok'd application although air temperature below minimum requirements.
8:50	35	42	Placing 30-inch wide wtrips along upper side of elastomeric expansion dam on 45° concrete fillet.
9:30	38	39	Began placing seventh full width strip.
10:55	44	33	Final strip complete. Placing mastic along curb line and removing polyethylene release film from the surface of the membrane.
12:00	47	29	Application complete. Began paving.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	721	s. y.	@	$4.25/s. y.	= $ 3,064.25
Bituminous Concrete	166.8	tons	@	$9.90/ton	= $ 1,651.32
Tar Emulsion on Approach Slab	76	gals.	@	$2.00/gal.	= $ 152.00

DISCUSSION

For more detailed information on the application, refer to "Observations Made During Membrane Application", on pages 23 & 24.

Initial 30-inch wide rolls of the membrane were placed 2-2-1/2 inches up the curb face slightly above the top of the 45° epoxy mortar fillet. When it was noted that the material did not remain sealed against areas where the granite face was uneven, the membrane was cut so the top edge was in contact with the mortar fillet.

The use of a pick-up truck to aid in placing the 60-inch wide membrane sheets resulted in a significant reduction in the installation time. The procedure was considered satisfactory although it appeared that slightly more air was trapped beneath the membrane than when the material was placed by hand and a squeegee was used to press the sheets against the concrete. The procedure also resulted in a

DISCUSSION (con't)

greater variation in the amount of side lap between sheets, with a range of 2 to 6 inches noted.

The first 1-inch course of asbestos modified pavement was placed as soon as the membrane installation was completed. The temperature of the mix in the trucks averaged 278°F, while the initial in-place temperatures were recorded at an average of 245°F. There were no blisters or visible cracks in the hot-mix either prior to or after compaction with the steel and rubber tired rollers.

Electrical resistance readings on the completed membrane-pavement system were recorded at infinity, indicating the system was impervious.

WORK LOCATION #2

I 91 northbound bridge over State Aid Highway No. 1 at station 5486 + 77.80 - 5487 + 82.00, approximately 5.7 miles north of the Vermont Route 25 interchange in Bradford. (Material was substituted for Royston #10, due to material supply and scheduling problems).

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth finish.

Cracks - None visible.

Average Initial Chloride Level - 22 parts per million.

Preparation - A 2 to 4 inch layer of sand was removed from the deck on July 19, and the concrete was sandblasted 3 feet out from the curb faces on July 22, 1974.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	7-23-74		Air temperature recorded in shade. Clear a.m. 80% cloud cover in p.m.
8:15	61	62	Blowing deck clean with air compressor.
9:15	68	57	Priming deck, using paint rollers. Brushes used on curb face.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
11:20	77	42	Primer application complete, with 34 gallons applied on 4311 square feet for application rate of 127 square feet per gallon.
12:45	80	35	Placing 30-inch strips of Protecto Wrap along curb lines. Copper foil strips placed 2.5 feet from easterly curb.
1:45	79	37	Using pick-up truck to place 60-inch wide rolls.
2:45	78	39	3 full width sheets in place.
4:00	79	37	7 strips complete. Placing 4 to 5-inch wide strips along curb face covering the epoxy mortar with the bottom of the strips lapping over the 30-inch wide membrane sheets.
5:35	74	44	Finished placing mastic along curb lines. Application complete.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS WEARING SURFACE

Membrane Treatment	485 s. y.	@	$4.25/s. y.	=	$ 2,061.25
Bituminous Concrete	109 tons	@	$9.90/ton	=	$ 1,079.10
Tar Emulsion on Approach Slab	51 gals.	@	$2.00/gal.	=	$ 102.00

DISCUSSION

For more detailed information on the application, refer to "Observations Made During Membrane Application", on pages 25 & 26.

The membrane system was installed without difficulty. The day following the installation, approximately 2000 square feet of P-100 protection sheet was placed. The 2-foot wide by 50-foot long rolls were placed longitudinally from the northerly expansion dam. The installation was completed quickly, with individual strips butting each other. After rolling the material with a 1-ton truck, a check of several areas revealed excellent adhesive bond between the P-100 protection sheet and the M-400 membrane. Entrapped air was noted at about 10 locations, and was released by puncturing the protection sheet.

The first 1-inch course of asbestos modified pavement was placed on July 25, 1974. The temperature of the mix in the trucks averaged 280°F, while initial in-place temperatures averaged 240°F. Although no blisters occurred in the pavement during compaction, a blister was noted in the completed system approximately 2 weeks

DISCUSSION (con't)

later. After puncturing the 15-inch diameter blister, no further difficulties were noted.

WORK LOCATION #3

I 91 southbound bridge over State Aid Highway No. 5 at station 5614 + 19 - 5615 + 47, approximately 4.6 miles south of the U.S. Route 302 interchange in Bradford. (Material was substituted for Heavy Duty Bituthene, due to material supply and scheduling problems).

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth finish.

Cracks - None visible

Average Initial Chloride Level - 29 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb faces and was blown clean prior to the membrane installation.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	8-12-74		Air temperature recorded in shade. Clear. 2-5 m.p.h. breeze.
8:45	60	43	Warming primer with torch to reduce viscosity.
9:00	62	40	Priming deck, using paint rollers.
10:40	78	23	Primer application complete. Numerous bubbles visible in the prime coat, with the largest ranging up to 5/8-inch in diameter.
11:15	80	18	Finished placing 30-inch wide membrane sheets along curb line. Beginning placement of 60-inch wide sheets with aid of a pick-up truck.
12:25	83	17	System complete except for cap section and mastic.
1:30	84	16	Installation complete.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS WEARING SURFACE

Membrane Treatment	594	s. y.	@	$4.25/s. y.	= $ 2,524.50
Bituminous Concrete	114.4	tons	@	$9.90/ton	= $ 1,132.56
Tar Emulsion on Approach Slab	33	gals.	@	$2.00/gal.	= $ 66.00

DISCUSSION

For more detailed information on the application, refer to "Observations Made During Membrane Application", on page 27.

The membrane installation was completed without difficulty. The pavement application scheduled for August 22, 1974, was cancelled when the temperature of bituminous mix supplied for the project was recorded at 330°F to 375°F in the trucks. Positioning of a rubber tracked paver on the deck also resulted in slight damage to the membrane near the centerline on the southerly half of the deck. The damage was confined to 26 half-inch square areas where the portion of the membrane above the reinforcement was pulled off the sheets. The pavement was placed the following day at which time the temperature of the mix ranged from 250°F to 270°F, with initial in-place temperatures averaging 230°F. There were no blisters or cracks visible in the pavement either prior to or after compaction. Electrical resistance readings on the completed membrane and first course of pavement were recorded at infinity, indicating a waterproof system.

WORK PLAN - NO. 27B

NEA 4000

DESCRIPTION

A single component, hot applied PVC Polymer membrane system. The liquid polymer is heated to 275°F-300°F in a double-boiler kettle or special field extruder and is applied with squeegees in a minimum 90-mil thickness. The material is covered with asphalt roll roofing prior to its' polymerization upon cooling. The NEA 4000 system is manufactured by Posh Chemical, Inc., 17 Matinecock Avenue, Port Washington, N. Y. 11050.

TEST RESULTS

Samples of the material did not crack when bent around a one-inch mandril at 0°F, but failed to bridge cracks in cement mortar slabs when broken over a 3/16-inch anvil at 0°F. Adhesion to concrete was rated only as fair, but did not appear to worsen after six months immersion in water. The material was not damaged by puncture or heat from bituminous mix when protected with roofing paper. Applications of the material without the roll roofing on concrete test slabs produced satisfactory resistivity readings of two to four million ohms.

RECOMMENDED APPLICATION PROCEDURE

1. Place the liquid PVC polymer in a double-boiler indirect fired melter-applicator or special field extruder and heat to 275°F-300°F.
2. After the compound has attained the proper temperature, pump it directly onto the concrete deck and use a squeegee to obtain the desired 90-mil thickness at two square yards per gallon.
3. Place 65-pound roll roofing (ASTM D-224) over the membrane, butting all joints.

WORK LOCATION

The I 91 southbound bridge over State Aid Highway No. 1 at station 5488+15 - 5489+20, approximately 5.7 miles north of the Vermont Route 25 interchange in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Typical burlap dragged finish.

Average Initial Chloride Level - 30 parts per million.

Preparation - A two to four inch layer of sand was removed from the deck and the concrete was sandblasted three feet out from the curb faces.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	8-5-74		50-100% cloud cover. Showers occurred previous day.
10:45	71°	41	Began placing NEA 4000 along north westerly curb line. Roofing sheet placed in twelve to fifteen foot strips with end joints staggered.
11:45	73°	31	152 s.y. of deck covered in first of three thirteen foot wide passes. Material temperature recorded at 255°F-260°F at tip of extruder hose.
12:35	74°	28	Bubbles and craters noted in material prior to installation of roofing sheet. Concrete visible
1:30	75°	30	beneath a small number of the bubbles broken open for inspection.
1:55	72°	40	Deck complete. Placing second coat of elastomer immediately adjacent to curb face.
2:05			Installation complete. 280 gallons applied on 485 s.y. for rate of 1.7 s.y. per gallon or an approximate 105-mil thickness.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	485 s.y.	@ $4.00/s.y.	=	$1,940.00
Bituminous Concrete	95.9 tons	@ $9.90/ton	=	$ 947.43
Tar Emulsion on Approach Slab	35 gals.	@ $2.00/gal.	=	$ 70.00

DISCUSSION

The NEA 4000 system was placed utilizing a heater-field extruder supplied by the manufacturer. Technical representatives were also present during the application. Six workmen completed the 485 square yard deck in three hours and twenty minutes. Their duties included moving the truck and tire-mounted extruder; keeping the extruder tanks filled with five-gallon units of the liquid polymer; applying the material via an extruder hose; leveling the material with a squeegee; and placing the roll roofing on the liquid membrane.

A few bubbles were noted in the liquid membrane prior to the installation of

the roofing sheets. Concrete was visible beneath approximately 25% of the bubbles broken open. Adhesion of the material to the deck surface varied with the texture and quality of the concrete. Tracking or pulling of the material occurred at a few locations where workmen stepped on it prior to placing the roll roofing. The roofing sheets were placed in ten to twelve foot strips as soon as the liquid membrane was leveled with a squeegee. All joints were butted with few gaps over 1/4-inch noted between sheets. Adequate adhesion was noted between the membrane and roofing sheet and there was no evidence of any entrapment of air beneath the sheets.

When the system was complete, an additional bead of the liquid membrane was applied along the vertical curb face and allowed to flow down onto the horizontal membrane surface and the edge of the outer sheet of roll roofing. A total of 280 gallons were applied, for an application rate of 1.7 square yards per gallon and a film thickness of 105 mils.

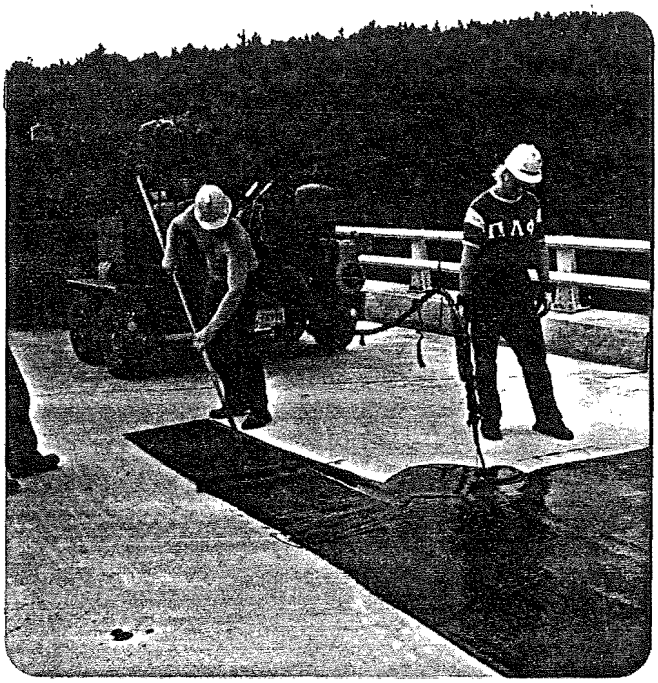
Electrical resistance readings were taken at three locations not covered with roofing sheets at the end of the protective system. The readings ranged from 1.1 million to 2.9 million ohms. Readings taken on the roll roofing were recorded at infinity, while readings on two coats of tar emulsion placed on the approach slabs averaged 700 ohms.

The first course of asbestos modified pavement was placed on August 6, 1974, twenty-four hours after the system was completed. Initial in-place mix temperatures ranged from 210°F to 255°F. Some pulling of the modified mix was noted beneath the paver's screed with the lower mix temperatures. Because a reduction in the stability of the membrane was anticipated during the pavement application, the deck was paved from north to south on a negative 3.5% grade. The only significant problem occurred when the paver began the final pass along the easterly curb line with its tires riding on the edge of the mix placed on the previous pass. After progressing eighteen feet, the paver's small front tire sank into the bituminous mix and began plowing the mix and occasionally tearing and peeling the roofing

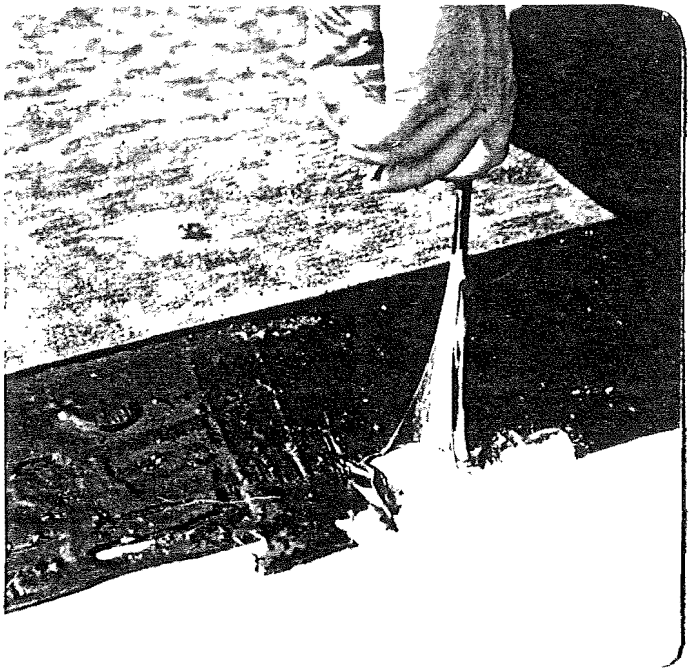
sheet and portions of the membrane off the concrete. The plowing problem was solved by backing the paver up and then using a steel plate as a ramp to get the tire back on the surface of the bituminous mat. Damage to the membrane was limited to areas along a twenty-foot strip at 12.5 to 13.5 foot offsets from the easterly curb. A limited amount of construction traffic was allowed over the deck during the following week, at which time seven short transverse and longitudinal cracks were noted. All were within an area six to twenty feet south of the expansion dam in the travel lane. The cracks were the result of shoving of the bituminous pavement in an area with less than one-inch thickness, combined with reflective cracks from edges and ends of the roll roofing strips. The traffic volume declined during the next thirty day period and nearly all of the cracks sealed over prior to the application of the top course of pavement on September 13, 1974.

The final one-inch course of pavement was placed on the deck on a +3.5% grade in conjunction with the finish roadway pavement. The operation included the use of two pavers, with the largest machine placing a twenty-four foot wide mat. Soon after moving onto the deck, the large paver's tires began spinning and digging up the first course of pavement. Occasional shreds of roofing sheet and membrane were also revealed at a few locations. Attempts to reduce the load in the hopper were not sufficient to allow the paver to move forward without damaging the first course of pavement. The northerly half of the deck was completed by using a ten-wheeler to tow the paver.

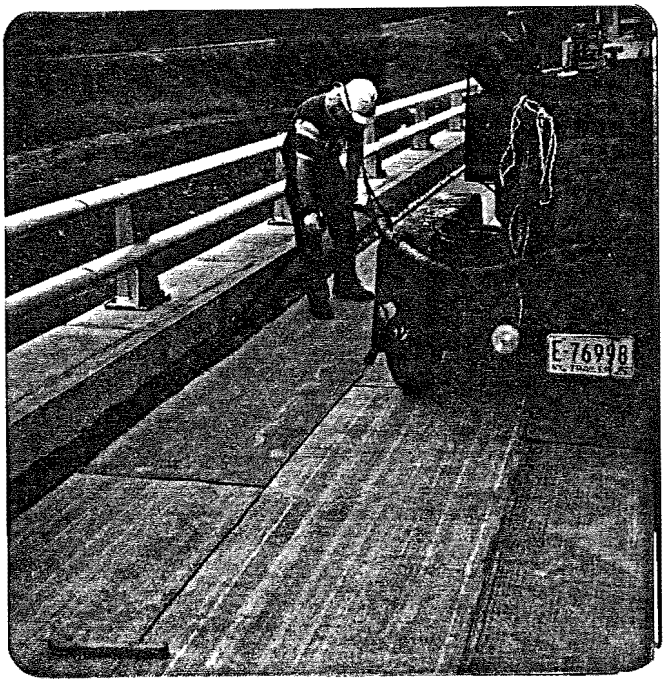
Future evaluations of the membrane system will be conducted in areas where there was no initial damage to the membrane system.



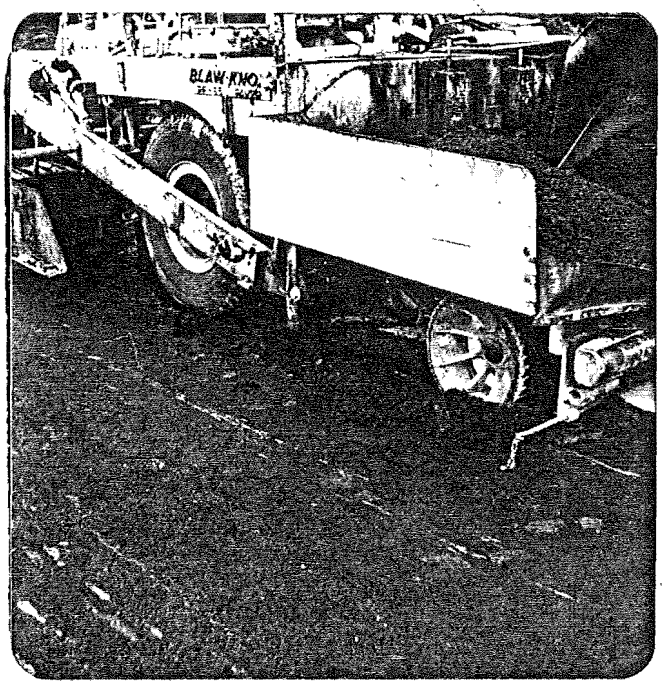
Extruding and leveling the hot PVC polymer liquid.



Membrane adhesion varied with the texture and quality of the substrate.



Applying a second coat along the curb face. Note roofing sheet protection system.



Problems due to the paving procedure combined with reduced pavement stability over the membrane.

