Field Performance of Fabrics and Fibers to Retard Reflective Cracking

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The purpose of this project was to determine whether any, or various, uses of geotechnical fabrics and fibers will significantly retard reflective cracking in an asphaltic concrete overlay. Four paving fabrics, one fiberized-asphalt membrane, and one fiber-reinforced asphaltic concrete were the treatment alternatives being evaluated. All treatments were compared with each other and with untreated control sections to determine relative performance. Considerations in making these comparisons were construction and maintenance costs, ease of placement, and the ability to prevent or retard reflective cracking. Performance data are presented for surveys conducted at 8 months, 26 months, and 44 months after construction. All treatments retarded cracks over the evaluation period, although the amount and rate of reduction varied. One paving fabric and fiber-reinforced asphalt concrete had the highest crack reduction ratios after the 44-month evaluation. On the basis of all factors considered in the evaluation—cost, ease of construction, and performance relative to distress treated—the fiber-reinforced concrete provided superior performance relative to the treatment alternatives. However, on the basis of the extent of cracking evident after the 44-month survey, and considering current and proposed crack sealing costs in addition to the documented construction costs, none of the treatments used on this project was found to be cost-effective or recommended for use.

Reflective crack formation in asphalt concrete pavement has confronted highway engineers for many years. Since the first flexible overlay was placed, there has been a need to restrict underlying deficiencies or weaknesses or prevent them from reflecting through the new surface. The primary cause of the cracking phenomenon has been recognized for some time—differential movement of the pavement layers occurs because of stresses produced by traffic and the environment (moisture and thermal-induced). The preventive treatments that have been, and are being, attempted vary in material composition and application method. Most treatments, though different in some respect, share common design aspects. In general, an interlayer is formed that is intended to both separate old and new pavement with a waterproof membrane and reinforce and bond the entire layered system.

The experience of the Pennsylvania Department of Transportation (PennDOT) includes several research projects that field evaluate either the use of construction fabrics or stress-absorbing membrane interlayers (SAMIs). Research Project 73-20 considered the effects of placing a full-width, nonwoven polypropylene fabric (Petromat) over alligator-cracked, flexible-base roads before overlaying in 1973 and 1976. The final report issued in 1981 stated that although cracking was retarded, use of the fabric was not recommended because the benefits were insufficient to justify the additional cost (*1*). Research Project 79-6, the evaluation of which was completed in August 1985, considered fabric as a strip treatment over rigid base joints and cracks. Final report conclusions indicate that significant crack reduction occurred due to treatment (*2*). However, Research Project 79-2, which is a continuing evaluation of SAMIs, appears to be inconclusive. Two projects constructed in 1980 currently indicate that the untreated pavement sections are performing equal to or better than the treated sections (*3*). Other states with similar evaluations have reported similar results (*4*).

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PLAN OF STUDY

In the summer of 1982, PennDOT Engineering District 4-0 (Northeast Pennsylvania) expressed interest in placing paving fabrics on a scheduled overlay project and requested guidance to set up a research project, because such usage is not standard practice in Pennsylvania.

One conclusion from Research Project 73-20, documented by other work (*5*), was significant in the selection of the proposed District 4-0 site. It was determined that fabric was more effective in retarding transverse cracking (in asphalt concrete) associated with thermal changes than cracking associated with structural inadequacies. Because the site was characterized as a mostly stable base with predominant surface, block-type cracking, fabric treatment represented a potentially effective benefit. The characterization of this type of cracking and its association with low distress levels would later prove to be invalid on the basis of actual posttreatment evaluation. However, at the time of planning, the consensus was that this condition could be successfully treated in the manner proposed based on the available technical literature.

Four fabrics or geotextiles and one SAMI-type, fibrous-membrane application were selected for evaluation. Before actual field placement, fiber-reinforced asphalt concrete was included in the study at the request of the District. Because fiber-reinforced concrete is a simpler application with lower overall cost relative to the other treatments, its consideration in the comparison was desirable. Table 1 summarizes the treatments compared.

OBJECTIVES

The primary objective of this study was to determine whether any of various treatments would significantly retard reflective crack formation in the asphalt concrete overlay. All treat-

