INITIAL RESULTS OF VERMONT FIELD TRIALS OF WATERPROOFING MEMBRANES

BY

R. I. FRASCOIA

RESEARCH SPECIALIST

VERMONT DEPARTMENT OF HIGHWAYS

FOR PRESENTATION AT THE
FIFTY-THIRD ANNUAL MEETING
HIGHWAY RESEARCH BOARD

WASHINGTON, D. C.
JANUARY 21-25, 1974

INITIAL RESULTS OF VERMONT FIELD TRIALS OF WATERPROOFING MEMBRANES

BY

R. I. Frascoia
Research Specialist

INTRODUCTION

Over the past 20 years, it has been Vermont's policy to place a waterproofing system and bituminous pavement over nearly all new concrete bridge decks. The procedure was initially designed to reduce freeze-thaw damage by sealing out moisture and also to provide a smoother riding surface. Prior to 1960, cutback and emulsified asphalts were the primary materials used for waterproofing. In 1960, a two coat application of coal tar emulsion became the standard treatment.

In July 1971, the Department of Highways began active participation in the National Experimental & Evaluation Program - Bridge Deck Protective Systems. The purpose of the Federal Highway Administration sponsored program is to evaluate and report on the many products available for use as bridge deck waterproofing systems. The decision to participate was due to the fact that maintenance was proving necessary on bridge decks within six to eight years after construction. Deterioration was primarily confined to areas adjacent to the curbs and expansion dams. Removal of the pavement from such areas often disclosed concrete in a state of rubble making it possible to be removed with hand shovels.

The cause of the deterioration is believed due to the combination of corrosion of the reinforcing steel which is accelerated by chloride solutions and weather conditions; eg. 75 to 125 freeze-thaw cycles per year, a freezing index of 1200 to 2000 degree-days, and 70 to 150 inches of snow. Although a program is in effect to limit the use of deicing chemicals, applications on state highways have averaged over 98,000 tons per year for the past five years. This has amounted to an average annual application of 36.9 tons per two lane mile.

LABORATORY EVALUATIONS OF MEMBRANE PRODUCTS

Initial selections of membrane products were made without extensive laboratory testing. However, as laboratory and field experience was gained, a series of tests were developed to eliminate products which lacked properties known to be required if the system was to perform satisfactorily. In some cases the tests are similar to procedures developed by other agencies.

All products placed in the field are first applied on 18 inch square concrete test slabs constructed with 2 inch high shoulders and a steel grid reinforcement. The test slabs are exposed to the weather, but are not exposed to sunlight. Each slab is periodically observed for visual signs of deterioration and tested for decreases in electrical resistance. Selected test slabs have also been ponded with a chloride solution and will be cored at specified time intervals. To date, visual observations have disclosed cracks or other signs of deterioration on several of the samples.

All liquid applied materials have been placed on concrete test slabs to determine the product's resistance to moisture absorption and the effect of continuous immersion. Many products have displayed low absorption initially; however, blisters and bubbles have often appeared in the coatings after periods of 90 days or more. Although immersion in water may be considered a severe test, it should be noted that moisture can usually be found between the pavement and membrane under field conditions.

The flexibility of the membrane products has been checked at room temperature and at -10°F by bending samples around a 1 inch mandrel. Crack bridging properties have been checked by breaking cement mortar blocks coated with the membranes over a 3/16 inch anvil.

The sheet membranes have been tested for resistance to puncture or heat damage under conditions similar to those which would occur when the bituminous pavement is applied. This test has been accomplished by placing 275°F, 300°F and 325°F bituminous concrete on membrane samples placed on aluminum panels and applying a load of 200 pounds per square inch. A wetting agent is then ponded on the membrane and bituminous brickette and electrical resistance readings are taken over a period of time to determine if the wetting agent is able to penetrate through the membrane to the metal ground.

Whenever possible, small samples of new membrane products are applied in the field to check the materials' tendency to pinhole or bubble and to obtain electrical resistance readings. Resistance tests on an impervious material should produce readings in excess of 500,000 ohms per square foot.