WORK PLAN - NO. 28

HYLOAD 125

DESCRIPTION

A 125 mil thick preformed sheet membrane composed of pitch and poly vinyl chloride polymer reinforced with inert fibers. The material is manufactured by Ruberoid Building Products, Ltd., 1 New Oxford Street, London WC1A 1PE (England).

TEST RESULTS

The material was selected as one of the 5 most promising bridge deck membrane systems in the National Cooperative Highway Research Program, Project 12-11. The selection of Hyload 125 was based on the results of laboratory tests conducted by Materials Research & Development of Oakland, Calif.

RECOMMENDED APPLICATION PROCEDURE

1. Apply a prime coat of cutback asphalt at the rate of 90-150 square feet per gallon and allow to dry thoroughly.
2. Place Glasphalt Perforated Underlayer to avoid risk of blistering.
3. Place 125 mil membrane sheet into an application of hot Type III or Type IV roofing grade asphalt using pour and roll technique, or with the aid of a roofer's mop. The membrane shall be placed in such a manner that a shingling effect will be achieved and any water which accumulates will drain toward the curb and the drain tubes. The asphalt and membrane shall overlap previously applied membrane by at least 4 inches at the sides and 6 inches at the ends.

WORK LOCATION

I 91 northbound bridge over Town Highway #6 at station 5218 + 74 - 5220 + 24, approximately 0.4 mile north of the Vermont Route 25 interchange in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Moderate to smooth finish.

Cracks - A few light pattern cracks noted at scattered locations.

Average Initial Chloride Level - 48 parts per million.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION (con't)

Miscellaneous - Failure noted between the epoxy mortar and the granite curb face on approximately 75% of the curb lines. The failures occurred as a fine crack between the 2 materials where the mortar was very thin or as a definite separation with partial pull-off of granite facing where the mortar was thick at the top of the fillet.

Preparation - The concrete was sandblasted 3 feet out from the curb face. Air compressor was used to blow deck clean just prior to primer application.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	4-27-74		Air temperatures recorded in shade. Clear.
1:30	68	37	Applying RC 70 asphalt primer on deck with squeegees. Material, manufactured by Philip Carey Corp., meets ASTM D41-41 and AASHTO M116-42 specifications.
2:30			47 gallons of primer applied on 59,600 square feet for application rate of 127 square feet per gallon. Bubbles were noted forming and breaking continually in the primer system due to solvent evaporation and moisture vapor outgassing from the concrete.
	4-29-74		75-100% cloud cover.
9:00	61	64	Thin shelled air bubbles noted throughout the prime coat at rates of 170-750 per square foot. Electrical resistance readings on the prime coat averaged 3500 ohms per square foot.
10:30	67	62	10-foot long copper foil strips placed 2.6 feet from westerly curb at a point 11 to 21 feet north of approach slab joint.
2:00	71	62	Placing Glasphalt Perforated Underlayer on primed concrete. 60-foot by 3.275-foot sheets butted at sides and ends.
2:40			Placing Hyload 125 membrane into Type III roofing grade asphalt, using pour and roll technique.
3:50	73	57	1-3/4 strips in place.
4:45	72	60	Asphalt temperature ranging from 340°-460°.
5:30	71	63	4-1/2 strips in place. Application stopped at 6:15 due to showers.
	4-30-74		10-25% cloud cover.
10:45	64	45	Placing strip along easterly curb line. Asphalt temperature 395°F.
1:15	69	39	Foot traffic on membrane shortly after application results in some of the asphalt squeezing out, leaving imprint.
1:40	70	35	5 strips in place.
3:45	75	31	Placing Hyload system on 18-inch square test slab.
4:45	74	32	Application complete. Placing tar emulsion on approach slabs.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	676	s.y.	@	$8.00/s.y.	= $5,408.00
Bituminous Concrete	125.4	tons	@	$9.90/ton	= $1,241.46
Tar Emulsion on Approach Slab	68	gals.	@	$2.00/gal.	= $ 136.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application", on page 35.

Representatives of the Ruberoid Company were on the project during the installation of the membrane system.

A Type III roofing grade asphalt was used as the bonding adhesive. Type IV asphalt, which was not available, would have been preferred by the manufacturer since it would be less apt to flow during the application of the bituminous pavement or during warm weather conditions. The pour and roll technique was used to adhere the 125 mil membrane sheet to the perforated underlayment. It consisted of placing the sheet in position, then re-rolling the membrane back to the midpoint of the roll. Hot asphalt was then poured directly in front of the membrane which was rolled back into the asphalt. Hand pressure on the roll of material forced excess asphalt to the side of the sheet where workmen spread the material with wide spatulas.

The first course of asbestos modified pavement was placed on May 2, 1974, three days after the membrane system had been completed. The mix temperatures in the trucks ranged from 270°F to 295°F, with initial in-place temperatures averaging 255°F. Pavement compaction was obtained with a steel wheeled 8-10 ton roller.

Removal of the hot bituminous mix from a small area revealed slight penetration of the mix into the asphalt adhesive along the butt joints but no penetration into the membrane. One boil was noted in the pavement adjacent to the expansion dam. The escape of air was noted when the pavement and membrane were punctured with a knife. Three longitudinal cracks measuring 8 inches, 12 inches

and 48 inches in length were also noted at 13 foot, 12.8 foot and 9.7 foot offsets from the westerly curb. Slight air pressure was noticeable under foot pressure over two of the three cracks.

Electrical resistance readings ranged from 5 million to infinity on the pavement-membrane system.

A 2-inch thick sand blanket was placed over the first one-inch course of bituminous pavement and construction traffic was routed over the bridge for approximately 2-1/2 months. On August 5, 1974, several weeks after the sand blanket was removed, inspection of the deck revealed 5 blisters in the bituminous pavement and membrane system. The blisters were recorded at 12 inches in diameter, 16 by 24 inches, 18 by 24 inches, 18 by 36 inches and 6 by 48 inches. The pavement thickness immediately adjacent to the blisters ranged from a minimum of 3/8 of an inch to a maximum of 13/16 inches. There was no evidence of any air pressure problem when the blisters were first noted in the early morning. However, as the day progressed and air temperatures began rising, the membrane lifted the pavement from 1 to 3 inches off the deck at the center of the blisters. The vertical movement of the pavement resulted in numerous cracks in the mix and a loss of some pavement in areas subject to traffic. The following day the blisters were punctured with a jackknife and the cracked bituminous pavement over and adjacent to the blisters was removed. Asphalt emulsion was brushed over the exposed membrane and bituminous mix was placed by hand and compacted with a one-ton roller. No further problems occurred at the five locations. However, three new blisters formed within the next few days. The areas were patched on August 19th, by cutting open the membrane and underlayment and rebedding both materials in an application of hot asphalt. A strip of the membrane sheet was then placed in hot asphalt over the cut areas. The final one-inch course of bituminous pavement was placed without difficulty several days later.

Inspection of the deck on October 11, 1974, disclosed a 14 foot longitudinal

crack approximately 15.4 feet from the easterly curb, beginning at a point 28.3 feet from the northerly expansion dam. The northerly portion of the crack was adjacent to the site of an earlier blister and the offset from the curb was also approximately the same as that of three other blisters. The width of the crack varied from a barely visible condition near the middle, to a maximum of 1/4 inch near the ends where air pressure was noted. The escape of air was noted when a spike was used to puncture the membrane at each end of the crack. One foot long transverse and longitudinal cracks were also noted 6 to 8 feet west of the center-line, approximately 2 and 11 feet from an earlier blister. All cracks were filled with a cutback asphalt prior to November 1, 1974.

Five additional blisters occurred in the pavement-membrane system during the spring of 1975. The first blister was noted in April near the midpoint of the 14 foot longitudinal crack. Additional blisters occurred at 13.3 foot to 15.7 foot offsets from the easterly curb line in close proximity to earlier blisters. Repairs, to date, have consisted of puncturing the membrane and replacing the cracked bituminous pavement with cold patch.

On August 26, 1975, a detailed inspection was made in an attempt to determine why the ventilating underlayment was not insuring the lateral dissipation of vapor pressures and their eventual release via drain tubes placed along each curb line. The inspection included removal of the pavement over 3 drain tubes opposite the majority of the blisters and inspection of an 18 inch square area in the breakdown lane. All 3 drain tubes were partially blocked with bituminous mix; however, 2 allowed the flow of water and should have permitted the escape of air or moisture vapor pressures from beneath the underlayment portion of the membrane system. The plugged tube was probably never functional and may have been pinched shut when the deck was cast. Removal of the pavement from the 18 inch test area revealed a noticeable concentration of moisture on the surface of the 125 mil thick sheet membrane. Very little adhesion was detected between the pavement and the membrane,

possibly due to the existance of the moisture. The surface of the membrane displayed no ill effects from the pavement application appearing virtually the same as it had been prior to its installation. Removal of a 6 inch square section of the sheet membrane, bonding asphalt and underlayment revealed a slight bond of underlayment to the primed concrete as evidenced by the presence of 1 - 2 percent laitance or concrete fines on the bottom of the underlayment sheet. Although the adhesion was greater than anticipated, the overall bond of underlayment to concrete did not appear great enough to prevent lateral movement of air or moisture vapor pressures.

The inspection appears to confirm that the system is free of voids or punctures which would allow the deck to breathe and apparently developing pressures are simply finding it easier to lift the membrane and pavement rather than move laterally across the deck and vent via the drain tubes. It is possible that the blistering problem would not have occurred if both pavement courses had been placed shortly after the membrane application and if the total pavement thickness was closer to the 3 inch range rather than 2 inches.

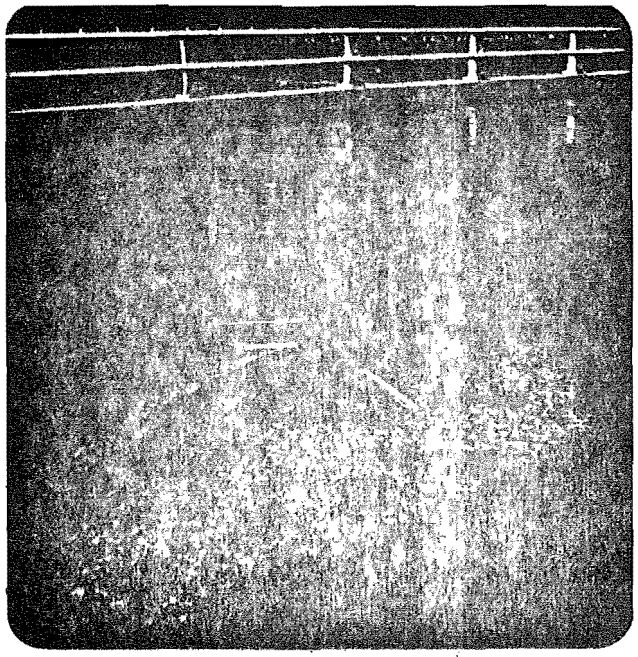
A recommendation has been made to cut out and repave patched areas and apply a third lift of pavement over the deck. The third course should be as thick as possible, since additional dead weight on the membrane is probably the best insurance against further blistering.

HYLOAD 125

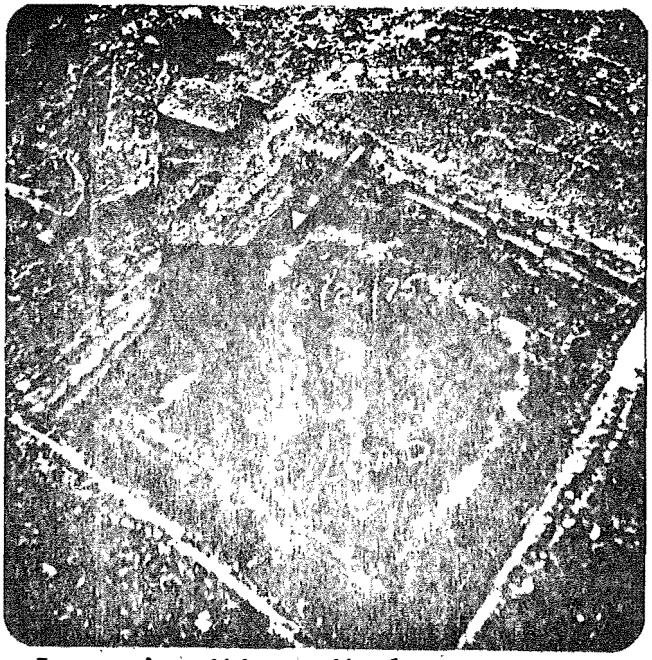
I 91 NB over TH #6

Rolling Hyload Membrane into application of hot roofing grade asphalt.

Blisters in Membrane and first course of pavement.



Blisters which rose daily with the increase in ambient temperature ranged up to 18" x 36" in size.



Inspection did not disclose any reason why pressures should not have dispersed laterally via the ventilating underlayment.

WORK PLAN - NO. 29

SURE-SEAL BUTYL MEMBRANE

DESCRIPTION

A preformed sheet membrane composed of vulcanized butyl rubber. The system is manufactured by the Carlisle Corporation, Carlisle, Pa. 17013.

TEST RESULTS

The material was selected as one of the 5 most promising bridge deck membrane systems in the National Cooperative Highway Research Program, Project 12-11. The selection of Sure-Seal Butyl Membrane was based on the results of laboratory tests conducted by Materials Research & Development of Oakland, Calif.

RECOMMENDED APPLICATION PROCEDURE

1. Position the membrane sheet on the deck allowing for a 4-inch lap on joints. Fold the sheet back onto itself along its entire length so that 1/2 of the sheet width is exposed. Apply Sure-Seal bonding adhesive to both the membrane and the deck with a roller.
2. After the required drying time, roll the membrane back onto the deck taking care to avoid any wrinkles or air bubbles. Assure firm and uniform contact with the deck by rolling the membrane. Repeat procedure for the second half of the sheet and continue application toward the centerline or high side of the deck.

   In the event air bubbles or blisters form under the membrane, puncture such areas and patch with additional material.
3. Splice joints between sheets a minimum of 4 inches, using splicing cement, gum tape and lap sealant supplied by the manufacturer.
4. Place protection board over the membrane, using Sure-Seal adhesive as the bonding agent.

WORK LOCATION

The northerly half of the I 91 northbound bridge over the Wells River at station 5861 + 05 - 5864 + 39, approximately 0.1 mile north of the U.S. Route 302 interchange in Ryegate.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth to moderately rough burlap dragged finish.

Cracks - See crack layout on Figure 1 , page 46 . Thirty-eight transverse cracks ranging up to 39 feet in length were noted in the deck surface, with most also visible on the bottom of the deck.

Steel Potential Readings - Initial readings on the deck averaged 0.10 volts.

Average Initial Chloride Level - 56 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb faces and blown clean prior to the membrane application.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	6-4-74		Air temperatures recorded in shade. Clear a.m.; 40% cloud cover p.m. Two Carlisle representatives on project.
8:30	54	58	Deck surface dry although showers occurred 12 hours earlier.
11:15	69	41	Four 10'-8" x 85' butyl rubber sheets placed in position on the northerly end of the deck. Sheet overlap at the 3 joints averages 1.1'. Lap up the epoxy mortar fillet at the curb face averages 1-1/2". Two sets of moisture sensing copper foil strips placed 2-1/2' from the curb on each side of the bridge at a point 118' to 128' south of the northerly approach slab joint.
11:55	71	34	Began placing 90-8-30A Bonding Adhesive with paint rollers on the concrete along the westerly curb and on the bottom of the rubber sheet.
12:25	71	34	92° in the sun. Carlisle representative advised that the sheet should be rolled back onto the concrete when the adhesive is tack free to the touch but still sticky. Entrapment of any solvent in the bonding adhesive would result in blisters.
12:35	71	34	Rolling half of first sheet back onto the concrete by sliding the sheet over itself.
1:20	74	32	A few 1/8-inch diameter air bubbles visible in the bonding adhesive on both the concrete and the butyl sheet.
3:00	80	26	Four men placing adhesive on first half of second sheet.
3:35	78	30	Noted increase in adhesive bond between the butyl sheet and deck over that found shortly after placement.
5:05	80	20	Installation complete on first 4 sheets covering 3315 square feet. 48 gallons of bonding adhesive used for application rate of 69 square feet per gallon.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
6:25	78	25	Noting a few 2"-3" diameter bubbles in the sheets placed earlier. Light foot pressure bonds the membrane back on the deck. Application stopped for day with half of 2 additional sheets bonded along westerly half of deck.
	6-5-74		Clear. 2-5 m.p.h. breeze. Four workmen on project.
8:30	66	48	Bonding second half of last 2 sheets placed.
10:15	72	39	Cleaning mica from edges of sheets along longitudinal joints with xylol solvent. Splicing sealant applied with paint brushes on adjacent faces of overlapping sheets at a rate of approximately 100 square feet per gallon. 4-1/4-inch wide by 20-mil thick non-curing butyl gum tape placed along the bottom edge of the top sheet after the splicing sealant becomes tack free.
11:45	82	35	Note overlapping sheet not bonded down to underlying sheet between lap splice and edge of overlap where bonding adhesive was not placed. Build-up of air pressure in these areas due to high temperatures might cause difficulties in compacting the bituminous pavement.
1:50	83	35	94° in sun.
2:50	83	33	Splices complete on sheets in place. Not able to continue until additional bonding adhesive is obtained.
	6-6-74		Clear. 0-3 m.p.h. breeze.
8:20	60	53	Applying adhesive on first half of last 2 sheets.
10:00	77	48	Finishing last 2 sheets. Noting an increase in 2"-3" diameter air bubbles beneath sheets placed on June 5 and June 6, although nearly all can be sealed down with foot pressure.
3:00	78	48	Applying 4 gallon batch of Liquiseal, a two-component polyurethane along butyl sheet at curb face.
6:15	72	53	Finished sealing curb line with polyurethane. Application averaging 55 lineal feet per gallon.
	6-8-74		
2:00	78	41	Protection boards (Carey Elastibord Vapor Stop) complete on EPDM system. Beginning installation on Butyl membrane.
5:30	85	35	Half of Butyl system covered.
	6-10-74		
8:30	65	47	Three man crew on project to complete installation of protection boards.
11:00	86	42	102° in sun.
3:30	92	33	Mixing final batch of Liquiseal for curb line seal.
5:30	88	36	Installation complete.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	740	s.y.	@	$9.75/s.y.	= $ 7,215.00
Bituminous Concrete	245.7	tons	@	$9.90/ton	= $ 2,432.43
Tar Emulsion on Approach Slab	42	gals.	@	$2.00/gal.	= $ 84.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application," on pages 42 & 43.

Two representatives of the Carlisle Company were on the project to oversee the installation of the Butyl and EPDM systems. The 11-foot by 85-foot size of the individual Butyl sheets made them appear unwieldy; however, their application progressed without difficulty using the technique described in the application procedure on page 41 Initial wrinkles in the sheets due to packaging were worked out by positioning the material on the deck and allowing it to relax with the heat of the sun. Although care was taken to insure the membrane and concrete surface were both completely coated with the bonding adhesive, several 2"-3" diameter blisters in the membrane revealed a lack of bonding adhesive on one interface when cut open for inspection. In such cases the membrane could be stuck down with very little pressure, but would not remain bonded as the air pressure developed. Although concern was expressed over the amount of mica dust visible on the sheets, the bonding adhesive apparently tied up such particles since there was no evidence that excesses of the powder prevented the development of bond between the membrane and the deck.