TABLE 1 TREATMENT DESCRIPTION

	Treatment Identify	Product Description & Application
(1)	Control	No treatment - 1-1/2" ID-2 Wearing Overlay Existing Pavement.
(2)	Reepav T-376 Fabric Interlayer	Nonwoven, spunbonded, heatbonded polyester; rolled and tacked on existing pavement with asphalt cement prior to 1-1/2" ID-2 Wearing Overlay.
(3)	Amopave Fabric Interlayer	Nonwoven, needle punched, polypropylene; rolled and tacked on existing pavement with asphalt cement prior to 1-1/2" ID-2 Wearing Overlay.
(4)	Trevira 1115 Fabric Interlayer	Nonwoven, spunbonded, needle punched polyester; rolled and tacked on existing pavement with asphalt cement prior to 1-1/2" ID-2 Wearing Overlay.
(5)	Mirafi Fabric Interlayer	Nonwoven, needle punched, some heatbonding, polypropylene; rolled and tacked on existing pavement with asphalt cement prior to 1-1/2" ID-2 Wearing Overlay.
(6)	Fiber Pave 3010 Fiber-Reinforced Asphalt Interlayer	Asphalt cement (AC-20) composed of min. of 6% fine denier, short length polypropylene fiber; cast in place with specially designed mixing kettle/applicator prior to 1-1/2" ID-2 Wearing Overlay.
(7)	Bonifibers B Fiber-Reinforced Asphalt Overlay	Addition of 0.3% (by wt. of mix) fine denier, short length polyester fiber to ID-2 wearing at mixing plant; 1-1/2" Modified ID-2 Wearing Overlay of existing pavement.

ments involved the use of synthetic fabric or fibers and were compared with control pavement sections in which only a conventional hot-mix overlay was placed. As a secondary objective all treatments were compared with each other to determine relative performance, considering cost, ease of placement or adaptability to normal overlay practice, and effective length of time in resisting reflective cracking. The pavement sections were monitored in the field for approximately 4 years to determine overall and relative performance of each treatment.

PROJECT SITE

Roadway Location and Description

The project site is identified on the state highway system as State Route (SR) 11, Segment 650-661 (Traffic Route U.S. 11) in the Borough of Wyoming, Luzerne County. As a principal arterial highway, it is designated as Primary on the Federal-Aid System. Current average daily traffic (ADT) is about 14,000 vehicles.

The pavement section is a tangent 4,350 ft long, 55 ft wide, and curbed; there are four travel lanes with parking in both directions. Originally constructed and maintained by the county, the road was turned over to state jurisdiction in 1934. Today the pavement consists of both a rigid and a flexible base, because the original portland cement concrete was separated by a trolley-car area constructed on native stone (in the center of the highway). When the trolley service was abandoned before 1934, the track area was paved with bituminous concrete. A schematic of the pavement's cross section (Figure 1) summarizes the construction and maintenance history.

Preconstruction Roadway Condition and Analysis

Two types of survey were utilized to describe the roadway condition before overlay construction. A pavement-condition survey was performed using the Systematic Technique to Analyze and Manage Pennsylvania Pavements (STAMPP) format to analyze the observed surface conditions (*6*). A structural survey based on deflection measurements with a road rater was also obtained to determine relative movement of the underlying base when under load. Although the condition survey, which is based on visual observation, readily identified surface distress, such as cracking, it was essential to determine whether any distress was related to structural weakness. According to the Road Rater data, areas or pockets of base failure had occurred. Identification of these areas was particularly important to prevent biased evaluation.

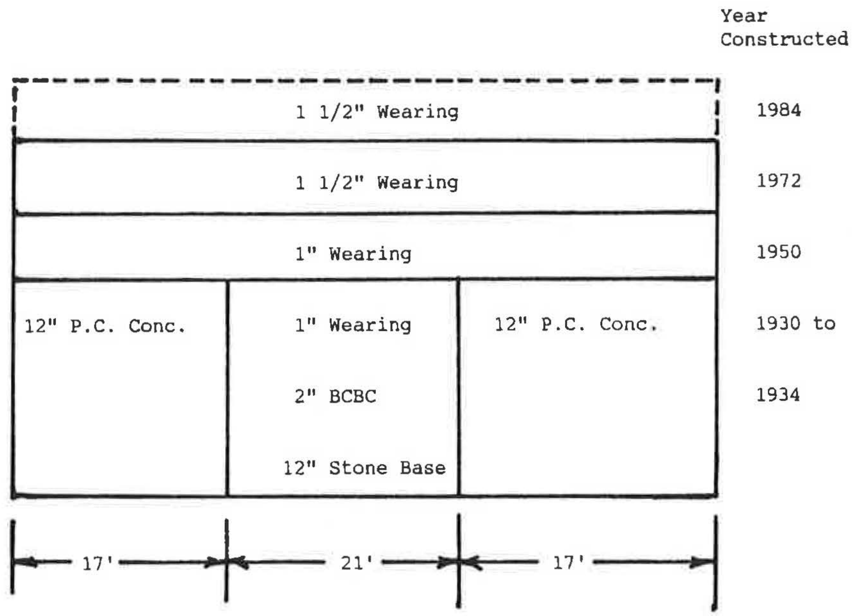

FIGURE 1 Pavement cross section.

