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IOWA STATE HIGHWAY COMMISSION

MATERIALS DEPARTMENT

R-262

Bridge Deck Waterproofing Membrane Study

December, 1974

Iowa a place to grow

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[redacted]

H. E. GUNNERSON
Chief Engineer

January 6, 1975

REFER TO: 435.24031

KHD
p/s acknowledge
w/ thanks etc
LH
1-20-75

Mr. George Zuehle
Department of Transportation
Madison, WI 53702

Dear Mr. Zuehle:

Enclosed is a copy of project R-262, "Bridge Deck Waterproofing Membrane Study", which may be of interest to you.

Any comments or suggestions concerning this report would be welcomed.

Yours very truly,

George Calvert

George Calvert
Materials Engineer

GC:ab
Enclosure

Report given to
DLL for indexing
and fwding to 3TC
TCD

IOWA STATE HIGHWAY COMMISSION

MATERIALS DEPARTMENT

Special Investigations Section

R-262

BRIDGE DECK WATERPROOFING MEMBRANE STUDY

December, 1974

Materials Laboratory

By

Terry L. Legvold
Senior Engineer-in-Training

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BRIDGE DECK MEMBRANE REPORT

1.0 Introduction

One of the main problems of bridge maintenance in Iowa is the spalling and scaling of the decks. This problem stems from the continued use of deicing salts during the winter months. Since bridges will frost or freeze more often than roadways, the use of deicing salts on bridges is more frequent.

The salt which is spread onto the bridge dissolves in water and permeates into the concrete deck. When the salt reaches the depth of the reinforcing steel and the concentration at that depth reaches the threshold concentration for corrosion(1) (1.5 lbs./yd.^{3}), the steel will begin to oxidize. The oxidizing steel must then expand within the concrete. This expansion eventually forces undersurface fractures and spalls in the concrete. The spalling increases maintenance problems on bridges and in some cases has forced resurfacing after only a few years of service.

There are two possible solutions to this problem. One solution is discontinuing the use of salts as the deicing agent on bridges and the other is preventing the salt from reaching or attacking the reinforcing steel. This report deals with one method which stops the salt from reaching the reinforcing steel.

(1) From the report "Corrosion Autopsy of a Structurally Unsound Bridge Deck" by Richard A. Stratfull of the California Division of Highways.

The method utilizes a waterproof membrane on the surface of a bridge deck. The waterproof membrane stops the water-salt solution from entering the concrete so the salt cannot reach the reinforcing steel.

2.0 Purpose

The purpose of this study is to:

1. Determine a set of tests to evaluate bridge deck membranes.
2. Evaluate the various membranes.

3.0 Materials

The concrete blocks (12"x12"x2 1/2") used in this study were made from a D-57 mix. The coarse aggregate was crushed limestone from the Fort Dodge quarry meeting the grading requirements of AASHO 57. The fine aggregate was sand from Hallett's pit at Ames and met the grading requirements of Section 4110.03 Standard Specifications. A blend (R-11 blend) of Type I cements from seven different producers was used in the blocks. The air entraining agent was a neutralized vinsol resin produced by Carter-Waters of Kansas City, Missouri.

Some of the blocks had a concaved top surface and others had a flat top surface. For some of our testing 4" cores were drilled out of the blocks with the flat surface. These cores were then cut down to a thickness of about 1 1/2" for shear testing.

The crack bridging test utilized 16"x8"x1 3/4" concrete patio blocks purchased from a local company. The surfaces of these blocks were quite porous so a mortar was used to seal one surface. The mortar was made from the R-11 blend cement and a washed concrete sand.

A number of 3/8" Type A asphaltic concrete hot mixes were used for the shear testing and the resistivity testing. Some of the mixes had asbestos fibers and a higher asphalt content.

A penetrating epoxy sealer, PE 50, manufactured by the Steelcote Manufacturing Company, was used in the blister study.

The following is a list of membranes, their manufacturers, and the membrane type that has been tested to date:

Membrane	Manufacturer	Material Type
Coal Tar Emulsion	Koppers Company, Inc.	Liquid Coal Tar Emulsion
Deck Coat	Steelcote Mfg. Co.	Gray Liquid Coating
Carlisle Butyl	Carlisle Corp.	1/16" Butyl Rubber Sheet
Gacoflex N-36	Gates Engr.	1/16" Neoprene Rubber Sheet
Heavy Duty Bituthene	W. R. Grace Co.	Preformed Reinf. Rubberized Asphalt
NEXDECK	U. S. Steel Corp.	Hot Applied Rubberized Asphalt
Husky Deck #4	George M. Jones Co.	Hot Applied Rubberized Asphalt
Polytok 165	Carboline Co.	Liquid Urethane
Gacoflex UWM-28	Gates Engr.	Liquid Urethane
Polyguard #875-G	Polyguard Pipeline Products Co.	Preformed Reinf. Coal Tar

Membrane	Manufacturer	Material Type
Nordel	DuPont Dist. by Carlisle	Hydrocarbon Rubber Sheet
Protecto Wrap M-400	Protecto Wrap Co.	Preformed Reinf. Coal Tar
Petroset & Petromat	Phillips 66 Petroleum	Fabric Reinf. Asphalt Emulsion
Super Seal 4000	Superior Products Co.	Hot Applied Elastomeric Polymer

A list of protection boards with the manufacturer and their material type that has been used in testing follows:

Manufacturer	Protection Board Type
W.R. Grace Co.	1/8", filled asphalt board
Protecto Wrap Co. (P-100)	40 mil, coal tar on each side with reinf. between
W.R. Meadows (Vibraflex-Highway)	1/8", mineral filled asphalt board with asphalt felt on one side

A list of adhesives, their manufacturers, and their material type follows:

Adhesive	Manufacturer	Material Type
Sure Seal #9600	Carlisle Corp.	Contact cement
Sure Seal 90-8-30A	Carlisle Corp.	Contact cement
Polyguard #800	Polyguard Pipeline Products Co.	Coal Tar, Solvent Solution
Bituthene Primer	W.R. Grace Company	Asphalt, Solvent Solution
Protecto Wrap Primer	Protecto Wrap Co.	Coal Tar Synthetic Resin
Gacoflex N-7	Gates Engr.	Contact Cement

Adhesive	Manufacturer	Material Type
Speedepoxy SY-1 White	Steelcote Mfg. Co.	Rapid Set Epoxy Primer
MC-70 Tack	--	Asphalt cut back
Coal Tar Emulsion	--	Coal Tar emulsion
Ureloid Liquid Mem. Adhesive	Applied Polymers of America	1 comp. polyurethane bitumen
Asphalt Cement	--	Asphalt cement
Gardox	W. R. Meadows, Inc.	Liquid coal tar base neoprene
Gacoflex UWM-28	Gates Engr.	2 comp. polyurethane

4.0 Initial Tests

When bridge deck membranes were first considered for use in Iowa there were no standard tests available for evaluating them. For this reason the initial membrane testing was conducted on an experimental basis. From this initial testing a set of suitable standard tests was to be found.

A. Compaction - Visual Observation Testing (Membrane)

The visual observation membrane tests were to visually determine the effect of the hot mix on the membrane. It was suspected that the addition of the hot mix could possibly harm a membrane's waterproofing properties.

1. Test Procedure

6"x6"x30" aluminum beam molds were filled to 2/3 of their capacity with concrete as shown in Figure 1.

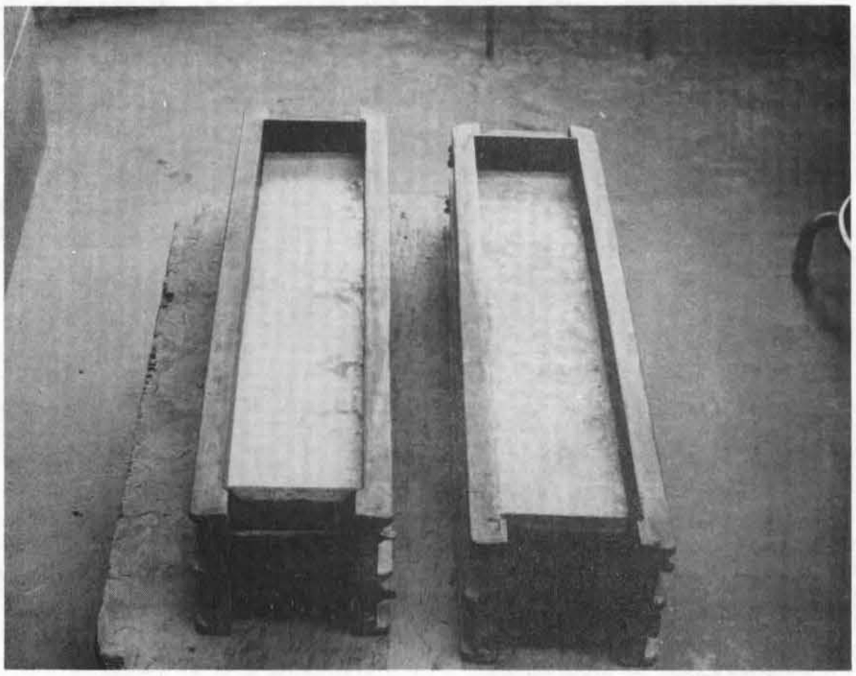

Figure 1

6"x6"x30" aluminum beam molds with the concrete used in Visual Membrane Testing and Visual Adhesion Testing

A polyethelene plastic sheet was placed in the molds on the concrete so the membrane could later be separated from the beam. The membrane followed by another plastic sheet was applied to the first layer of polyethelene. A vibrator compacted layer of hot (270°F to 310°F) asphaltic concrete was then placed on top of the sheet of plastic in half of the mold as shown in Figure 2.