The laboratory tests have resulted in the elimination of approximately 15 products from consideration for field use.

FIELD APPLICATIONS AND INITIAL REPORTS

All experimental membrane applications have been made on newly constructed interstate bridges with the applications made in accordance with the manufacturers' specifications. The manufacturers were also encouraged to have a technical representative on the project to insure that the proper application procedures were adhered to; however, this was often not possible due to erratic scheduling by the contractors.

Inspection during application has included the logging of pinholes, bubbles, or blisters, placement of moisture sensing copper foil strips beneath the membranes, electrical resistance testing and the application of each membrane system on 18 inch square concrete test slabs for future observation and testing.

Observations have also been made during placement of the bituminous concrete overlays to note any damage to the membrane or difficulties with the application. The bituminous mix is applied with a rubber tired paver in 2 one inch thick courses with 1 1/2 percent asbestos fibers added to the first course. The mix has a maximum aggregate size of 3/8 inches and utilizes an AC 5 viscosity graded asphalt which had an average penetration of 190. Stability problems have occurred on some membrane systems particularly during the construction process due to the low viscosity of the asphalt and the fineness of the mix; however, it is hoped that the absence of large coarse aggregate will prevent future damage to the membrane under continuous traffic loading.

Reports covering each application have included information on bridge and deck construction data; extent and location of any cracks; texture and surface condition of the concrete; membrane product information and prior laboratory test results; application procedure; observations made during the application, including time, temperature, humidity and cloud cover; application rates and any difficulties which occurred during the application; plus initial electrical resistance readings on both the membrane and completed membrane-pavement system. Discussions covering each application have concluded with tentative recommendations regarding continued use of each system.

Follow-up reports shall include information on climatic conditions, deicing chemical applications, traffic data, results of follow-up electrical resistance tests, copper foil strip readings, steel potential readings and chloride analysis of concrete core samples.

EXPERIMENTAL MEMBRANE PRODUCTS

To date 16 products have been applied on 28 bridges under the conditions previously described. The materials can be broken down into two basic types, preformed sheet and applied in place liquid systems. The liquid applied materials can be further broken down into three types, namely polyurethanes, epoxies, and hot or cold applied asphalt or tar based materials.

Following is a summary covering the application and initial performance of each system.

Preformed Sheet Materials

(1) A 65 mil thick sheet composed of a rubberized asphalt and non-tacky bituminous compound reinforced with a woven mesh. The system includes a prime coat

and the use of a mastic along curb joints and at sheet termination points. Attaining proper alignment of the rolls to insure sufficient overlap without waste was somewhat difficult. The material displayed excellent bond and self-sealing characteristics. Water was detected between the membrane and the vertical curb face on the first application and complete loss of bond between membrane and concrete occurred where rain water ponded against expansion dams on a second installation. Air bubbles trapped beneath the membrane did not cause any problems with the pavement application. Reflective cracks occurred in the first course of pavement over the edges and ends of the membrane sheets. They were believed due to expansion and contraction of the sheets caused by the high temperature of the bituminous mix. No cracks occurred in the final course of pavement. Electrical resistance readings were recorded at infinity on the membrane and the pavement membrane system. The material is recommended for further use.

(2) A 70 mil thick sheet composed of coal tar, modified with synthetic resins and reinforced with synthetic non-woven fabric. The system includes the use of a solvent release primer and mastic. Numerous bubbles which occurred in the prime coat were broken with a squeegee prior to placing the membrane. The 50 foot rolls were supplied in 30 inch widths for placement along the curbs and 60 inch widths for the remainder of the deck. A reduction in the amount of entrapped air was accomplished by using a squeegee to apply pressure on the sheet at the point where initial contact was made with the primed concrete. Electrical resistance readings were recorded at infinity on the membrane system. A high volume of heavy construction traffic over the deck for an eight week period following the installation of the membrane resulted in migration of the first one inch course of bituminous pavement. Depressions in the wheel paths were recorded at 3/8 to 3/4 of an inch. Electrical resistance tests averaged 430,000 ohms per square foot in the wheel paths indicating some damage to the membrane system. The material is recommended for further use.