TABLE 2 PRECONSTRUCTION PAVEMENT DISTRESS RATING

Location			STAMPP Condition Survey						Road Rater		
	Sec. No.	Begin Sta.	Block Cracking	Joint Cracking	Alligator Cracking	Patching	Potholes	Widening Drop-off	Average Deflection (Mils)	Total Rating Cumulative	Subjective Rating
			1 2 LOW	3 4	5 6 MEDIUM	7 8 HIGH	9				
NB	1	145+50	2,4	3	0	4	0	0	*	13***	L
	2	150+00	2,5	2	0	1,4	1,4	0	1.01	20.01	M
	3	156+00	2,5	2	0	0	0	0	1.04**	10.04	L
	4	162+00	3,6	2	1,4	4,7	2	0	1.11	30.11	MH
	5	168+00	3,6	2	1	1	0	0	1.06**	14.06	L
	6	174+00	3,5	2	0	1,4	1,4	0	1.03	21.03	M
	1	180+00	3,5	2	1	4,7	3	1	1.49	27.49	MH
	7	184+40	3,5	2	1	4,7	3	1	1.49	27.49	MH
SB	7	145+50	3,5	2	1	4,7	1	0	*	23***	M
	1	152+00	3,5	2	1	4,7	1	0	1.29	24.29	M
	6	156+00	6,7	2	1	4,7	5,7	0	1.20**	40.20	H
	5	162+00	6,7	2	1	1	1	0	1.01	19.01	ML
	4	168+00	6,7	2	0	1	1	0	0.94**	17.94	ML
	3	174+00	5,7	2	4	4	1	1	0.90	24.90	M
	2	180+00	3,5	2	4	1	2,4	1	1.16	23.16	M
	1	186+00	6,8	3,7	0	1,4	0	3	1.16	33.16	H

Total Rating Key

15.35 - Low (L) 15.35 - 19.20 - Medium Low (ML) 91.20 - 26.90 Med. (M)
26.90 - 30.75 Med. High (MH) 30.75 High (H)

*No reading taken **Interpolated from readings ***Missing Data

By combining the results of both surveys, a numerical rating was developed for each pavement section. Statistical analyses of the sections' total ratings revealed that the data closely approximated a normal distribution or bell-shaped curve. Five subjective categories of distress were determined on the assumption that the calculated mean represents average or medium distress. The five distress levels were classified as low, medium-low, medium, medium-high, and high. A summary of distress rating based on the preconstruction surveys is presented in Table 2.

Despite the range of initial pavement distress, one type of cracking—block cracking—appeared to be dominant and more or less uniformly distributed throughout the project. This distress, as the primary object of treatment in this study, was considered an important indicator of relative performance between treatments. Other types of distress, as identified in Table 2, were also considered significant in the performance analysis, because of the application of selective preliminary repair work, which included base patching and placement of a scratch course for sealing and leveling.

CONSTRUCTION

Preliminary Work

Areas exhibiting the highest level of distress received base repair in combination with a variable-width scratch course for leveling and sealing of open cracks. Areas indicating the least distress received nothing or only minimal scratch course placement, primarily for the purpose of leveling.

Although crack sealing was not made part of this contract, many of the numerous cracks had been previously sealed by maintenance forces during the fall of 1983 or were covered by the scratch course. It should be noted that not all cracks had been sealed or covered before interlayer placement. Generally, it is recommended by the paving fabric manufacturers that cracks averaging ¼ in. or wider be treated in this manner.

General Description of Interlayer and Overlay Construction

Interlayer and overlay placement was accomplished as a consecutive and continuous two-step process. When control and fiber-reinforced ID-2 hot mix were specified, the interlayer step was eliminated and no changes in conventional paving operations were required. Paving of approximately 27,000 yd^2 was completed in 3 days (June 26–28, 1984). A fourth day was spent sealing joints with asphalt cement (construction joints, curbs, manholes, etc.). Weather conditions during this period were good for paving construction. Daily temperatures averaged between approximately 56° to 80°F during working hours.

The additional procedures required in conjunction with each treatment were variable and thus the effect on paving efficiency varied. In general, delays due to such procedures were infrequent; however, on occasion significant problems were encountered, causing delays and less satisfactory treatment. Early occurrence and greater frequency of these more significant problems tend to indicate that inexperience with the applications was a major factor.

Although the contractor indicated some experience in installing paving fabric, this experience was quite limited. This was most evident during the first fabric placement which resulted in the poorest application of all treated pavement sections. However, there were other factors that were less dependent on experience and more relevant to a treatment's application requirements or material properties. In yet other instances, problems occurred because the equipment for a particular operation was improper, not correctly adjusted, or just difficult to use.

The bituminous paving on this project was governed and accepted in accordance with PennDOT's Restricted Performance Specifications (RPS) (7).

A summary of loose and compacted field samples of hot mix tested for acceptance is presented in Table 3. Although spot deviations in the mix composition, particularly low asphalt content, are noted, the overall quality of the mix and its placement is acceptable on the basis of the bonus-penalty point system, which is a standard part of the specification.