The procedure for sealing the side and end lap joints between sheets appeared very effective. Although the butyl sheets were not bonded to the deck at the joint locations and a build-up of air was noted with time, such areas did not cause serious problems with the placement of the protection boards or with the pavement application.

Liquiseal, a two-component polyurethane was placed along the curb line to assist in sealing between the butyl sheets and the granite and epoxy mortar fillet. The procedure consisted of placing the polyurethane behind the membrane, forcing the excess material out from behind the sheet and allowing it to flow down the outside

face. The material was then reworked up onto the granite face several times, with each application building up the coating as the material thickened with additional cure time.

The butyl membrane was covered with butted 3-foot by 8-foot by 1/8-inch thick Carey Elastibord Vapor Stop protection boards. The material was satisfactorily bonded to the membrane with applications of the bonding adhesive on the surface of the membrane and the bottom of the boards. The procedure was time consuming, with approximately 34 manhours required to place the protection boards on 740 square yards of membrane.

Electrical resistance readings taken on the Butyl Membrane ranged from 9,500 to 18,000 ohms. Such readings indicate the presence of conductive material/s such as carbon in the butyl sheets. Readings on the protection board covered membrane were recorded at infinity, with the exception of variable readings noted over butt joints in the protection boards. Due to the variation in readings, follow-up evaluations of the Sure-Seal Butyl System would not appear practical utilizing the electrical resistance test.

The presence of rain water beneath a small percentage of the protection boards resulted in postponement of the pavement application following completion of the membrane system. After allowing 3 drying days, the first course of bituminous mix was placed on June 14, 1974. The initial in-place mix temperatures ranged from an average of 276°F on the first pass to 220°F on the fourth pass. Although blisters or cracks were not noted during paving or initial compaction, close inspection of the deck several hours later revealed 15 fine cracks averaging 2.4-feet in length. Of the 15 cracks, all but 2 were longitudinal and 11 occurred at 15, 25 and 35-foot offsets, which indicates they were probably the result of incomplete bonding adhesive coverage at the midpoint of the 11-foot wide sheets.

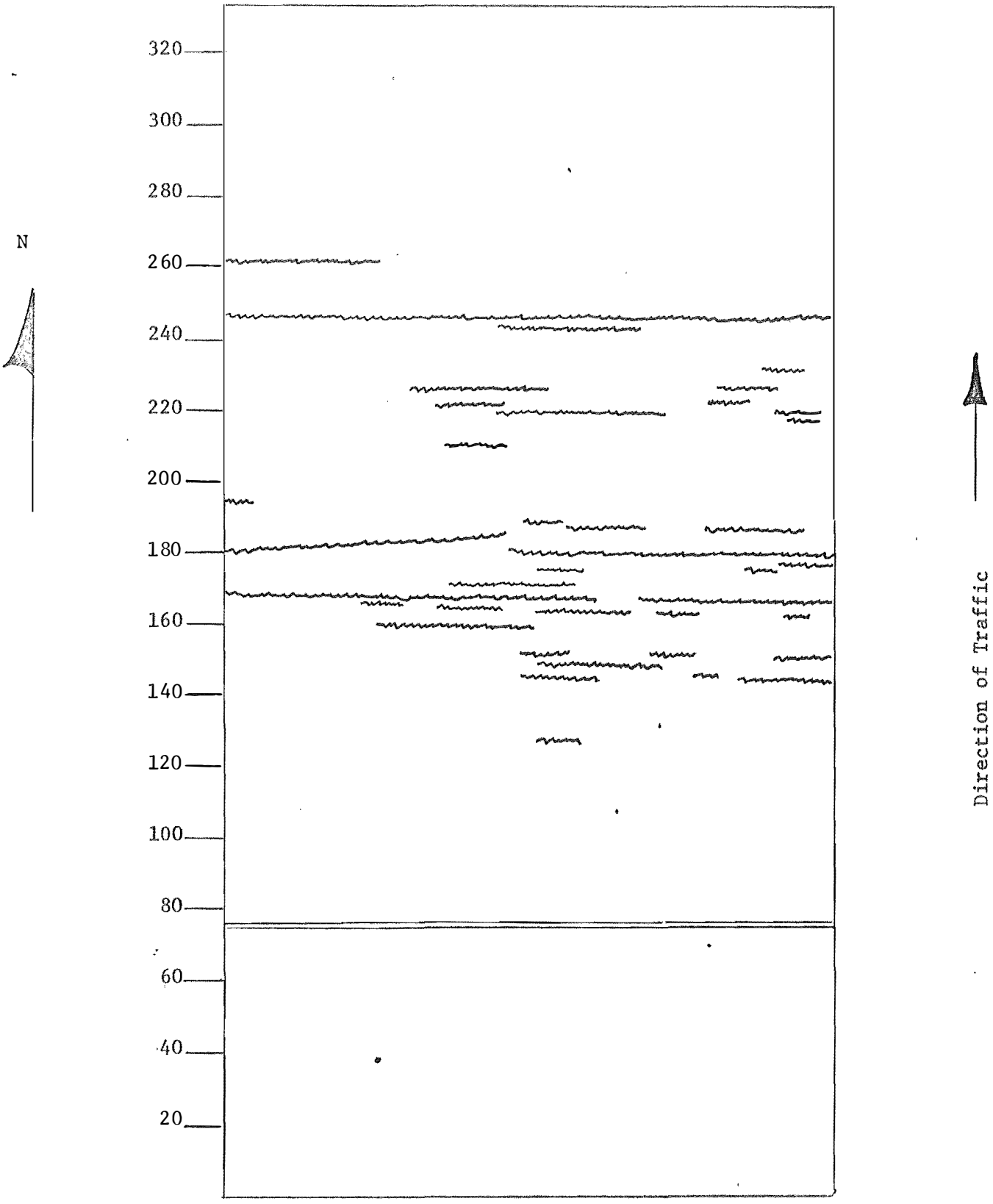
There was no noticeable change or increase in the number of cracks over the Butyl system prior to the application of the final course of pavement in late September, nor did any cracks or blisters occur in the finish pavement.

FIGURE 1

I 91 Northbound over Wells River

Cracks in Concrete Deck

All cracks were noted on surface of deck. Length of cracks and locations are to scale. Vertical scale 40'/in. Horizontal scale 10'/in.



WORK PLAN - NO. 30

SURE-SEAL EPDM MEMBRANE

DESCRIPTION

A preformed sheet membrane composed of a cured EPDM rubber (Ethylene-Propylene-Diene-Monomer). The system is manufactured by the Carlisle Corporation, Carlisle, Pa. 17013.

TEST RESULTS

The material was selected as one of the 5 most promising bridge deck membrane systems in the National Cooperative Highway Research Program, Project 12-11. The selection of Sure-Seal EPDM Membrane was based on the results of laboratory tests conducted by Materials Research & Development of Oakland, Calif.

RECOMMENDED APPLICATION PROCEDURE

1. Position the membrane sheet on the deck allowing for a 4-inch lap on joints. Fold the sheet back onto itself along its entire length so that 1/2 of the sheet width is exposed. Apply Sure-Seal bonding adhesive to both the membrane and the deck with a roller.
2. After the required drying time, roll the membrane back onto the deck taking care to avoid any wrinkles or air bubbles. Assure firm and uniform contact with the deck by rolling the membrane. Repeat procedure for the second half of the sheet and continue application toward the centerline or high side of the deck.

   In the event air bubbles or blisters form under the membrane, puncture such areas and patch with additional material.
3. Splice joints between sheets a minimum of 4 inches, using splicing cement, gum tape and lap sealant supplied by the manufacturer.
4. Place protection board over the membrane, using Sure-Seal adhesive as the bonding agent.

WORK LOCATION

The southerly half of the I 91 northbound bridge over the Wells River at station 5861 + 05 - 5864 + 39, approximately 0.1 mile north of the U.S. Route 302 interchange in Ryegate.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Smooth to moderately rough burlap dragged finish.

Cracks - See crack layout on Figure 1 , page 46. Thirty-eight transverse cracks ranging up to 39 feet in length were noted in the deck surface, with most also visible on the bottom of the deck.

Steel Potential Readings - Initial readings on the deck averaged 0.10 volts.

Average Initial Chloride Level - 56 parts per million.

Preparation - The concrete was sandblasted 3 feet out from the curb faces and blown clean prior to the membrane application.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	6-6-74		Air temperatures recorded in shade. 50% cloud cover. 5-15 m.p.h. breeze. One Carlisle representative on project.
9:30	72	50	Placing 100-foot by 20-foot EPDM sheets along southeasterly curb line. Sheets will be cut in half longitudinally to aid in placement.
11:10	80	46	Copper foil strips placed 2-12 feet north of first drain scuppers along both curb lines.
11:45	80	44	Several small wrinkles noted in sheet placed along easterly curb. Material may not have been stretched out enough when first placed on the deck.
1:00	80	49	3-1/2 sheets bonded in place.
3:00	78	48	1 man cleaning mica dust from edge of sheet at curb face prior to placing Liquiseal polyurethane.
4:30	79	51	2 men placing Liquiseal along Butyl and EPDM sheets at curb line while remainder of crew continues sheet application.
6:45	71	53	Application stopped.
	6-7-74		Clear. 5-10 m.p.h. breeze.
8:45	62	45	5 man crew on project splicing EPDM and Butyl sheets at midpoint of deck.
12:00	73	25	All sheets in place.
1:30	74	27	Splicing lap joints between membrane sheets.
3:00	77	25	Sealing membrane around scuppers with lap sealant along westerly curb and using Liquiseal around scuppers on easterly curb.
4:15	76	24	Curb line seal complete. Placing Carey Elastibord Vapor Stop on EPDM membrane at southerly end of deck.
5:30	72	27	Application stopped with protection boards placed on 40 lineal feet of deck.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
	6-8-74		Clear.
8:00	56	48	5 man crew placing protection boards.
10:20	69	41	Taking electrical resistance tests on areas not yet covered with protection boards.
11:00	75	39	93° in sun. 14 lineal boards in place, by 13 boards wide.
12:00	76	28	Protection boards complete on the EPDM system.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	740 s.y.	@	$9.75/s.y.	= $ 7,215.00
Bituminous Concrete	122.8 tons	@	$9.90/ton	= $ 1,215.72
Tar Emulsion on Approach Slab	21 gals.	@	$2.00/gal.	= $ 42.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application," on pages 48 & 49.

The procedure used to install the EPDM membrane was the same as that used on the Butyl system. The material was supplied in 20-foot by 100-foot lengths, which required cutting in 10-foot wide strips. A total of 4 laps were required across the deck with an 18-inch cap strip placed at the midpoint of the 39.3-foot width.

Electrical resistance readings were taken on the membrane prior to placement of the protection boards. As was the case with the Butyl membrane, the material produced low resistance values. Average readings on 3 different sheets were recorded at 52,000, 92,000 and 184,000 ohms. Readings taken on lapped joints averaged 39,000 ohms. The lower readings over the joints may have been due in part to the absence of bonding adhesive directly beneath the spliced sheets. Readings on the protection boards were recorded at infinity except for lower variable readings over butt joints in the boards. Due to the low readings on the membrane sheets, follow-up evaluations of the system would not appear practical utilizing the electrical resistance test.

The EPDM sheets were for the most part free of any air bubbles or unbonded areas prior to placing the protection boards. As the boards were being placed, a definite

softening and/or swelling was noted in the EPDM membrane at several locations where the workmen dripped adhesive off their paint rollers. The softening or swelling may have been due to the solvent in the adhesive and may have resulted in a partial loss of membrane adhesion to the concrete at some locations. Such a condition was not noted when the adhesive was applied in a thin coating over the surface of the membrane in order to bond down the protection boards.

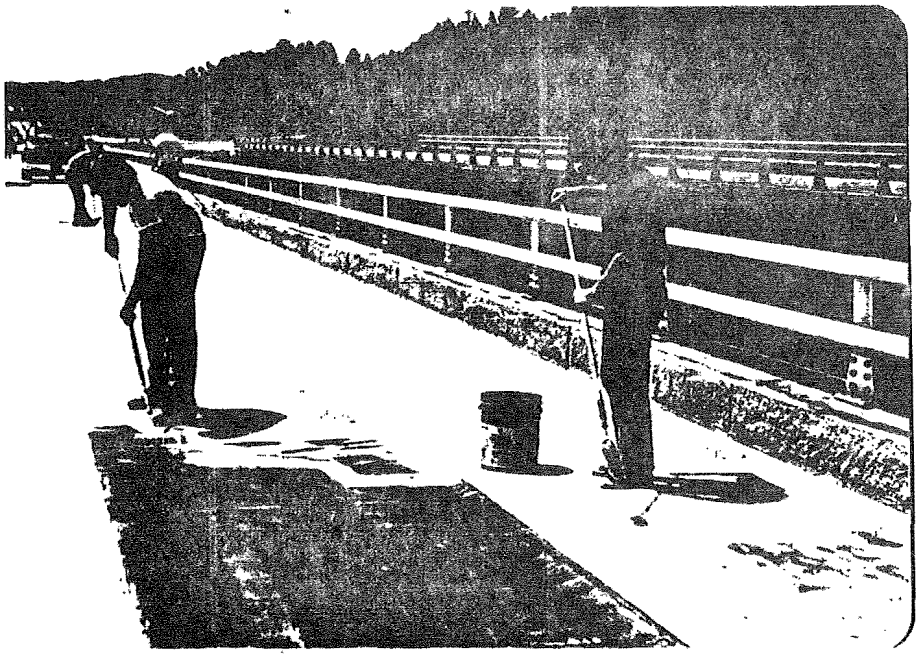
The first course of bituminous mix was placed on June 14, 1974 after allowing 3 days for rain water to dry out from beneath the protection boards at scattered locations. The initial in-place mix temperatures ranged from an average of 268°F on the first pass along the easterly curb line to 235°F on the last pass. Numerous blisters and cracks appeared in the mix both prior to and during compaction. The blisters required puncturing of the protection board and membrane in order to allow compaction of the mix. A total of 10 areas were vented with an ice pick. The smell of solvent was noted at one of the 10 locations and water was noted seeping from one of the crack locations. A total of 19 cracks averaging 1.1 foot in length were recorded in the completed pavement in addition to the 10 areas where blisters or blister-crack combinations occurred. Nearly all of the cracks were longitudinal in nature with all but one occurring at 5, 15, 25 and 35 foot offsets from the curb line. Such locations would be approximately at the midpoint of the 10-foot wide sheets. This would indicate the problem was the result of an incomplete application of the bonding adhesive on the middle of the sheets where they were folded over or on the concrete at the same location. Soundings taken on the pavement over or immediately adjacent to blistered or cracked areas disclosed hollow sound indicative of unbonded layers. Such a condition would be expected adjacent to cracks. However, when continuous soundings were taken across the deck at 3 locations 13 days later, the testing revealed the existance of hollow areas over 11 percent, 27 percent and 30 percent of the 3 areas. Each location had an average of 12 hollow areas with individual areas averaging 0.7 feet in width. Earlier checks of pavement bond to the protection board were always positive,

so it could be assumed that the lack of bond occurred between the protection boards and membrane or membrane and concrete deck.

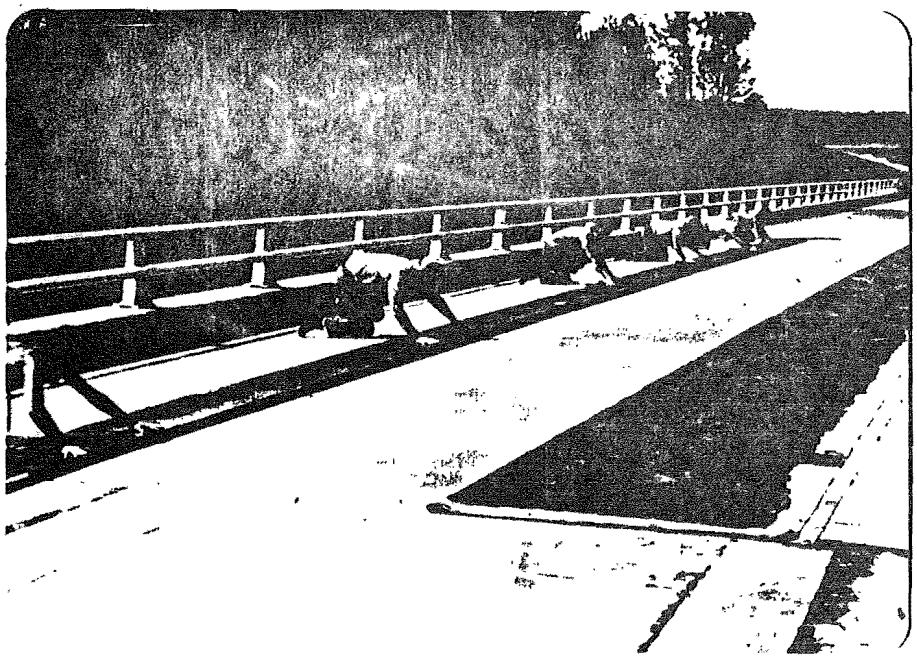
Gradual changes were noted in the pavement prior to placement of the final 1-inch course in late September. Although relatively little traffic was allowed over the deck, a total of 74 cracks were noted on September 13, 1974. Most of the new cracks occurred on the easterly side of the deck in areas which had been free of initial cracking. They varied in size and shape but often occurred as 6-inch long irregular cracks with 3 or more 1-inch to 3-inch spur cracks extending off the main branch. In some cases, the pavement within the crack areas appeared to be elevated 1/4-inch or more above the level of the adjacent pavement. Such a condition suggests the cracks were caused by air or moisture vapor pressure build-up beneath the membrane. No attempt was made to remove and replace the pavement at crack locations.

Repair work was required on both sides of the expansion joint where pavement shoving and moisture leakage were experienced. The leakage occurred where traffic loosened the membrane and protection boards from the 45° face of the concrete shoulder encasing the expansion dam. The shoving occurred on the approach slab where a strip of the membrane had not been covered with protection boards.

The final course of pavement was placed in late September. Soundings taken on the completed pavement system did not reveal the definite existance of any delaminated or unbonded areas as had been noted earlier. Two short transverse cracks were detected on the south-easterly side of the deck during an inspection in October of 1974. No further cracking or blistering has been noted in inspections through July 2, 1975.