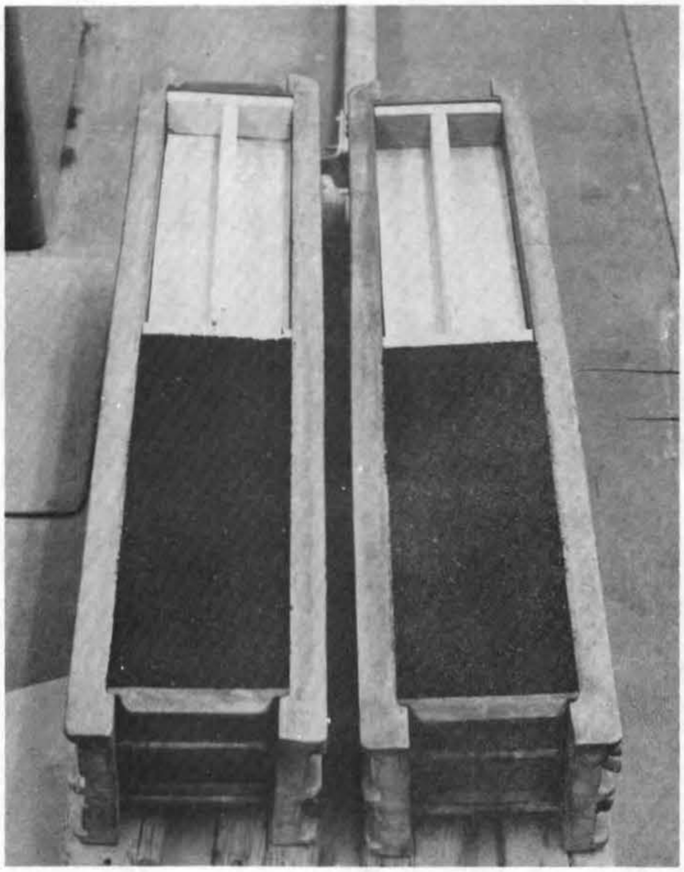

Figure 2

Molds with membrane system and asphaltic concrete in place

After a 24 hour curing period the test specimens were removed from the molds and the asphaltic concrete and portland cement concrete was separated from the membrane. The membrane was then visually inspected for possible damages caused by the asphaltic concrete.

2. Results of Membranes Tested

The membranes tested in this manner were: Heavy Duty Bituthene, butyl rubber and coal tar emulsion.

The Heavy Duty Bituthene membrane was a preformed, reinforced, rubberized asphalt. A visual observation of this membrane after testing showed that there was no damage done by the asphaltic concrete overlay.

The butyl membrane is a 1/16" thick preformed sheet of butyl rubber. The visual evaluation of the butyl also showed no damage done by the overlay.

The coal tar emulsion membrane was built up in layers of liquid coal tar emulsion and fiberglass mesh. The first two layers were coal tar emulsion followed by a layer of fiberglass mesh, another layer of emulsion, a layer of fiberglass and a final layer of emulsion in the form of a slurry. Each layer of emulsion was allowed to dry at least eight hours with the slurry coat receiving a 24 hour drying period. This membrane had a considerable amount of melting and holes where the overlay had been placed (Figure 3). It had lost its waterproofing properties.

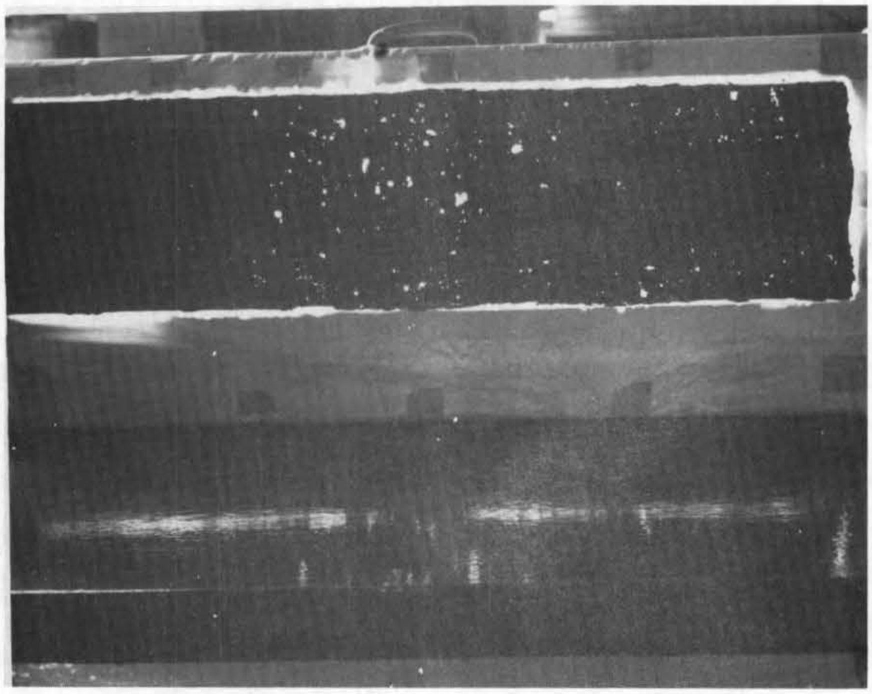

Figure 3

Coal tar emulsion membrane after asphalt overlay had been removed

Another test was made on the coal tar emulsion membrane to verify the results of the first test. Again the results were the same, the membrane sustained a large amount of damage from the overlay.

B. Compaction-Visual Observation Testing (Adhesives)

The visual observation adhesive tests were for the purpose of visually evaluating the effect of the hot mix on adhesives. These tests were also used to determine the proper application procedure for some adhesives.

1. Test Procedure

A beam mold 2/3 filled with P.C. concrete was used for this test also. On half of the first test specimen a contact adhesive was applied to the concrete and the butyl rubber with a short nap paint roller (Figure 4). After the adhesive had dried the butyl was placed on the concrete.

The other half of this specimen had the adhesive applied only to the butyl rubber. Again when the adhesive had dried the butyl was placed on the concrete.

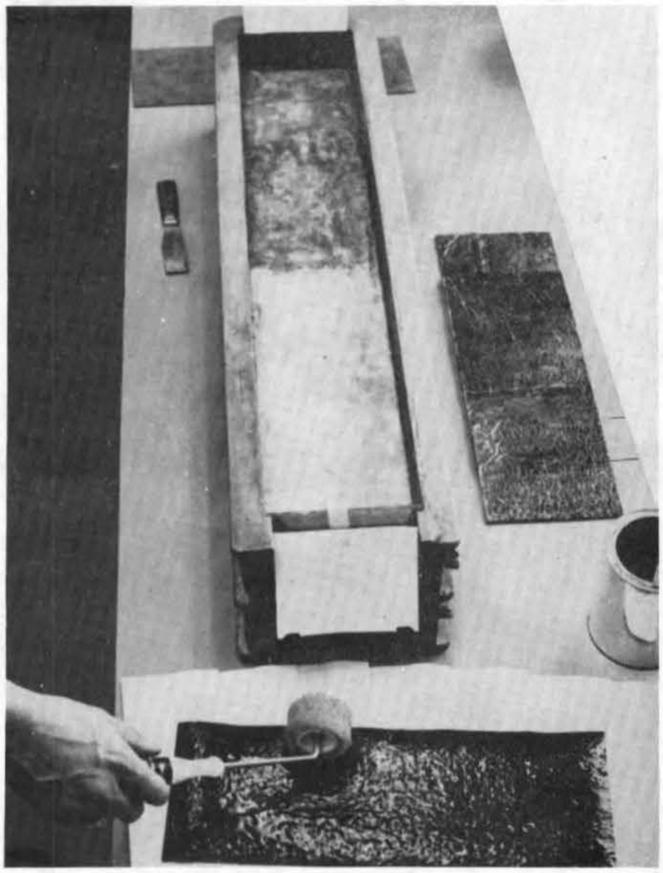

Figure 4

Contact adhesive being applied to butyl rubber

A piece of Meadows protection board was then laid unbonded onto the butyl. This protection board was placed on the membrane as a protective layer between it and the asphaltic concrete.

The second test specimen had a piece of butyl placed unbonded over the full length of the beam. The protection board was then bonded to the butyl with an asphalt emulsion on half of the specimen and an asphalt cement on the other half as shown in Figure 5.

A vibrator compacted layer of asphaltic concrete was then placed on the protection board of both specimens. After a 24 hour curing period the specimens were removed from the mold and the asphaltic concrete was separated from the membranes.

2. Results of Adhesives Tested

The contact adhesive used on the first specimen was Sure Seal 90-8-30A. A much better bond was observed between the beam and the butyl where both surfaces had been treated with the Sure Seal indicating that the contact cement should be applied to both contacting surfaces to be effective.

The second specimen used a C-SS1-H asphalt emulsion and an 85-100 penetration asphalt cement as the test adhesives. Both adhesives were difficult to apply evenly and the asphalt cement was especially hard to handle because it cooled rapidly. Neither adhesive appeared to provide a satisfactory bond between the butyl rubber and the protection board.

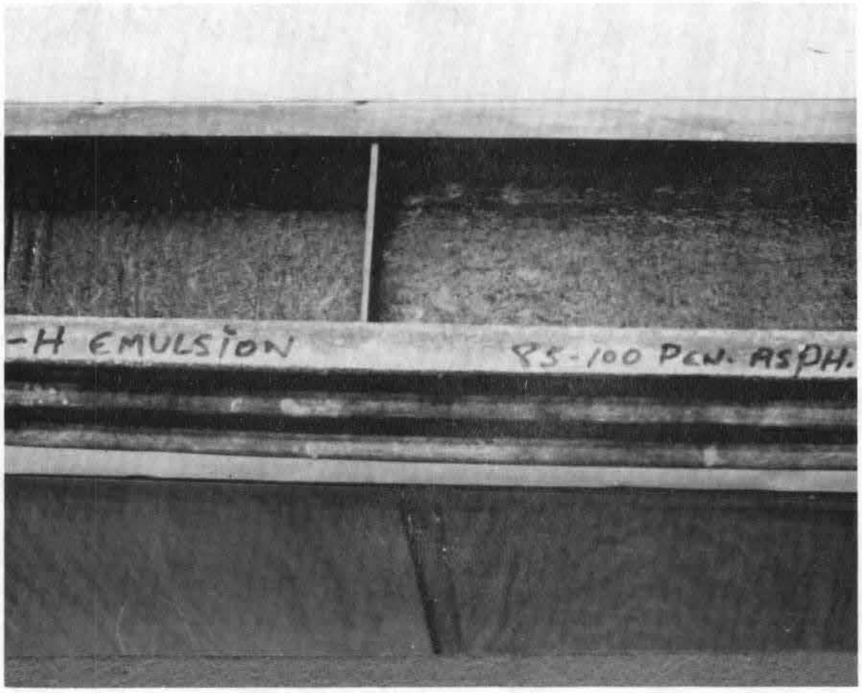

Figure 5

Beam with C-SS1-H asphalt emulsion and 85-100 penetration asphalt as adhesives between butyl and protection board

An excellent bond was obtained between the asphaltic concrete and the protection board on both specimens. A portion of the asphalt cement on the protection board melted into the asphaltic concrete overlay forming this firm bond.

