Dix-Toledo Road Stress Relieving/Waterproofing Membrane Project

Control Section 82071 Job Number 36000A

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Metro Region Construction & Technology Division

MDOT

MICHIGAN DEPARTMENT OF TRANSPORTATION

Contributors

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Executive Summary

In 1994, the Michigan Department of Transportation Metro Region completed a project to evaluate the performance of waterproofing and stress relieving membranes. In 2001, seven years after construction, a final evaluation of the project began. The results are presented in this report.

The membranes were placed within a section of Dix-Toledo Road, a connector between US-24 (Telegraph Road) and I-75 (Fisher Freeway). These membranes were placed over longitudinal cracks and joints in the roadway with the expectation that reflective cracking would be reduced and/or delayed for several years. The different membranes that were used were Polyguard NW-75 Waterproofing, Polyguard 665 Waterproofing, Petrotac Waterproofing, Paveprep Stress Relieving, and Pro-Guard Stress Relieving. Also, a control section without membrane placement was established within the project.

Both types of stress relieving membranes and one of the waterproofing membranes were effective in reducing reflective cracking in comparison to the control section. The stress relieving membranes cost $2.45 per lineal foot while waterproofing only cost $1.53 per lineal foot. However, a benefit/cost analysis revealed that neither type of membrane was cost efficient in comparison to not using membranes at all. In this analysis, the benefit was measured by the length of the joint that did not need future rout and seal crack treatment multiplied by the cost to perform the repair.

Conclusions

The 2001 measured longitudinal reflective crack percentage and the benefit/cost ratio for each membrane is presented in the following table.

Type		Waterproofing Membranes			Stress Relieving Membranes		
Test Section	Control Section	Polyguard NW-75	Polyguard 665	Petrotac	PavePrep	18" Pro-Guard	24" Pro-Guard
% Reflective Cracking	27.0	43.1	47.1	20.9	16.7	13.6	10.8
B/C Ratio	2.70	0.38	0.35	0.63	0.45	0.47	0.50

- Membrane placement was shown to be effective in reducing pavement cracking for four of the six products as compared to the control section.
- The stress relieving membranes performed better overall than the control section and the waterproofing membranes.
- Two of the three waterproofing membranes performed worse than the control section.
- The control section had the highest benefits/cost ratio, an evaluation that determines the most economical project.

- Of the membranes, Petrotac waterproofing membrane had the highest benefit/cost ratio. The stress relieving membranes were second with similar B/C ratios. The other two waterproofing membranes were the worst.
- Using the waterproofing membranes on every longitudinal joint in the project would have increased the total project cost by 8.9%.
- Placing stress relieving membranes throughout the entire project would have increased the total project cost by 13.6%.
- Membrane usage should be limited to areas where prevention of reflective cracks is at a premium.

Project History

This project was located in Brownstown Township, Michigan on Dix-Toledo Road, a connector between US-24 (Telegraph Road) and I-75 (Fisher Freeway). The original concrete pavement, constructed in 1929, was 9" thick and 20' wide. In 1935, an 11' concrete widening was added to the west side of the roadway. Another concrete widening was completed in 1959 in addition to a 2.5" bituminous overlay placed over the entire width. In 1975, the concrete was resurfaced with approximately 2.25" of bituminous material. A 3" mill and resurface job was completed in 1994, along with a 1' widening on each side. A cross-section of the pavement is displayed in Appendix A.

This roadway was selected for testing due to its low traffic volumes and the presence of longitudinal joints and cracks throughout its length. During the 1994 project, MDOT placed two stress relieving and three waterproofing membranes over these pavement joints and cracks. The stress relieving membranes used were Paveprep and Pro-Guard (18" & 24" width). The waterproofing membranes placed were Polyguard NW-75, Polyguard 665, and Petrotac. The physical properties for each of these products are summarized in Appendix C.

Both the waterproofing and the stress relieving membranes were expected to delay the onset of reflective cracking. The waterproofing membranes were expected to accomplish this by keeping moisture out of the underlying pavements. The stress-relieving membranes were expected to absorb and dissipate stress, as well as keep moisture out of the underlying pavement.

Test Sections

The waterproofing and stress relieving membranes were placed between stations 38+00 and 90+00, divided into four test sections. The description of each of the sections is as follows:

> ***Station 38+00 to 51+00*** - Three joints on the northbound side contain 3,900' of 18" **Polyguard NW - 75** Waterproofing Membrane. Three joints on the southbound side contain 3,900' of 18" **Polyguard 665** Waterproofing Membrane.

Station 51+00 to 64+00 - Six joints on both the northbound and southbound sides contain 7,800' of 18" **Petrotac** Waterproofing Membrane.

Station 64+00 to 77+00 - Six joints on both the northbound and southbound sides contain 7,800' of 18" **Paveprep** Stress Relieving Membrane.

Station 77+00 to 90+00 - Three joints on the northbound side contain 3,900' of 18" **Pro-Guard** Stress-Relieving Membrane. Three joints on the southbound side contain 3,900' of 24" **Pro-Guard** Stress-Relieving Membrane.

A diagram of the area with the product locations can be found in Appendix B. Each of the test sections were originally identified by a 4" white thermoplastic pavement marking on the southbound shoulder of Dix-Toledo Road. These markings were perpendicular to the lane lines, and were placed at stations 38+00, 51+00, 64+00, 77+00, and 90+00. In addition to the test sections, a control section without a membrane was constructed for comparison purposes. The control section was located between stations 20+25 and 38+00.

Construction

The placement of waterproofing and stress-relieving membranes was a component of a larger project on Dix-Toledo Road that took place in 1994. The entire project included 2.17 miles of cold milling, bituminous resurfacing, widening, cantilever reconstruction, guardrail upgrading, culvert modifications, and signing.

Included in the project package were Special Provisions for the placement of the membranes, which can be found in Appendix D. Although the stress relieving and waterproofing membranes were expected to perform the same basic function, each had a separate Special Provision. Prior to installing the membranes, approximately 3" of the existing 5" of bituminous material was milled off. The 2.5" to 4" bituminous shoulder was trenched out, and an 11A bituminous base course was placed to match the surface elevation of the milled composite mainline.

Once the longitudinal joints and cracks were cleaned and prepared as recommended by the manufacturer, an asphalt binder or adhesive was applied to ensure a strong bond. Procedures and recommended products varied for each membrane. After surface preparation was complete, the membranes were installed.

The four inner membranes were placed onto the milled surface over longitudinal reflective cracks caused by joints in the underlying concrete. The outer two membranes were placed over the joint between the milled composite pavement and the 1' of bituminous widening. A 3" bituminous overlay was placed to complete the job. Because of the varying lane widenings, the membrane locations were not uniformly spaced, as illustrated in Appendix A. The project was completed and opened to traffic on November 1, 1994.

Field Review

Using longitudinal reflective cracking as the measure of effectiveness for membrane performance, two field reviews were completed. The product that provided the most reduction in reflective longitudinal cracking in a 1996 cursory field survey was the 18" Pro-Guard stress relieving membrane. At the time of the survey, this area did not show any reflective cracking. The performance of the other membranes followed in this order: Polyguard 665 waterproofing, Polyguard NW-75 waterproofing, 24" Pro-Guard stress relieving, Paveprep stress relieving, and finally Petrotac waterproofing. The reflective cracks were expressed in terms of a percentage of the total length of the joints and cracks covered with membrane for each section.

A more comprehensive study on Dix-Toledo Road was performed in March of 2001. The MDOT Metro Region sought to determine the location of each underlying concrete joint. To relocate the joints, plans from all previous construction on the roadway were retrieved. The locations were then established by coring the pavement in several places. However, some areas were not evaluated due to the bituminous paving joint being in the same location as the membrane. All analysis was completed only with the measurements from cracks that were the direct result of reflective cracking.

The 2001 survey showed that the 24" Pro-Guard stress relieving was most beneficial in deterring cracking. The performance of the other membranes followed in this order: 18" Pro-Guard stress relieving, Paveprep stress relieving, Petrotac waterproofing, Polyguard 665 waterproofing, and Polyguard NW-75 waterproofing. Polyguard 665 and the Polyguard NW-75 actually performed worse than the control section. Again, reflective cracking was expressed in terms of a percentage of the total length of the joints and cracks covered with membrane for each section. The results from the 2001 field review are shown in Appendix E.

Analysis

Average ride quality index and distress index values from 1992 to 1998 are shown in Appendix F. The pavement conditions from the different test sections were shown to be similar. As such, no meaningful performance conclusions could be made. Determinations concerning performance were based solely on field review observations.

It was difficult to base membrane performance judgement on the 1996 field review. This survey was completed less than a year and a half after the Dix-Toledo Road was opened to traffic. At the time of the review, cracking was just beginning to appear and the results may not have been representative of the true performance of these products. In addition, the 1996 field review only noted cracks along the two outside membrane locations; the other four locations were not recorded.