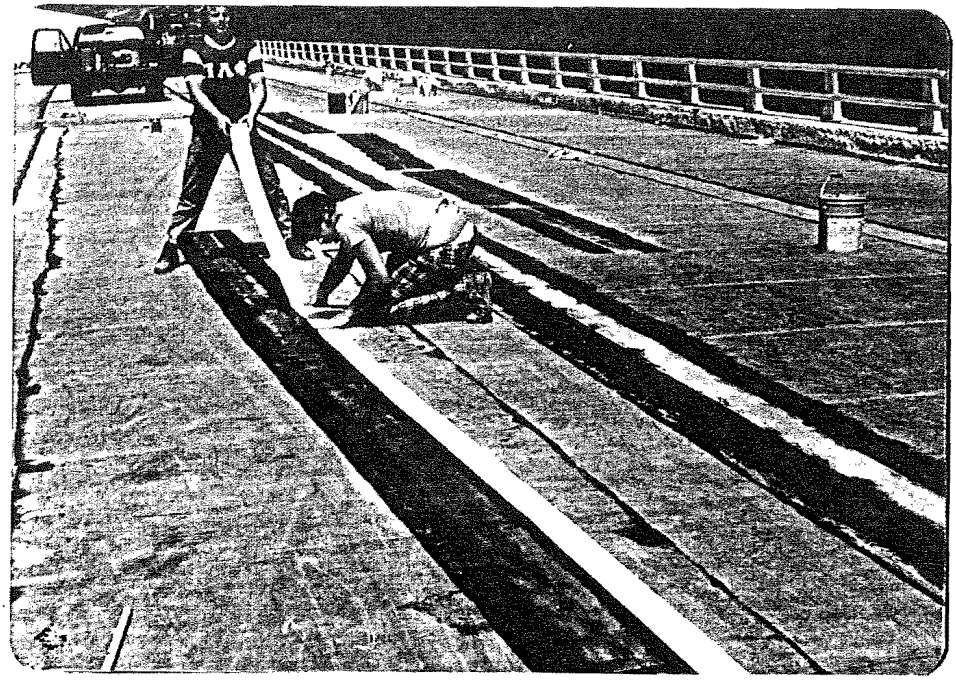
Applying bonding adhesive on the deck surface and the bottom of one-half of a 10' x 80' sheet.



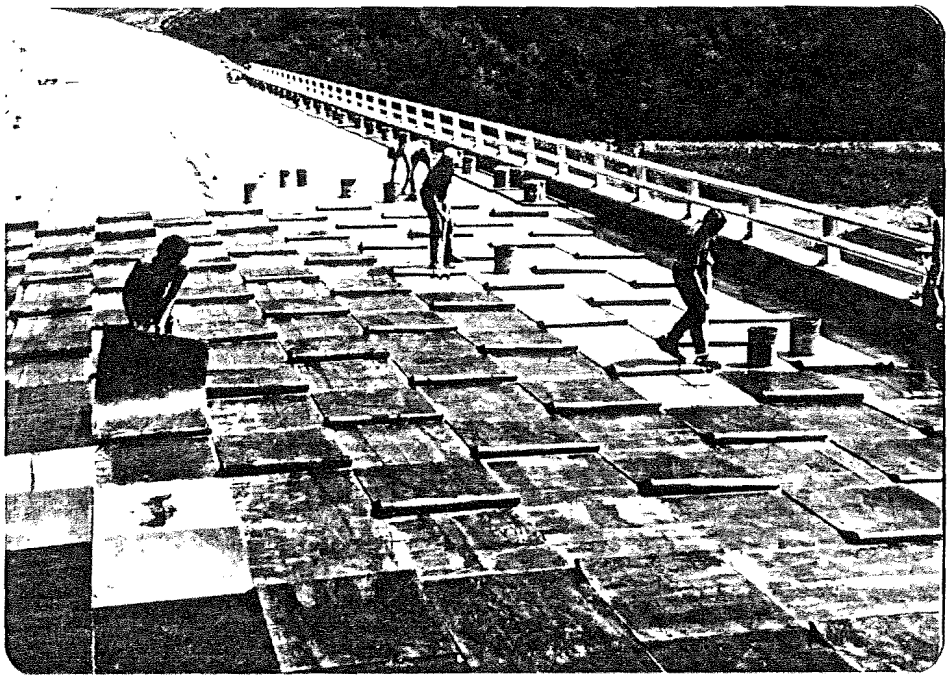
Rolling the membrane back into uniform contact with the deck.

SURE-SEAL EPDM MEMBRANE

I 91 NB over Wells River



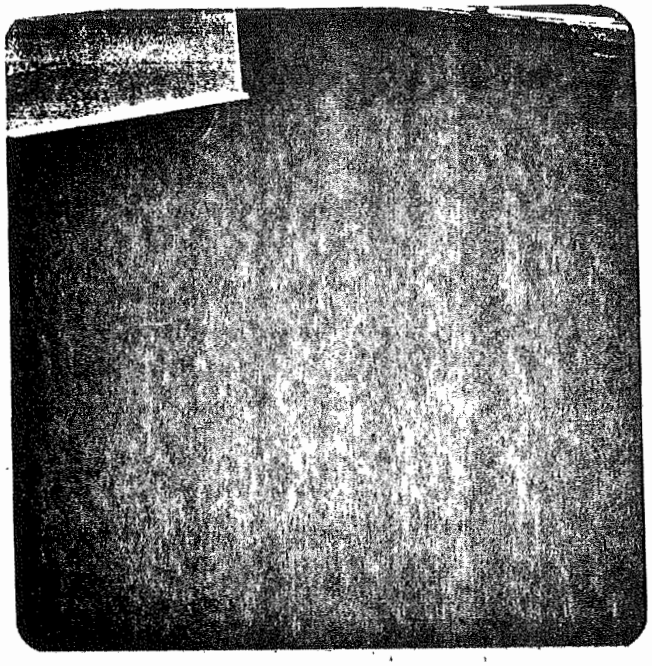
Splicing joints between sheets with splicing cement, gum tape, and lap sealant.



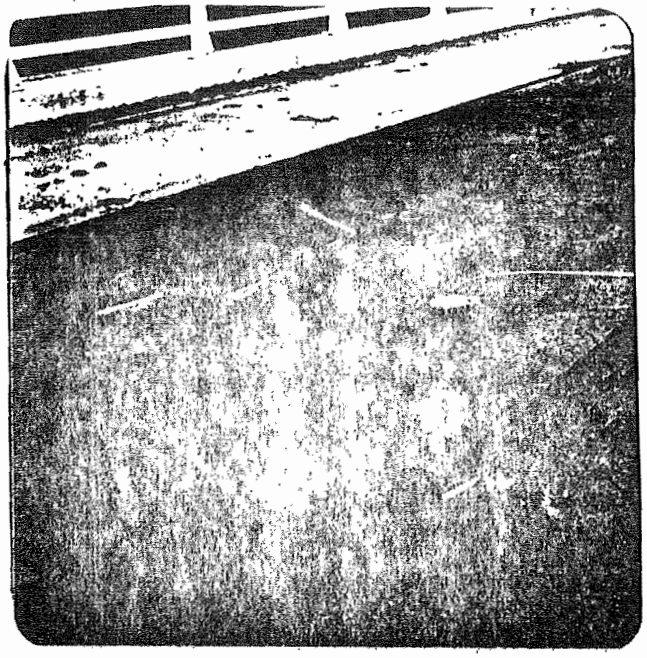
Placing 3' x 8' protection boards over EPDM Membrane.

SURE-SEAL EPDM MEMBRANE

I 91 NB over Wells River



Blisters in membrane and pavement prior to compaction.



Cracks in first course of pavement after compaction.

Irregular cracks in 3-month-old first course of pavement believed due to air and/or moisture, vapor pressures beneath the membrane.

WORK PLAN - NO. 31

GACOFLEX N-3S MEMBRANE

DESCRIPTION

A 1/16-inch thick preformed sheet membrane composed of cured and buffed Neoprene rubber. The system is manufactured by Gates Engineering Company, Inc., P. O. Box #1711 Wilmington, Delaware 19899.

TEST RESULTS

The material was selected as one of the 5 most promising bridge deck membrane systems in the National Cooperative Highway Research Program, Project 12-11. The selection of Gacoflex N-3S Membrane was based on the results of laboratory tests conducted by Materials Research & development of Oakland, Calif.

RECOMMENDED APPLICATION PROCEDURE

1. Position the membrane sheet on the deck allowing for a 3-inch overlap and allow 2 hours for the relief of roll tension.
2. Fold the sheet lengthwise to expose 1/2 of the underside of the sheet. Apply N-7 adhesive on the bottom of the sheet and the deck substrate at the rate of 125 square feet per gallon per coat, using solvent resistant brushes or rollers.
3. When the adhesive is tacky but does not come off on fingers, roll the sheet back onto the deck taking care to avoid wrinkles or entrapment of air.
4. Assure firm and uniform contact with the deck by rolling the sheet with 1-1/2-inch diameter by 2-inch wide flat faced rollers.
5. Repeat the procedure for the remaining half of the sheet and continue the installation toward the centerline or high side of the deck.
6. Flash the perimeter of the membrane system with strips of the N-3S sheet or Gacoflex Counterflash sheeting.
7. Place protection boards over the membrane by spot bonding with N-7 adhesive or hot-mopped asphalt.

WORK LOCATION

The I 91 southbound bridge over TH #6 at station 5219 + 21 - 5220 + 43, approximately 0.4 miles north of the Vermont Route 25 interchange in Bradford.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Burlap dragged finish. Slightly gritty texture due to acid etching.

Cracks - A few fine random shrinkage cracks were noted.

Average Initial Chloride Level - 128 parts per million. 30 parts per million chloride recorded in samples taken before deck was acid etched.

Miscellaneous - Scattered cracks noted between the epoxy mortar and the granite curb face, primarily along the easterly curb line.

Preparation - The deck was etched and flushed in 3 segments, using 4 parts water to one part acid, on June 11, 1974.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	6-19-74		Air temperatures recorded in shade. 75% cloud cover. 3-8 m.p.h. breeze.
1:00	75	45	Positioning 42" by 115' sheet along southeasterly curb line. Placed 5' long copper foil strips 2 feet from the easterly curb face at a point 5-10 feet south of the expansion dam.
2:00	77	45	Membrane placed approximately 2 inches up curb face with top edge 1/2-inch or less below top of epoxy mortar.
3:15	80	43	Workmen rolling membrane sheet with 1-1/2" diameter by 2" wide flat faced rollers.
3:45	78	48	Using goose neck stitching tool (1" diameter roller with 1/16" diameter face) to press edge of sheet into adhesive. Maintaining close inspection to insure that adhesive is placed along midpoint of folded sheet and on concrete substrate beneath fold.
4:35	80	46	Rolling second half of first sheet into adhesive.
5:30	80	44	Placing adhesive on second half of second sheet.
	6-20-74		50% cloud cover A.M. 30% P.M.
9:30	72	54	Blowing deck clean with air compressor. Placed 10' copper foil strips 2.5 feet from westerly curb at a point 9-19 feet north of southerly approach slab joint.
10:20	76	51	Applying adhesive on third sheet and deck. 6 workmen on project.
11:55	78	42	Applying adhesive on third and fourth sheets plus first sheet along westerly curb line.
1:30	82	40	20 gallons of N-7 adhesive applied on 2200 square foot area for rate of 110 square feet per gallon.
2:10	85	45	Applying neoprene troweling compound, N-250-1, over edge of membrane sheet along easterly curb.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
3:25	83	41	99°F in sun. Applying adhesive on fifth sheet on easterly half of deck and second and third sheets on westerly side.
4:00	85	43	Mixing 4 gallons of UWM-28 polyurethane to bond 200 square feet of "Elastibord" protection board. Area marked off to insure desired 30-mil thickness.
5:00	81	42	Continuing sheet application. 432 square feet of protection board placed using 8 gallons of UWM-28.
6:10	82	42	Application stopped with approximately 335 square yards or 60% of the deck completed.
	6-21-74		80% cloud cover.
8:10	66	55	Applying adhesive.
10:20	74	52	Noted membrane sheet has pulled away from the easterly curb fillet at some rough locations, but top edge is still sealed with the cured neoprene compound.
12:15	73	60	Completed twelfth 42" by 110' ± strip.
1:15	75	61	Installation stopped due to showers after placement of 6" cap strip.
	6-28-74		Overcast. 52° at 7:30 A.M.
9:30	58	68	Placing 30' long rolls up to expansion dam.
10:10	59	66	No open areas detected along easterly curb line but a few noted on westerly side where the edge of the sheet was placed against the granite curb slightly above the epoxy mortar.
11:00	65	65	Sheet membrane application complete.
	7-2-74		80-100% could cover.
8:00	57	80	Placing protection boards on UWM-28. Noted protection boards placed on 6-20-74 not bonded to polyurethane at all locations.
9:20	61	74	
10:20	62	84	Coating edge of membrane sheet and lower portion of westerly granite curb with UWM-28. Material reworked after a short period to increase thickness on vertical face.
11:25	66	75	Removed portions of protection boards placed along curb line on 6-20-74 after noting water was trapped beneath the boards. Polyurethane not completely cured at all locations as evidenced by pick-up of color when touched.
12:30	68	67	Attempting to seal butt joints between sheets with a bead of polyurethane.
12:50	68	61	Installation complete. Protection boards not placed on the northerly 40 lineal feet of deck and polyurethane omitted from final 16 lineal feet.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	555 s.y.	@	$17.00/s.y.	= $ 9,435.00

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Bituminous Concrete	123.3 tons	@	$9.90/ton	=	$ 1,220.67
Tar Emulsion on Approach Slab	50 gals.	@	$2.00/gal.	=	$ 100.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application", on pages 56 & 57.

Representatives of Gates Engineering and their distributor, Technical Coatings, Inc., were on the project to oversee the installation of the Gacoflex Membrane.

The cured neoprene rubber sheets were furnished in 42-inch wide rolls averaging 115-feet in length. The sheets were not coated with mica or talc dust as was the case with the other rubber sheet membranes. Sticking of the rolled sheets was prevented by the fabric-like texture of the membrane, which was the result of blanket curing of the calendered sheets during their manufacture.

Few changes were made from the recommended application procedure. The representatives cautioned that the 65 percent solvent N-7 neoprene adhesive should dry approximately one hour to insure that all solvents were removed. The solvent flashoff is slowed by a blush over of the surface which inhibits removal of the underlying solvent. In most cases, good drying conditions reduced the time requirement to 20 to 25 minutes. Continuous application of the adhesive was achieved by coating half widths of adjoining membrane strips.

The requirement that the entire surface of the membrane be rolled with 2-inch wide rollers was a major factor in the labor required to place the system. Such rolling is designed to insure that all portions of the sheet are in contact with the concrete and any entrapped air is removed.

A neoprene troweling compound, N-250-1, was placed over the edge of the membrane and on the exposed epoxy mortar along the easterly curb line. The compound was mixed with a small quantity of litharge curing agent and was then kneaded by hand while immersed in alcohol to insure complete dispersion of the activator. The 65 percent solids compound was applied by hand using the fingers to smooth the material and to

insure a continuous coating over the desired area. Inspection of the material after curing revealed a continuous seal between the Gacoflex membrane and the granite curb face. Although inspections prior to paving disclosed that the membrane sheet pulled away from the lower portion of the curb fillet at several rough locations, no voids were found in the cured neoprene compound along the perimeter of the membrane, making it appear to be the best curb seal to date.

The sheet membrane was placed above the epoxy mortar on the granite curb along the westerly curb line. Initially the N-7 adhesive generated enough bond strength so that the membrane conformed to the irregularities of the curb face. However, after one day a few openings were noted along the edge of the membrane as well as 12 of 16 areas where the sheet pulled away from the cove between joints in the granite sections. Such areas were sealed when a continuous application of Gates UWM-28 polyurethane was applied along the curb face.

Carey Elastibord Vapor Stop protection boards were placed over the neoprene membrane using the UWM-28 2-component polyurethane as an adhesive. The polyurethane was squeegeed on at a measured rate of 50 square feet per gallon so that a 30-mil coating would be obtained. When the first area covered with protection boards was checked after several rainy days, a lack of bond was noted between the boards and membrane at several locations. When the poorly bonded portions were lifted, the polyurethane did not appear to be completely cured as evidenced by color pick-up when touched and trapped water was also noted at some locations. When the installation began again, an attempt was made to seal the butt joints between boards by pouring an additional bead of the polyurethane over the joints. Although the procedure was partially successful, it did not always work because the initial coat of polyurethane did not develop enough tack to hold down the edges of some boards.

Due to problems sealing the protection boards and based on information furnished by other agencies (Illinois and Minnesota) relating to problems with adhesion, the protection system was omitted on approximately 1/3 (40 lineal feet) of the membrane.

DISCUSSION (Con't)

The polyurethane was placed on an additional 24 lineal feet, leaving 16 lineal feet of exposed sheet membrane on the northerly end of the deck.

The first course of bituminous mix was placed on July 3, 1974, the day after the membrane system was completed. The initial in-place mix temperatures ranged from 265°F to 310°F. One blister type crack was noted in the pavement during placement. When the bituminous mix was removed from the area, an air pocket was noted between the protection board and the neoprene sheet. As the bituminous mix was being compacted, a number of additional longitudinal and transverse cracks were noted with the pattern suggesting that they were reflections from the sides or ends of the protection boards. Upon completion of the rolling, only two 12-inch long cracks were visible at points 4 feet 11 inches from the easterly curb line.

Further inspection of the deck disclosed that compaction of the pavement immediately adjacent to the westerly curb line resulted in stripping of the polyurethane and Gacoflex membrane from the curb face at numerous locations. An attempt was later made to reseal such areas with an application of UWM-28 polyurethane prior to the application of the final course of pavement.

Periodic inspections of the deck during the following 6-week period revealed a gradual increase in the number of cracks in the pavement even though nearly all of the construction traffic was maintained on the adjoining northbound structure. A total of 10 cracks were recorded on August 12, one day before the final course of pavement was to be placed. All of the cracks were longitudinal with most occurring in areas where the polyurethane and protection boards were omitted. The cracks ranged from 12 to 24 inches in length, except for the widest crack, which included uplifted pavement and was 18 feet in length. The pavement was less than 1/2-inch thick at many of the crack locations although it did measure 7/8-inches over the most serious crack.

Repairs were made to the membrane at several locations. In all cases, removal of the cracked bituminous mix revealed the existance of air pressure between the

neoprene membrane and the deck surface. In most cases, the blistered areas occurred at the midpoint of the 42-inch wide membrane sheets, where the coverage with adhesive was apparently incomplete even though a special effort had been made to obtain the proper coverage. Repairs included slitting the neoprene sheet along the blister, cutting excess material caused by stretching of the rubber and rebonding the material onto the substrate using the N-7 adhesive. Four inch wide membrane strips were also placed over the splices.

Damage to the pavement-membrane system was also noted due to stone punctures which occurred during a period of limited construction traffic over the structure. Resistivity readings indicated damage at 12 locations, with the number split between areas covered with protection boards and those without. The initial resistance readings on the Gacoflex Membrane had ranged from 5 million ohms to infinity, while readings on the membrane system complete with protection board were recorded at infinity.