C. Initial Tests Summary

The initial tests led to the development of our present tests and testing procedures. They illustrated what properties were important for a bridge deck waterproofing membrane. It was found, however, that the results determined only from visual observations were helpful but did not fully evaluate the situation. Tests having specific results were a necessity.

Some positive results were obtained from the initial testing. The coal tar emulsion was found to be unsatisfactory. Tests showed that its waterproofing ability was severely impaired when the asphaltic concrete overlay was added. The overlay made holes completely through the membrane as was shown in Figure 3.

Additional tests made at this time showed that the Heavy Duty Bituthene membrane and the butyl rubber membrane were acceptable. When a protection board was used in the membrane system the addition of the overlay had no adverse effects on the membrane. If the protection board was not used there was a possibility that the membrane might be harmed.

A variety of adhesives were tested to investigate the effect of the hot overlay. Some were found to be of little value because they were hard to handle and melted when heated by the overlay. The contact cements were most effective when both contacting surfaces were treated with adhesive.

5.0 Qualitative Test Selection

Up to this point, the results of all of the testing had been determined visually. It was decided to utilize tests that had qualifying answers. The tests introduced at this time were called the resistivity test, the shear test and the crack bridging test.

A. Resistivity Test

The resistivity test was developed from HRR-357 "An Electrical Method for Evaluating Bridge Deck Coatings" by Donald L. Spellman and Richard E. Stratfull of the Materials and Research Department, California Division of Highways.

The resistivity test determines the waterproofing ability of a membrane. The test consisted of placing the membrane system, including the protection board and asphaltic concrete overlay, on a 12"x12"x2½" portland cement concrete slab and determining the resistance to flow of electrical current through the membrane.

The measure of resistivity was made through the asphaltic concrete overlay, the membrane system, and the portland cement concrete slab. The effect of the asphalt overlay could be observed by making a resistivity test both before and after its placement.

The anode and cathode for this test were 8"x9" (one half square foot) sponge pads attached to copper plates. After the pads were wetted to provide a medium for electrical flow, one of them was placed on the bottom of the test specimen and one on top. The sides of the specimens were coated with parafin to prevent the water from escaping and providing a path of lesser resistance between the test pads. An ohmmeter was then attached between the two pads and the resistance measured through the specimens. The resistivity apparatus and a resistivity test is shown in Figures 6 and 7 respectively.

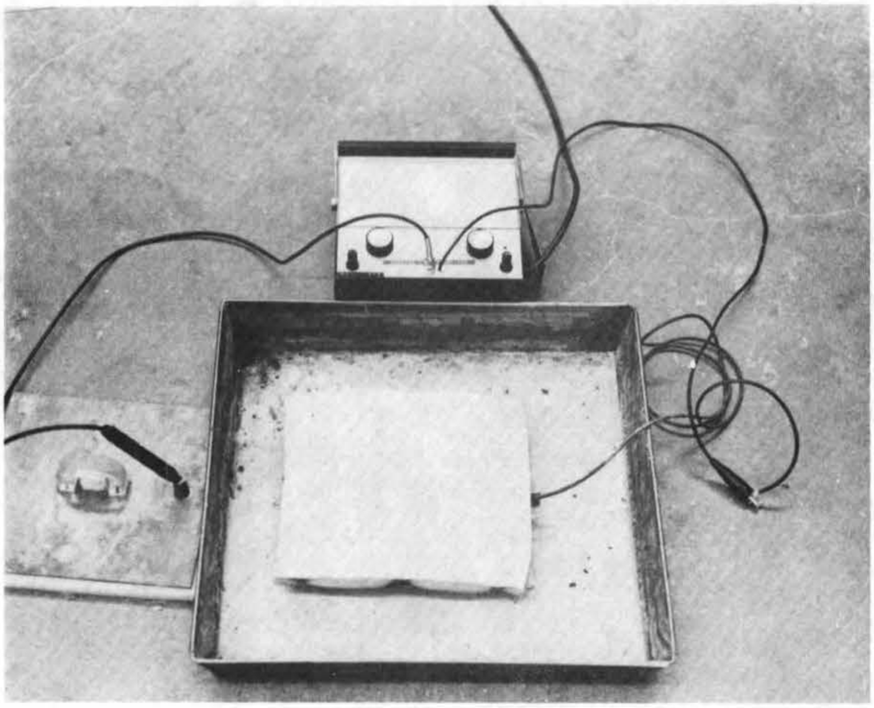

Figure 6

The Resistivity test apparatus

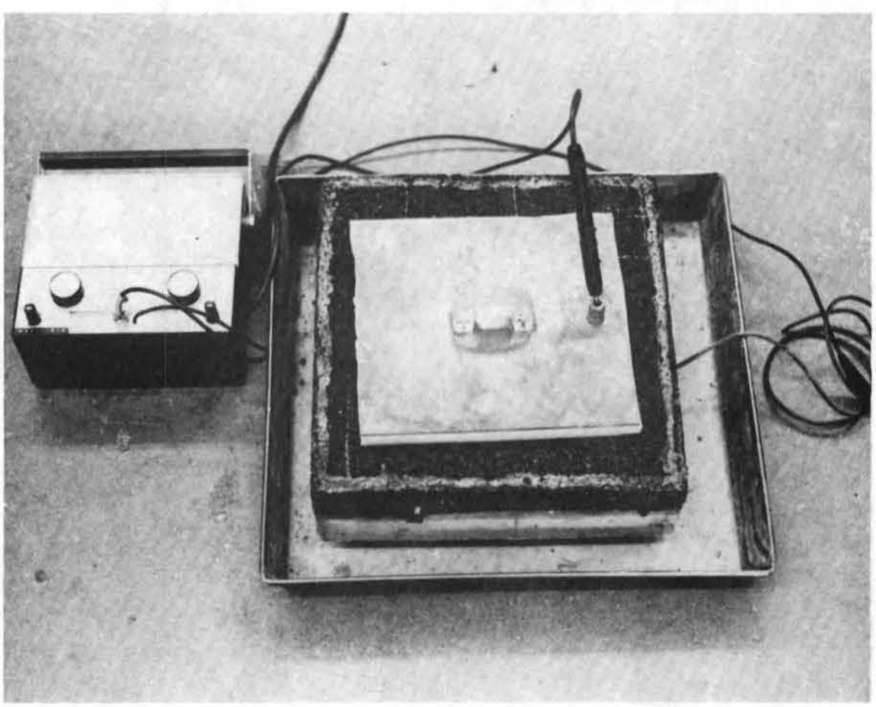

Figure 7

A resistivity test

B. Shear Test

This test, which originated in the State of Illinois' Interlayer Membrane Investigation, dealt specifically with a membrane system's shearing strength. The membrane system was placed on the top surface of a four inch portland cement concrete core that was approximately one and one half inches thick as shown in Figure 8. An asphaltic concrete overlay 1-½ inches thick was then compacted in a 4 inch Marshall density mold on the top of the membrane system (Figure 9). As shown in Figure 10, one of the circular clamps was placed around the portland cement concrete and the other was placed around the asphaltic concrete, concentrating the shearing stress in the membrane area. The specimens were then pulled in shear in a laboratory testing machine.

Usually there were three specimens made for each test. The load required to cause failure in the membrane system was recorded along with the location of the failure, i.e. between protection board and membrane, within the protection board, etc.