The results of the 2001 field review concluded that the stress relieving membranes performed better overall than the waterproofing membranes. The example included in Appendix G determines the percent increase in total project cost if each joint was covered by either type of membrane. This

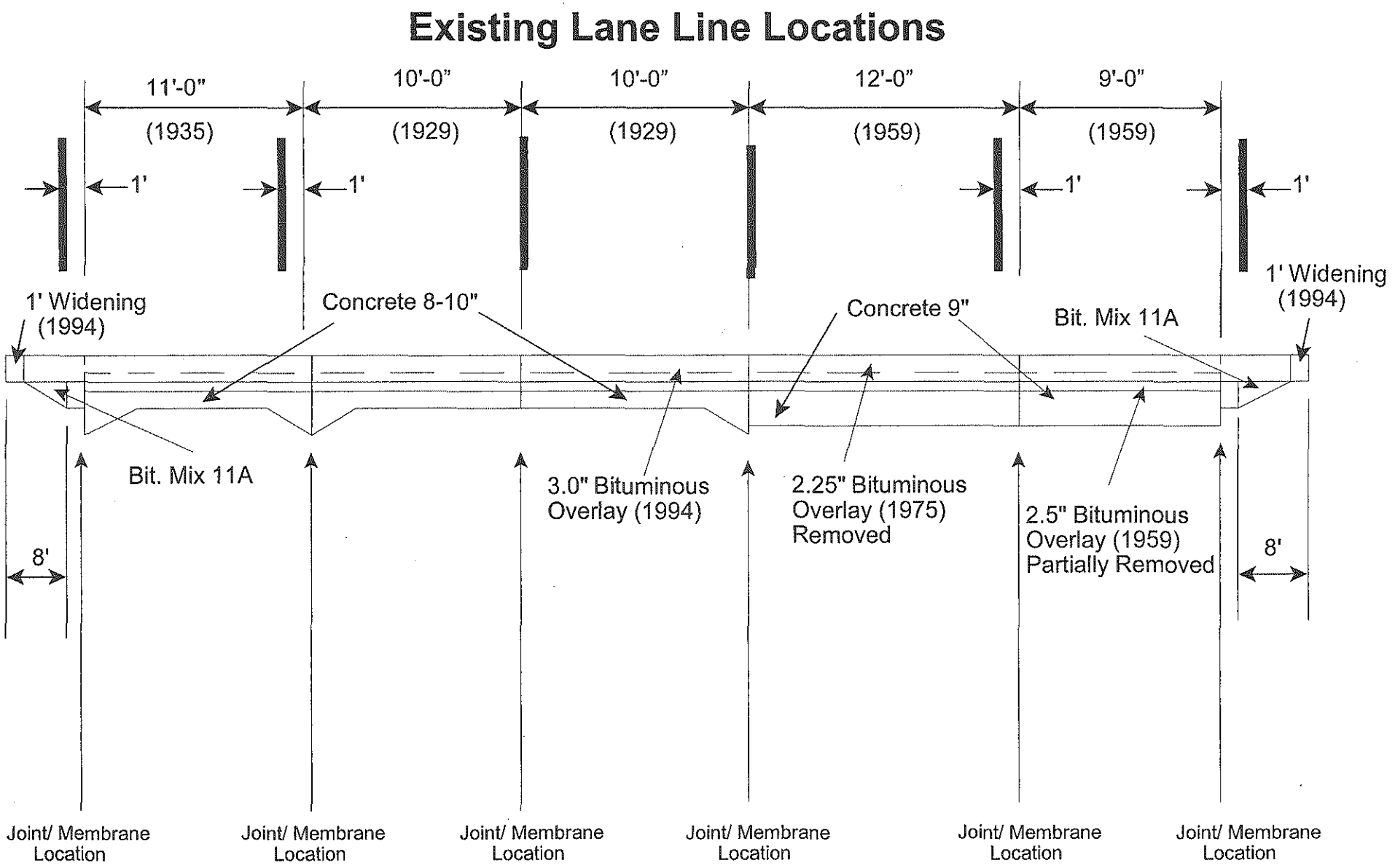
example demonstrates a considerable increase in total project cost using actual unit prices from the 1994 project.

A benefit/cost analysis was performed and is also provided in Appendix G. The cost included the initial 1994 price of membrane placement and the net present worth in 1994 of repair work completed in 2001 based on a 3% discount rate. This analysis assumes a cost for repair work at $1.78 per foot and that the rout and seal repair work was actually completed. Benefit was computed as the price to perform repair work multiplied by the joint length that did not need crack treatment. This analysis illustrates that although the do-nothing method may not maintain the quality of the road as effectively as placing membranes, overall it is more cost efficient. However, this does not suggest the discontinuation of the use of pavement membranes. On roadways in which aesthetics, not cost, are the main priority, membrane usage can be an effective preventative measure to reduce longitudinal cracking.

These results must be considered qualitative as it was assumed the severity of the underlying cracks was controlled and cracking was consistent among test sections. Different underlying pavements may have altered the performance of the test sections. There was also uncertainty whether the membranes would have a beneficial effect on pavement performance after the reflective cracking has occurred. Extended pavement life could lower the overall cost of the roadway. However, continued monitoring is necessary to determine if future pavement repairs can be postponed. It has yet to be determined how the performance of pavement with membranes compares to performance of pavement in which an equal amount was spent on increasing the thickness of the overlay. An additional 0.83" of bituminous material could have been added to the experimental roadway for the price of installing waterproofing membranes. An additional 1.32" of overlay could have been placed for the same cost to install stress relieving material.