Although not required by contract, field samples of all treatment products were obtained and tested in the laboratory. A summary of the test results is presented in Table 4. Primarily, testing was to verify certain physical properties and composition relative to those specified or published by the manufacturers.

TREATMENT PLACEMENTS

Paving Fabric Interlayer

Fabrics supplied by four manufacturers were installed in test sections 2, 3, 4, and 5, generally conforming with the prescribed procedures and methods provided by those technical representatives in attendance. The recommended procedures and requirements for placement are essentially the same for each fabric.

Based on the observations from this project's construction and the recommendations by technical representatives, five critical considerations affect satisfactory placement of a paving fabric.

1. The tack coat should be applied at the proper rate and uniformly spread for complete coverage.
2. Fabric laydown should be smooth, with minimal wrinkling.
3. The tack coat application and fabric laydown should be coordinated for effective tacking.
4. Overlapped joint construction should be used to achieve complete coverage.
5. The pavement overlay should closely follow fabric placement to avoid potential damage by traffic.

Extremely poor placement was observed during the first day's fabric laydown. The laydown crew had difficulty in maintaining a straight and wrinkle-free roll despite guidance by the fabric technical representative. The first day's placement, attempted by using the tractor-mounted rig and then manual rolling, was unsuccessful. Perhaps the most significant causes of trouble for this placement were the crew's inexperience and a poorly applied tack coat preceding the laydown.

Inadequate heating of the AC-20 resulted in clogging of the distributor nozzles in the middle of the spray pattern, causing nonuniform and inadequate coverage. To correct the skips, hot AC-20 was applied with a hand-held pot. This method did not provide a uniform and satisfactory correction. The initial heating of AC-20 to approximately 300°F was apparently insufficient to prevent the distributor nozzles from clogging. Not until the next application, when a heating range between 350° and 375°F was maintained in the kettle, did the distributor produced a continuously uniform spray pattern.

Poor bonding between the hot-mix overlay and the underlying pavement was also documented to have occurred, but only during the first day's placement. Two of the five core samples taken for density acceptance indicated either total or partial bond failure. It was easily understood that poor bonding occurred with one of the samples, because the location had been insufficiently tacked. For the second sample the fabric had bonded to the underlying pavement but the overlay achieved only partial bonding to the top of the fabric. Apparently, the tack was not drawn up through the fabric sufficiently. Normally, complete absorption occurs because of the heat of the hot mix and the pressure of the rollers. Insufficient pressure was most likely the problem here, because the den-

TABLE 3 SUMMARY OF LABORATORY TESTS OF FIELD SAMPLES FOR OVERLAY ACCEPTANCE: STANDARD HOT MIX (ID-2 WEARING) EXTRACTION SUMMARY

		U.S. Sieve Size (Opening) - Percent Passing									Asphalt Content (%)
		1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	A.C.
	Upper Limit	100	100	72	51	40	32	23	14	6.3	6.8
	Design	100	96	64	45	34	26	17	8	4.3	6.4
	Lower Limit	92	88	56	39	28	20	11	2	2.3	6.0
No. Samples											
(5)	Ave. 1st Day	100	96	61	45	34	25	15	8	3.9	6.0*
(5)	Ave. 2nd Day	100	94	60	44	34	26	16	9	4.6	6.0*
(7)	Ave. 3rd Day	100	95	64	46	35	26	16	8	5.0**	6.2

* 1 sample each day below lower limit (5.9)
**1 sample above upper limit, calculated to be an outlier (8.6) statistically

ID-2 Wearing Density Summary

Design Density (Theoretical, voidless mix) - 150.4 lbs/cu. ft.

No. Samples		Density (lb/cu. ft.)	Compaction (%)
(5)	Ave. 1st day	140.6	94
(5)	Ave. 2nd day	141.4	94
(7)	Ave. 3rd Day	142.0	94

sity core measured a marginal compaction of 90 percent; this was the lowest compaction recorded for the project.

The two most common problems observed initially—poor tack coat application and badly wrinkled fabric laydown—were largely influenced by the contractor's inexperience. However, as early as the second day of placement, the efficiency and quality of laydown efforts improved considerably. Poor laydown observed after this could be attributed to other factors, mostly related to individual fabric properties.

Difference in fabric manufacture is identified as the primary factor contributing to the ease or difficulty of laydown. Because all the fabrics considered are nonwoven, their structure is formed by locking or bonding the fibers together by methods other than weaving. The bonding methods considered here consisted of varying combinations of spun bonding, needle-punching, and heat bonding.

Fabric 2 is formed by a combination of spun bonding and heat bonding. Heat bonding for this fabric is the primary method of locking the fibers together into a mat. The fibers are brought to a semiliquid state and pressed together. This process results in a fabric with significantly different physical properties than one formed by needle-punching, a mechanical bonding method. This fabric is thinner, lighter, and more rigid than the other fabrics. Table 4 indicates that lower grab-strength values were obtained with Fabric 2 than with the other fabrics. Apparently because of this rigid nature, Fabric 2 was considerably more difficult to place wrinkle-free, even after almost 3 days' experience with fabric laydown.