The final course of pavement was placed on August 13, 1974. Four very fine 8 to 12 inch longitudinal cracks were noted in the completed pavement, with 2 occurring at the offset where previous repairs had been made to the system. No further problems were noted in the pavement until April 2, 1975. Inspection at that time revealed additional cracking of the pavement and shoving in the wheelpaths just south of the finger plate expansion dam. As warmer air temperatures prevailed, additional rippling and shoving of the pavement occurred, making it necessary to place cold patch over an area approximately 4 feet square.

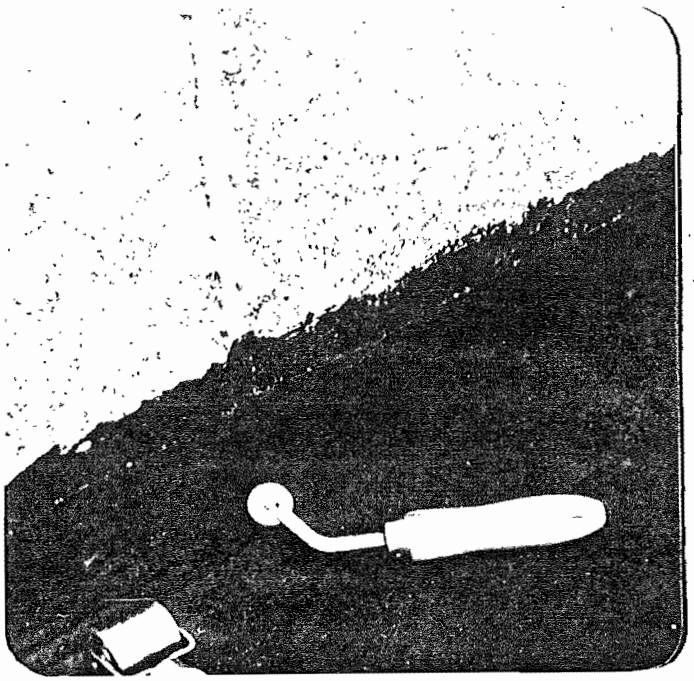
Permanent repairs were carried out on a 19.5 foot by 42 foot area of the pavement-membrane system on August 18th and 27th, 1975. The initial plan was to remove and patch only the portions of the neoprene membrane which were no longer adhered to the deck as was evidenced by cracks in the pavement surface. However, when the pavement was removed, the lack of membrane bond was found to be so widespread that a decision was made to remove all of the sheet rubber. The polyurethane

DISCUSSION (Con't)

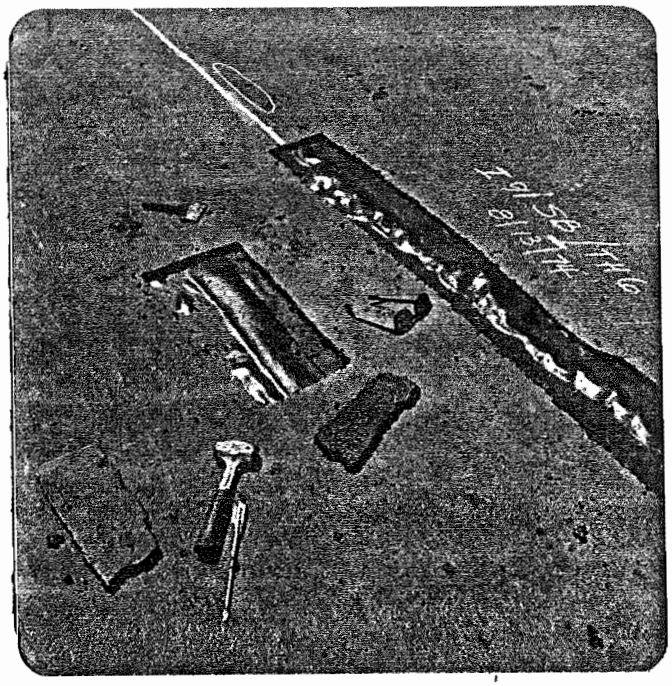
coating which had been applied over 24 of the 42 lineal feet under repair apparently had an adverse effect on membrane bond since in excess of 70 percent loss of adhesion was noted on the area so treated, as compared to 10 percent loss on the uncoated sheet membrane. The removal of the sheet membrane also revealed the existance of flowable concentrations of water on the deck surface in areas where the membrane was not adhered to the concrete. Such moisture originated from within the concrete deck since there were no tears or holes in the neoprene sheets which could have resulted in moisture leakage. Repair of the system consisted of an application of UWM-28 polyurethane and the installation of protection boards. There have been no post repair problems with the pavement-membrane system.

GACOFLEX N-3S MEMBRANE

I 91 SB over TH #6



Membrane surface rolled with 1-1/2" diameter by 2" wide flat faced roller while goose neck stitching tool used along curb face.



Cracks occurred in the first course of pavement where air pressure lifted the membrane.

Removal of the pavement revealed up to 70% of the neoprene sheet coated with polyurethane was no longer bonded to the concrete.

Measurable amounts of water were noted on the concrete in areas where the impervious membrane was not bonded.

WORK PLAN - NO. 32

BUTYLFELT

DESCRIPTION

A preformed sheet membrane composed of 30 mils of butyl rubber laminated to a 30-mil asphalt saturated felt. The system is manufactured by Storey Brothers & Company, Ltd., White Cross, Lancaster, England.

TEST RESULTS

The material was selected as one of the 5 most promising bridge deck membrane systems in the National Cooperative Highway Research Program, Project 12-11. The selection of Butylfelt Membrane was based on the results of laboratory tests conducted by Materials Research & Development of Oakland, Calif.

RECOMMENDED APPLICATION PROCEDURE

1. Prime the concrete with a cutback asphalt applied at the rate of 100-150 square feet per gallon and allow to dry for at least 24 hours.
2. Unroll Butylfelt prior to laying to relieve roll tension.
3. Place Butylfelt face down in a hot-applied 85/25 or 95/25 blown bitumen, using the pour and roll technique. The sheets should be placed with 4-inch side laps and 6-inch end laps.
4. Place a 3/4-inch protective layer of sand-asphalt or other material over the membrane prior to placing the bituminous pavement.

WORK LOCATION

The I 91 southbound bridge over the Wells River at station 5861 + 05 - 5864 + 39, approximately 0.1 mile north of the U.S. Route 302 interchange in Ryegate.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Both end spans have very gritty surface. Center span less gritty.

Cracks - Fifteen transverse cracks averaging 12.8 feet in length were noted on the center span, with all but 4 of the cracks located between 148 feet and 185 feet north of the expansion dam. See crack layout on page 70

Average Initial Chloride Level - 44 parts per million.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION (con't)

Preparation - Deck was washed clean, sandblasted 3 feet out from curb faces and blown clean.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	6-27-74		Air temperatures recorded in shade. Overcast a.m. 50% cloud cover p.m.
10:00 - 3:00			Finished placing epoxy mortar fillet along curbs.
4:10	72	59	Applying Philip Carey Specification Primer Asphalt with squeegee - Fed. Spec. SS-A-00701A - ASTM D41-41 - AASHTO M116-42 - blend of blown asphalt and mineral spirits.
5:00	71	59	Primer applied above mortar onto granite along easterly curb and 1/2 way up mortar on westerly curb.
6:10	71	53	Application complete. 103 gallons applied on 13,320 s.f. for an application rate of 129.4 s.f. per gallon. Prime coat contains numerous bubbles ranging up to 1/4" diameter.
	6-28-74		Clear. 5-15 m.p.h. breeze.
12:45	71	39	Primer dry except for a few heavy areas along the curb. Unrolling membrane so material can flatten and relax. 84° in sunshine. Material supplied in 40-inch wide by 72.6 - 74.5-foot long rolls.
1:45	74	38	2 rolls complete along westerly curb. Copper foil strips placed 2-1/2-feet from westerly curb at a point 184-194 feet north of expansion dam, with lead wires placed down northerly of 4 scuppers.
2:20	76	35	4 strips in place. Air bubble found between Butyl and felt on one roll (felt had fold in it). Necessary to cut butyl so material would lay flat. Many transverse wrinkles in the sheets prior to rerolling the material for asphalt application and some ripples visible in bonded sheet. Sheet edge does not always remain sealed down in the asphalt even when reworked with leveling spatulas.
3:05	77	35	6 sheets complete. Asphalt averaging 370°F.
4:00	77	38	Asphalt 405°. 9 strips complete. Foot pressure on bonded sheets results in imprints due to asphalt flow as occurred with the Hyload system. Felt tears and pulls from butyl quite easily if sheet is handled roughly.
	7-1-74		Clear a.m. 50% cloud cover p.m.
8:45	64	55	4 men working. Asphalt 445°F. Began placing first roll.
9:30	66	49	4 strips in place.
9:45	67	55	Asphalt 410°F. Began application along north-easterly curb line with 35-foot strip placed 2 inches up curb face. Sheet folded back, asphalt poured on concrete adjacent to fold and membrane rolled back into asphalt, working excess up curb face. Procedure unsatisfactory due to inability to work excess asphalt out from some areas.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
10:15	69		10-foot copper foil strips placed 2.5 feet from easterly curb at a point 113-123 feet north of expansion dam with lead wires placed down southerly scupper.
11:45	72	46	Asphalt 480°F. First strip complete along easterly curb. Sheet butted at base of concrete shoulder at fingerplate expansion dam.
12:35	71	48	Asphalt 420°F. Second strip complete along easterly curb.
1:45	74	41	Asphalt 455°F. Wind blowing 15-20 m.p.h. Starting third strip.
3:15	78	40	Completed fourth strip.
4:35	75		Heavy rain shower on project. Work stopped.
	7-2-74		100% cloud cover.
8:00	61		Crew placing tar emulsion on approach slabs and protection boards on I 91 SB/TH 6.
2:45	72	69	Placing 4 gallon batch of Carlisle Liquiseal Waterproofing Membrane (vertical grade) along 145 lineal feet of curb line on north-westerly end of deck. Material poured in bead at base of curb and worked up face with wide putty knives. Material should provide a satisfactory seal if it will retain its bond with the asphalt along the edge of the membrane sheet.
3:30	71	70	Placing final strip along easterly side of deck. Using an average of 13 gallons of asphalt per roll of membrane.
4:25	70	71	Asphalt 410°F. Placing first strip along westerly curb from a point 142 feet south of northerly approach slab joint.
5:00	77	58	Asphalt 350°F. Curb line complete.
6:20	74	64	Asphalt 460°F. Asphalt 400°F at 6:50 p.m.
8:00	72		Operation stopped due to rain shower. One strip plus cap strip remaining.
	7-3-74		75-100% cloud cover.
8:00	68	69	Placing final roll of membrane and cap strip.
9:50	73	77	Mixing Liquiseal for remainder of westerly curb.
12:45	82	53	Placing additional asphalt along easterly curb line. Using 2 x 4 to work material up curb face and following up with a trowel.
1:30	82	60	Began placing Carey Elastibord Vapor Stop protection boards, using RS-1 asphalt emulsion as the adhesive.
2:15	82	62	Placing 12-1/2, 3-foot wide boards on membrane, leaving 8" open areas along each curb line so rain water will not be trapped beneath outer boards if they are not completely bonded to the Butylfelt.
3:00	83	61	Emulsion complete on 7600 s.f. and boards in place on 2500 s.f.
3:30	85	60	Noted boards first placed are not bonded satisfactorily. Emulsion had apparently not broken completely before installation of boards. First 10 rows of boards placed with plastic coated side up but remaining boards placed with plastic side down when better adhesion noted.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (con't)

Time	Air Temp.	% Humid.	
4:15	81	61	25 rows in place.
5:25	82	61	Placing boards and rolling those in place with a truck.
6:45	80	61	Removed 2 rows of boards from northerly end of deck for use on southerly end. 20-inch gap without protection boards 72-feet north of expansion dam. Boards on southerly end of deck do not seem to be sticking down as well as those placed later.
7:00			Application complete.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment	1479 s.y.	@	$8.75/s.y.	=	$12,941.25
Bituminous Concrete	219 tons	@	$9.90/ton	=	$ 2,168.10
Tar Emulsion on Approach Slab	41 gals.	@	$2.00/gal.	=	$ 82.00

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application," on pages 65 & 66.

The Butylfelt membrane was placed using the pour and roll technique. Type III roofing grade asphalt was used as the bonding adhesive. Although the material was unrolled on the deck to relieve roll tension, occasional transverse wrinkles or ripples were visible in the bonded membrane. The sheets also displayed a tendency to curl along the edges. This made it necessary to rework the excess asphalt squeezed out from beneath the roll before the edges would remain bedded in asphalt.

The felt portion of the Butylfelt sheet is designed to provide dimensional stability during placement. Nevertheless, the membrane displayed flexibility sufficient to cause some alignment problems as it was unrolled into the asphalt. Such problems were particularly evident during the installation along the curb lines. Rough handling also resulted in tearing of the felt and its separation from the butyl portion of the sheet in several cases.

Electrical resistance readings taken on the membrane without the protection boards or pavement indicated the existance of conductive material in the membrane sheet. The readings ranged from 95,000 to 10 million ohms, with most averaging

one million ohms.

An RS-1 asphalt emulsion was used to bond the protection boards to the membrane. Because it was difficult to recognize when the emulsion had dried enough to permit installation of the protection boards, complete adhesion of the boards was not achieved at all locations. Areas where the emulsion had not broken prior to overlayment with the boards became evident later during the pavement application, with bleeding of the emulsion up through the first course of bituminous mix. This in turn caused some tracking or pulling of the bituminous mix when a build-up occurred on the steel wheeled roller.

Rain showers, which resulted in entrapment of moisture beneath segments of the protection boards, forced the cancellation of paving until July 11, 1974. Initial in-place mix temperatures during paving ranged from 245°F to 290°F with readings averaging 261°F. The thickness of the compacted mix varied from 7/8-inch to 1-1/2-inches, with most areas noted at 1-1/8-inches.

A total of 5 transverse cracks averaging 15-inches in length with 6 longitudinal cracks averaging 3-feet in length were recorded on the first pass of pavement on the westerly side of the deck. All occurred during compaction with a 10-ton steel wheeled roller. A few of the cracks appeared at points where the roller stopped or turned, while others appeared to be reflections of edges or ends of the protection boards. The second pass of pavement was placed and compacted without difficulty. The third pass was also free of problems except for a single location where protection board slid ahead as the paver and roller passed over it. A small bleed-out of asphalt emulsion was noted within the area.

The greatest number of problems occurred on the fourth pass along the easterly side of the deck. A combination of deck superelevation and slippage of the protection boards resulted in lateral movement of the roller and plowing of the bituminous mix at a point 80 to 90 feet south of the expansion dam. Movement of the protection boards and the development of cracks were also noted at other locations, despite the fact

that almost no bleeding of asphalt emulsion was observed. A close inspection of the exposed asphalt emulsion coating adjacent to the curb line revealed a soft and somewhat slippery condition. Such observations suggest that the RS-1 emulsion may not provide satisfactory adhesion and stability under certain conditions, even if allowed to dry for several days. A total of 20 cracks were logged in the pavement along the easterly curb line. Four were transverse cracks averaging 2.7 feet in length, while the remaining 16 were longitudinal and averaged 5.6 feet in length. No blistering was noted in the pavement or membrane system.

A 2-inch thick sand blanket was placed and maintained on the bridge for approximately 2 months prior to placing the final 1-inch course of bituminous mix. The bridge deck was inspected on September 17, 1974 after removal of the sand blanket. Cracks noted during the pavement installation were basically unchanged. A number of additional cracks were noted with most occurring 40 to 60 inches from the easterly curb face on the northerly half of the deck. The new cracks often occurred as 6-inch long irregular or circular cracks with 2 or 3 spur cracks extending from the main branch. As was the case with the EPDM membrane, the pavement within the crack areas appeared to be elevated somewhat suggesting that the problem was caused by air or moisture vapor pressures beneath the membrane system. The removal of the pavement and membrane from 2 typical crack locations disclosed a lack of membrane adhesion to the substrate. In both cases the lack of adhesion was believed due to an insufficient coating of bonding asphalt beneath the membrane sheet. Excellent bond was noted between the pavement and protection board, as well as the protection board and Butylfelt sheet.

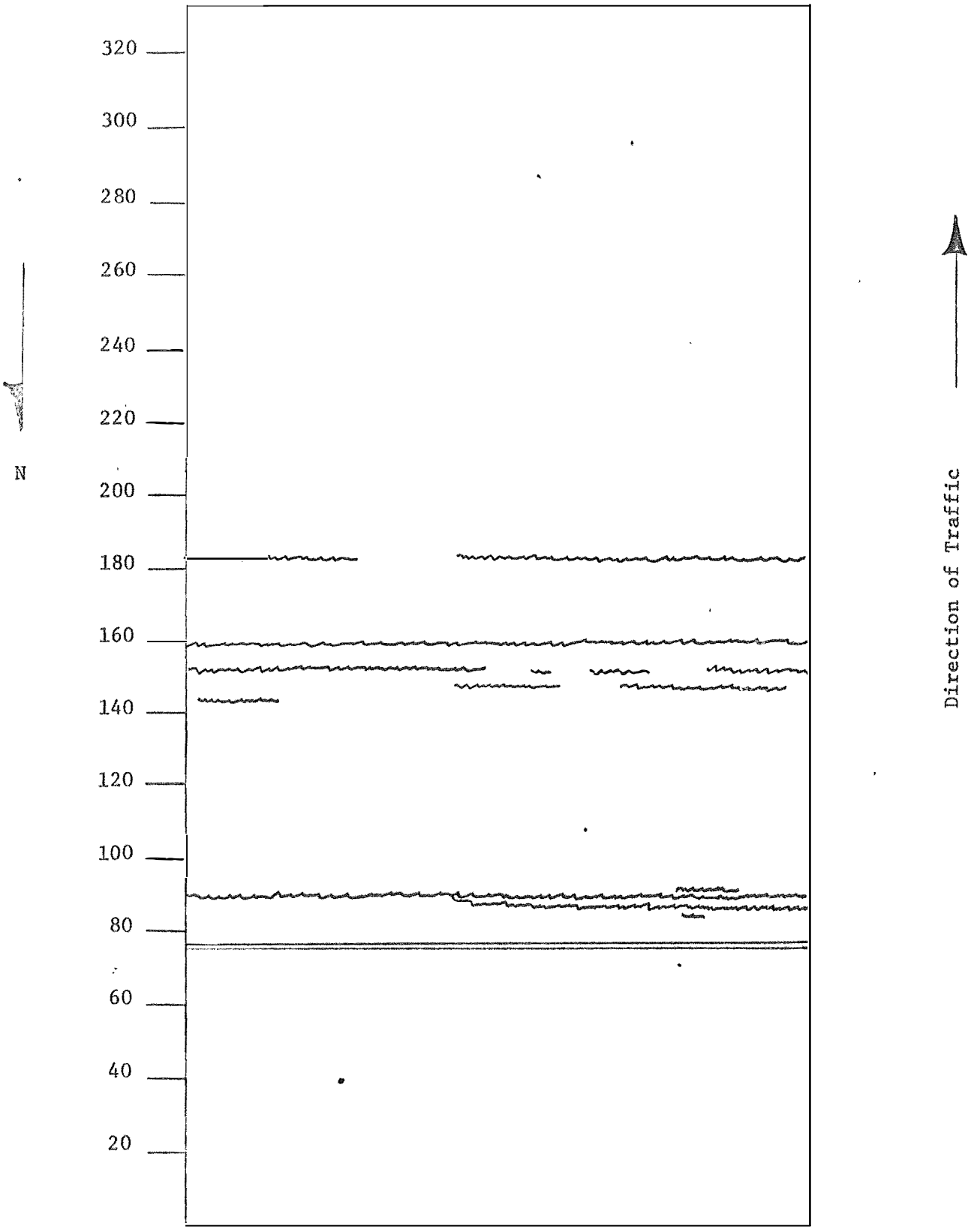
The final course of pavement was placed in mid-September. Inspection of the deck at a later date revealed the existance of a single 18-inch longitudinal crack at a point 13.8 feet from the curb on the southwesterly end of the deck. In addition, approximately 12 fine blister type cracks were noted along the easterly curb line. The latter were all 48 to 52 inches from the curb at points 15 to 60 feet and 240 to 290 feet from the southerly expansion dam. No further blistering or cracking has been noted in the pavement in inspections made through July 2, 1975.