APPENDIX A

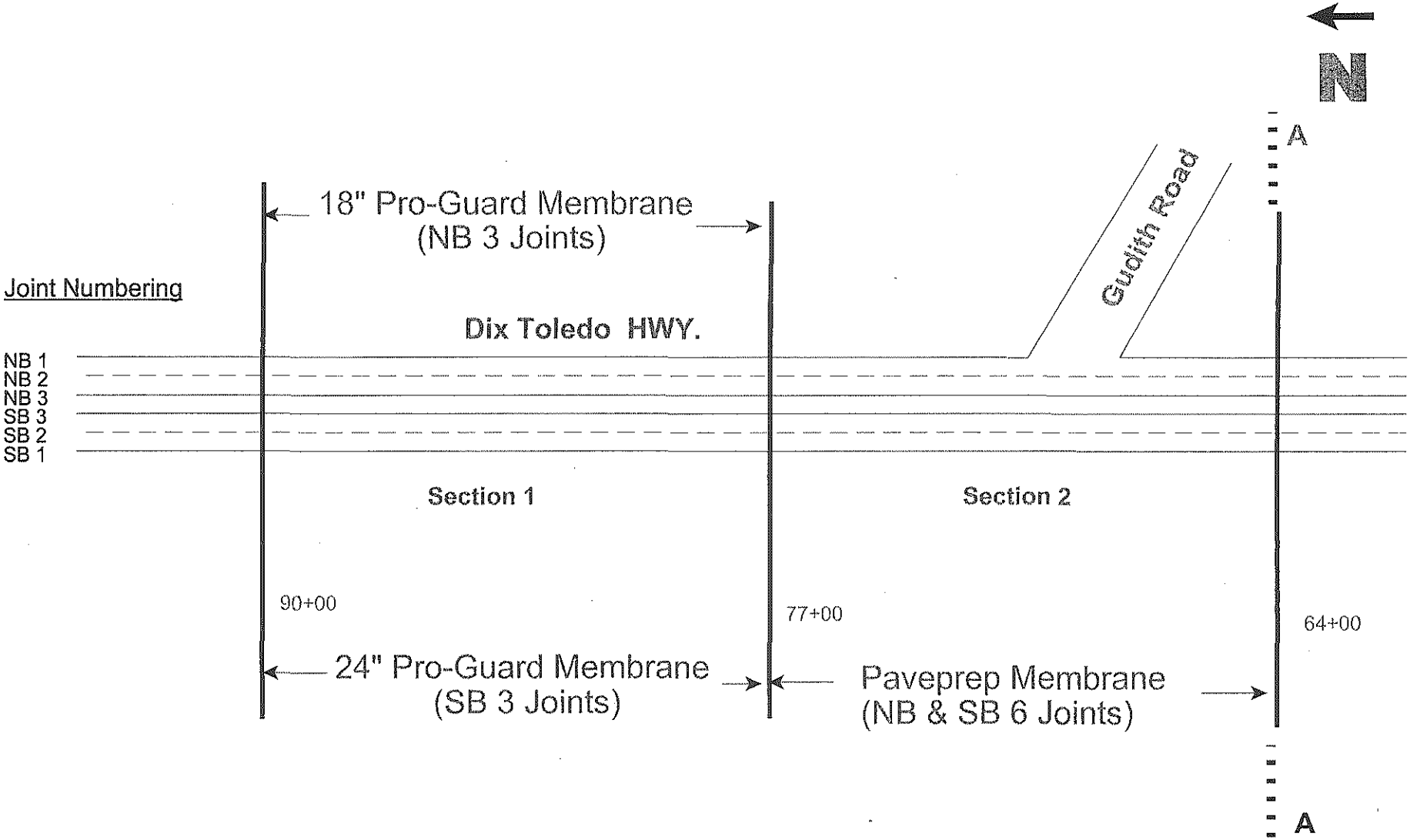
CROSS-SECTION PAVEMENT HISTORY



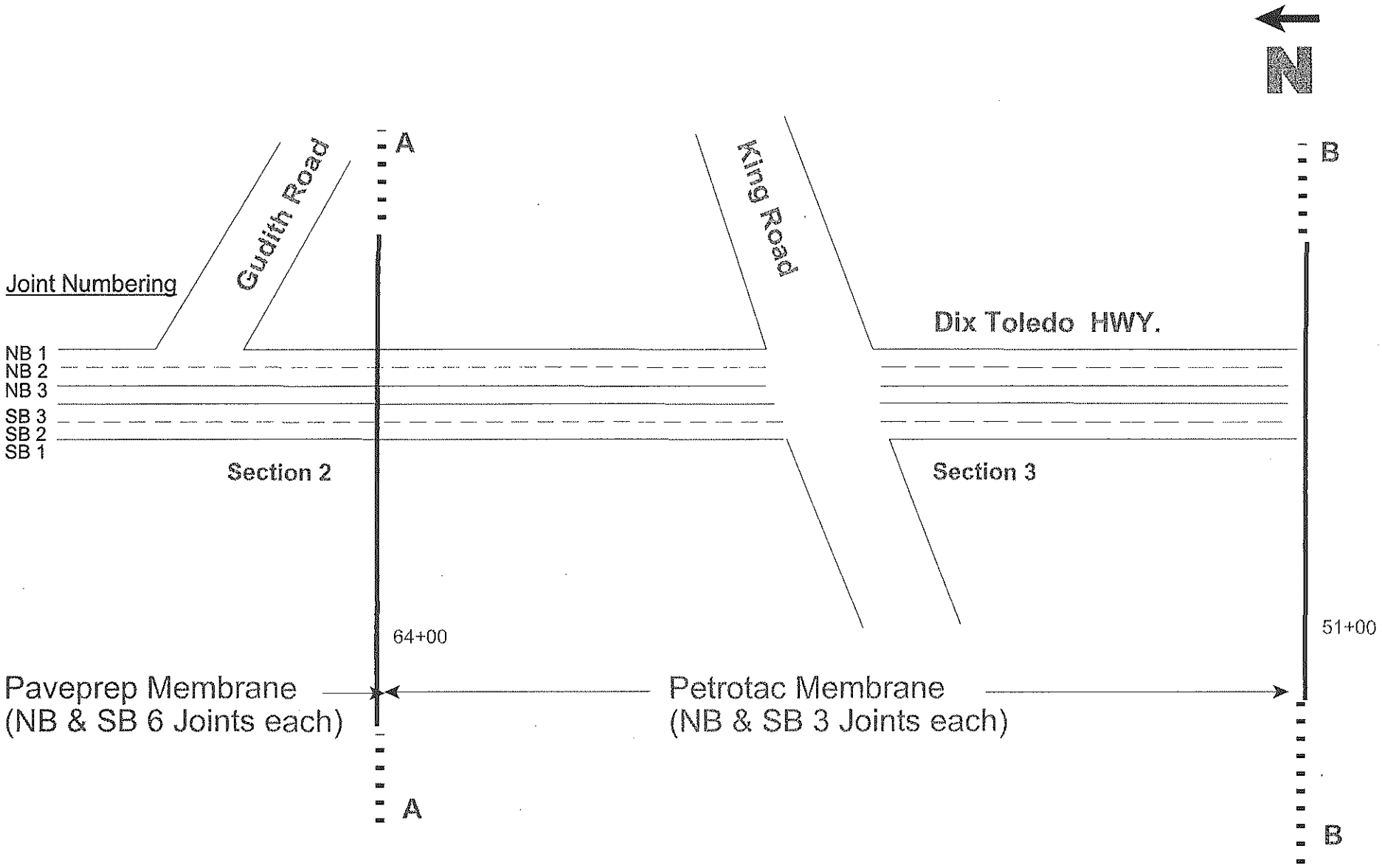
Cross-Section History

APPENDIX B

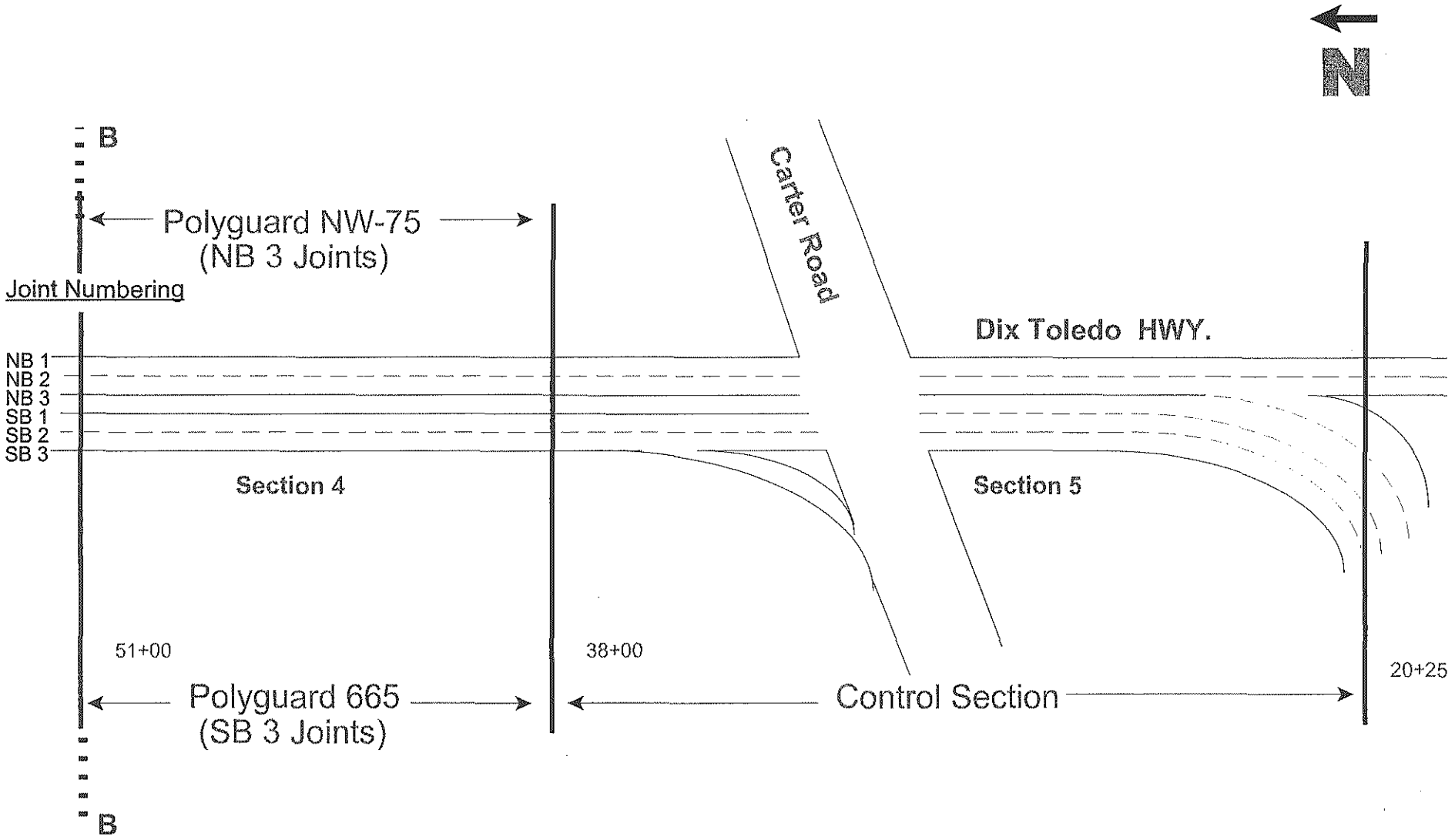
PRODUCT LOCATIONS


N
A
Gudith Road
18" Pro-Guard Membrane
(NB 3 Joints)
Joint Numbering
Dix Toledo HWY.
NB 1
NB 2
NB 3
SB 3
SB 2
SB 1
Section 1
Section 2
90+00
77+00
64+00
24" Pro-Guard Membrane
(SB 3 Joints)
Paveprep Membrane
(NB & SB 6 Joints)
A

Sections 1 & 2


N
A
B
Gudith Road
King Road
Joint Numbering
Dix Toledo HWY.
NB 1
NB 2
NB 3
SB 3
SB 2
SB 1
Section 2
Section 3
64+00
51+00
Paveprep Membrane
(NB & SB 6 Joints each)
Petrotac Membrane
(NB & SB 3 Joints each)
A
B

Sections 2 & 3


N
B
Polyguard NW-75
(NB 3 Joints)
Joint Numbering
Carter Road
Dix Toledo HWY.
NB 1
NB 2
NB 3
SB 1
SB 2
SB 3
Section 4
Section 5
51+00
38+00
20+25
Polyguard 665
(SB 3 Joints)
Control Section
B

Sections 4 & 5

APPENDIX C

PROPERTIES OF EACH PRODUCT

Properties of Polyguard NW-75 Waterproofing Membrane

PROPERTY	VALUE	TEST METHOD
Thickness	0.065* in	
Tensile Strength	50 lbs/in width	ASTM D 882 Method B
Puncture Resistance	200 lbs	ASTM E 154
Permeance	0.10 Perms	ASTM E-96 Method B
Pliability at Low Temps. (0°F, -15°F, 25°F)*	No Cracks	ASTM D 146
Elongation	80%	ASTM D 4632
Grab Tensile	246 lbs	ASTM D 4632

*Polyguard NW-75 is manufactured to the specifications of D.O.T.'s. Most material shipped meets a -15°F specification. However, if an agency has specified a higher or lower pliability specification, the product will be produced with formulation meeting those requirements.