Fabric 5 presented similar, but less severe, wrinkling during placement. Although needle-punched, it is also partially heat bonded, which results in a smooth glossy surface on one side.

Heat bonding may also have been partially responsible for another minor problem experienced during paving, which was only observed during placement of Fabrics 2 and 5. Occasionally, the paving foreman noted that the paver was slipping and the underlying fabric was moving. This was minimized by shoveling hot mix in front of and underneath the paver tires, as recommended by fabric technical representatives.

Fiber-Reinforced Asphalt Membrane Interlayer

This treatment (No. 6) was considered an alternative method to placing paving fabrics. It consists of placing an asphalt cement membrane formed from AC-20 and polypropylene fibers. The fiber-reinforced membrane was selected for comparison with paving fabrics because of prior evaluation. As part of another research project (*8*), it was indicated that when applied in a narrow band over joints and cracks, the asphalt membrane performed well as a sealant. When this treatment is applied full width across the pavement, as in this project, it results in a fiberized SAMI.

TABLE 4 SUMMARY OF LABORATORY TESTS FOR FIELD SAMPLES OF TREATMENT MATERIALS: FABRIC PHYSICAL PROPERTIES

Fabric Treatment Designation Number	Weight	Thickness	Grab Tensile Strength[a] (lb)	Elongation[a] (%)	Calculated Tack Coat Requirement[b]
	oz./yd^2	mils	*MD/CD	*MD/CD	gal./yd^2
2	2.86 (3.0-4.0)	14.2 (-)	96/73 (-)	27/32 (-)	0.17 (0.20-0.30)
3	4.80 (4.0)	55.9 (-)	132/127 (90)	42/36 (55)	0.29 (0.20-0.25)
4	4.58 (4.5)	55.8 (85)	155/114 (130/110)	45/51 (85/95)	0.29 (0.25-0.30)
5	5.91 (4.0)	73.2 (-)	169/134 (115)	35/37 (60)	0.34 (0.20-0.25)

a - Test method ASTM-D-1682
b - Based on formula developed by Caltrans laboratory research using measured weight and thickness properties of fabric
( ) - Available manufacturer data or recommendations
* - Machine Direction/Cross Direction

Extraction Results of Fiber-Reinforced ID-2

	U.S. Sieve Size (Opening) - Percent Passing									Fiber Content	Asphalt Content (%)
	1/2"	3/8"	#4	#8	#16	#30	#50	#100	#200	(%)	
Upper Limit	100	100	72	51	40	32	23	14	7.3	---	7.3
Design	100	96	64	45	34	26	17	8	4.3	0.38	6.6
Lower Limit	100	88	58	39	28	20	11	2	3.0	---	5.9
Sample (6-28-84)	100	96	64	47	38	29	18	8	3.6	0.3	6.9

Sample represents 2nd section of fiber-reinforced mix (3rd day paving, southbound lanes). Sample contained 0.3% fibers by weight, which is equivalent to 6.0 lb/ton of hot mix. The fiber manufacturer recommends 7-1/2 lbs/ton when traffic density is greater than 10,000 ADT.

Fiber Content of Fiber Reinforced Asphaltic Membrane

Sample (6-28-84) 8.9% fibers (weight basis; average of 2 increments).
Sample represents 2nd section of fiber-reinforced membrane (3rd day paving, southbound lane
The manufacturer recommends a minimum of 6.0% fibers.

The mix formulation for this project specified proprietary fibers at a rate of 6.0 percent by weight of the asphalt. An additive, which is an adhesion promoter, was also blended in the mix at a rate of 2.0 percent by weight of the asphalt. The mixture was first heated and blended in a special trailer-mounted, kettle applicator provided by the manufacturer. After the proper heating and blending were achieved, the mixture was applied directly on the old pavement surface (no tacking was required).

Because the treatment requires the operation of specialized equipment, the mixture was prepared and applied by the manufacturer's technical representatives. The only work performed by the contractor was the application of the stone cover following the membrane laydown. The two sections of this treatment were placed on separate days. The northbound section's placement was the first feature observed on the project, and similar to the first fabric placement, the startup was plagued with problems, which resulted in significant delay of the overlay paving. The overall control and efficiency of the second placement was better, apparently because of the experience gained during the first day's work.

The aggregate cover to protect the membrane before and during paving was considered to be poorly applied for both section placements. This was the result of using inappropriate equipment for the material applied. The use of a dump truck with a hand-held tailgate lever resulted in coverage that varied from excessive in many areas to inadequate in others. Also, the aggregate, which is a Pennsylvania 1-B (equivalent to an AASHTO No. 8), was noted to contain high-moisture pockets. To complicate the situation further, the aggregate was rolled into the membrane using a steel-wheeled rather than a pneumatic roller, which resulted in considerable crushing and pulverizing of the aggregate.