(3) An 80 mil thick sheet composed of an impregnated fiberglass mesh sandwiched between layers of a bituminous mastic and coated with a polyester film. The system includes the use of a solvent release primer and depends on pavement temperatures in excess of 300°F to bond the membrane to the primed concrete. Heat fusion with a torch is recommended to seal the ends of each roll and to bond the membrane to the curb. This method was used with fair success on the first installation; however, care must be exercised to prevent damage by overheating and subsequently melting the membrane. On the second installation a 125 mil thick, four inch wide mastic tape was placed along the base of the curbs and the sheet membrane was pressed into it. This method of sealing the curbs appeared satisfactory; however, water was detected beneath the membrane at several locations prior to paving the deck. Entrapped air and wrinkles were kept to a minimum by applying pressure with a squeegee as the sheets were unrolled. Additional benefits derived from the use of a sidewalk roller were hard to distinguish. The membrane was applied without difficulty on a 5° curve by placing the sheets in a series of 25 foot long tangent strips. On the second installation little bond was noted between the membrane and the concrete when the pavement and membrane were removed from several locations for inspection. The lack of bond was believed due to a rapid heat loss from the bituminous mix caused by 38°F to 43°F air temperatures which prevented sufficient transfer of heat to satisfactorily soften the membrane. The lack of bond between membrane and deck would not necessarily be a problem if the entire system remained waterproof; however, if leakage did occur at any location, the water would be free to travel laterally beneath the membrane thus contaminating a larger area. Electrical resistance

readings were recorded at infinity on the membrane and the pavement membrane system. The material is recommended for further use.

Liquid Applied Materials

Polyurethanes

(1) A two component modified polyurethane elastomer. The system includes a solvent thinned prime coat, 40 mil finish coat, and a roofing sheet protective overlay. Lack of bond between the roofing sheet and the polyurethane resulted in pavement application problems on the first of two decks. Quicker installation of the roofing sheet on the second deck prevented a recurrence of the problem; although, fishmouths occurred at periodic intervals along the edges of the sheet. The polyurethane appeared to effectively seal the concrete along the critical curb areas. Poor bond was noted between the prime and finish coats in one area. Pinholes and bubbles were noted in areas not covered with roofing sheets. Electrical resistance readings in such areas varied from an average of 60,000 ohms on one deck to over 2 million ohms per square foot on the second deck. Readings on the membrane with roofing sheet were generally satisfactory on both decks ranging between 1 million and 7 million ohms. Bubbles formed in coatings immersed in water for a 10 month period. Further use of the material is suspended until long term evaluations can be obtained.

(2) A two component, tar modified polyurethane elastomer. The system includes the use of a solvent based urethane primer, 40 mil finish coat and a 30 to 50 pound roofing felt overlayment. The roofing felt was not used due to the problems which had occurred with the earlier polyurethane application (see (1) above). The completed membrane contained an average of 49 pinholes and 10 bubbles per square foot; although, few were apparently open to the concrete since electrical resistance readings averaged 480,000 ohms per square foot. Foaming was noted in areas where the thickness of the polyurethane exceeded the recommended 40 mils. Tests conducted on foamed samples cut from the deck disclosed absorption rates ranging from 4% to 102%. The manufacturer has recently advised that the components have been modified to prevent foaming. The material effectively sealed the concrete along the critical curb areas and has sufficient flexibility to bridge small cracks in the concrete. Copper foil strips placed beneath the membrane have disclosed a gradual decrease in electrical resistance and now indicate that chloride solutions have migrated though the pavement and membrane at the test location. Further use of the material is suspended until long term evaluations can be obtained.

Epoxies

(1) A two component, solvent cut epoxy applied in two coats using paint rollers. Application rates averaged 117 and 164 square feet per gallon for a total dry film thickness of 12 mils. Although no pinholes could be detected in the completed system, electrical resistance readings were very low, averaging 1100 ohms per square foot. Samples of the epoxy displayed excellent flexibility at all temperature ranges, but could not bridge new cracks in a bridge deck due to the thinness of the coating. Further use is suspended until long term evaluations

can be obtained.