Properties of Polyguard 665 Waterproofing Membrane

PROPERTY	VALUE	TEST METHOD
Thickness	0.065 in	
Tensile Strength	90 lbs/in width	ASTM D 882 Method B
Puncture Resistance	200 lbs	ASTM E 154
Permeance	0.10 max	ASTM E-96 Method B
Pliability at Low Temps. (0°F, -15°F, 25°F)*	No Cracks	ASTM D 146 Modified
Elongation	15%	ASTM D 4632

*Polyguard 665 is manufactured to the specifications of D.O.T.'s. Most material shipped meets a -15°F specification. However, if an agency has specified a higher or lower pliability specification, the product will be produced with formulation meeting those requirements.

Properties of Petrotac Waterproofing Membrane

PROPERTY	VALUE	TEST METHOD
Grab Tensile	200 lbs	ASTM D 4632
Elongation	40%	ASTM D 4632
Strip Tensile	50 lbs/in	ASTM D 882 (Modified)
Puncture Resistance	200 lbs	ASTM E 154
Permeance	0.10 Perms (max)	ASTM E 96 Method B
Pliability - 1/4" Mandrel 180° blend at -25°F	No cracks in fabric or rubberized asphalt	ASTM D 146 (Modified)

Properties of Pro-Guard Stress Relieving Membrane

PROPERTY	VALUE	TEST METHOD
Tensile Strength: MD XMD	370 lbs/in (2700lbs/in^2) 340 lbs/in (2450 lbs/in^2)	ASTM D 882*
Elongation	100%	ASTM D 882*
Puncture Strength	650 lbs (1" rod)	ASTM E 154
Peel Adhesion**	2.5 lbs/in	ASTM D 413
Specific Gravity (Mastic)	1.67	ASTM D 70-82
Weight/Gallon (Mastic)	14.0 lbs	ASTM D 70-82
Density	80 lbs/ft^3	ASTM E 12-70
Weight	0.9 lbs/ft^2	
Thickness	0.135 in, 95% retained after loading	ASTM D 1777
Water Absorption (Mastic)	1% maximum	ASTM D 517-92
Brittleness	Passes	ASTM D 517-92
Softening Point (Mastic)	205°F minimum	ASTM D 36-86
Cold Flex	No separation - 2" x 5" specimen, 180° bend on 2" mandrel @ 0°F	ASTM D 146-90
Heat Stability	No dripping or delamination after 2 hours @ 190°F on a 2" x 5" sample suspended vertically in a mechanical convection oven	
Polymeric Reinforcment	Cycles to break (single fiber) PFC 3,500,000 cycles	
Flammability	Self-extinguishing/NBR	Federal FMVSS 302

*12 in/min test speed and 1 inch initial distance between the grips were used.
**Critical property for product performance and dimensional stability during installation and in service life.

Properties of Paveprep Stress Relieving Membrane

PROPERTY	VALUE	TEST METHOD
Heat Stability	No dripping or delamination after 2 hours @ 190°F on a 2 " x 5" sample suspended vertically in a mechanical convection oven	
Flammability	Self-extinguishing/NBR	Federal FMVSS 302
Cold Flex	No separation 2" x 5" specimen, 180° bend on 2" mandrel @ 0°F	ASTM D 146-90
Polymeric Reinforcement	Cycles to break (single fiber) 2,100,000	
Equivalent Glass Reinforcement	Cycles to break (single fiber) 30,500	
Elongation	100%	ASTM D 412-87
Tensile Strength	2380 lbs/in^2	ASTM D 412-87
Weight	0.9 lbs/ft^2	
Density	80 lbs/ft^3	ASTM E 12-70
Caliper	0.135 in, 95% retained after loading	ASTM D 1777
Absorption	1% maximum	ASTM D 517-92
Brittleness	Passes	ASTM D 517-92
Softening Point	212oF minimum	ASTM D 36-86
Specific Gravity (Mastic Compound)	1.67	ASTM D 70-82

APPENDIX D

SPECIAL PROVISIONS

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION
FOR
OVERLAYING LONGITUDINAL PAVEMENT JOINTS AND CRACKS WITH WATERPROOFING MEMBRANE

a. Description.-This work shall consist of furnishing and placing a composite waterproofing membrane over longitudinal pavement joints/cracks prior to resurfacing. Application of these materials on this project will be experimental. Two different waterproofing membranes will be used. Each material shall be installed at designated locations as shown on the plans and contract documents.

b. Materials.-The waterproofing membrane shall incorporate a high strength, heat resistant geotextile embedded in a layer of self-adhesive rubberized asphalt membrane (mastic). The composite membrane shall meet the following physical property requirements:

Thickness (ASTM D 1777)	0.06 in minimum
Tensile Strength (ASTM D 882[1])	50 lbs/in minimum
Permeance (ASTM E 96)	0.10 Perms maximum
Puncture Resistance (ASTM E 154)	200 lbs minimum
Softening Point - Mastic (ASTM D 2398)	200 °F minimum
Pliability (ASTM D 146 Modified[2])	No Cracks in Mastic or geotextile

[1]Specimen shall be 1" x 6" with a 4" initial grip separation. Rate of test shall be 2 in/min.
[2]Specimen shall be bent 180 degrees over a 1/4" mandrel at 0 °F.

The specified properties shall be certified as minimum values with a 95 percent confidence level (mean value minus two standard deviations). Values which represent directional properties are specified for the weaker principle direction. With each material shipment, the manufacturer shall provide a Type A certification which includes a certified report of quality control test results obtained from the lot(s) of material in the shipment.

Each of the following products (or approved substitute) meeting the specified physical properties shall be installed in the designated demonstration section as shown on the plans:

Bituthene 5000, manufactured by Grace Construction Products, Inc.
Petrotac, manufactured by Amoco Fabrics & Fibers Company (Phillips Fibers)

Waterproofing membrane shall be provided in accordance with Section 1.06.01, and Sections 1.06.05 through 1.06.08 of the 1990 Standard Specifications for Construction, with the following additional requirements:

Materials shall be stored and handled in accordance with the manufacturer's recommendations. Each roll of material shall be labeled to provide product identification sufficient for correlation to certified test results. Information shall include product name, dimensions, lot or control unit numbers, and date and place of manufacture. Labeling shall be visible on unopened packaging.

Adhesive, asphalt binder (tack coat), crack/joint filler, and other incidental materials which are recommended by the membrane manufacturer for proper installation, shall be in accordance with the membrane manufacturer's specifications.

c. Construction Methods.-During installation, the manufacturer shall provide to the contractor an experienced technical support representative to insure the contractor employs proper installation techniques and equipment. The waterproofing membrane shall be installed in accordance with the manufacturer's recommendations and the following supplemental requirements:

1. Conditioning Existing Surface.-Prior to the placement of the membrane, the pavement surface, joints, and cracks shall be cleaned and dried. The prepared pavement shall be free of sharp edges, oil, grease, fines, and loose or foreign materials. Joints and cracks shall be prepared (filled if necessary) as required by the membrane manufacturer.

2. Binder Placement.-When required, binder or adhesive shall be placed on the prepared pavement at the temperature and application rate specified by the membrane manufacturer.

3. Membrane Placement.-The membrane shall be placed on the pavement or binder material (while the binder material is still liquid), centered over the particular joint or crack. Abutting membrane strips shall be overlapped in the paving direction a minimum of 5 inches. Any wrinkles, tears, punctures, or air blisters in the membrane shall be repaired as specified by the manufacturer. Membrane which is damaged due to the Contractor's operations shall be removed and replaced at the Contractor's expense. The installed membrane shall be approved by the Engineer prior to paving operations.