FIGURE

I 91 Southbound over Wells River

Cracks in Concrete Deck

All cracks were noted on surface of deck. Length of cracks and locations are to scale. Vertical scale 40'/in. Horizontal scale 10'/in.



WORK PLAN - NO. 34

CHEVRON'S BRIDGE DECK MEMBRANE

DESCRIPTION

A 2-component asphalt modified polyurethane system which is applied in a 100 mil thickness with metered spray equipment on a preheated substrate. The material is manufactured by Chevron Research Company, 576 Standard Avenue, Richmond, California 94802.

TEST RESULTS

The membrane was not damaged by puncture or heat when subjected to the application of bituminous mixes at temperatures up to 300°F. Samples did not crack when bent around a 1-inch mandril at -10°F and satisfactorily bridged cracks in cement mortar slabs when broken over a 3/16-inch anvil at 0°F. Adhesion to concrete was good before and after submersion of samples in water.

RECOMMENDED APPLICATION PROCEDURE

1. Use infra-red heaters to preheat the substrate from 30°F to 50°F above the ambient deck temperature.
2. Apply the polyurethane in a 100 mil thickness using automatic metering and spraying equipment capable of delivering at least 2 gallons per minute. The spray application should be made within 5 minutes of the heat cycle.
3. Apply a 0.10 to 0.15 gallon per square yard tack coat of hot 85/100 asphalt cement over the membrane to insure adhesion of the bituminous overlay.

WORK LOCATION

Town Highway #61 bridge over I 91 at station 10 + 76 - 14 + 11. Project - Ryegate I 91-2 (49).

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION

Surface Texture - Moderately rough. Bleed water pores visible over approximately 50 percent of the deck surface.

Laitance - Moderate to heavy amount of fines on surface, but no scaling or flaking visible.

DECK CONDITION AND PREPARATION PRIOR TO MEMBRANE APPLICATION (Con't)

Cracks - Eighteen transverse cracks were noted in the deck surface. All were located within a 42 lineal foot span of the 332 foot long deck.

See crack layout on Figure 3 , page 77 .

Preparation - The deck was blown clean immediately prior to starting the membrane application.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION

Time	Air Temp.	% Humid.	
	7-31-74		Air temperatures recorded in shade. 40% cloud cover during afternoon, clear after 6:00 P.M.
9:45	72	59	Cleaning deck and masking off curb face to protect against over-spray. Eight Chevron representatives on project.
11:10	73	55	Sandblasting 3 foot by 20 foot area along curb line on north-westerly end of deck for control comparison with remainder of deck.
1:00	79	42	Began moving infra-red heaters over deck at rate of approximately 4 feet per minute.
1:35	79	42	Spraying urethane along north-easterly curb. Ambient deck surface temperature of 78°F ranging from 97°F to 115°F after heating.
2:00	78	41	Many bubbles noted in the urethane at all locations. Some membrane flow due to grade and parabolic of deck. Strings of bubbles noted where continuous outgassing has occurred.
2:35	78	41	Little if any difference in the number of bubbles where concrete surface heated up to 150°F by slowing movement of heaters.
3:00	78	40	Approximately 3/4 of first 8 foot wide pass complete. Ambient deck temperature of 82°F to 84°F raised to 110°F to 140°F with heater movement of 3 to 3-1/2 feet per minute. Urethane boiled on small area where surface temperature apparently approached 180°F.
3:30	78	39	Slight reduction in the number of bubbles noted over area where polyurethane reworked with squeegee.
3:45	78	39	First pass complete. Light rain shower at 3:55 P.M. resulted in some penetration of water into the polyurethane on the last 44 lineal feet treated. Penetration occurred because supply of activation component had run out and material had not begun curing.
4:50	78	35	Clear. 84°F in sunlight.
5:15	78	32	Making first of 2 passes with heaters on first 50 lineal feet of deck from east to west.
6:20	75	42	Applying polyurethane on second pass. Resistance readings recorded at infinity on all areas checked on first pass.
7:00	71	52	Fewer and smaller air bubbles noted in the membrane in all areas possibly due to receding air temperatures.
7:50	65	56	Ambient deck temperature of 70°F averaging 120°F after heating.

OBSERVATIONS MADE DURING MEMBRANE APPLICATION (Con't)

Time	Air Temp.	% Humid.	
8:15	63	58	Application stopped 60 feet short of end dam due to threat of rain. Bubbles still occurring in polyurethane. Continuous outgassing noted from a single bleed channel for approximately 10 minutes.
8:35			Raining hard on project.
	8-1-74		50% average cloud cover. 15-20 mph breeze A.M.
9:15	74	44	Rain previous evening resulted in depressions in the surface of the membrane except for the first 50 lineal feet which had been heated twice and 3 short areas where the heaters were stopped for longer periods of time and the heated deck quickened the membrane cure.
10:10	73	42	Began heating final 8 foot wide pass along southerly curb line. Will attempt to eliminate outgassing by preheating the deck twice and by raising the concrete temperature over 150°F.
11:30	75		Deck temperatures ranging from 180°F to 220°F. Air temperature beneath heaters ranging from 250°F to 300°F. Heat caused 1/4-inch thick by 4-inch diameter area of deck surface to pop.
12:35	79	31	Began recoating final 44 feet of first pass after first removing all excess premix component and applying activator by squeegee to insure cure of any material remaining on the concrete.
1:45	82	31	Began applying polyurethane on final pass following second heat application.
2:35	83	29	Numerous small individual bubbles and strings or clusters of bubbles noted although fewer generally occur where the surface is heated for longer time periods.
3:00	83	28	Noting fewer bubbles in area where polyurethane extruded and then worked and leveled with a squeegee.
3:10	83	28	Continuing with different heating periods and application methods in an attempt to eliminate bubbling.
4:30	78	34	Tried extruding and then leveling with rubber squeegee followed by extrusion of heavy coat and leveling with a guaged squeegee.
5:05	78	39	170°F deck surface temperature resulted in surface fractures over two, 4-inch diameter areas and two, 12-inch diameter areas. Damage may have been due to entrapped moisture which had been drawn up near the surface during the initial pass with the heaters.
5:55	77	37	Moisture sensing copper foil strips placed 2 feet from southerly curb at a point 8 to 13 feet from the westerly expansion dam.
6:05	76	38	Third pass complete. Beginning to spray curb lines with second coat.
6:15	75	38	Area of first pass treated without activator is curing on surface but still remains unstable beneath.
7:00	72	42	Application started on final 60 feet of middle pass.
7:55			Application complete. 455 gallons of premix and 52 gallons of activator applied on the 854 square yard deck for average application rate of 0.595 gallons per square yard or 16.7 square feet per gallon. The rate results in average wet film thickness of 97 mils.

COST OF PROTECTIVE MEMBRANE AND BITUMINOUS CONCRETE WEARING SURFACE

Membrane Treatment		584	s.y. @ $6.88/s.y. =	$4,017.92
Bituminous Concrete	(first course)	53.7	tons @ $27.50/ton =	$1,476.75
	(second course)	43	tons @ $13.50/ton =	$ 580.50

DISCUSSION

For more detailed information on the installation, refer to "Observations Made During Membrane Application", on pages 72 & 73.

The deck selected for the Chevron Bridge Deck Membrane System had been cast 50 days earlier. Although much of the deck surface was covered with a tight white laitance, the Chevron representatives did not feel that any special surface preparation was necessary.

The gas-fired infra-red heater unit furnished for the project was capable of producing 1.2 million B.T.U.'s per hour. Movement of the heater was accomplished with a small garden tractor. A rate of 4 feet per minute produced an average 35°F increase in the deck surface temperature. When blisters were noted in the liquid membrane, the movement of the heaters was reduced to 3 to 3.5 feet per minute. This increased the deck temperature 28°F to 58°F above ambient but did not noticeable reduce the number of air bubbles which appeared in the surface of the membrane. Some of the bubbles were apparently due to entrappment of air during the spray application. This was proven when air bubbles were noted in a coating applied on an 8-inch diameter plate. However, most of the bubbles were believed due to air and moisture vapors outgassing from the concrete. The latter condition was evident at many locations where continuous streams of air bubbles were noted rising to the surface of the membrane. The bubbles generally ranged from 1/64-inch to 1/16-inch in diameter, while crater type depressions were generally 1/16-inch to 3/16-inch in diameter upon curing. Probing with a pencil revealed the existance of varying amounts of membrane material at the bottom of nearly all bubbles or craters checked. The absence of continuous holes through the membrane was also later born out by infinite electrical resistance readings obtained at nearly all locations on the completed membrane system.

DISCUSSION (Con't)

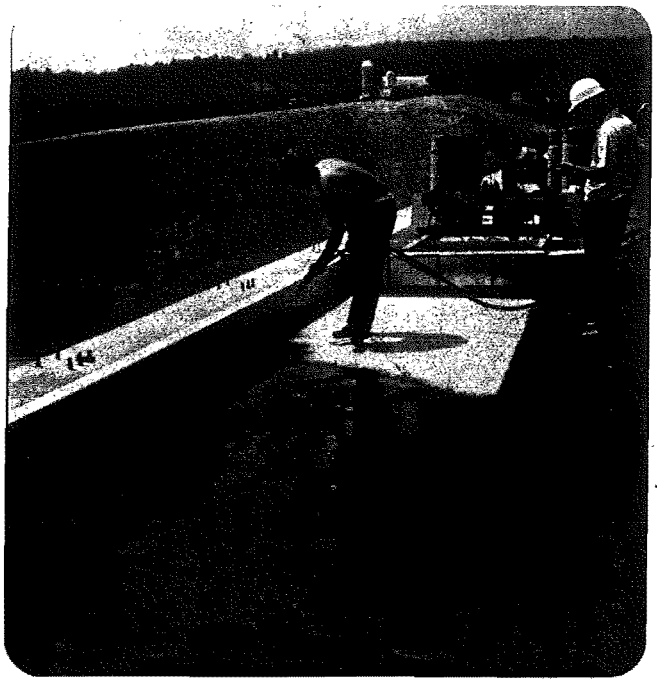
Attempts to eliminate the bubbling and pinholing included varied heat cycles combined with spray, extrusion and squeegee applications of the polyurethane. The second day's application included 2 passes of the heater unit. Somewhat fewer and smaller bubbles and pinholes were subsequently noted; however, areas with 50 to 100 bubbles per square foot were still common. Although many different procedures were tried, the only area which remained completely free of bubbles or holes was achieved with a 3-minute heat cycle, followed by a squeegeed prime coat at 3:00 P.M. and a sprayed finish coat at 6:20 P.M. Even though preheating the deck did not eliminate blistering, the value of the procedure was evidenced by the formation of many large bubbles and craters which occurred in the membrane over a small area of the deck which was not preheated. The heating process did result in fracturing of the deck surface at 5 locations when the temperature of the concrete exceeded 170°F. The fractures were limited to 1/4-inch deep by 4 to 12 inch diameter areas.

The low initial viscosity of the polyurethane resulted in flow of the material on the 2.5 percent grade and movement toward the curb line, due to the deck's parabolic curvature. Membrane thicknesses of up to 1-inch were noted upon completion of the system when drain tubes were cut open along the curb lines. The flow could have been prevented by adding Chevron thickening agent which is recommended for grades over 5 percent, but had not been considered necessary for the application.

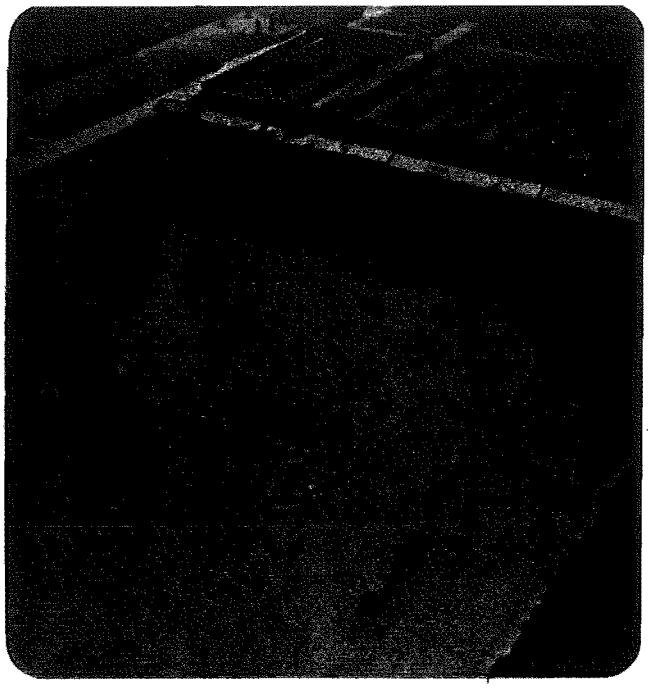
A total of 507 gallons of premix and activator were applied on the 854 square yard deck, for an average wet film thickness of 97 mils. A tack coat of AC-10 asphalt cement was applied on the membrane the day prior to placing the bituminous pavement. The spray application, made with a distributor truck, averaged 0.11 gallons per square yard. The pavement application was completed without problems, although the paver's tires occasionally pulled bits of the tack coat off the surface of the membrane.

CHEVRON'S BRIDGE DECK MEMBRANE

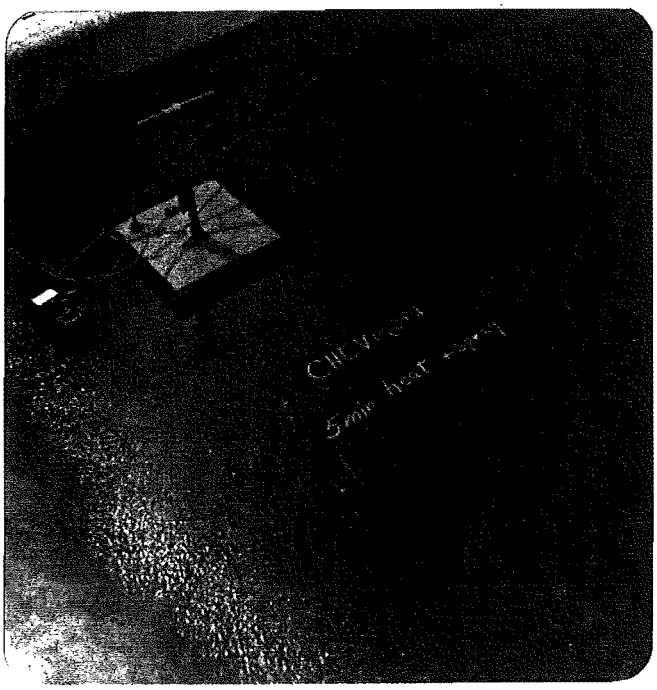
TH #61 over I 91



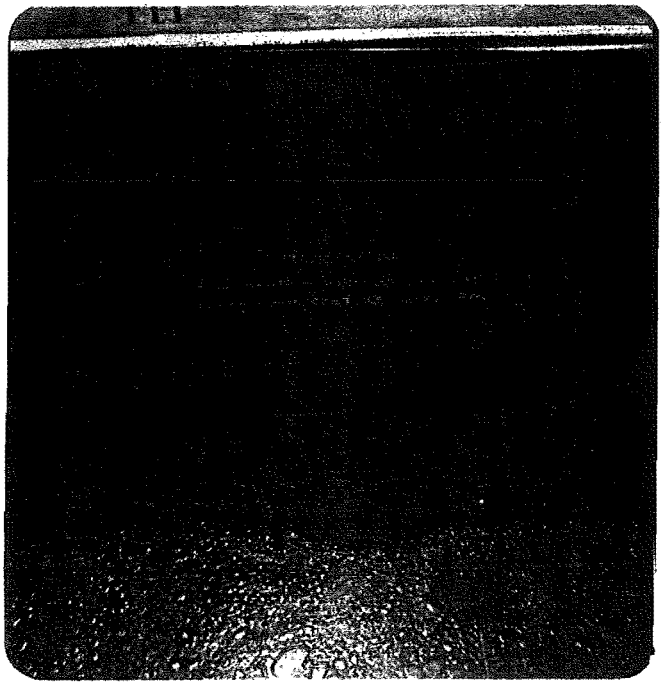
Spray applying Chevron polyurethane. Note infra-red heaters.



Concrete surface fracturing which occurred at several locations when the deck temperature exceeded 170°F.



High resistivity readings indicated the membrane was generally impervious even though bubbles and pinholes were noted in nearly all areas.