Much of the responsibility for the improper application lies with the fiber manufacturer. The original membrane design had specified a sand cover, which required a steel-wheeled roller. Within only several days of the scheduled work, the manufacturer recommended changing the cover to stone because recent experience had shown that a more stable mat resulted, with less tendency for the asphalt to bleed. However, the contractor was not prepared to provide the proper roller for stone or a more sophisticated aggregate spreader.

Fiber-Reinforced Asphalt Concrete (No Interlayer)

A single proprietary polyester fiber was selected at the request of the District, even though other fibers, such as polypropylene, are also marketed for hot-mix reinforcement. The District's selection was primarily based on the paving contractor's recommendation and his prior experience with this fiber. Fibers of polypropylene and polyester differ in a number of ways, including physical and dimensional characteristics. Perhaps the most significant difference between them is that polypropylene melts and the fibers are destroyed when exposed to temperatures between 320° and 350°F, whereas polyester does the same but at temperatures between 480° and 490°F. Thus, if polypropylene fibers are used to reinforce a hot mix, it is essential that mix temperatures be tightly and properly controlled.

The mix formulation for this project was 0.3 percent fiber content or 6 lb of fiber per ton of hot mix. The fibers were added to the mix in premeasured and packaged bags at the beginning of the dry mixing cycle along with the dried aggregate.

This treatment, without question, was the easiest application observed on the project to adapt to normal paving operations. No additional manpower was required and the modified hot mix was applied with conventional equipment without any noticeable difficulty or delay.

RATING OF TREATMENTS BASED ON APPLICATION/COST

To summarize and provide a means of comparing the relative constructibility of the treatments observed, a rating system was developed. The rating summary of treatments is presented in Table 5. The criteria for comparison are essentially the three general factors: cost, potential for causing delay in construction, and potential for causing related paving or post-application problems.

PERFORMANCE

An initial crack survey was performed on February 26, 1985, 8 months after construction. Approximately 350 distinct cracks were identified, which totaled approximately 1,500 linear ft. The primary type of crack observed was a tight 2- to 4-ft transverse crack; however, the length of the cracks varied considerably, including a few that extended the full width of

TABLE 5 CONSTRUCTION APPLICATION RATING

Rank	Test Product	Cost	No. Steps	Ease of Application[a]	Potential for Related Paving Problems[b]	Total* Score
		($/yd^2)				
6	2	1.65	2	4	2	9.65
2	3	1.50	2	2	0	5.5
3	4	1.70	2	2	0	5.7
5	5	1.45	2	3	1	7.45
4	6	2.00	2	3	0	7.0
1	7	1.04	1	1	0	3.04

[a]Key
1 - Easy 2 - Moderately Easy 3 - Moderately Difficult
4 - Difficult

[b]Key

0 - None observed 1 - One problem observed
2 - Two or more problems observed

*Lowest score is equivalent to highest ranking

What is desired most is a treatment that is cost-effective as well as trouble free to apply. However, cost-effectiveness is dependent on performance data which indicates relative benefit versus distress treated at a reduced cost.

a treatment section or were severe in nature (1/4 in. wide or more). Approximately 7 percent of the transverse cracks measured a full paving-lane width or more. Of all the cracks observed, 60 percent were located in the travel lane. Although the number of longitudinal cracks accounted for only 10 percent of the total number observed, this was equivalent in length to about 20 percent of all cracking. Many of the longitudinal cracks were located along the paving joints where interlayer treatments were not overlapped during construction.

Follow-up Crack Surveys

A follow-up crack survey was performed on August 13 and 14, 1985, during the first of three scheduled annual pavement condition surveys. No new distress conditions were apparent and there was no significant change in the relative number and location of cracks. Even though some of the tight hairline cracks noted in February were no longer easily seen, the relative condition between all pavement sections was unchanged since the earlier survey.

Two additional crack surveys were performed after the evaluation of construction and early performance data in September 1985, the first occurring at 26 months and the last at 44 months after construction. By identifying the location and length of each crack during each survey, the growth of initial cracks and development of new cracks has been documented with reasonable precision. Postconstruction deflection measurements should also have been gathered because of the varying base conditions resulting from construction; however, this aspect of the evaluation was overlooked.

Crack Development

Overall, cracking has been increasing at a significant rate. Cracking multiplied more than eight times between the 8- and 44-month surveys. The 26-month survey indicated that cracking had more than doubled relative to the first survey, whereas the 44-month survey determined that cracking had more than tripled since the previous survey. Examination of the 16 individual sections indicated that the rate, in feet per month, has fluctuated, with most sections actually measuring a decrease in rate between 8 and 26 months. This trend was even consistent in the control areas. However, all sections indicate a relatively sharp increase in cracking rate after 26 months (see Table 6).