4. Open to Traffic.-Traffic shall not be allowed on areas where the membrane has been placed until after the pavement is placed, unless recommended by the manufacturer's specifications.

d. Weather Limitations.-No materials shall be applied when the air or pavement temperature is below 45 °F, or while the pavement surface is damp.

e. Measurement and Payment.-The completed work as measured for OVERLAYING LONGITUDINAL PAVEMENT JOINTS AND CRACKS WITH WATERPROOFING MEMBRANE will be paid for at the contract unit price for the following contract pay item:

Pay Item	Pay Unit
Waterproofing Membrane (18")	Lineal Feet

Waterproofing Membrane will be measured in place in lineal feet, without credit for laps. Payment for Waterproofing Membrane includes the cost of furnishing all materials, equipment, labor, and manufacturer's technical support required for preparing the pavement, filling joints as required, placing the asphalt binder or adhesive, and placing the waterproofing membrane.

MICHIGAN
DEPARTMENT OF TRANSPORTATION
BUREAU OF HIGHWAYS

SPECIAL PROVISION FOR OVERLAYING LONGITUDINAL PAVEMENT JOINTS AND CRACKS WITH STRESS RELIEVING MEMBRANE

M&T:DJT 1 of 3 04-22-94
C.S. 82071/J.N. 36000 C:APPR 00/00/94

a. Description.-This work shall consist of furnishing and placing a composite stress relieving membrane over longitudinal pavement joints/cracks prior to resurfacing. Application of these materials on this project will be experimental. Two different stress relieving membrane materials will be used. Each material shall be installed at designated locations as shown on the plans and contract documents.

b. Materials.-The stress relieving membrane shall consist of a flexible, impermeable, high density asphalt membrane (mastic) laminated between two high strength, permeable, heat resistant geotextiles. The composite membrane shall meet the following physical property requirements:

Thickness (ASTM D 1777)	0.13 in minimum
Tensile Strength (ASTM D 882[1,2] or D 412[2])	300 lbs/in minimum
Permeance (ASTM E 96)	0.10 Perms maximum
Puncture Resistance (ASTM E 154)	400 lbs minimum
Density - Mastic (ASTM E 12)	80 lbs/ft^3 minimum
Softening Point - Mastic (ASTM D 2398)	200 °F minimum
Pliability (ASTM D 146 Modified[3])	No Cracks in Mastic

[1]Specimen shall be 1" x 6" with a 4" initial grip separation.
[2]Rate of test shall be 2 in/min.
[3]Specimen shall be bent 180 degrees over a 2" mandrel at 0 °F.

The specified properties shall be certified as minimum values with a 95 percent confidence level (mean value minus two standard deviations). Values which represent directional properties are specified for the weaker principle direction. With each material shipment, the manufacturer shall provide a Type A certification which includes a certified report of quality control test results obtained from the lot(s) of material in the shipment.

Each of the following products (or approved substitute) meeting the specified physical properties shall be installed in the designated demonstration section as shown on the plans:

Paveprep, distributed by Contech Construction Products, Inc.
Pro-Guard, manufactured by Amoco Fabrics & Fibers Company (Phillips Fibers)

Stress Relieving Membrane shall be provided in accordance with Section 1.06.01, and Sections 1.06.05 through 1.06.08 of the 1990 Standard Specifications for Construction, with the following additional requirements:

Materials shall be stored and handled in accordance with the manufacturer's recommendations. Each roll of material shall be labeled to provide product identification sufficient for correlation to certified test results.

Information shall included product name, dimensions, lot or control unit numbers, and date and place of manufacture. Labeling shall be visible on unopened packaging.

Adhesive, asphalt binder (tack coat), crack/joint filler, and other incidental materials which are recommended by the membrane manufacturer for proper installation, shall be in accordance with the membrane manufacturer's specifications.

c. **Construction Methods.**-During installation, the manufacturer shall provide to the contractor an experienced technical support representative to insure the contractor employs proper installation techniques and equipment. The stress relieving membrane shall be installed in accordance with the manufacturer's recommendations and the following supplemental requirements:

1. **Conditioning Existing Surface.**-Prior to the placement of the membrane, the pavement surface, joints, and cracks shall be cleaned and dried. The prepared pavement shall be free of sharp edges, oil, grease, fines, and loose or foreign materials. Joints and cracks shall be prepared (filled if necessary) as required by the membrane manufacturer.

2. Binder Placement.-When required, binder (tack coat) or adhesive shall be placed on the prepared pavement at the temperature and application rate specified by the membrane manufacturer.

3. Membrane Placement.-The membrane shall be placed on the pavement or binder material (while the binder material is still liquid) centered over the particular joint or crack. Adjoining membrane strips shall be overlapped in the paving direction a minimum of 5 inches. Any wrinkles, tears, punctures, or air blisters in the membrane shall be repaired as specified by the manufacturer. Membrane which is damaged due to the Contractor's operations shall be removed and replaced at the Contractor's expense. The installed membrane shall be approved by the Engineer prior to paving operations.

4. Open to Traffic.-Traffic shall not be allowed on areas where the membrane was placed until after the overlay pavement is placed, unless recommended by the manufacturer's specifications.

d. **Weather Limitations.**-No materials shall be applied when the air or pavement temperature is below 45 °F, or while the pavement surface is damp.

e. **Measurement and Payment.**-The completed work as measured for OVERLAYING LONGITUDINAL PAVEMENT JOINTS AND CRACKS WITH STRESS RELIEVING MEMBRANE will be paid for at the contract unit price for the following contract pay item:

Pay Item	Pay Unit
Stress Relieving Membrane (18")	Lineal Feet

Stress Relieving Membrane will be measured in place in lineal feet, without credit for laps. Payment for Stress Relieving Membrane includes the cost of furnishing all materials, equipment, labor, and manufacturer's technical support, required for preparing the pavement, filling joints as required, furnishing and placing the asphalt binder or adhesive, and placing the stress relieving membrane.

e. Measurement and Payment.-The completed work as measured for OVERLAYING PAVEMENT JOINTS AND CRACKS WITH STRESS RELIEVING MEMBRANE will be paid for at the contract unit price for the following contract pay item:

Pay Item	Pay Unit
18" Stress Relieving Membrane	Lineal Feet

The Stress Relieving Membrane quantity will be measured in place to the limits as shown on the plans without credit for laps. Payment for Stress Relieving Membrane includes the cost of furnishing the material, labor, and equipment for preparing the pavement, filling joints as required, furnishing and placing the asphalt binder or adhesive, placing the Stress Relieving Membrane, and furnishing the manufacturer's technical support representative.

APPENDIX E

RESULTS FROM 2001 FIELD REVIEW

TABLE 1 - Summary of Reflective Cracking (2001)

		No Membrane	Waterproofing Membranes			Stress Relieving Membranes		
Type		N/A	18" Polyguard NW-75	18" Polyguard 665	18" Petrotac	18" Paveprep	18" Pro-Guard	24" Pro-Guard
Location		20+25 - 38+00	NB 38+00 - 51+00	SB 38+00 - 51+00	51+00 - 64+00	64+00 - 77+00	NB 77+00 - 90+00	SB 77+00 - 90+00
Total Membrane Placed	feet	N/A	3,900	3,900	7,800	7,800	3,900	3,900
Total Membrane Evaluated	feet	N/A	2,600	1,300	3,900	3,900	2,600	1,300
NB Reflective Cracking at Joint 1	feet	417	1,016	N/A	510	396	286	N/A
	%	23.5	78.2	N/A	39.2	30.5	22.0	N/A
NB Reflective Cracking at Joint 2	feet	316	104	N/A	76	63	68	N/A
	%	17.8	8.0	N/A	5.8	4.8	5.2	N/A
NB Reflective Cracking at Joint 3	feet	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SB Reflective Cracking at Joint 1	feet	707	N/A	612	230	193	N/A	141
	%	39.8	N/A	47.1	17.7	14.8	N/A	10.8
SB Reflective Cracking at Joint 2	feet	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
SB Reflective Cracking at Joint 3	feet	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	%	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Total Reflective Cracking	feet	1,440	1,120	612	816	652	354	141
	%	27.0	43.1	47.1	20.9	16.7	13.6	10.8

APPENDIX F

RQI & DI INFORMATION

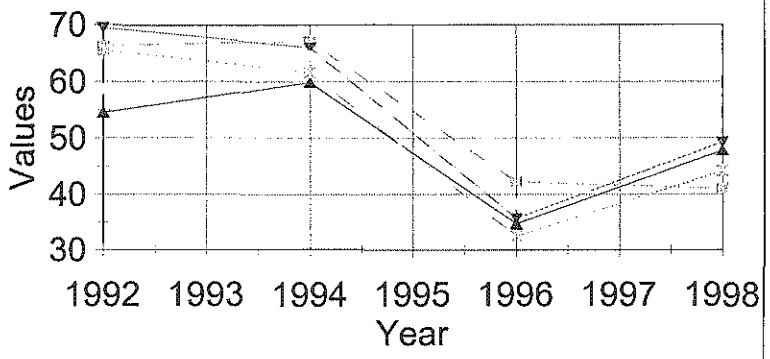
RQI Northbound					
Segment	Station	1992	1994	1996	1998
Control	20+25 to 38+00	66.35	67.21	42.27	41.06
Polyguard NW-75	38+00 to 51+00	69.54	66.12	35.75	49.30
Petrotac	51+00 to 64+00	58.72	64.67	38.24	44.57
Paveprep	64+00 to 77+00	54.60	59.89	34.75	47.84
18" Pro-guard	77+00 to 90+00	65.69	61.64	32.49	44.13