(2) A two component, solvent cut epoxy applied in two coats using paint rollers. Application rates averaged 128 and 143 square feet per gallon for a total wet film thickness of 26 mils. Pinholes were detected throughout the system ranging from few in number to as many as 1700 per square foot. Air bubbles were also noted in areas given a heavier than average coat. Electrical resistance readings were low averaging 40,100 ohms per square foot. Field observations have recently disclosed that the coating has cracked and peeled from the concrete at many locations adjacent to the curbs. Blisters and bubbles have formed in coatings immersed in water. The material is not recommended for further use as a bridge deck membrane.

(3) A two component solvent cut polyamide epoxy applied in two coats by airless spray and squeegee. Application rates were in the range of 100 to 120 square feet per gallon per coat for a total wet film thickness of 30-34 mils. Air bubbles and bubble-crater combinations averaging 91 per square foot were logged on the system applied with squeegees while the number of bubbles and pinholes varied on a spray application. Electrical resistance readings averaged 65,700 and 76,500 ohms per square foot. The material was selected for use because of good flexibility characteristics; however, concrete samples coated in the field have developed cohesive cracks in the coating even though the epoxy remains flexible to the touch. The material is not recommended for further use as a bridge deck membrane.

(4) A two component 100% solids epoxy, applied in one coat by troweling. Application rate averaged 19.7 square feet per gallon for a dry film thickness of 82 mils. The coating contained an average of 49 pinholes per square foot at least 40% of which were open to the concrete. Electrical resistance readings were low averaging 5100 ohms per square foot. The epoxy is very durable but has poor flexibility and is not recommended for further use as a bridge deck membrane.

(5) A two component 100% solids epoxy applied in two coats using squeegees. Application rates averaged 60 and 90 square feet per gallon for a total dry film thickness of 48 mils. Air bubbles and a few pinholes were noted in the system, although testing did not disclose any exposed concrete. Electrical resistance readings were generally satisfactory, averaging 1.15 million ohms. Follow-up electrical resistance readings have decreased indicating failures in the coating possibly due to the materials' lack of flexibility. The material is not recommended for further use as a bridge deck membrane.

(6) A two component 100% solids stress-relieving epoxy. The material was applied in three coats using squeegees. Application rates averaged 51, 77, and 80 square feet per gallon for a total dry film thickness of 72 mils. Pinholes averaging 90 per square foot in the first coat were reduced to 35 per square foot with the second coat and were further reduced to an average of 4 with the third coat of epoxy. Electrical resistance readings rose from an average of 11,700 with one coat to 53,000 ohms per square foot for the completed system. Although initial laboratory tests indicated the epoxy possessed average resistance to moisture absorption, extended testing has since disclosed that the epoxy will soften under continuous immersion. The material is not recommended for further use as a bridge deck membrane.

(7) A two component, 100% solids coal tar modified epoxy. The product has been placed on two structures utilizing a two coat system applied with squeegees. Application rates on the first structure averaged 90 and 32.9 square feet per gallon for a total dry film thickness of 69 mils. A large number of bubbles and pinholes occurred in the first coat; but very few were found in the completed system. Electrical resistance readings were high, averaging 30 million ohms per square foot. Application of the product on a second bridge proved unsatisfactory due to extensive bubbling (30/sf) and pinholing (171/sf). Electrical resistance readings averaged 90,500 ohms per square foot. Laboratory tests indicate low moisture absorption and fair flexibility. Further use is suspended until long term evaluations can be obtained.

Coal Tar Systems

(1) Tar emulsion, applied in two coats at the rate of 0.1 to 0.2 of a gallon per square yard per coat. This material was initially used as the control system. It is not moisture sensitive and requires little surface preparation of the concrete. Tar emulsion is the only liquid applied material used to date which has not developed air bubbles or pinholes. The absence of bubbles or pinholes may be due in part to the slow set time and the low viscosity of the material (specifications allow a maximum of 55 percent water) or it may be due to bleed channels in the coating caused by the evaporation of water which in turn allow the escape of air and moisture vapor from the concrete. Cured samples of tar emulsion gained weight when immersed in water but did not regain their flexibility. Concrete samples treated with tar emulsion absorbed as much water as untreated samples. Chlorides have been detected in concrete cores taken from bridge decks treated with two coats of tar emulsion. The system is not recommended for further use as a bridge deck membrane.