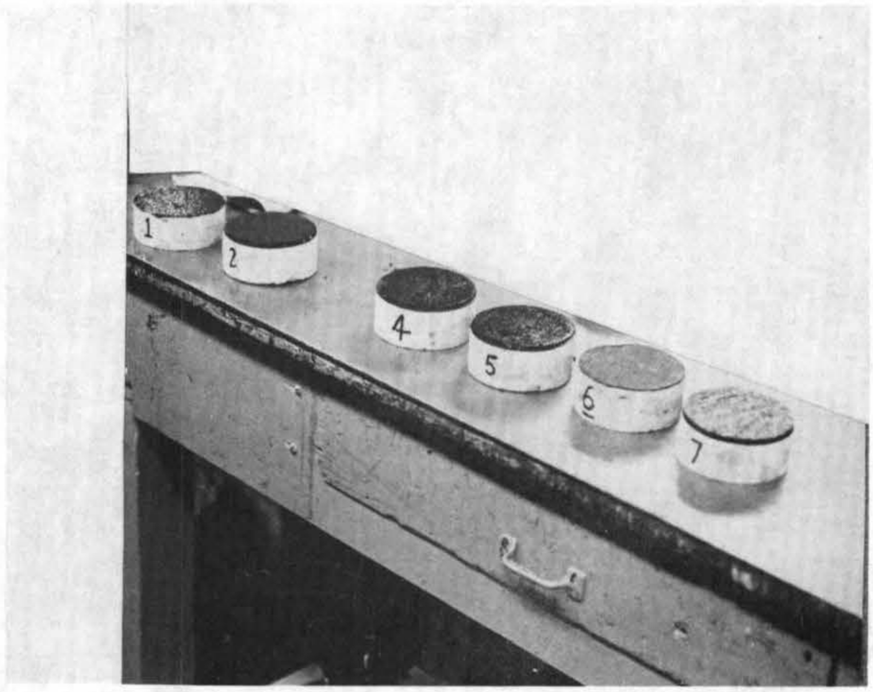

Figure 8

Shear test specimens with membrane system applied

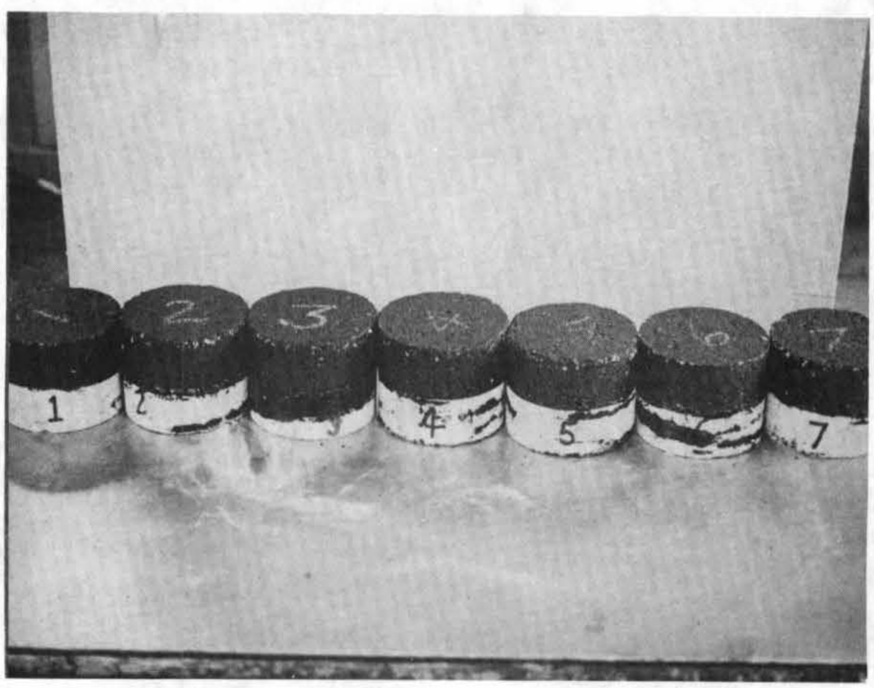

Figure 9

Shear test specimens with membrane system and asphaltic concrete applied

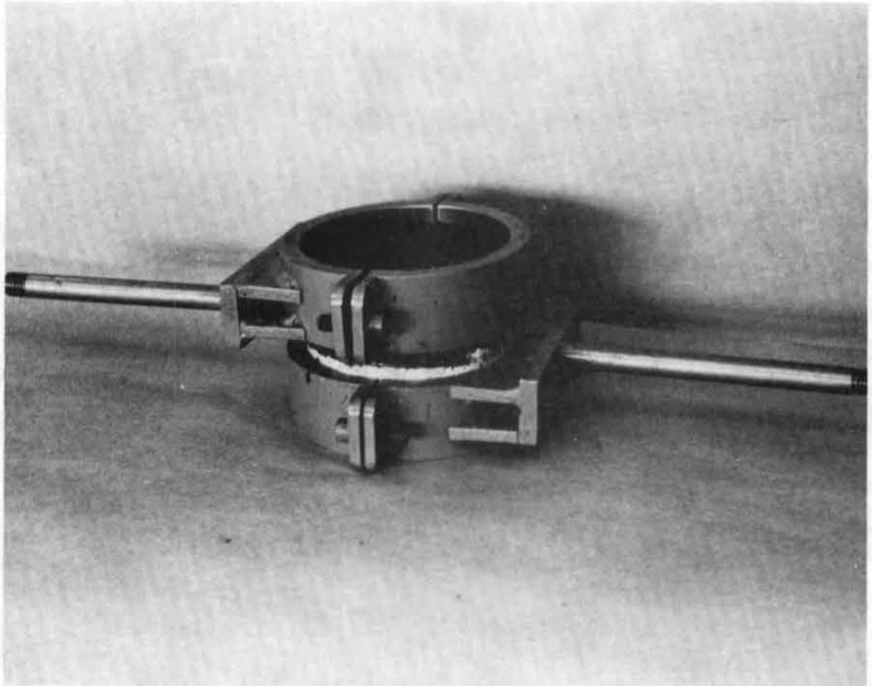

Figure 10

Shear test specimen ready for testing

C. Crack Bridging Test

The crack bridging test was developed to investigate a membrane's ability to bridge cracks in concrete at low temperatures. This crack bridging test, with some Iowa modifications, was developed by C. J. Van Til of Materials Research and Development in Oakland, California.

The crack bridging test utilized a 16"x8"x1 3/4" patio block with a cement mortar mix applied to the top surface. After a one inch deep saw cut was made in the middle on the bottom surface of the slab, the membrane was applied to the top surface. The testing machine, shown in Figure 11, and the slab were then placed into a freezer at $0^{O}F$ for 24 hours before testing. (Some testing was conducted with the temperatures at $-15^{O}F$.)

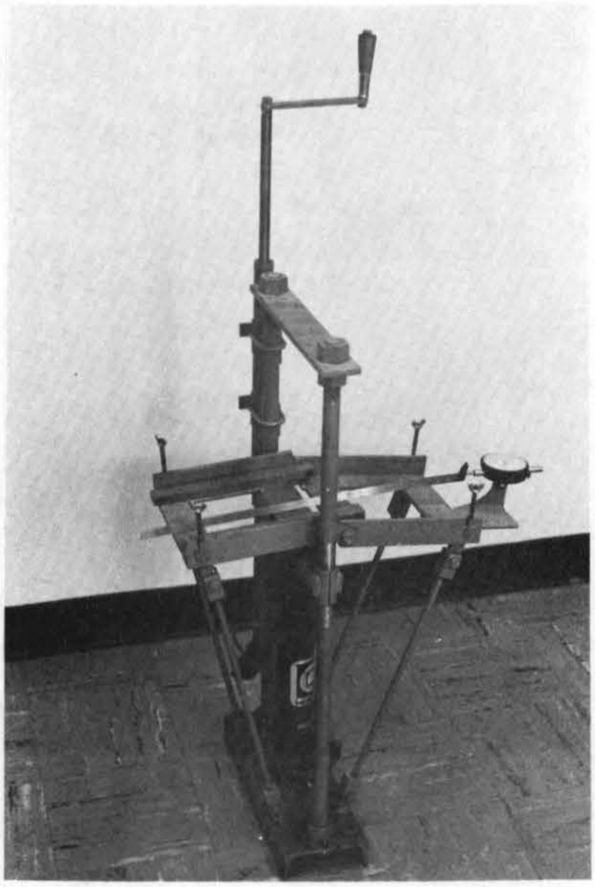

Figure 11

Crack bridging test machine

Prior to testing the ends of the slab were clamped into the machine as shown in Figure 12. The slab was cracked along the saw cut when the hydraulic jack raised the center area of the machine. The machine continues to raise the slab, which **widens** the crack and forces the membrane to bridge it.

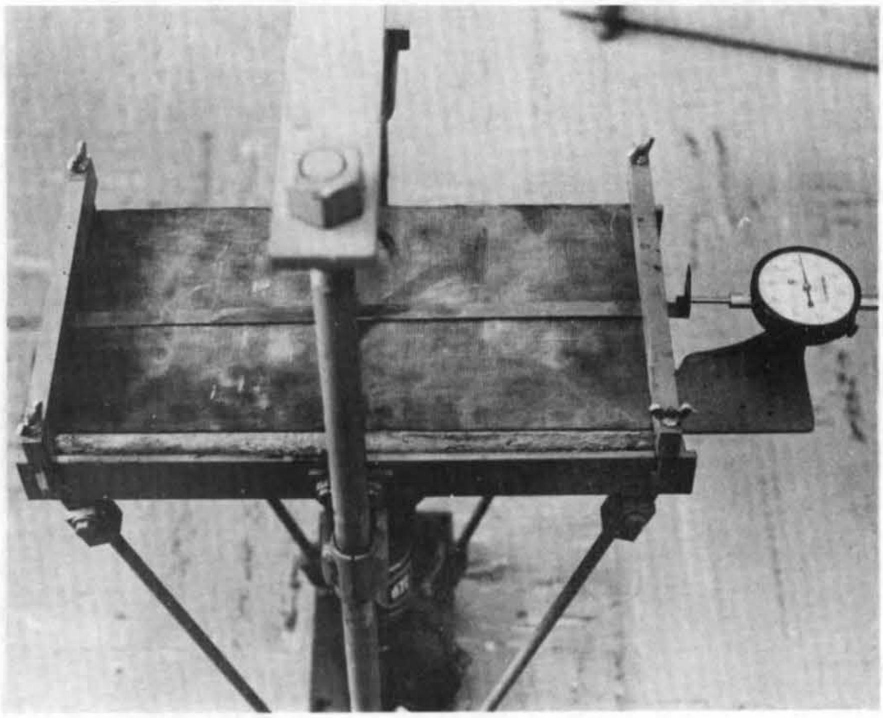

Figure 12

Crack bridging slab placed in testing machine

The crack is widened at the rate of 0.01 inch per minute until the elongation is 0.10 inch and then at a rate of 0.05 inch per minute until the elongation reaches 0.25 inch. The elongation at failure, if it has failed, and the nature and location of fractures in the membrane were recorded. Other observations such as chipping, flaking or debonding were also recorded.

D. Qualitative Tests Summary

The three tests considered important for evaluating bridge deck membranes were, resistivity, crack bridging and shear. The following minimum requirements were set for these tests so proper evaluation of the membranes was possible.

Resistivity

500,000 ohms/sq. ft. (1,000,000 ohms for the 1/2 sq. ft. test pads) after 3 hours.

Crack Bridging

The membrane must bridge a .25 inch crack at 0°F without any tears totaling 1/2 inch in length.[2] (The first 1/2 inch of membrane at slab edges was not considered.)

Shear

No minimum set - tack coat adhering asphaltic concrete to portland cement concrete, 11.5 psi, used for comparisons.

These three tests were then used to classify all membranes as acceptable or not acceptable. After the minimums were set, the resistivity and the crack bridging tests were used to screen membranes. If a membrane failed one of these two tests, further testing of this membrane was discontinued and it was classified as not acceptable.

6.0 Product Screening

The initial testing led to the adoption of the resistivity, shear, and crack bridging tests as standards for evaluating membranes. Minimum requirements were set on the resistivity and crack bridging tests for the purpose of rating membrane systems. Although the shear test had no minimums set, the shear strengths of the membrane systems were compared to the strength (11.5 psi) of an asphaltic concrete overlay on portland cement concrete with an MC-70 tack coat as the adhesive.

[2] From C. J. Van Til, Materials Research and Development

A. Resistivity Tests

The resistivity test which checked for conductivity of the membrane systems showed many systems to be impervious. Butyl, neoprene, Nordel, Polyguard, Heavy Duty Bituthene, UWM-28, Superseal 4000 and Protecto Wrap (test number five of five) are membrane systems that had infinite resistance after three hours. Other membrane systems that passed the 500,000 ohms/ft.^{2} requirement were: Deck Coat, Polytok, Protecto Wrap (test number 2 and 3 of five) and Phillips 66 Petromat. This test also confirmed the loss of waterproofing properties discovered in the initial testing on the emulsion membrane. Table 1 shows a complete list of results of the membrane systems that were tested for resistivity.