RQI Southbound					
Segment	Station	1992	1994	1996	1998
Control	20+25 to 38+00	51.26	52.63	42.95	45.24
Polyguard 665	38+00 to 51+00	52.28	57.44	41.62	44.29
Petrotac	51+00 to 64+00	57.17	63.26	42.91	56.39
Paveprep	64+00 to 77+00	63.29	67.76	47.18	51.50
24" Pro-guard	77+00 to 90+00	49.80	52.63	49.49	58.60

DI Northbound					
Segment	Station	1992	1994	1996	1998
Control	20+25 to 38+00	64.8	0.0	8.3	15.5
Polyguard NW-75	38+00 to 51+00	55.8	0.0	6.9	15.5
Petrotac	51+00 to 64+00	48.9	0.0	7.6	16.2
Paveprep	64+00 to 77+00	136.4	0.0	9.5	14.3
18" Pro-guard	77+00 to 90+00	224.3	0.0	7.1	12.0

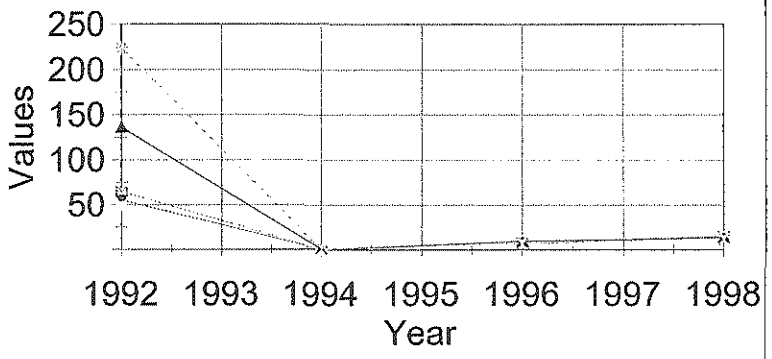
DI Southbound					
Segment	Station	1992	1994	1996	1998
Control	20+25 to 38+00	65.3	0.0	8.1	5.6
Polyguard 665	38+00 to 51+00	71.0	0.0	12.9	9.9
Petrotac	51+00 to 64+00	112.1	0.0	7.4	11.3
Paveprep	64+00 to 77+00	110.6	0.0	4.2	7.4
24" Pro-guard	77+00 to 90+00	109.0	0.0	8.2	3.1

RQI Northbound



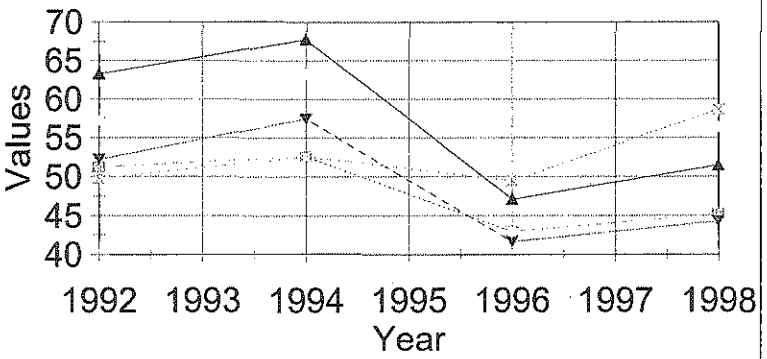
20+25 to 38+00 — 38+00 to 51+00
51+00 to 64+00 — 64+00 to 77+00
77+00 to 90+00

DI Northbound



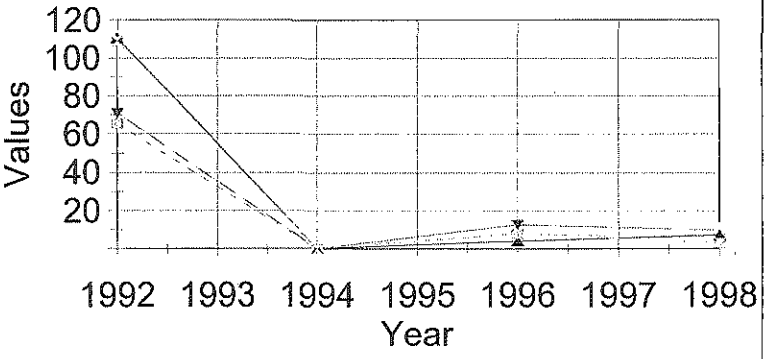
20+25 to 38+00 — 38+00 to 51+00
51+00 to 64+00 — 64+00 to 77+00
77+00 to 90+00

RQI Southbound



20+25 to 38+00 — 38+00 to 51+00
51+00 to 64+00 — 64+00 to 77+00
77+00 to 90+00

DI Southbound



20+25 to 38+00 — 38+00 to 51+00
51+00 to 64+00 — 64+00 to 77+00
77+00 to 90+00

APPENDIX G

TOTAL PROJECT COST EXAMPLE & B/C RATIO ANALYSIS

Total project cost example

This example first takes the "final project cost" per contract bidding documents and subtracts the amount spent on both membranes. This gives the "cost without membranes". Then, the amount it would cost to place either membrane on every joint throughout the entire project is computed and labeled either "waterproofing cost" or "stress relieving cost". This value is added to the "cost without membranes" to obtain the "total project cost". The increase in total cost if every joint was covered by membranes was then computed as "percent increase".

Final Project Cost	$1,136,459.40
18" Waterproofing Membrane	$23,868.00
18" Stress Relieving Membrane	$38,220.00
Cost Without Membranes	$1,074,371.40
Waterproofing Cost/Lft.	$1.53
Total Lft.	68,724
Waterproofing Cost	$105,147.72
Total Project Cost	$1,179,519.12
Percent Increase	**8.9%**
Stress Relieving Cost/Lft.	$2.45
Total Lft.	68,724
Stress Relieving Cost	$168,373.80
Total Project Cost	$1,242,745.20
Percent Increase	**13.6%**

Assumed Values	
Rout and Seal Cost (m) =	$3.85
Rout and Seal Cost (ft) =	$1.17
Maintaining Traffic Cost (km) =	$2,000.00
Maintaining Traffic Cost (ft) =	$0.61
Total Cost Per Foot =	$1.78
Present Worth Factor (i = 3%, n = 7)	0.8131

Segment	Evaluated (ft)	Initial Cost to Place Membrane
Control	5325	$0.00
Polyguard NW-75	2600	$3,978.00
Polyguard 665	1300	$1,989.00
Petrotac	3900	$5,967.00
Paveprep	3900	$9,555.00
18" Pro-Guard	2600	$6,370.00
24" Pro-Guard	1300	$3,185.00

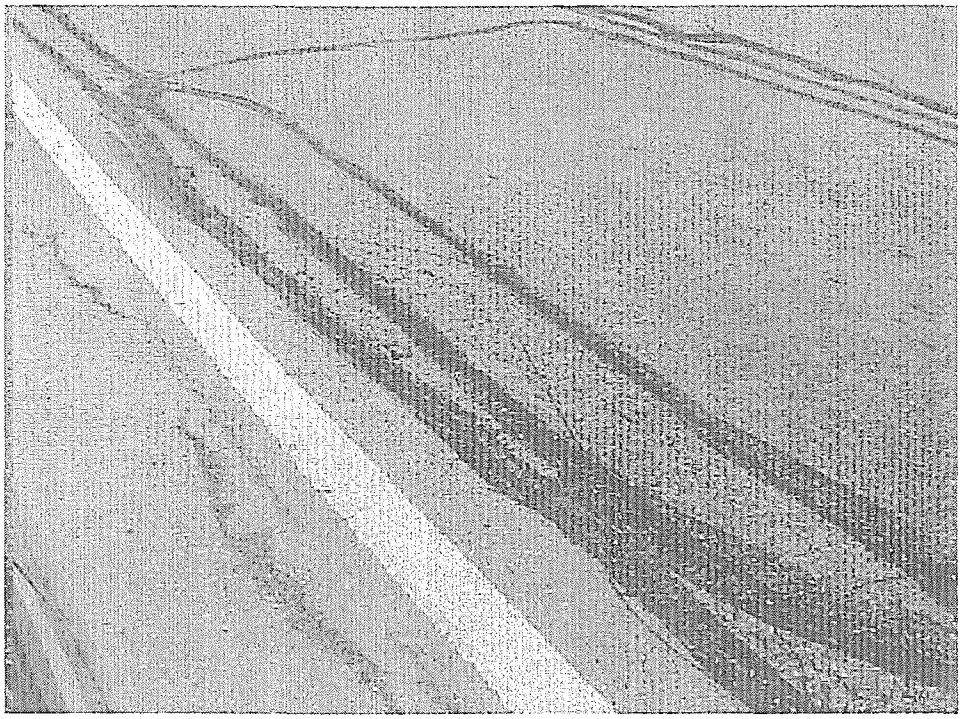
Segment	Cracked (ft)	Rout & Seal Cracks Cost *
Control	1440	$2,087.72
Polyguard NW-75	1120	$1,623.78
Polyguard 665	612	$887.28
Petrotac	816	$1,183.04
Paveprep	652	$945.27
18" Pro-Guard	354	$513.23
24" Pro-Guard	141	$204.42