(2) Tar emulsion and woven glass fabric. The system consists of five coats of tar emulsion and two layers of glass fabric. The tar emulsion is applied at the rate of 0.1 gallon per square yard per coat. The material was used on five bridges as the control system. The normal, rough configuration of the curb sections made it impossible to obtain a seal at many points. Electrical resistance readings averaged 3800 ohms per square foot indicating that the system allows moisture to pass through it. Some concrete test slabs treated in the field developed blisters and delaminations of the individual layers when exposed to water and freeze-thaw cycles. The system is not recommended for further use as a bridge deck membrane.

Hot Applied Materials

(1) A hot-applied rubberized asphalt compound. The system includes a prime coat and rubber sheet used to reinforce the system along the curbs and over cracks or joints. The rubberized asphalt was applied by squeegee at the rate of one pound per square foot for an average thickness of 3/16 inch. Air bubbles were noted in the membrane on all applications, with visible areas of concrete often detected when individual bubbles were broken open for inspection. Generally, the material bonded well to the concrete; although, exceptions were noted. Water was able to enter the system and travel along the curbs beneath the membrane and rubber

sheet on two of the four decks treated. Electrical resistance readings on the membrane were low, averaging 51,600 ohms per square foot. Softening of the membrane caused by the heat of the bituminous mix made the compaction of the first course of pavement difficult. Migration of the first course of pavement and membrane due to construction traffic necessitated the removal of the pavement from one deck. Lateral migration of the finish pavement has occurred on a bridge deck banked 15/16 inches per foot. The material should not be considered for use on bridges with excessive superelevation or grades over approximately 3%. Further use is suspended until long term evaluations can be obtained.

(2) Hot mopped asphalt and woven glass fabric. The system consists of a cutback asphalt prime coat, three coats of asphalt and two layers of glass fabric. The asphalt is applied at the rate of 0.33 gallon per square yard per coat. The glass fabric is placed in the hot asphalt beginning at the curb line and each succeeding strip overlaps the previous strip by a half-width. Asphalt temperatures often exceeded the 350°F maximum specified, due to local overheating in the kettle and because the roofing applicator was accustomed to heating the asphalt in excess of 450°F to increase workability. Such overheating could decrease the coatings' flexibility. Application rates were difficult to control. Large wrinkles in the glass fabric were cut out with knives and patched. Air bubbles and pinholes were noted in the prime coat and in each of the three mopped coatings. The holes were generally 1/16 inch or less in diameter with the number averaging 121 per square foot. Electrical resistance readings averaged 46,000 and 71,000 ohms per square foot on the two decks treated. The system is not recommended for further use as a bridge deck membrane.

SUMMARY

As the product summaries note, initial observations and test results indicate that the preformed sheet systems show the most promise in preventing moisture and chloride solutions from entering the concrete. The major problem noted with such systems lies in obtaining a satisfactory seal along the curb lines and expansion dams. Consideration is being given to the application of a polyurethane coating along such areas in conjunction with the use of preformed sheet materials on the deck surface. Laboratory tests are now under way to determine compatibility of the different products.

In nearly all cases, applications of liquid applied materials were plagued by pinholes, air bubbles or blisters due to outgassing of air/or moisture vapor from the concrete. The condition is caused primarily by increases in air temperature or a reduction in the barometric pressure. The pinholes or craters do not always remain open to the concrete; however, this often depends upon conditions such as the weather which cannot be controlled or duplicated. Although close visual inspection or testing with hydrochloric acid may not reveal exposed concrete, electrical resistance tests will often indicate that a system is not impervious. It should be recognized that even if pinholes or craters are not initially open to the concrete, they are potential weak points due to the lack of cover and may act as funnels if the pinholes later open up. This could happen due to shrinkage of the coating from additional curing or aging.