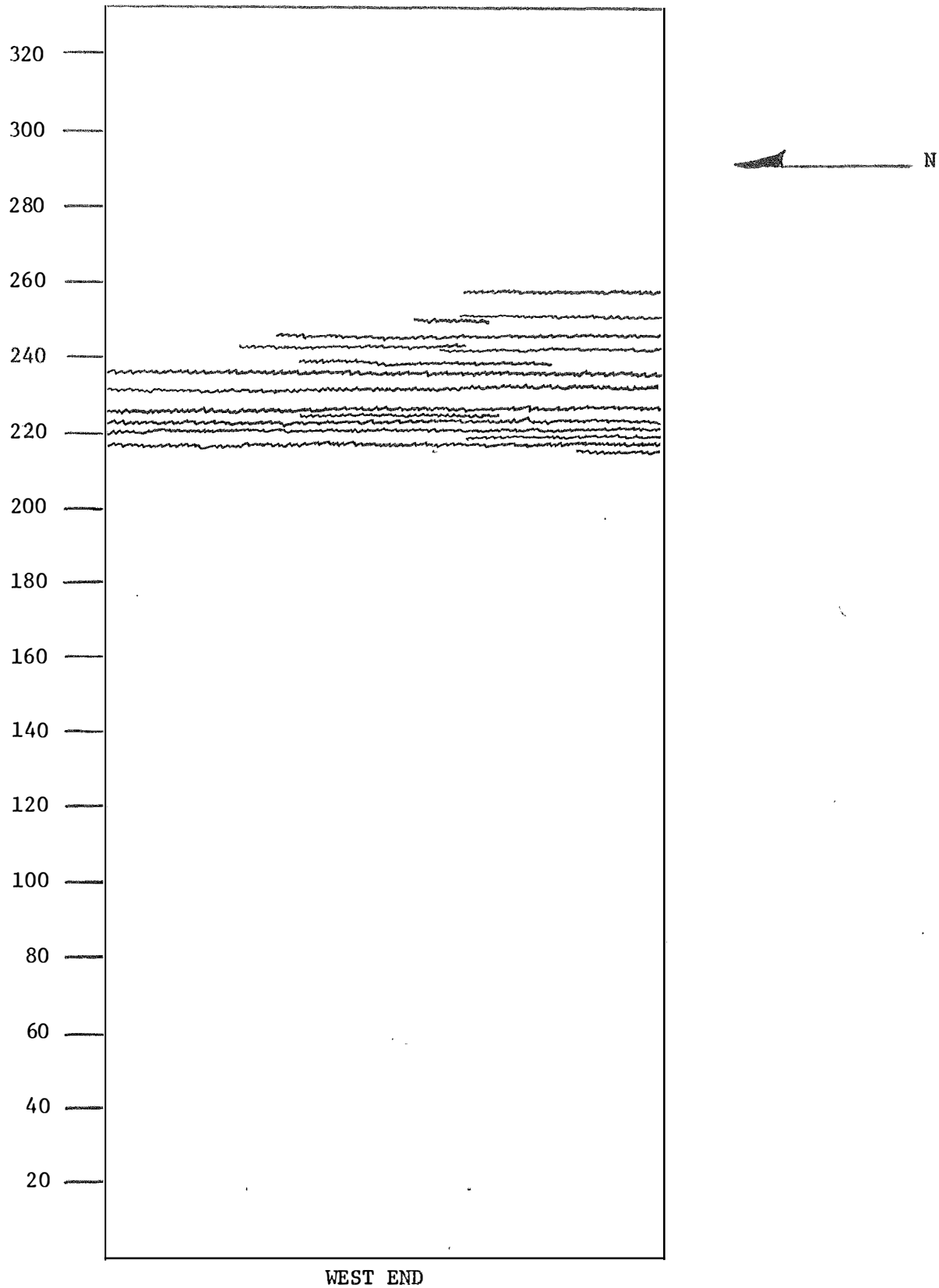
The above area remained free of blisters or holes. Roughened but undamaged membrane in foreground due to rain on partially cured membrane.

FIGURE

TH #61 over I 91

Cracks in Concrete Deck

All cracks were noted on surface of deck. Length of cracks and locations are to scale. Vertical scale 40'/in. Horizontal scale 6'/in.



BRIDGE DECK CONSTRUCTION DATA

BRIDGE	MEMBRANE SYSTEM	STATION	TYPE	TOTAL LENGTH	CURVATURE	SUPER-ELEVATION	GRADE	DATE DECK CAST
I 91 NB over Waits River	Royston #10	5191±	(2) Simple Spans	251'	3°-30'	15/16"	4.2%	4-30 & 5-1-73
I 91 SB over Waits River	Heavy Duty Bituthene	5191±	(2) Simple Spans	271'	3°-30'	15/16"	4.65%	5-30 & 5-31-72
I 91 NB over Route 25B	Duralseal 3100	5148±	Simple Span	136'	3°-30'	15/16"	4.2%	10-18-72
I 91 SB over Route 25B	Protecto Wrap M-400	5148±	Simple Span	160'	3°-30'	15/16"	4.65%	10-26-72
I 91 NB over TH #6	Hyload 125	5219±	Simple Span	150'	None	Normal	1.5%	10-5-72
I 91 SB over TH #6	Gacoflex N-3S	5220±	Simple Span	122'	"	"	1.2%	9-26-72
I 91 NB over SA #1	Protecto Wrap M-400	5487±	Simple Span	105'	"	"	3.5%	6-15-73
I 91 SB over SA #1	NEA 4000	5489±	Simple Span	105'	"	"	3.5%	6-19-73
I 91 NB over SA #5	Heavy Duty Bituthene	5613±	Simple Span	98'	"	"	4.8%	11-6-72
I 91 SB over SA #5	Protecto Wrap M-400	5615±	Simple Span	128'	"	"	4.8%	11-1-72
I 91 NB over Wells River Northerly Half	Sure-Seal Butyl	5862±	3-Span Continuous	334'	"	"	0.6%	8-14 & 8-15-73
I 91 NB over Wells River Southerly Half	Sure-Seal EPDM	5862±	3-Span Continuous	334'	"	"	0.6%	8-14 & 8-15-73
I 91 SB over Wells River	Butylfelt	5862±	3-Span Continuous	334'	"	"	0.6%	10-1 & 10-2-73
TH #61 over I 91	Chevron	14+00	2-Span Continuous	335'	"	"	2.5%	6-7 & 6-11-74

SUMMARY OF FINDINGS & RECOMMENDATIONS

The following discussions summarize the good and bad characteristics of each of the eleven systems tried and conclude with recommendations on further use. It is emphasized that the recommendations are tentative since long term evaluations will be required to draw definite conclusions on the overall effectiveness of each product.

Product recommendations are based upon the following desirable characteristics which would be expected in the ideal membrane system.

Minimum necessary surface preparation of the concrete.

An application suitable to most weather conditions. Not moisture sensitive.

Easy application.

Impervious to moisture penetration. 500,000 ohms minimum electrical resistance.

Not subject to bubbling or pinholing.

Adequate bond to the concrete.

Adequate seal along the curb lines.

Sufficient flexibility to resist cracking.

Not susceptible to heat damage.

Sufficient toughness to resist damage during paving application.

Sufficient stability to resist movement during paving and under continuous traffic.

The membrane should not affect the performance of the bituminous pavement.

Resistant to age deterioration.

High ratio of service life to in-place cost.

ROYSTON BRIDGE MEMBRANE #10

Summary of Findings

The Royston system was installed and paved without problems. Electrical resistance readings taken on the membrane indicated a waterproof seal. There were no indications of damage to the membrane at locations where the first course of pavement was removed for inspection. Numerous short cracks which occurred in the first inch of pavement were believed due to the formation of air and moisture vapor pressures beneath the membrane. Such pressures indicate the membrane was providing a complete seal including all edge and end laps. It is suspected that the cracks would not have occurred if both pavement courses had been applied initially, thereby providing additional dead weight over the membrane.

Because obtainment of a complete membrane seal along curb lines on some Royston installations has been questionable, current specifications covering the installation of the system include the use of a compatible polyurethane membrane sealant along the curb lines. Field evaluations conducted on the first bridge treated with Royston Membrane in May of 1973 have disclosed no chloride contamination after two winters of deicing salt applications. Localized pavement-membrane failures have been recorded on a single Royston installation made in October of 1973. The failures were believed due to a combination of factors including the absence of the normal asphalt coating on the fiberglass reinforcement, incomplete membrane bond to the deck caused by concrete surface laitance, and/or low bituminous overlay temperatures combined with low ambient temperatures. Based on the recorded failures and visual observations made on other structures, a recommendation has been made to require pavement lay-down temperatures between 310°F and 335°F, to insure adequate bond between the membrane and bridge deck, as well as the membrane and pavement.

Recommendation

Royston Bridge Membrane #10 is currently included as one of three optional systems covered under Section 519 - Sheet Membrane Waterproofing. Continued use of the system is recommended if recommendations on temperatures are approved.

Summary of Findings

Problems with the installation of Heavy Duty Bituthene included difficulties in realigning sheets due to immediate membrane adhesion to the substrate, and tearing and sticking of the release paper. Air bubbles trapped beneath the membrane did not result in problems with the bituminous overlay. It is suspected that such pockets of air vent out through the membrane while it is in a heated liquid state. Cracks occurred in the bituminous mix over the edges and ends of approximately twenty percent of the total sheet perimeters. The cracks were due to shrinkage of the membrane's woven polypropylene surface. Polypropylene mesh now used in production is reported to be pre-shrunk, thereby preventing the formation of pavement cracks when overlay temperatures do not exceed 300°F. Problems occurred while paving the second bridge due to reduced pavement stability over the softened membrane.

Cores taken from the first bridge treated with Heavy Duty Bituthene in August of 1972 have disclosed chloride contamination at two of seven locations after three winters of deicing salt applications. The concentrations amounted to 0.6 pounds chloride per cubic yard of concrete in the top inch at one of five wheelpath locations, and 0.3 pounds chloride at one of two areas 18 inches from the curb line. Leakage in the wheelpaths may have been due to membrane damage during paving or subsequent cold flow under traffic. Although the core results indicate a protective system may be necessary over Bituthene, the use of such a system is not a viable option since there is no way of adhering such materials to the surface of the membrane.

Recommendation

Heavy Duty Bituthene is currently included as one of three optional systems covered under Section 519 - Sheet Membrane Waterproofing. The system is recommended for further use, with the following limitations. Due to the material's low softening point (160°F) it is recommended that the first course of pavement be placed at a temperature range of 245°F to 275°F. If chloride intrusion is detected on other structures treated with Bituthene, further use of the system would not be recommended.

DURALSEAL 3100

Summary of Findings

The 100 percent solids polyurethane displayed excellent toughness and flexibility in laboratory tests. Although an earlier, limited field trial was completely satisfactory, both the epoxy primer and the polyurethane deck application were plagued by pinholing caused by air and moisture vapor outgassing from the concrete. Slight reductions in the number of pinholes were obtained by reworking the materials, applying the coating as air temperatures were declining late in the day and by applying a second coat. An average of 89 holes or bubbles were noted per square foot; however, many were apparently not open to the concrete, since half of the electrical resistance readings were recorded in excess of 400,000 ohms. The epoxy prime coat averaged 13 mils while the average wet film thickness of the polyurethane was 65 mils. There were no problems with the pavement application. Removal of the compacted pavement disclosed no visible signs of damage to the membrane, but little adhesion was noted between the bituminous mix and polyurethane.

Recommendation

The Duralseal 3100 system is not recommended for further use. Continued use of the system would be considered if the material could be made less susceptible to outgassing from the concrete and if the system included a topping which would insure adhesion between the membrane and the bituminous overlay.

PROTECTO WRAP M-400

Summary of Findings

The Protecto Wrap system was installed without significant problems. The use of a pick-up truck and 60-inch wide membrane sheets resulted in the lowest labor cost of any preformed sheet system placed to date. An application of mastic was placed along the edge of the membrane at the curb line, but obtainment of a complete seal at all locations was questionable. The specification now covering the installation of Protecto Wrap includes the use of a compatible polyurethane membrane sealant along the curb lines. There were no problems with the pavement applications; however, a single blister was noted on one of three bridges approximately two weeks after paving. Electrical resistance readings on the completed membrane-pavements were recorded at infinity, indicating the systems were impervious.

Field cores taken from the first bridge treated with Protecto Wrap in May of 1973 have disclosed no chloride contamination after two winters of deicing salt applications.

The occurrance of blisters in the membrane and pavement have been noted on several other Protecto Wrap installations. The problem generally occurs when the bituminous overlay temperature is in the 300°F range. A recommendation has been made to require pavement lay-down temperatures between 245°F and 275°F to lessen the potential for blistering and also to reduce the material's susceptibility to damage during paving. An exception to the temperature requirement could be made if a protective system such as Protecto Wrap P-100 were placed over the membrane.

Recommendation

Protecto Wrap M-400 is currently included as one of three optional systems covered under Section 519 - Sheet Membrane Waterproofing. Continued use of the system is recommended if recommendations on temperatures are approved.

NEA 4000

Summary of Findings

The PVC Polymer membrane system was applied without difficulty, utilizing a heater-field extruder supplied by the manufacturer. Labor costs for the installation were low due to the steady production obtained with the mechanical application. Adhesion of the liquid polymer to the concrete varied with the deck's surface condition, but generally appeared weak. A few bubbles were noted in the liquid membrane prior to the installation of the roofing sheet protection course. The liquid membrane appeared to provide an excellent seal along the curb lines. Electrical resistance readings on the completed system indicated a waterproof seal. Problems occurred with the installation of both the first and second courses of pavement. The problems were due to a combination of paving procedures and reduced pavement stability due to the underlying membrane. A second experimental application of the system was completed and paved without problems in 1975.

The basic polymer cost of approximately $5.00 per gallon is about one-half the cost of the average liquid applied material. Low in-place unit costs could be expected on the system if contract quantities are sufficient to warrant a contractor's purchase of a field extruder.

Recommendation

NEA 4000 is recommended for further use with the following limitations. Due to the material's low temperature softening point, it is recommended that the first course of pavement be placed at a temperature range of 245°F to 275°F, and that initial compaction be carried out with a light-duty roller.

HYLOAD 125

Summary of Findings

The Hyload system consisted of a cutback asphalt prime coat, perforated underlayment and 125-mil membrane sheet placed in a hot application of Type III roofing grade asphalt. The toughness and stability of the reinforced pitch and PVC polymer membrane suggests that a lighter 75-mil version of the membrane may be adequate without requiring an additional protective course in addition to the bituminous pavement. The installation required an extensive amount of labor, but was completed without serious difficulty. A hot application of roofing grade asphalt was used to seal the joint between the deck and curb face; however, cold weather shrinkage of the asphalt and bituminous pavement may result in loss of adhesion to the epoxy mortar and granite, with subsequent leakage in such areas.

Although few problems occurred during the application of the first course of pavement, blisters began appearing in the membrane and pavement prior to the application of the final course. Additional blistering occurred in the completed pavement the following spring, with the advent of warm weather. Inspection of the system confirmed that the ventilating underlayment was not sealed to the deck and should have allowed continuous lateral movement and dispersion of any developing air or moisture vapor pressures. The blister formation may not have occurred if the additional dead weight of both courses of pavement had been applied upon completion of the membrane system.

Recommendation

The Hyload system is not recommended for further use. Continued use of the system would be considered if the less expensive standard membrane systems prove to be inadequate and if provisions can be made to insure that blistering of the Hyload membrane does not occur.

SURE-SEAL BUTYL MEMBRANE

Summary of Findings

The installation of the Butyl rubber sheet system was time consuming due to the necessity of a paint roller application of the bonding adhesive on the deck surface and the bottom of the membrane, and also the surface of the membrane and the bottom of the protection boards. Since the installation procedure entailed placing the membrane sheets while the bonding adhesive was sticky, the risk of membrane-pavement blisters was present due to the potential entrapment of solvents in areas given heavy applications of the adhesive or where puddling might occur. The system included a very effective procedure for sealing side and end lap joints between sheets and a polyurethane seal between the butyl sheets and the granite curb. Use of the electrical resistance test procedure for evaluation of the system is not practical due to the presence of conductive materials in the butyl rubber sheets. The first course of pavement was applied without problems, although fifteen fine cracks were noted in the compacted pavement. Most were longitudinal cracks occurring at 15, 25 and 35 foot offsets, indicating they were the result of incomplete bonding adhesive coverage along the mid-point of the 11-foot wide sheets. The pavement-membrane system has remained free from problems since the final course of pavement was placed.

Recommendation

Sure-Seal Butyl Membrane is not recommended for further use until follow-up evaluations can be completed. Continued use of the system would be considered if the less expensive standard membrane systems prove to be inadequate.

SURE-SEAL EPDM MEMBRANE

Summary of Findings

The installation of the cured EPDM rubber sheet system was time consuming due to the necessity of a paint roller application of the bonding adhesive on the deck surface and the bottom of the membrane, and also the surface of the membrane and the bottom of the protection boards. Since the installation procedure entailed placing the membrane sheets while the bonding adhesive was sticky, the risk of membrane-pavement blisters was present due to the potential entrapment of solvents in areas given a heavy application of the adhesive or where puddling might occur. The system included a very effective procedure for sealing side and end lap joints between sheets. Softening and/or swelling of the membrane was noted at several locations where a heavy application of adhesive was applied prior to the installation of the protection boards. Use of the electrical resistance test procedure for evaluation of the system is not practical due to the presence of conductive materials in the EPDM rubber sheets. A number of cracks and blisters occurred in the first course of pavement, requiring puncturing of the protection board and membrane in order to allow compaction of the mix. Nearly all of the cracks occurred at the mid-point of the 10-foot wide sheets where coverage with the bonding adhesive was apparently not complete due to the necessity of folding the sheets in half. Approximately forty-five additional cracks were noted in the first course of pavement over a three month period prior to the installation of the riding surface. Most appeared as a series of short irregular cracks with a slightly elevated surface, which suggests they were caused by air or moisture vapor pressures beneath the membrane. Soundings taken on the pavement also revealed the existance of hollow or unbonded areas in up to thirty percent of the areas checked. The pavement-membrane system has remained free from problems since the final course of pavement was placed.

Recommendation

Sure-Seal EPDM Membrane is not recommended for further use due to it's high cost and difficulty of application.

GACOFLEX N-3S MEMBRANE

Summary of Findings

The deck surface was acid etched in lieu of sandblasting, at the request of the manufacturer. The 42-inch wide membrane sheets were bonded to the concrete with applications of neoprene adhesive on the bottom of the sheets and on the deck surface. The requirement for rolling the entire surface of the membrane with 2-inch wide hand rollers was a major factor in the labor required to place the system. An excellent seal was obtained along the curb line, using a trowel grade neoprene compound. A two-component polyurethane was used to adhere protection boards to the membrane surface. The protection system was omitted on a third of the deck due to problems with the installation. A few cracks and a single blister were noted during the pavement application. Prior to placing the riding surface, additional cracks were noted, with most occurring in the area where the protection boards were omitted. Repairs made to the membrane revealed the existance of air pressure generally at the mid-point of the sheets where coverage with the adhesive was apparently not complete. Cracking and shoving of the finish pavement necessitated the repair of such areas in August of 1975. Removal of the pavement disclosed that the polyurethane coated neoprene membrane was no longer adhered to the substrate over approximately seventy percent of the area, while ten percent of the untreated membrane was no longer bonded. Measurable amounts of water were noted on the deck surface when the membrane was removed, even though there were no holes or tears in the system. The problems with the pavement-membrane system may not have occurred if protection boards had been placed over the entire membrane and if both courses of pavement had been applied upon completion of the system.

Recommendation

The Gacoflex N-3S Membrane system is not recommended for further use due to it's high cost and the probability that the system would not be installed properly under typical field conditions where an application specialist was not present.