Data summaries provided in Table 6 indicate some relative performance factors regarding crack development and growth. This may explain some of the differences observed. Deflection measurements (as indicated by the Road Rater) and adequate preliminary treatment (such as base patching and scratch-course placement, when required) may be the significant factors correlating relative performance. Separating the project into two components, northbound and southbound, appears to illustrate this best.

Table 7 summarizes crack development by type (transverse and longitudinal) for each project half (northbound and southbound). The southbound lanes received a significantly greater portion of preliminary treatment in the form of base patching and scratch-course placement relative to the northbound lanes. It is apparent that an initial benefit from this treatment of additional retarding of all types of cracking occurred for a period of approximately 1 to 2 years. However, after that period, the treatment's effectiveness diminished and both halves of the project cracked at very nearly equal rates. This trend is apparent for both transverse and longitudinal cracking. It is also apparent that even though primarily transverse cracks occurred initially, the longitudinal type had increased by the time of the 44-month evaluation, and both longitudinal and transverse cracks were occurring at a nearly uniform rate. The block-cracked, preconstruction condition had clearly reflected through the overlay at 44 months.

Table 7 also includes an additional summary of control

TABLE 6 RELATIVE CRACK OCCURRENCE BETWEEN TREATMENTS

Treatment Designation	Total Area (ft^2)	Total Cracking Identified by Survey (Time After Construction) 8 months (ft)	26 months (ft)	44 months (ft)	Crack Ratio Length Relative to Area 8 Months (ft/ft^2)	26 Months (ft/ft^2)	44 Months (ft/ft^2)	Crack Ratio Reduction Relative To Control 8 Months (%)	26 Months (%)	44 Months (%)
(1)	38,160	543	1,118	3,633	0.0142	0.0293	0.0952	---	---	---
(2)	28,800	225	565	2,134	0.0078	0.0196	0.0741	45.0	33.0	22.2
(3)	28,800	164	469	1,586	0.0057	0.0163	0.0551	59.9	44.4	42.2
(4)	28,800	32	308	1,298	0.0011	0.0107	0.0451	92.2	63.5	52.7
(5)	28,800	183	474	1,508	0.0064	0.0165	0.0524	55.2	43.8	45.0
(6)	28,800	103	260	1,471	0.0036	0.0090	0.0511	74.8	69.2	46.4
(7)	26,640	277	454	1,247	0.0104	0.0170	0.0468	26.8	41.8	50.8
Overall	208,800	1,527	3,648	12,877	0.0073	0.0175	0.0617	*59.4	*49.4	*43.1

*Based on Overall Excluding Control

TABLE 7 CRACK COMPARISON BY TYPE AND LANE DIRECTION

ALL TREATMENT SECTIONS*

	Transverse Cracks (FT)			Longitudinal Cracks (FT)		
Direction	8 Months	26 Months	44 Months	8 Months	26 Months	44 Months
Northbound Lanes	807	1,015	3,362	192	1,010	3,065
Southbound Lanes	450	884	3,441	78	739	3,009
Combined	1,257	1,899	6,803	270	1,749	6,074

CONTROL SECTIONS

	Transverse Cracks (FT)			Longitudinal Cracks (FT)		
Direction	8 Months	26 Months	44 Months	8 Months	26 Months	44 Months
Northbound Lanes	306	365	921	86	342	905
Southbound Lanes	106	194	816	45	217	991
Combined	412	559	1,737	131	559	1,896

*Including Control

sections only. This was done primarily to verify that the trends noted overall were also occurring in untreated pavement (as defined in Table 1).

Cost-Benefit Analysis

Given the apparent conclusion that all treatments have provided some benefit in performance by retarding crack development for a period of time, it is important to determine whether the benefit is of sufficient magnitude and long-term enough to provide a true life-cycle cost benefit. This is particularly important because for most of the treatments the benefits are currently diminishing.

Based on a life cycle of 10 years for the applied overlay and using current performance and costs, several estimates of future performance and the related costs are proposed and summarized in Table 8. An initial maintenance activity of crack sealing is proposed, followed by a second sealing activity during the life cycle. Several estimates of future total cracking are proposed, because this is an important unknown and will have a significant impact on life-cycle costs. The proposed rates are based on current weighted averages calculated using the three previous crack surveys as a basis. It is assumed that cracking will continue at an average rate not greater than the current weighted average and that proportional differences in performance between treatments will remain the same. This is obviously a hypothetical assumption and is subject to future verification.

However, it is the opinion of the authors of this paper that the estimates are conservative and that future increases may be actually much higher in the treated sections relative to the control because of diminishing benefits.

Despite probable inaccuracies in the assumptions presented, several conclusions appear to be significant. It is apparent that crack sealing as proposed is a relatively low-cost item in the life-cycle cost prediction relative to the initial construction costs of all of the treatments compared.