Table 1

Resistivity Tests

Membrane	Resistivity Measurements (Ohms) 1 hr.	2 hr.	3 hr.	Ohms/ft.^{2} @ 3 hr.
Uncoated Concrete	--	--	2,000	1,000
M-70 Tack with Asphaltic Concrete	--	85,000	--	42,500 (2 hr.)
Nordel	∞	∞	∞	∞
Polyguard 875 G	∞	∞	∞	∞
Coal Tar Emulsion	20,000	10,000	10,000	5,000
Coal Tar Primer and Slurry	--	36,000	--	18,000 (2 hr.)
Steelcote - Deck Coat	--	20,000,000	12,000,000	6,000,000
Steelcote - Deck Coat with primer	--	9,500,000	7,500,000	3,750,000

Table 1 (cont.)

Membrane	Resistivity Measurements (Ohms) 1 hr.	2 hr.	3 hr.	Ohms/ft.^{2} @ 3 hr.
Steelcote - Deck Coat with primer and sand	--	--	3,000,000	1,500,000
Steelcote - Deck Coat with sand	--	--	2,250,000	1,125,000
Bituthene	∞	∞	∞	∞
UWM-28	∞	∞	∞	∞
Steelcote Deck Coat	--	--	3,900,000	1,950,000
Carboline Polytok 165	240,000	185,000	164,000	82,000
Carboline Polytok 165 (retest)	--	--	3,250,000	1,625,000
Butyl	∞	∞	∞	∞
Neoprene	∞	∞	∞	∞
Super Seal 4000 (smooth slab)	5,000,000	2,500,000	1,400,000	700,000
Super Seal 4000 (retest)	∞	∞	∞	∞
Phillips 66 Membrane	10,000,000	10,000,000	9,000,000	4,500,000
Phillips 66 (retest)	5,000,000	4,800,000	4,200,000	2,100,000
Phillips 66 (about 1 month old)	5,200,000	4,400,000	3,200,000	1,600,000
Asphalt Cement Membrane with Petromat	∞	20,000,000	4,000,000	2,000,000
Phillips 66 with Protection Board	4,700,000	3,900,000	3,700,000	1,850,000
Phillips 66 with Protection Board (About 1 month old)	∞	∞	∞	∞
Protecto Wrap (#1)	460,000	240,00	220,000	110,000
Protecto Wrap (retest) (#2)	∞	∞	5,000,000	2,500,000
Protecto Wrap with P-100 (very rough slab) (#3)	3,000,000	1,200,000	1,000,000	500,000
Protecto Wrap with P-100 (#4)	800,000	700,000	650,000	325,000

Table 1 (cont.)

Membrane	Resistivity Measurements (Ohms) 1 hr.	2 hr.	3 hr.	Ohms/ft.^{2} @ 3 hr.
Sheet of Protecto Wrap	∞	∞	∞	∞
Protecto Wrap only on Block	∞	∞	∞	∞
Protecto Wrap and P-100 on Block	∞	∞	∞	∞
Entire Protecto Wrap System (#5)	∞	∞	∞	∞

B. Shear Tests

The shear test was valuable in checking the strength of adhesives and membrane systems. A few materials were found to be of no value as adhesives such as an emulsion or asphalt cement while in some cases an adhesive that was better than the proposed one was found. The polyurethane, UWM-28, was found to be excellent adhesive as well as an acceptable membrane. It was reaffirmed that the contact cements must be applied to both contacting surfaces to be effective.

Since no minimums were set for this test an asphalt tack coat adhering asphaltic concrete to portland cement concrete served as a guideline having a shear strength of 11.5 psi. A complete list of the shear testing results follows in Table 2 showing the adhesives used, the membrane, the protection board, the shear strength obtained and the location of failure.

Table 2

Shear Testing

Adhesive to Concrete	Membrane	Adhesive to Protection Bd.	Protection Board*	No. of Tests	Shear Strength (psi) Avg.	Max.	Min.	Area of Failure**
MC-70 Tack	Asphaltic Concrete	--	5	1	11.5			5
Sure Seal #9600	Nordel	--	3	5	8.1	10.3	6.8	1
PolyGuard Primer	PolyGuard	--	3	5	26.4	29.0	22.7	2 and 3
--	Polytox 24 hr. cure	--	1	1	10.7			3
--	Polytox 132 hr. cure	--	1	1	17.5			3
Primer	Deck Coat	--	1	3	11.6	12.7	11.1	3
--	UWM-28	--	1	3	28.8	30.2	27.9	4
Sure Seal 90-8-30A	Butyl	Emulsion	1	1	1.2			3
Sure Seal 90-8-30A	Butyl	Asphalt Cement	1	1	8.8			3
Sure Seal 90-8-30A	Butyl	Sure Seal on Butyl only	1	1	6.0			3
Sure Seal 90-8-30A	Butyl	Sure Seal Both Surfaces	1	4	7.2	7.5	6.8	1 and 3
Bituthene Primer	Bituthene	--	5	1	13.5			2
Bituthene Primer	Bituthene	--	3	1	20.3			2
Bituthene Primer	Bituthene	--	3	5	12.6	13.9	11.5	2
Contact Adhesive	Neoprene	Contact Adh. on Neo. only	1	5	11.6	12.3	10.3	3

Table 2 (cont.)

Adhesive to Concrete	Membrane	Adhesive to Protection Bd.	Protection Board*	No. of Tests	Shear Strength Avg.	Max.	Min.	Area of Failure**
Contact Adhesive	Neoprene	Contact Adh. on Neo. and Pro. Bd.	1	3	22.3	24.3	19.5	4
N-7	Neoprene	--	2	1	28.6			3
N-7	Neoprene	UWM-28 94 ft.^{2}/gal.	1	1	31.8			4
N-7	Neoprene	UWM-28 188 ft.^{2}/gal.	1	1	29.4			3
N-7	Neoprene	Emulsion	1	1	0			3
N-7	Neoprene	Asphalt Cement	1	1	3.2			3
N-7	Neoprene	N-7 on Both Surfaces	1	6	12.5	15.1	8.8	1 and 3
N-7	Neoprene	N-7 on Neo. only	1	1	1.6			3
N-7	Neoprene	N-7 on Neo.-dry	1	1	4.8			3
15 mil UWM-28	Neoprene	15 mil UWM-28	1	3	31.8	33.0	30.6	4
15 mil UWM-28	Neoprene	30 mil UWM-28	1	3	26.5	29.0	23.1	3
N-7	Neoprene	15 mil UWM-28	1	2	21.3	23.5	19.1	3
Applied Polymers	Neoprene	Applied Polymers	1	3	18.6	18.7	18.3	3 and 4
Protecto Wrap Primer	Protecto Wrap	--	3	3	15.8	16.7	14.7	2

Table 2 (cont.)

Adhesive to Concrete	Membrane	Adhesive to Protection Bd.	Protection Board*	No. of Tests	Shear Strength Avg.	Max.	Min.	Area of Failure**
Protecto Wrap Primer	Protecto Wrap	--	1	3	7.4	9.5	6.0	3
Primer	Protecto Wrap	Gardox	1	6	14.4	15.5	11.1	2 and 3
Primer	Protecto Wrap	Gardox	2	2	15.3	15.9	14.7	2-1 day old
Primer	Protecto Wrap	Gardox	2	2	10.7	11.1	10.3	2 and 4 days old
Primer	Protecto Wrap	Gardox	2	2	11.7	12.7	10.7	4-7 days old
Primer	Protecto Wrap	Gardox	2	1	12.3			4-13 days old
Primer	Protecto Wrap	Gardox	2	2	14.1	14.3	13.9	4-18 days old
Primer	Protecto Wrap	--	4	3	13.8	14.3	13.1	2
--	Super Seal 4000	--	1	3	7.3	8.0	6.4	3 damaged in testing
--	Super Seal 4000	--	1	2	10.6	11.1	10.0	3
--	Phillips 66	--	5	2	1.0	2.0	0	2 damaged in testing
--	Phillips 66 (retest)	--	5	2	6.4	8.0	4.8	2
--	Phillips 66 (retest)	--	5	3	5.1	5.6	4.8	2

Table 2 (cont.)

* Protection Board

1 - Meadows, felt side placed down

2 - Meadows, felt side placed up

3 - Grace, asphalt on both sides

4 - Protecto Shield

5 - None

** Area of Failure

1 - between concrete and membrane

2 - within membrane

3 - between membrane and protection board

4 - within protection board

5 - between PCC and AC

C. Crack Bridging Tests

The crack bridging test was a severe test of a membrane's ability to elongate at cold temperatures. There were a number of membrane systems that had very little difficulty passing this test even when the temperature was lowered to -15°F. The membrane systems passing at -15°F were: Heavy Duty Bituthene, Nordel, UWM-28, Protecto Wrap, neoprene and butyl. Deck Coat and Superseal 4000 passed the test at 0°F. The UWM-28 membrane failed the test at 0°F but passed at -15°F. Inspection of the 0°F specimen showed that at the area of failure the thickness of the membrane was less than the specified 60 mils. A complete list of the crack bridging tests to date is in Table 3 showing the type of failure if failure occurred.

Table 3

Crack Bridging

0° F. Tests

Membrane	Elongation	Pass or Fail	Comments
Husky Deck No. 4	0	Fail	Complete full length fracture when concrete fractured.
USS Nexdeck	0	Fail	Complete full length fracture when concrete fractured.
Bituthene	.50"	Pass	Reinforcing strands broke at .35" elongation, returned slowly to original shape after tension relaxed.
Butyl	.50"	Pass	Returned to original form soon after tension released.
Neoprene	.50"	Pass	Returned to original form soon after tension released.

Table 3 (cont.)

Membrane	Elongation	Pass or Fail	Comments
Polyguard 875 G	.055"	Fail	Full length fracture.
Protecto Wrap M-400	.25"	Pass	Lower ply had a full length fracture but upper ply undamaged.
UWM-28	.22"	*	First fracture appeared at .16", was 1/2" long at .22" elongation.
Carboline - Polytok 165	.195"	Fail	First fracture at .15" elongation, 1/2" long at .195 elongation.
Steel Kote "Deck Coat"	.25"	Pass	Returned soon to original form, tore in some on sides.
Super Seal 4000	.25"	Pass	No cracks returned to original form quickly.
Phillips 66 Petroset and Petromat	.25"	Fail	Cracked in 2 layers of AC and Petroset but fabric did not crack. Small debonded area.
Asphalt Cement with Petromat	.09"	Fail	Petromat broke loose from the brittle AC 5" back from crack.