BUTYLFELT

Summary of Findings

The Butylfelt membrane was placed in a hot application of roofing grade asphalt using the pour-and-roll technique. Minor problems with the installation included rippling of the sheets and curling of their edges. A two-component polyurethane was applied along the curb line in addition to the asphalt application since the sheet membrane did not have sufficient flexibility to conform to the irregular granite curb face. Use of the electrical resistance test procedure for evaluation of the system is not practical due to the presence of conductive materials in the butyl rubber sheets. The use of an RS-1 asphalt emulsion to bond protection boards to the membrane resulted in problems at locations where the emulsion had not broken prior to overlayment and also in areas where the coating reliquified with heat. The difficulties included bleeding of emulsion up through the bituminous mix and slippage of some protection boards. A total of 31 transverse and longitudinal cracks were recorded in the first course of pavement. All were located in the first and fourth paving passes made adjacent to the bridge curbs. A number of additional cracks were noted in the first course of pavement over a two-month period prior to the installation of the riding surface. Most appeared as a series of short irregular cracks with a slightly elevated surface, which suggests they were caused by air or moisture vapor pressures beneath the membrane. Inspection of two typical crack locations revealed the absence of sufficient bonding asphalt beneath the membrane. Excellent bond was noted between the pavement and protection board, as well as the protection board and Butylfelt sheet at both locations. With the exception of a few fine cracks which occurred initially in the riding surface, the pavement-membrane system has remained free of problems.

Recommendation

The Butylfelt system is not recommended for further use due to it's cost, difficulty of application and lack of adequate provisions for sealing the critical curb line area.

CHEVRON'S BRIDGE DECK MEMBRANE

Summary of Findings

The Department's interest in the Chevron Membrane System was due in large part to an application made in Redding, California, where preheating of a bridge deck eliminated blistering and pinholing of the liquid membrane. Although the same procedure was used in Vermont, preheating was not successful in preventing the formation of blisters or bubbles in the coating due to air and moisture vapors outgassing from the concrete. It is suspected that the preheating procedure was not completely adequate due to a very high moisture content in the deck, which had been cast 50 days earlier, and also due in part to almost daily rain showers prior to the membrane application. The value of the heat application was confirmed when numerous large blisters and craters occurred in the polyurethane applied on a small area of the deck which was not heated. Reductions in the number of blisters were achieved with varied heat cycles combined with spray, extrusion and squeegee applications of the polyurethane. The only area which remained free of bubbles or holes was treated with a squeegeed prime coat followed by a sprayed top coat approximately 3-1/2 hours later. High electrical resistance readings obtained on the completed membrane indicate that few if any of the bubbles or holes were open to the concrete. Concrete surface temperatures in excess of 170° F resulted in deck surface fracturing at five locations. Restricting such temperatures to a maximum of 150° F would appear desirable since little if any further reduction in blistering was noted with the higher surface temperatures. The membrane provided an excellent seal along the curb line and passed all laboratory requirements for puncture resistance and flexibility.

Recommendation

Chevron's Bridge Deck Membrane displayed sufficient promise to warrant further experimental use.

CONCLUSIONS

As a result of experiences encountered with the application of experimental membranes in the years 1971 through 1973, a specification was written which covers the use of the three standard preformed sheet systems; Heavy Duty Bituthene, Royston #10 and Protecto Wrap M-400. The specification, which has been used on most non-experimental bridges, allows the contractor the option of selecting the preformed system. The experiences gained with the membrane systems covered in this report, combined with the latest results of continuous follow-up testing, do not indicate that any major shift should be made away from the preformed sheet systems. Characteristics such as flexibility and controlled membrane thickness, plus ease of application and the resulting low in-place cost, continue to make the standard preformed sheet systems more desirable than any other membrane type.

It is recognized that the preformed membranes do have several weak points or problem areas. These include the curb line seal, the formation of blisters during the pavement application and the question of whether a protective system should be placed over the materials. Although all three systems have the potential for waterproofing the gutter line and curb face, the end result depends to a great extent on the care and expertise of the workmen making the installation. For that reason, Vermont's specification now calls for the placement of a compatible liquid polyurethane seal along the membrane perimeter and the vertical curb face when Royston or Protecto Wrap are used. Bituthene mastic will continue to be used with the Bituthene system since the polyurethanes do not develop adhesion to the membrane. Problems with the formation of blisters in both the membrane and pavement during paving have been recorded on Protecto Wrap and a number of other experimental systems. The blisters are believed due to small concentrations of moisture which collect beneath the membrane due to outgassing of moisture vapor from the concrete. Such moisture consequently turns to a vapor or gas when exposed to the high temperatures of the bituminous overlay. Recommendations have been made to reduce the temperature

of the first course of bituminous pavement. It is believed that such action would eliminate nearly all blistering and also lessen the potential for damaging thermo-plastic materials which have a relatively low melting point, such as Heavy Duty Bituthene.

The use of a protective course over individual membrane systems is a procedure which should be considered to protect against damage during the pavement application, as well as cold flow damage and/or creep under continuous traffic loading. Observations and field test results to date indicate that Royston and Protecto Wrap do not require a protective overlay if the full depth of pavement is placed shortly after the membrane application. Chemical analysis of cores taken from a structure treated with Heavy Duty Bituthene in 1972, have disclosed the penetration of chlorides in some wheelpath areas. Such findings suggest that the system may require a protective course. If such a need is confirmed by further test results, the use of Heavy Duty Bituthene would be discontinued since there is no reliable means of adhering a protective course to the membrane.

Agencies contemplating the use of the three standard sheet membranes are advised to consider the use of a protective course over the systems if coarse aggregates in their bridge pavements exceed 3/8-inch in size; if traffic volumes in excess of 10,000 vehicles per day are anticipated; or, if ambient temperatures often exceed 90°F.

The installation of Protecto Wrap's P-100 protection course was considered successful in the application discussed in this report. Other companies which market membrane systems are encouraged to develop and supply protective materials which would compliment their membranes, for use by agencies which desire to include the use of such materials.

The five preformed sheet systems selected as most promising in the NCHRP Project 12-11 were generally considered difficult to install. Actual or potential problem areas varied with the individual systems but included the use of adhesives with critical air curing requirements, difficulties in obtaining complete coverage with bonding adhesives, inadequate provisions for sealing curb lines and difficulties in

adhering the protection boards to the membrane. The Sure-Seal EPDM and Butyl membranes plus the Gacoflex membrane included the use of bonding adhesives with critical air curing requirements. Although few difficulties occurred with the use of such materials, the potential for problems does exist on any future installations made under typical field conditions, when an application specialist might not be present. The Gacoflex system provided an excellent seal along the curb line with a trowel grade neoprene compound which cured into a tough rubber seal. However, the use of a polyurethane to adhere the protection board to the neoprene membrane should be reconsidered in light of the fact that repairs revealed up to seventy percent of the membrane so treated did not remain adhered to the deck substrate. The Hyload and Butylfelt systems call for the use of hot-applied asphalts to seal off the deck-curb joint and the lower curb face. Because the asphalt would be expected to develop greater adhesion to the bituminous pavement than to the mortared joint and granite curb, shrinkage of the pavement with cold weather and aging may result in leakage at the curb face. Although blisters and/or cracks occurred in the initial pavements placed over all five systems, it is believed that most of the problems would not have occurred if a thicker initial course of pavement had been placed and if lower pavement temperatures had been maintained.

As a group, the five preformed membrane systems identified by the NCHRP Project 12-11 are not recommended for further use due to the difficulty in obtaining the proper application of the materials and also because of their high in-place costs; however, use of several of the systems would be reconsidered if follow-up evaluations prove the standard preformed systems are not satisfactory.

NEA 4000, the east coast low temperature version of Superseal 4000, shows sufficient promise to warrant further use. Experiences with two applications of the system indicate that potential paving problems can be prevented by reducing bituminous mix temperatures to 275°F or lower and by applying initial compaction with a light-weight roller.

Duralseal 3100, a one-hundred percent solids polyurethane, provided the tough-

ness and flexibility required in a membrane, but was plagued by pinholing due to air and moisture vapors outgassing from the concrete. Since the material is not thermo-plastic and developed good adhesion to the substrate, there were no blistering or cracking problems with the pavement application. However, the material would be considered for further use only if it could be made less susceptible to outgassing and if the system included a topping which would insure adhesion of the bituminous overlay. Limited use of liquid applied polyurethanes such as Duralseal 3100 are recommended for deck repair or widening projects, where surfaces are often too rough to apply the preformed sheet membranes.

The Chevron Membrane System, although also affected by outgassing, displayed sufficient promise to warrant further experimental use.

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.

Annual evaluations are being conducted on all bridges treated with experimental membranes after they have been subjected to two winters of deicing salt applications. The evaluations have included resistivity tests, steel potential readings, moisture strip readings, and the recovery of concrete samples for the determination of chloride content. Information recorded on Table 5 page101 lists chloride concentrations recorded on bridge decks waterproofed between 1971 and 1973. The chloride levels can be compared with base chloride levels which ranged from 18 to 46 parts per

million in the newly constructed decks. The data also includes the chlorides detected in the paved but untreated approach slabs of the same structures. When compared with the approach slabs, the results show that most of the membrane systems have provided initial protection against leakage except for areas adjacent to the curb line. Although the findings may be considered tentative due to the relatively short evaluation period, the results indicate that simple inexpensive and less than impervious membrane materials may be adequate for protecting properly drained crack free structures, if curb line areas are treated with an impervious membrane material. Further research is required and will continue in this area.

Although the success of a membrane system is dependent upon a number of conditions which would vary in different localities, the observations and recommendations covered in this report should be of value to other agencies contemplating similar membrane usage.

The author wishes to emphasize that this report is not intended to promote the use of bridge deck membrane systems. Although experience indicates that a number of membrane systems are capable of providing the desired protection, the potential for improper placement and other related problems with individual applications is sufficient to discourage membrane usage in areas where a lack of sufficient attention and inspection might be anticipated.

PRODUCT EVALUATION SUMMARY

Field Observations	Royston Bridge Membrane #10	Heavy Duty Bituthene	Duralseal 3100	Protecto Wrap M-400	NEA 4000	Hyload 125
Surface Preparation Required	Wash & sweep	Wash & sweep	Sandblast or Acid Etch	Wash & sweep	Wash & sweep	Wash & sweep
Moisture Sensitive	Yes	Yes	Yes	Yes	Yes	Yes
Ease of Application	Easy	Average	Average	Easy	Easy	Difficult
Bond & Seal at Curb	Fair	Fair	Excellent	Fair	Good	Fair
Bubbles and/or pin-holes in Membrane	No	Yes/No	Yes	No	Yes/No	No
Electrical Resistance prior to Pavement in ohms/s.f.	Infinity	Infinity	1,450,000	Infinity	Infinity	Infinity
Bond Between Pave-ment & Membrane	Fair to Good	Fair to Good	Poor	Good	Good	Fair
Pavement Subject to Blistering and/or Cracking	No/Slight	No/Yes	No	Slight/No	No/Yes	Yes
Post Construction Problems with Pave-ment & Membrane	Cracks in 1st course of pavement	Shoving in 1st course under traf.	No	No	Shoving in 1st course under traf.	Blisters in Memb. & Pavement
Cost per s.y. not Including Pavement	$ 4.25	$ 4.50	$ 7.25	$ 4.25	$ 4.00	$ 8.00
Lab Observations						
Flexibility @ 0°F	Passed	Passed	Passed	Failed	Passed	Passed
Moisture Absorption	No Test	No Test	1.6%	No Test	No Test	No Test
Elongation Over Cracks @ 0°F	Passed	Passed	Passed	Passed	Passed	Passed
Recommendations						
Recommended for Further Use	Yes	Yes	No	Yes	Yes	No
Await Follow-up Evaluations						

PRODUCT EVALUATION SUMMARY

Field Observations	Sure-Seal Butyl Membrane	Sure-Seal EPDM Membrane	Gacoflex N-3S Membrane	Butylfelt	Chevron's Bridge Deck Membrane	
Surface Preparation Required	Wash & sweep	Wash & sweep	Sandblast or Acid Etch	Wash & sweep	Wash & sweep	
Moisture Sensitive	Yes	Yes	Yes	Yes	Yes	
Ease of Application	Difficult	Difficult	Very Difficult	Difficult	Average	
Bond & Seal at Curb	Fair	Fair	Excellent	Fair	Excellent	
Bubbles and/or pin-holes in Membrane	No	No	No	No	Yes	
Electrical Resistance prior to Pavement in ohms/s.f.	14,000	109,000	5,000,000	1,000,000	Infinity	
Bond Between Pave-ment & Membrane	Good	Good	Good	Good	Fair	
Pavement Subject to Blistering and/or Cracking	Slight	Yes	Slight	Yes	No	
Post Construction Problems with Pave-ment & Membrane	Few cracks in 1st course of pavement	Cracks & blisters in 1st course	Cracks in Pavement	Cracks & blisters in 1st course	No	
Cost per s.y. not Including Pavement	$ 9.75	$ 9.75	$ 17.00	$ 8.75	$ 6.88	
Lab Observations						
Flexibility @ 0°F	Passed	Passed	Passed	Passed	Passed	
Moisture Absorption	No Test	No Test	No Test	No Test	1.5%	
Elongation Over Cracks @ 0°F	Passed	Passed	Passed	Passed	Passed	
Recommendations						
Recommended for Further Use		No	No	No	Yes	
Await Follow-up Evaluations	X					

SUMMARY OF MEMBRANE SYSTEMS APPLIED IN 1973

(See Report 74-4)

Field Observations	Hot Mopped Asphalt and Glass Fabric	Tar Emulsion and Glass Fabric	Rambond 620-S Epoxy	Polyastic's Concrete Poxy Membrane Sealer	Duralkote 306 Epoxy	Royston Bridge Membrane #10	Protecto Wrap M-400
Surface preparation required	Wash & Sweep	Wash & Sweep	Sandblast or Acid etch	Sandblast or Acid etch	Sandblast or Acid etch	Wash & Sweep	Wash & Sweep
Moisture sensitive	Yes	No	Yes	No	Yes	Yes	Yes
Ease of application	Difficult	Average	Easy	Easy	Easy	Average	Averag
Bond & seal at curb	Fair	Poor	Fair	Fair	Fair	Fair	Good
Bubbles and/or pinholes in membrane	Yes/Yes	No/Yes	No/Yes	Yes/Yes	Yes/Yes	Yes/No	Yes/No
Electrical resistance prior to pavement overlay in ohms/sf	46,000 71,000	3,900	41,500	40,735	88,300	Infinity	Infini
Bond between pavement and membrane	Good	Good	Poor	Poor	Poor	Fair	Good
Difficulty with pavement application over membrane	No	No	No	No	No	No	No
Loss of pavement stability under traffic	No	No	No	No	No	No	*Yes
Cost per s.y. not including pavement	$3.75	$3.50	$12.30	$7.23	$7.23	$6.00	$5.50

*Would not have occurred under normal conditions

Lab Observations

Flexibility @ -10°F	Failed	Failed	Passed	Failed	Failed	Passed	Faile
Moisture absorption	1.4%	No Test	5.0%	1.6%	1.5%	No Test	No Te
Elongation over cracks @ 0°F	Failed	Failed	Failed	Failed	Failed	Passed	Passe

Recommendations

Recommended for further use	No	No	No	No	No	Yes	Ye
Await follow-up evaluations							

SUMMARY OF MEMBRANE SYSTEMS APPLIED IN 1971 & 1972

(See Reports 72-10 and 73-1)

Field Observations	Bon-Lastic Membrane (Polyurethane)	Polytok Membrane 165 (Polyurethane)	Polytok Membrane 165 (with roofing sheet overlay)	Uniroyal Liquid Membrane 6125 (Rubberized Asphalt)	Heavy Duty Bitu-thene (Sheet Membrane)
Surface preparation required	Wash & Sweep	Wash & Sweep	Wash & Sweep	Wash & Sweep	Wash & Sweep
Moisture sensitive	Yes	Yes	Yes	Yes	Yes
Ease of application	Average	Average	Average	Difficult	Difficult
Bond & seal at curb	Good	Good	Good	Fair	Fair
Bubbles and/or pin-holes in membrane	Yes/Yes	Yes/Yes	Unknown	Yes/Yes	Yes/No
Electrical resistance prior to pavement overlay in ohms/sf	480,000	60,000 to 2,600,000	1,300,000 to 8,000,000	51,600	Infinity
Bond between pave-ment and membrane	Poor	Poor	Fair	Good	Good
Difficulty with pavement applica-tion over membrane	No	No	No	Yes	Yes
Loss of pavement stability under traffic	No	No	No	Yes	No
Cost per s.y. not including pavement	$4.50	$4.50	$4.50	$9.00	$7.25

Lab Observations

Flexibility @ -10°F	Passed	Passed	No Test	Failed	Passed
Moisture absorption	3.0%	2.9%	No Test	No Test	No Test
Elongation over cracks @ 0°F	Failed	Failed	No Test	Failed	Passed

Recommendations

Recommended for further use	No				Yes
Await follow-up evaluations		X	X	X	

SUMMARY OF MEMBRANE SYSTEMS APPLIED IN 1971 & 1972

(See Reports 72-10 and 73-1)

Field Observations	Duralkote 304 (Epoxy Paint)	Duralbond 102 (Epoxy Bonding Compund)	Rambond 223 (Epoxy)	Rancoat Epoxy Paint	Tar Emulsion (2 Coats)
Surface preparation required	Sandblast or Acid Etch	Sandblast or Acid Etch	Sandblast or Acid Etch	Sandblast or Acid Etch	Wash & Swee
Moisture sensitive	Yes	No	No	Yes	No
Ease of application	Easy	Average	Difficult	Easy	Easy
Bond & seal at curb	Good	Good	Fair	Fair	Poor
Bubbles and/or pin-holes in membrane	Yes/Yes	Yes/Yes	Yes/Yes	No/Yes	No/Yes
Electrical resistance prior to pavement overlay in ohms/sf	41,000	1,200,000	5,100	1,100	No Test
Bond between pave-ment and membrane	Poor	Poor	Poor	Poor	Good
Difficulty with pavement applica-tion over membrane	No	No	No	No	No
Loss of pavement stability under traffic	No	No	No	No	No
Cost per s.y. not including pavement	$5.73	$9.99	$22.15	$1.32	$1.40

Lab Observations

Flexibility @ -10°F	Failed	Failed	Failed	Passed	Failed
Moisture absorption	3.6%	1.4%	No Test	0.8%	1.9%
Elongation over cracks @ 0°F	Failed	Failed	Failed	Failed	Failed

Recommendations

Recommended for further use	No	No	No		No
Await follow-up evaluations				X	

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 Uniroyal	8-18-71	4	52	56	82	50	63	51
3 Tar Emulsion	7-20-71	4	164	136	36	33	35	34
4 Uniroyal	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 Bonlastic	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 Duralkote 304	7-12-72	3	296	89	101	56		
10 Duralkote 306	7-29-72	3	117	64	82	84		
11 H. D. Bituthene	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 Polytok 165	5-13-72	3	53	40	32	37	31	38
16 Duralbond 102	7-20-72	2	50	31	55	36	22	41
17 Polytok 165	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 Rambond 620-S	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 Polyastics	5-7-73	2	127	69	38	34	55	39
23 Duralkote	4-21-73	2	30	29	40	35	39	32
24 Royston #10	5-2-73	2	37	39	40	46		
25 Protecto Wrap	4-16-73	2	32	46	44	21		
Approach Slabs (9)	No	3			88	58		
Approach Slabs (9)	Treatment	2			60	32		

Shading 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.