A number of different application techniques may be used to reduce the number of pinholes and air bubbles in a liquid membrane coating. They include application of a low viscosity prime coat to seal off a high percentage of the bleed channels in the surface of the concrete, application of a series of thin coats rather then one heavy coat, preheating the concrete with infrared heaters prior to the membrane application or application of the materials in the afternoon when air temperatures begin dropping. Such procedures will generally prove helpful but cannot always be depended upon. As an example, one of our epoxy applications was made late in the day to avoid the outgassing problem. Although the procedure was successful in preventing pinholes or bubbles from initially forming, insufficient overnight curing of the epoxy due to lower air temperatures resulted in extensive bubbling in the coating late the following morning when air temperatures began to rise.

Although many experiences have been reported relating to the outgassing problem, little is known on the actual effect of a specific number of pinholes in a membrane system. For this reason a laboratory study has been initiated to obtain information on the rate of chloride penetration through membrane coatings containing specific numbers of pinholes or bubbles. Concrete test slabs containing thirty-two individual test areas were constructed for this purpose and treated with polyurethane and epoxy products. Different numbers of pinholes were obtained by varying the number of coats and the time of application. A three percent sodium chloride solution is being applied daily on the test slabs and steel potential readings are being taken. As the tests progress, cores will be taken to determine the amount of chloride build up and its relationship to the potential readings. Electrical resistance readings taken on the coatings will also be compared with chloride penetration and the time to corrosion of the reinforcing steel. If the study proves that only harmless amounts of chlorides are able to penetrate through coatings containing pinholes, more extensive use of liquid applied materials will be considered.

FUTURE EXPERIMENTAL APPLICATIONS

Experimental membrane applications are scheduled for 19 bridges in 1974. The products include three preformed sheet membranes previously applied, a reinforced non-curing hydro-carbon rubber sheet system, and an unmodified polyurethane system which utilizes a low viscosity epoxy prime coat to reduce pinholing and bubbling. The experimental work will also include the application of the five most promising membrane systems selected during the first phase of the NCHRP Project 12-11, Waterproof Membranes for Protection of Concrete Bridge Decks. The installation of the five systems will be made in cooperation with Materials Research & Development of Oakland, California as a portion of the Phase II Study.

Membrane applications on bridges not included in the experimental program will be covered by a specification limiting the type of system to preformed sheet materials.