* Thickness of membrane in area of failure was less then specified 60 mils.

-15°F. Tests

Membrane	Elongation	Pass or Fail	Comments
Bituthene	.25"	Pass	Returned to original form soon after tension released.
Polyguard 875 G	.10"	Fail	Full length fracture.
Carboline Polytok 165	.13"	Fail	3/4" tear at .13 elongation 90% torn at .25" elongation.
Nordel	.25"	Pass	Adhesive yielded on each side of crack for 1", returned to original form in 30 min. Large debonded area.
UWM-28	.25"	Pass	Tore in 1/2" on one side and 1/4" tear 1/4" from other tear.

Table 3 (cont.)

Membrane	Elongation	Pass or Fail	Comments
Protecto Wrap M-400	.25"	Pass	Lower ply had a full length fracture but upper ply undamaged.
Steel Kote "Deck Coat"	.10"	Fail	3/4" total cracking at .1" elongation, 70% cracked at .25 elongation.
Gates Neoprene	.25"	Pass	Returned soon to original form.
Butyl	.25"	Pass	Returned soon to original form.

D. Product Screening Summary

All membranes submitted were classified as acceptable or not acceptable from the information gained through the resistivity, shear and crack bridging tests. A membrane had to equal or surpass the minimum requirements for the resistivity and crack bridging tests to be classified as acceptable. Table 4 shows the membranes tested, their classification and the test it failed (if any).

Table 4

Membrane	Classification	Test Failed
Coal Tar Emulsion	Not Acceptable	Resistivity
Deck Coat	Acceptable	
Butyl Rubber	Acceptable	
Heavy Duty Bituthene	Acceptable	
Gacoflex N-36, Neoprene Rubber	Acceptable	
NEXDECK	Not Acceptable	Crack Bridging
Husky Deck #4	Not Acceptable	Crack Bridging
Polytok 165	Not Acceptable	Crack Bridging
Gacoflex UWM-28	Acceptable	
Polyguard #875-G	Not Acceptable	Crack Bridging
Nordel	Acceptable	
Protecto Wrap M-400	Acceptable	
Petroset and Petromat	Not Acceptable	Crack Bridging
Super Seal 4000	Acceptable	

7.0 Field Application Problem Studies

Problems encountered during field application of the membrane systems required special studies. These studies were to investigate each specific problem and attempt to find suitable and practical solutions.

A. Blister Study

The initial testing led to the selection of the butyl rubber to replace the coal tar emulsion as the specified membrane on the I-74 bridge in Bettendorf. During application of the butyl system a problem of blisters forming under the membrane was encountered. The blisters would develop during the day while the sun was heating the bridge deck and disappear in the evening while the deck cooled.

This problem led to the development of a new series of tests. These tests on 12"x12"x2 1/2" concrete slabs, were made to discover the cause of the blisters. The first tests utilized three oven dried slabs, one saturated with water and another placed in a pan containing a small amount of water. The butyl membrane was then applied to each of these slabs and a pane of glass. The surface of these specimens were then heated to about 130°F using heat lamps.

After a short duration of heating, blisters began forming on the saturated specimen and the specimen in the pan of water, but blisters did not form on the oven dried specimens or on the glass specimen. These results indicated that the blisters were caused by water evaporating out of the concrete. The water in the bridge deck would "out gas" when heated by the sun or the hot asphalt overlay causing blisters. As the deck cooled and the vapor receded back into the concrete the blisters would disappear.

The blistering study continued with a series of tests on concrete slabs with various moisture contents. The moisture contents used were 0%, 25%, 50%, 75%, and 100% of saturation. These slabs were then placed into an environmental control machine manufactured by the Blue M Company which controlled the air temperature at 50°F and the relative humidity at 70%. Sure Seal adhesive, #9600, and the butyl rubber membrane were applied while the slabs were in this controlled environment. The following day the slabs were placed under the heat lamps raising their surface temperature to 130°F. Figure 13 shows the blister study testing equipment and specimen.

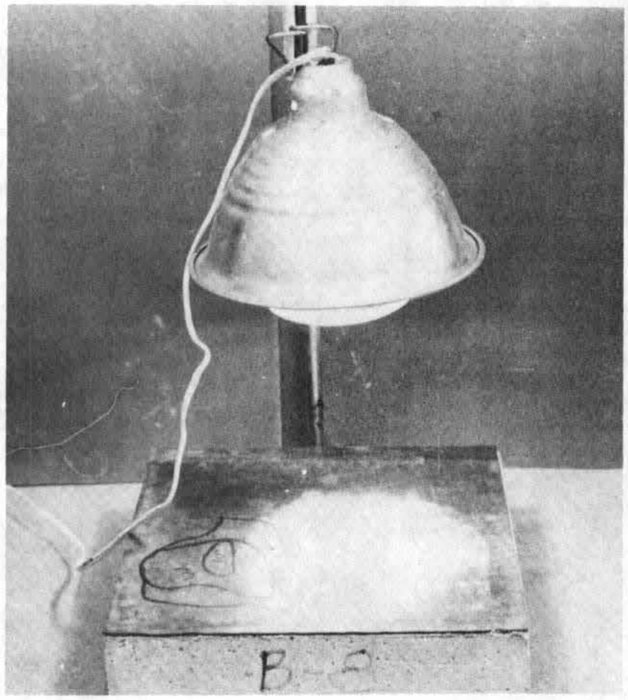

Figure 13

Blister Testing

Blisters occurred on the 25%, 50%, and 75% specimens within twenty minutes of heat application but no blisters appeared on the 0% and the 100% specimens even after the surface temperature was raised to 180°F. Close examination of the 100% saturation specimen showed a very poor bond between the concrete and the butyl allowing the vapor to escape out the edges. Figure 14 and Figure 15 show where the blisters occurred on the 25% and 50% saturation specimens respectively.

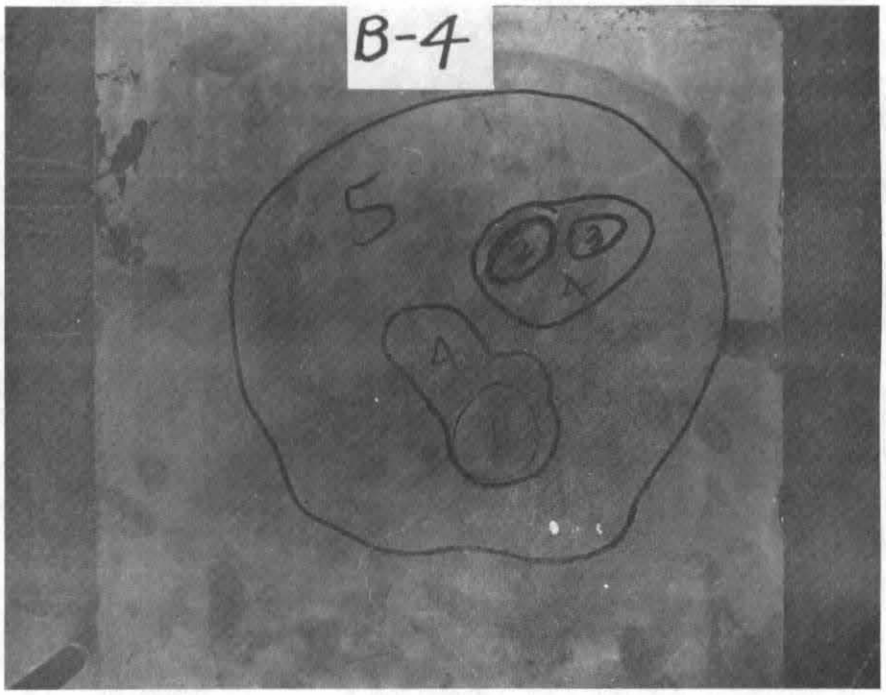

Figure 14

Blistered area on a 25% saturation specimen

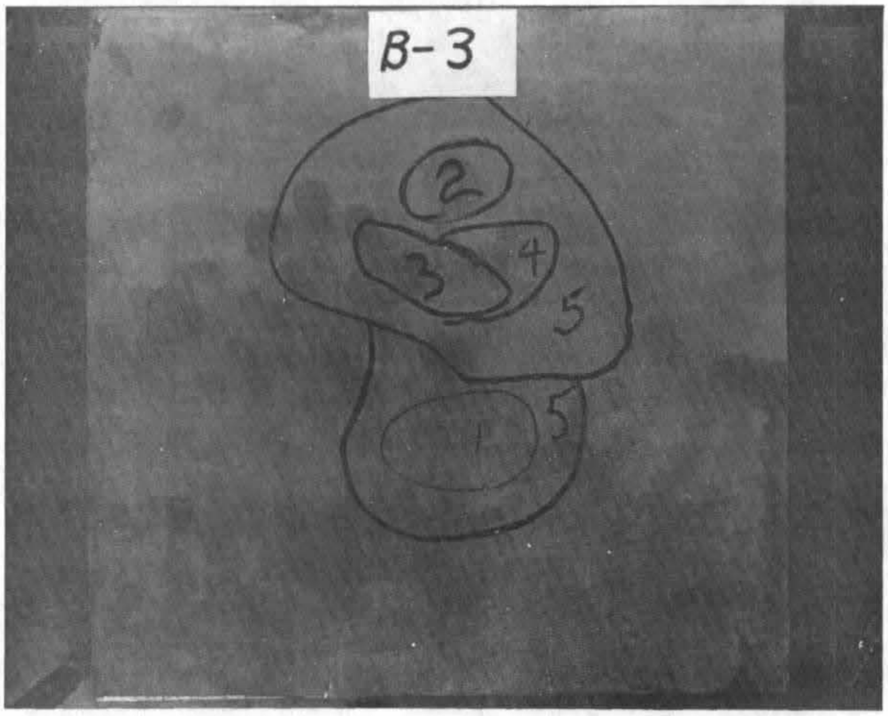

Figure 15

Blistered area on a 50% saturation specimen

This same series of tests was made on another set of slabs with the environment controlled at 70°F and 50% relative humidity. This time the 50% and 75% saturation specimens developed blisters after one hour of heat and after the temperatures were raised to 170°F a blister appeared on the 100% saturation specimen. No blisters formed on the 0% and 25% saturation specimens but again the butyl was bonded poorly to the concrete on the 25% specimen.