Segment	Uncracked (ft)	Prevented Cracks Benefit *	B/C Ratio
Control	3885	$5,632.50	2.70
Polyguard NW-75	1480	$2,145.71	0.38
Polyguard 665	688	$997.47	0.35
Petrotac	3084	$4,471.21	0.63
Paveprep	3248	$4,708.97	0.45
18" Pro-Guard	2246	$3,256.27	0.47
24" Pro-Guard	1159	$1,680.33	0.50

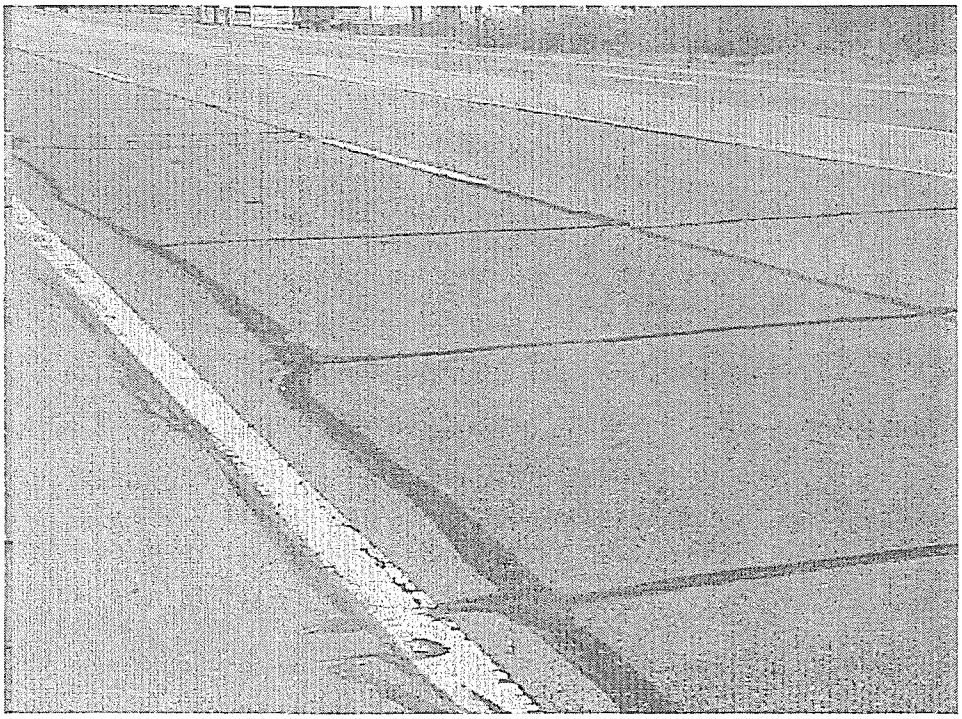
* Projected figures based on Net Present Worth

APPENDIX H

PICTURES TAKEN ON 2-26-01

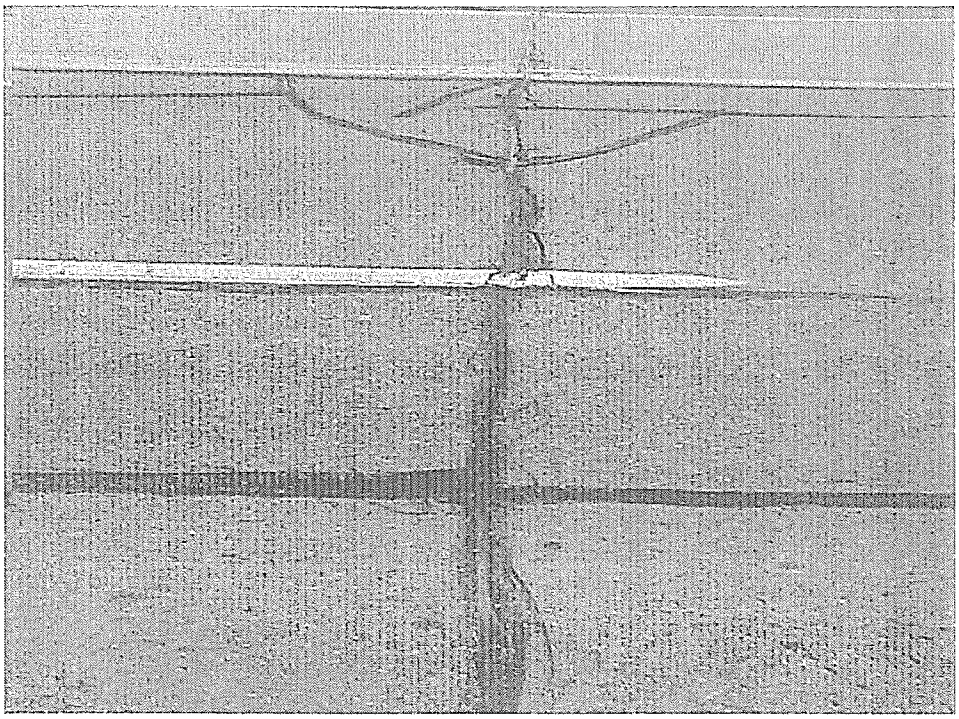


Station 49+70, SB Lanes Looking North (Polyguard 665)

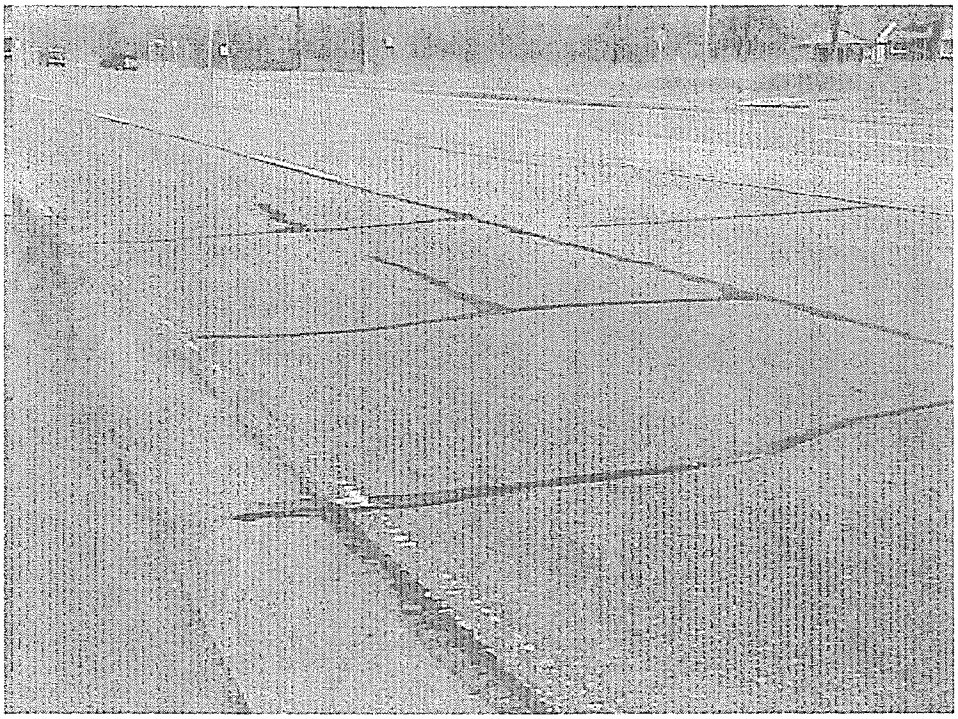


Station 56+00, SB Lanes Looking North (Petrotac)