These relative cost factors indicate that currently observed crack reduction ratios are insufficient to offset the construction costs by the end of the proposed life-cycle. In fact, even if no further cracking occurs in any of the treated sections while it continues at the maximum proposed rate in control pavement, a cost benefit will still not be realized.

On the basis of this analysis, none of the fabric and fiber treatments evaluated in this study are considered cost-effective for crack control when applied to a pavement with similar conditions and distress levels as those identified in this project. However, it is recommended that additional future surveys of this test site be conducted and that additional field testing, including full-depth pavement core samples, be evaluated to further document long-term results and effects of such treatments.

SUMMARY OF OBSERVATIONS AND CONCLUSIONS

Construction

- Primarily due to contractor inexperience, the construction using paving fabrics with fiberized membrane interlayer

TABLE 8 ESTIMATE OF LIFE-CYCLE COSTS

Treatment Designation	Current Cracks (LF)	Prop. Seal Cost ($) ($.25/LF)	Const. Treatment Cost ($)	Prop. Total Cost ($) @ 44 Mo. After Const.	Estimated Cracks (Total) (LF) 80 Mo. After Const.			Estimated Costs ($) Seal & Reseal @ 80 Mo. (Assume Cost Escalates @ 5% Annually, ($0.29/LF)			** Total Life Cycle Costs Based on Estimates ($)		
					1 Method A	2 Method B	3 Method C	Method A	Method B	Method C	Method A	Method B	Method C
(1)	2,742*	686	---	686	4,987	4,248	3,866	1,466	1,232	1,121	2,132	1,918	1,807
(2)	2,134	534	5,280	5,814	3,880	3,304	3,007	1,125	958	872	6,939	6,772	6,686
(3)	1,586	396	4,800	5,196	2,882	2,454	2,234	836	712	648	6,032	5,908	5,844
(4)	1,298	324	5,440	5,764	2,360	2,010	1,829	684	583	530	6,449	6,347	6,295
(5)	1,508	377	4,640	5,017	2,739	2,323	2,124	794	674	616	5,811	5,691	5,633
(6)	1,471	368	6,400	6,768	2,677	2,279	2,074	776	661	601	7,544	7,429	7,369
(7)	1,3[illegible]8*	337	3,285	3,622	2,450	2,086	1,899	710	605	551	4,332	4,227	4,173

1 - Cracking will continue at 100% of the current 44 month weighted average rate LF/Mo.

2 - Cracking will continue at 67% of the current 44 month weighted average rate LF/Mo.

3 - Cracking will continue at 50% of the current 44 month weighted average rate LF/Mo.

* - Adjusted to equivalent area of other treatments (28,000 SF)

** - Assume 10 year life cycle and this is last maintenance to be performed initially had some problems, resulting in less than satisfactory placement. The two most common problems encountered with paving fabric placement were poor tack coat application and excessive wrinkling of the fabric during laydown. Problems occurring with the fiberized membrane were primarily related to the equipment used.

- The fabric manufacturing process contributed to the laydown ease and quality. There were more construction difficulties with fabrics that were heat bonded, even if only partially.
- The fiberized hot-mix asphalt overlay (Treatment No. 7) was placed using normal paving equipment and operations. No additional manpower was required, and placement was achieved without difficulty or delay.

Performance

- Based on the cracking evident after 44 months and considering crack-sealing and construction costs, none of the treatments tested is now considered cost-effective. However, this is dependent on the assumptions that projected future cracking rates, sealing costs, and a normal pavement overlay service life of 10 years are reasonably correct.
- The differential movement of pavement layers produced stresses of greater magnitude than those previously assumed to occur in block-cracked pavement. None of the treatments considered could provide sufficient tensile strength to effectively resist those stresses for longer than about 1 to 2 years.
- All treatments retarded cracks over the evaluation period, although the amount and rates of reduction were very different. Based on all evaluation factors—ease of construction, cost, and final performance relative to distress treated—Treatment 7 is given the best current rating among all the treatments compared.
- Cracking in the southbound lanes were less than that in the northbound lanes after the initial crack survey. It is presumed that this is the result of the greater amount of base repair, patching, and scratch-course placement in the southbound lanes. However, by the time of the 44-month survey, the cracking became essentially equal in both directions. It can be inferred that the additional preliminary work contributed substantially to early crack reduction, but did not appreciably reduce it in the long term.

RECOMMENDATIONS

The following recommendations are made on the basis of this study:

1. Use of paving fabrics and fibrous treatments to retard reflective cracking is not recommended on the basis of the current analysis of life-cycle costs.
2. Cores should be removed from all sections of the experimental pavement to verify whether any sealing qualities remain from use of the interlayer-type treatments.
3. A follow-up inspection and crack survey should be made within 3 years to verify crack estimates and cost-evaluation considering actual sealing costs.
4. If similar investigations are considered by others, detailed documentation of surface and base distress, both before and after construction, is strongly recommended to minimize bias due to variations in distress conditions.

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