A blistering study was then made on various membrane systems to determine if all were affected by the out gassing phenomenon. Each slab used in these tests had a moisture content of about 50% of saturation. The membrane applications to the test specimens (T) were as follows:

T 1. The slab was heated to 90°F. UWM-28, a liquid polyurethane rubber, was applied in a 60 mil thickness and the curing time was noted.

T 2. A thin layer of UWM-28 was applied to a room temperature slab. When the UWM-28 became tacky a piece of butyl was placed in it.

T 3. UWM-28 was applied to another slab and immediately two pieces of butyl were placed in it and were butted together. More UWM-28 was poured along the butted joint.

T 4. UWM-28 was poured on a slab and then placed in the Blue M at 50°F and 70% humidity to find the cure time.

T 5. Heavy Duty Bituthene was applied to the slab.

T 6. N-7 adhesive was applied to the slab and a piece of neoprene rubber, then both were placed into the Blue M at 50°F and 70% relative humidity to determine a cure time. The neoprene was then placed on the slab.

After these applications all specimens were placed under heat lamps at 130°F-140°F.

The results of these tests were:

T 1. The UWM-28 was still tacky eight hours after it had been applied. Shortly after the heat was removed the UWM cured completely. No blisters were noted but there were a few pin holes visible in the membrane.

T 2. Blisters began appearing after 2 1/2 hours and spread over the entire slab after 5 hours under the heat lamp.

T 3. The membrane developed blisters after one hour including one blister directly beneath the sealed joint in the butyl (Figure 16).

T 4. The UWM-28 took over 24 hours to cure completely. After curing some pin holes in the membrane were noted. There was no other apparent change in the membrane due to heating.

T 5. After forty minutes small blisters began to appear and after 2 1/2 hours the entire center area was loose and spongy.

T 6. The cure time of the N-7 was 2 1/4 hours. One half hour after heating started a large blister appeared in the center of the specimen, but it disappeared when the heat was removed.

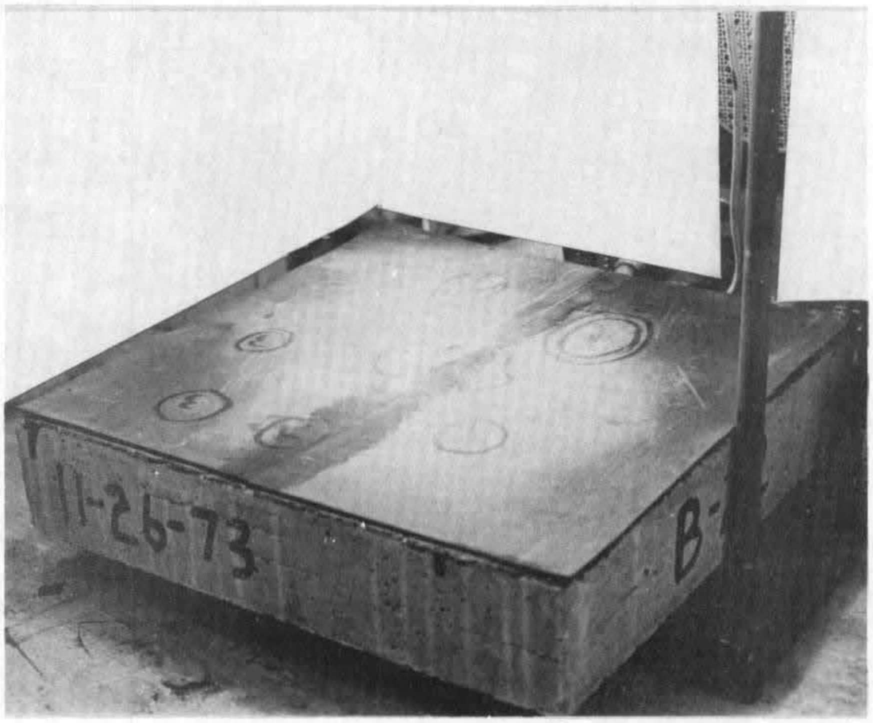

Figure 16

Split butyl specimen with blister forming under joint

Two more slabs, both at about the 50% moisture saturation level, had UWM-28 poured on their surfaces. The temperature of the first slab was 90°F while the second had been kept at room temperature. Immediately following the application of the UWM-28 both specimens were placed under heat lamps. Within the first hour both specimens had visible pin holes that remained when the heat was removed. After seven hours of heating both membranes were still tacky.

It was proposed that a coat of penetrating epoxy on the bridge deck would seal it preventing any out gassing. If this could be accomplished the blistering problem would be solved.

This proposal was tested by applying P.E. 50, a penetrating epoxy sealer, to a saturated surface dry 12"x12"x2 1/2" concrete slab at approximately 150 $ft.^2/gal$. The butyl membrane was applied to the epoxied surface 24 hours later and placed under a heat lamp. One area of this specimen was heated to 160°F where a slight blister was visible. Another area was heated to 180°F for two hours with no blister occurring. These results indicated that an epoxy coat should at least reduce the number of blisters occurring on the Bettendorf bridge.

P.E. 50 had been applied to portions of the deck in Bettendorf but it had not halted the blistering problem as anticipated. Therefore, another test was made using P.E. 50 and slabs with a moisture content of about 50% of saturation. Three coats of epoxy were applied to each slab and after the final coat had cured for 24 hours the membranes were placed. UWM-28, bituthene and neoprene were the test membranes for this study. The specimens were then placed under heat lamps at 120°F to 130°F.

The heat was raised to 175°F on the UWM-28 specimen after there was no change in the membrane at the lower temperature. Six small blisters appeared within 35 minutes at this higher temperature. The heat was again lowered to 120°F and the blisters disappeared within 45 minutes.

One hour after the heat was applied, blisters began forming under the bituthene membrane. When the heat was increased to 170°F the blisters did not change but the membrane showed signs of melting. The blisters disappeared but left an impression in the membrane when the heat was removed.

No blisters appeared under the neoprene even when the heat was increased to 200°F.

The apparent reason for the failure of the epoxy seal was again the out gassing phenomenon. The moisture within the concrete continues out gassing as the epoxy cures leaving pin holes in the epoxy seal. Then, when the membrane is in place, blisters will form where the pin holes in the epoxy seal permit out gassing.

B. Study of Liquid Adhesive Flow

UWM-28 was to be the adhesive between both the concrete and the neoprene, and the neoprene and the protection board on a bridge with a 7% grade in Cedar Rapids. This test investigated the amount of flow that the liquid UWM-28 would be expected to have on a 7% grade.

The test utilized three 6" x 12" x 2 1/2" concrete slabs set on a 7% grade. These specimens had the following treatments:

S 1. One coat of UWM-28 placed in a fifteen mil thickness.

S 2. A fifteen mil thick coat of UWM-28 followed by the immediate placement of a sheet of neoprene. After a

24 hour cure a thirty mil coat of UWM-28 was placed on the neoprene.

S 3. Same treatment as S 2. with a piece of protection board placed immediately after the addition of the second coat of UWM-28.

After each step the specimens were visually inspected for amount of flow.

The results of these tests showed that because the UWM-28 was a high viscosity liquid it would not flow when applied at a 15 mil thickness. A small amount of flow was visible when the UWM-28 was placed in a 30 mil thickness, however, the addition of the protection board held the liquid in place so no flow could occur.

C. Warped Protection Board Study

In the process of shipping and storing, some of the 4' by 8' sheets of protection board could become warped. The problem of placing this warped protection board into a liquid adhesive, such as Gardox or UWM-28, was the subject of another series of tests. A severely warped protection board would not stay in firm contact to these liquid adhesives since they were not cohesive until they had cured.

Seven 12"x12"x2 1/2" concrete slabs with the Protecto Wrap membrane and the Gardox adhesive were utilized in this testing. These test specimens (TS) had the following treatment (the Gardox application rate is noted first and all protection boards placed had been warped prior to placement).

TS 1. 150 $ft.^2$/gal., protection board placed and rolled felt side down immediately after Gardox applied.

TS 2. 300 $ft.^2$/gal., after a three hour cure for the Gardox the protection board was placed and rolled felt side down.

TS 3. 150 $ft.^2$/gal., same treatment as TS 2.

TS 4. 300 $ft.^2$/gal., after a 24 hour Gardox cure the protection board was applied felt side up and rolled.

TS 5. 300 $ft.^2$/gal., protection board placed felt side up immediately after Gardox application but it was not rolled till 24 hours later.

TS 6. 300 $ft.^2$/gal., protection board placed felt side up and rolled immediately after Gardox application. It was rolled again three hours later.

TS 7. 300 $ft.^2$/gal., after a three hour Gardox cure the protection board was placed felt side up and rolled. It was rolled again 5 1/2 hours later.

The results of these tests were as follows:

TS 1. There was not a satisfactory bond achieved with this method. The protection board had pulled away from the Gardox in two large areas.

TS 2. The delay improved the adhesive ability of the Gardox but there were places near the edges where no bonding was visible.

TS 3. The delay was beneficial but there was one poorly bonded area.

TS 4. Immediately after rolling there appeared to be a good bond to the protection board but within fifteen minutes it began pulling away especially near the edges.

TS 5. When the protection board was placed many areas did not seat into the Gardox. These areas rolled down but began pulling away again within about 20 minutes.

TS 6. The original bond was very poor and the bond obtained three hours later was better but was still not satisfactory.

TS 7. The protection board pulled away in some areas fifteen minutes after rolling. The second rolling improved the bond considerably with only a small amount of edge curling evident.

All seven specimens had some unbonded areas. Rolling the protection board three to five hours after the application of the Gardox helped but did not completely eliminate the problem. A complete bond could be obtained only if the protection board used on the projects was not warped.

D. Protecto Wrap Study

The Protecto Wrap Company introduced a new protection board, P-100, which was designed especially for use with the Protecto Wrap membrane. P-100 adhered to Protecto Wrap without the use of adhesives and eliminated the warping problem because of its flexibility.

A shear test and two resistivity tests were made on the new Protecto Wrap membrane system. The shear strengths of the new system were equal to the strengths of other Protecto Wrap systems while the resistivity tests showed one specimen to be failing and the other to be on the border line at 500,000 ohm/$ft.^2$.