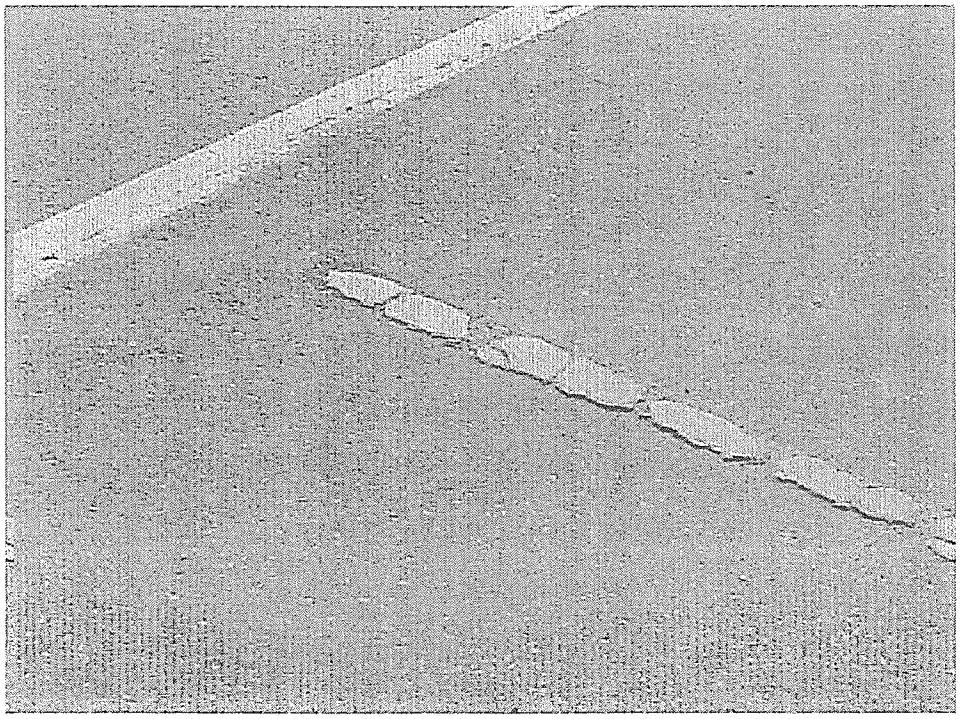
Station 58+20, SB Lanes Looking East (Petrotac)



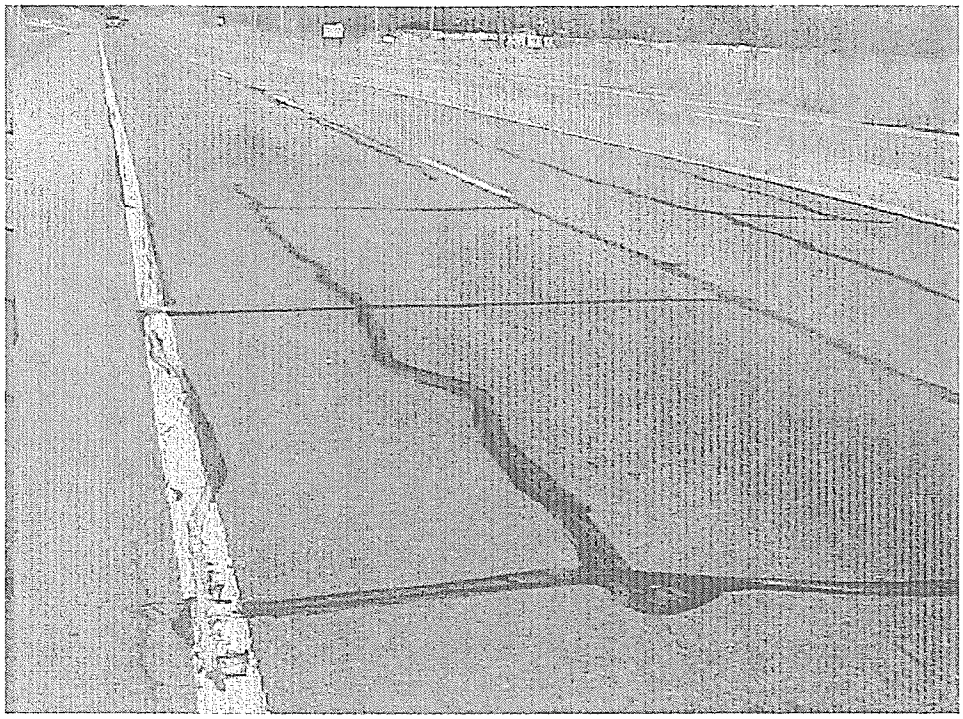
Station 65+30, SB Lanes Looking East (Paveprep)



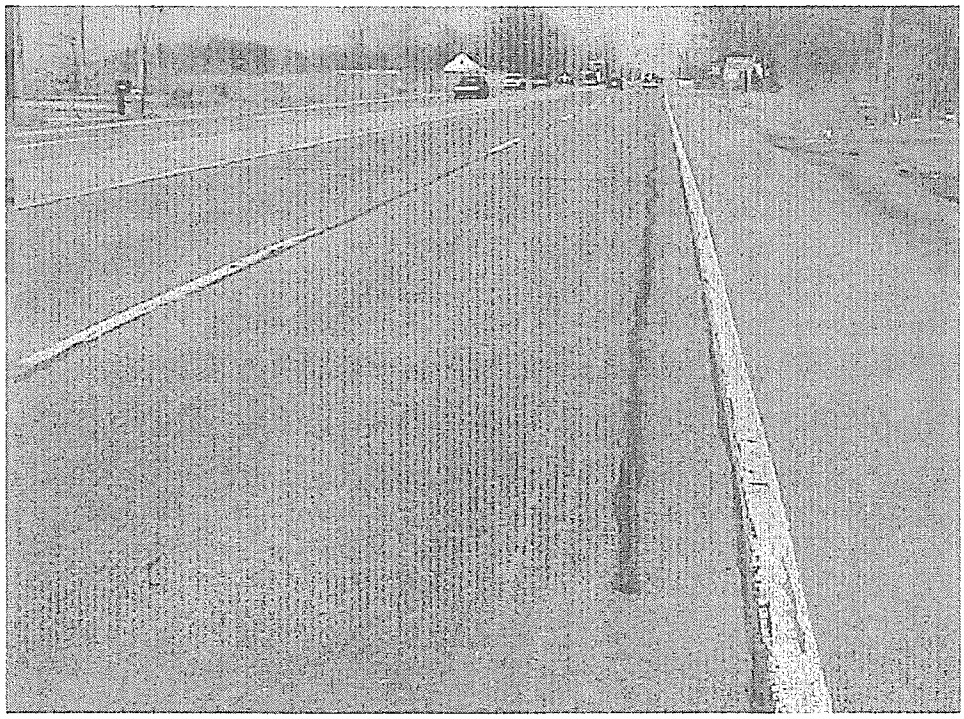
Station 75+00, SB Lanes Looking North (Paveprep)



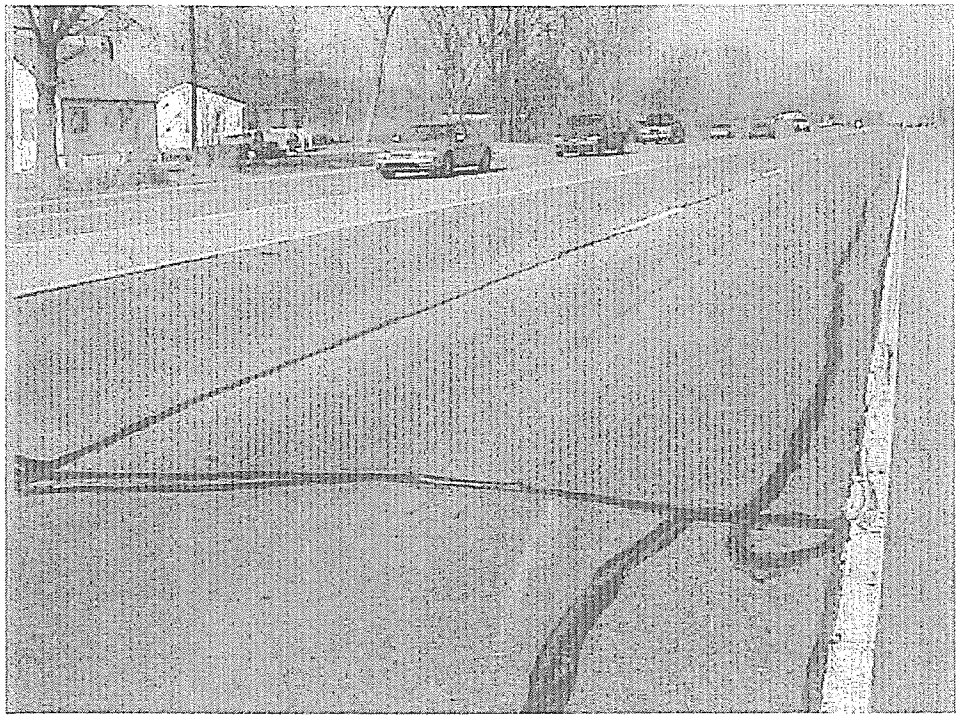
Station 77+00, SB Lane White Pavement Marking



Station 87+25, SB Lanes Looking North (24" Pro-Guard)



Stations 38+00 - 51+00, NB Lanes Looking North (Polyguard NW-75)



Stations 38+00 - 51+00, NB Lanes Looking North (Polyguard NW-75)

Stations 77+00 - 90+00, NB Lanes Looking North (18" Pro-Guard)