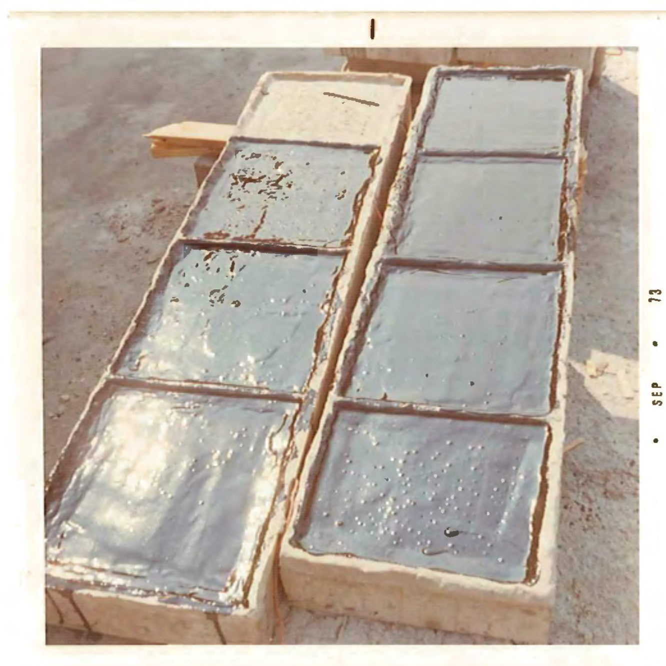
PRODUCT EVALUATION SUMMARY

Field Observations	Preformed Sheet Membranes	Asphalt or Tar Modified Polyurethanes	Solvent Cut Epoxies	100% Solids Epoxies	Cold Tar Modified Epoxies	Tar Emulsion and Glass Fabric	Hot Mopped Asphalt and Glass Fabric	Hot Applied Rubberized Asphalt
Surface preparation required	Wash & Sweep	Wash & Sweep	Sandblast or Acid etch	Sandblast or Acid etch	Sandblast or Acid etch	Wash & Sweep	Wash & Sweep	Wash & Sweep
Moisture sensitive	Yes	Yes	Yes/No	Yes	Yes	No	Yes	Yes
Ease of application	Average	Easy	Easy	Easy	Easy	Average	Diffi-cult	Diffi-cult
Bond & seal at curb	Fair/Good	Good	Poor	Poor	Fair	Poor	Fair	Fair
Bubbles and/or pin-holes in membrane	No	Yes	Yes	Yes	Yes	No	Yes	Yes
Electrical resistance prior to pavement overlay in ohms/sf	Infinity	60,000 2 M	1,100 40,100	5,100 53,000 1.15 M	90,500 30 M	3,900	46,000 71,000	52,000
Bond between pave-ment and membrane	Good	Poor/ Fair	Poor/ Fair	Poor/ Fair	Poor/ Fair	Good	Good	Good
Difficulty with pavement applica-tion over membrane	Yes/No	Yes/No	No	No	No	No	No	Yes
Loss of pavement stability under traffic	No	No	No	No	No	No	No	Yes
Cost per s.y. not including pavement	$6.15	$4.50	$4.76	$14.80	$11.25	$3.75	$3.75	$9.00
Lab Observations								
Flexibility	Good	Good	Poor/ Fair	Poor/ Good	Fair	Poor	Poor	Fair
Moisture absorption	----	Poor/ Fair	Fair/ Good	Poor/ Good	Good	Poor	Fair to good	----
Elongation over cracks	Good	Fair/ Good	Poor	Poor/ Fair	Fair	Poor	Poor	Fair
Recommendations								
Recommended for further use	Yes			No		No	No	No
Await follow-up evaluations		X	X		X			

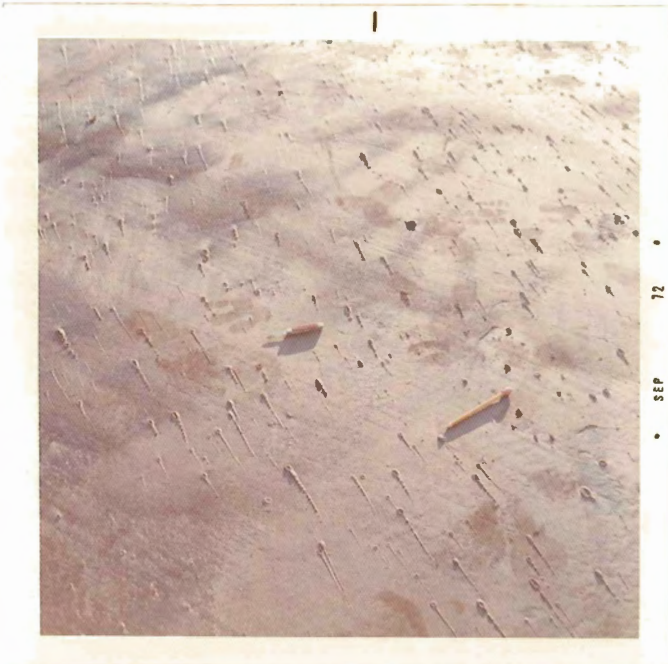
Puncture resistance of preformed sheet membranes being checked with an electrical resistance test

Laboratory and field applied membrane coatings are periodically checked for decreases in electrical resistance

Copper foil strips placed beneath a membrane to detect the passage of moisture



Two of eight concrete test slabs treated with liquid membrane products to study the relationship between pinholes and chloride intrusion



Air bubbles and craters in a cured polyurethane membrane. The type and number of holes and bubbles often varied with each application

Lack of bond between roofing sheet and polyurethane caused blockage of the paver screed

Water detected beneath top course of rubberized asphalt and rubber sheet along the base of the granite curb

Visual checks of air bubbles in a hot applied rubberized asphalt disclosed that most were open to the concrete