Since there seemed to be a problem obtaining good resistivity readings with Protecto Wrap, a series of resistivity tests was made on the new system. The first test was on a single sheet of Protecto Wrap. The second was on a piece of Protecto Wrap applied to a concrete slab without the protection board or the asphalt overlay. Another test was made after the P-100 protection board had been applied to the slab and the final test was made on the slab with the entire system applied including the asphalt overlay.

The resistivity in all four cases was infinite. The earlier resistivity problems may have come from a flaw in the roll of Protecto Wrap used for the testing or from the application of the asphalt overlay.

E. Incompatability Study

There was some concern involving the possible incompatability between Protecto Wrap, a coal tar product, and the asphalt side of the Vibraflex-Highway protection board as manufactured by W.R. Meadows. The concern was that the Protecto Wrap contained relatively slowly releasing aromatic solvents. These solvents may eventually soften the asphalt at the membrane-protection board interface causing a slippage plane.

Two specimens were prepared to investigate this phenomena. These specimens were identical to those used for resistivity testing. One specimen was constructed with the Protecto Wrap membrane in contact with the asphalt (tacky) side of the protection board. The other specimen was identical to the first except Heavy Duty Bituthene was used as the membrane. The Bituthene specimen was to serve as a basis of comparison since there was no concern over incompatability with this system. The exposed edges of the specimens were coated with a silicone sealant to prevent the escape of solvents.

These specimens were heat aged in an oven at 140° F. for approximately one month to accelerate the incompatability reaction if it were to occur. At the end of the heating period the specimens were sawed so the interface could be visually examined (Figure 17).

There was evidence of a darker line at the interface with the Protecto Wrap membrane which would possibly indicate some incompatability.

Small specimens were sawed from the larger specimens and tested in shear. The average of three specimens of each system was 17.5 psi for the Heavy Duty Bituthene and 16.7 psi for the Protecto Wrap.

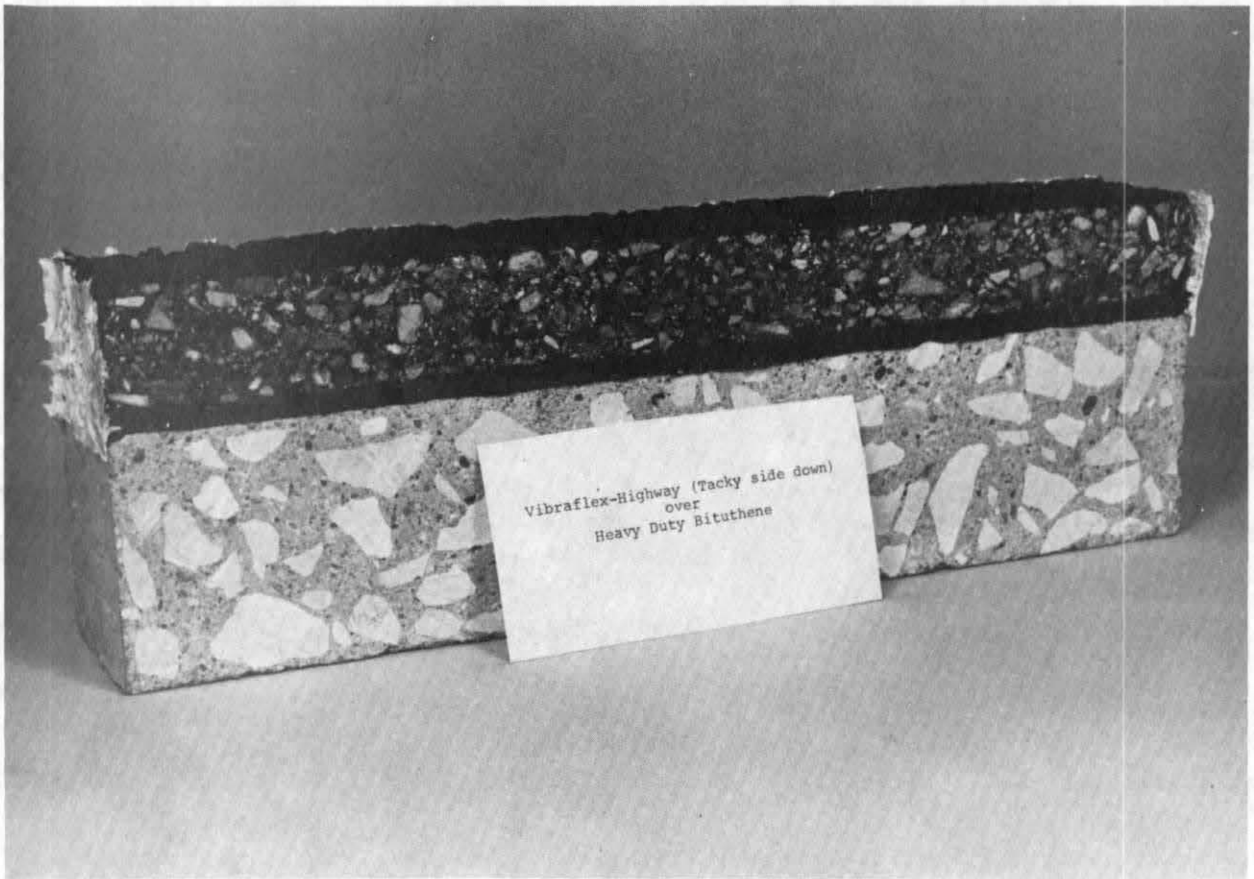

Figure 17

Bituthene specimen from incompatability study

F. Field Application Problem Summary

1. Blister Study

The blister study was initiated after a blistering problem was discovered on the I-74 Mississippi River bridge. The blisters appeared when the bridge deck was heated and disappeared when it cooled. Heat from the sun or heat from the asphalt overlay could cause blisters. The blisters were of various size and shape ranging from the size of a quarter up to a few with a diameter of one foot.

Laboratory tests proved that the blisters were caused by moisture in the bridge decks vaporizing or "out gassing" when heated. It was also found that blisters could develop when the moisture level in the concrete was as low as 25% of saturation and that all membrane systems are subject to some form of blistering problem. The liquid membrane may not actually blister but the out gassing vapors will leave permanent pin holes in the membrane as it cures. Even an epoxy sealer could not effectively keep the moisture from vaporizing out of the concrete and forming blisters under the membranes.

Another result of the blister study showed that UWM-28 and some contact adhesives had a much longer cure time in an environment of low temperature and high humidity.

2. Test for Liquid Adhesive Flow

The special membrane testing dealt with specific problems that may be encountered during construction. One test concerned the application of UWM-28 on a 7% grade. A series of tests established that the UWM-28 would not flow on the 7% grade when applied at a thickness of 15 mil but would flow when applied in a 30 mil thickness. The flow was blocked when the protection board was placed into the "wet" UWM-28.

3. Warped Protection Board Study

Another group of special tests resulted from the discovery of an adhesion problem between Protecto Wrap membrane and warped protection board. The test results indicated that warped protection board should not be placed into wet Gardox, the liquid adhesive, unless it is rolled again three to five hours later. The best bond was obtained when the Gardox was allowed to cure for three hours before the protection board was placed. If the protection board is severely warped, efforts should be made to straighten it before placing since it was proven that a complete bond to warped protection board could not be achieved by using any of the methods tested.

4. Protecto Wrap Study

This study was initiated when the Protecto Wrap Company introduced their new protection board. The P-100 protection board was made to be used specifically with the Protecto Wrap membrane. P-100 had no warping problems since it was flexible and did not need an adhesive when used with the Protecto Wrap membrane.

The shear test on this Protecto Wrap system was comparable to other Protecto Wrap systems. The first two resistivity tests were low but a third test showed impermeability. When used with Protecto Wrap, it would be desirable to use P-100 as the protection board.

Prior resistivity testing on the Protecto Wrap membrane system had indicated that it might not be effective, but the series of special tests showed infinite resistance after three hours. The possible reasons for this were: 1. The roll of Protecto Wrap tested may have had areas with flaws. 2. The addition of the asphalt overlay may have damaged the membrane in the early tests.

5. Incompatability Study

Accelerated aging tests to measure the possible incompatability of Protecto Wrap and the asphalt side of Vibraflex-Highway protection board indicated slight visual evidence of incompatability.

Quantifying tests could not verify the visual observation but rather indicated a plane of weakness between these materials was not sufficient to significantly lower shear test values.

8.0 Summary

The minimum requirements set for the tests used in evaluating bridge deck membranes were:

Resistivity

500,000 ohm/ft.^{2} after 3 hours.

Crack Bridging

Bridge a ¼ inch crack at 0° F. without tears totaling ½ inch in length.

Shear

No minimum - 11.5 psi used for comparison.

The minimum requirements set for these tests provided a means for classifying the numerous membrane systems. Each system was subjected to the tests to determine its reliability and effectiveness as a waterproofing membrane. A number of systems were found to be unacceptable when they failed either the crack bridging or resistivity test. The membrane systems which met the minimum requirements are:

Butyl Rubber (Carlisle)

Deck Coat

Gacoflex N-36 Neoprene Rubber

Gacoflex UWM-28

Heavy Duty Bituthene

Nordel

Protecto Wrap M-400

Super Seal 4000

While some of the above membrane materials are liquid their use may be questionable due to the "out-gassing phenomena. It would be anticipated that pin holes could develop through these materials before they have completely cured thereby allowing salt water to penetrate to the underlying bridge deck.

The field application testing determined:

A 1. that most blisters are caused by the "out gassing" of moisture in the bridge deck.

A 2. that all membranes are subject to some form of "out gassing".

A 3. that an epoxy seal could not effectively eliminate "out gassing".

B 1. that placing the protection board into "wet" UWM-28 would keep it from flowing on a grade of 7%.

C 1. if warped protection board is used it should not be placed till the Gardox adhesive has cured for three to five hours and then it may not fully bond.

D 1. that P-100 is the desired protection board with the Protecto Wrap membrane.

D 2. that the inconsistant resistivity readings on the Protecto Wrap system may have been due to flaws in the membrane or the addition of the asphalt overlay.

E 1. that possible incompatability between Protecto Wrap and asphalt protection board, if such incompatability exists, could not be measured by the methods utilized in this study.