Evaluation of Materials, Procedures, and Equipment for Pavement Maintenance

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Beginning in March 1991, the Strategic Highway Research Program (SHRP) Project H-106 began installing 22 test sites for the investigation of various pavement maintenance materials and procedures for four different pavement maintenance activities: pothole repair in asphalt concrete (AC) pavements, crack sealing and filling in AC pavements, joint resealing in portland cement concrete (PCC) pavements, and partial-depth spall repair in PCC pavements. Since the installation of the test sites, all of the 1,250 pothole repairs, 1,600 partial-depth spall repairs, 6700 m (22,000 ft) of crack sealing, and 1,600 resealed joints have been periodically evaluated to document their performance under actual field conditions. The SHRP H-106 project concluded in March 1993, with the production of final reports, manuals of practice, and training and implementation packages. A continued monitoring contract was awarded by the Federal Highway Administration beginning in September 1993 to ensure that the H-106 test sites continue to provide valuable information as the repairs are subjected to further traffic and environmental stress through September 1998. The test site installation process for each of the four experiments and the results of the most recent analysis effort are summarized. For the crack seal, joint reseal, and partial-depth spall repair experiments, the most recent data were collected during fall 1993. For the pothole repair experiment, the most recent data were collected in April 1994. Future activities to be completed under the current monitoring project are described.

The Strategic Highway Research Program (SHRP) Project H-106 installed and monitored 22 test sites situated in the four climatic regions in the United States beginning in March 1991 and continuing through March 1993. Figure 1 shows the locations of the test sites and the boundaries of the four climatic regions. Products developed during the H-106 project included a final report, manual of practice, and training and implementation packages for each of the four experiments (*1–3*).

Pothole Repair

Test Site Installation

The eight pothole repair sites were installed in two separate phases: spring 1991 (Texas, Illinois, New Mexico, Utah, California, and Vermont) and winter 1992 (Ontario and Oregon). At each of the test sites, potholes were created by removing previously placed pothole patches to allow for placement of the experimental repairs. An adverse moisture condition was created by filling the manufactured potholes with water brought to the test site. All repairs were placed with cold mix asphalt materials, with the exception of the spray injection repairs.

Four different procedures were used for repairing the potholes:

- Throw-and-roll: Pothole patches were placed by simply placing the cold mix into the pothole, through the water that had been placed in the hole. Once the holes were filled, the material was compacted using the tires of the vehicle that transported repair materials to the test site. Between six and eight passes of the truck tires were performed before moving onto the next repair.
- Edge seal: Throw-and-roll patches were allowed to set for 1 day to allow the moisture on the pavement surface to dry. Once the patch and pavement had dried, a band

FIGURE 1 SHRP H-106 test sites and climatic regions.

of asphaltic tack material was placed on the interface of the patch and pavement to prevent the intrusion of additional moisture. A layer of sand was placed on the band of tack to prevent tracking by passing vehicles.

- Semipermanent: The first step for this procedure was to remove the moisture and debris from the pothole. This was done using equipment ranging from shovels and brooms to compressed air. Once the potholes were clean, the edges of the pothole were straightened using a pavement saw, jackhammer, or milling machine. Cold mix was then placed into the cleaned and squared pothole, where it was compacted using a device other than the truck tires. The compaction devices included vibratory plate compactors, single drum rollers, dual steel-wheel rollers, and rubber-tire rollers.
- Spray injection: The three spray injection devices used at the eight test sites operated on the same principle: shoot virgin aggregate and heated emulsified asphalt simultaneously into the pothole. This basically mixed the patching material in the pothole, with a cover of aggregate being placed on the top of the patch to prevent tracking.

During the installation, data were collected on the size of the repairs and the time required for each of the different stages of the repair process. This information was used to calculate the productivity of the different repair procedures, found in Table 1.

Eight different materials were used for placing repairs at the eight test sites: UPM High Performance Cold Mix, QPR 2000, Perma-Patch, PennDOT 485, PennDOT 486, HFMS-2 with styrene butadiene, local material, and spray injection.

The first three of these materials are proprietary. The second three represent typical state-specified materials. The local materials were simply the cold mixes used by the participating agencies on a daily basis. These local materials ranged from inexpensive cold mixes ($20 per ton) to expensive proprietary materials ($100 per ton). The results for the local materials generally reflect the types of materials used. The final "material" type was simply the spray injection described in the previous section.

Repair Performance Evaluation

Each of the test sites was evaluated periodically to document the survival of the various repair types. For those

TABLE 1 Summary of Pothole Patching Productivity

Procedure	Average Productivity (1,000 kg/hr)	Laborers Recommended	Average Productivity (1,000 kg/person-day)
Throw-and-roll	1.45	2	2.90
Edge seal	1.27	2	2.54
Semi-permanent	0.27	4	0.27
Spray injection	1.54	2	3.08

1,000 kg = 1.10 tons

repairs still performing at the time of the evaluation, each was evaluated for seven different distress types: bleeding, cracking, dishing, edge disintegration, missing patch, raveling, and shoving.

Experimental Analysis

The primary comparison between the various pothole repairs has been on the basis of survival over time. Two basic patch arrangements were used for the experiment, depending on whether there were two sets of experimental repairs or only one. For two sets the placement order was E1, A1, G1, G2, A2, E2, E3, A3, G3, G4, A4, E4, ... The order for one set of experimental patches was H1, A1, H2, A2, H3, A3, H4, A4, H5, A5, . . . E, G, and H represent experimental repairs, and A represents a control patch. This arrangement allowed for direct comparison of each experimental set with a set of control patches while reducing the number of patches required and the length of pavement, and associated variability, within each comparison unit. Figure 2 shows survival plots over time for one of the comparison units.

On the basis of these survival comparisons, 11 of the 80 total possible comparisons showed a statistically significant difference between the set of experimental patches and the corresponding set of control patches as of the April 1994 performance evaluation. Table 2 summarizes the significant differences for all eight sites. As indicated in Table 2, 4 of the 11 significant differences involve local materials performing worse than the control repairs. In most cases, the failure of the local materials was dramatic and almost immediate. The next most prevalent difference was the performance of the HFMS-2 being poorer than the control in both New Mexico and Ontario.

Preliminary Findings

Several interesting items have come from the pothole repair project to date:

- There has not been a significant improvement in the performance of repairs placed using the semipermanent versus the throw-and-roll procedure when proprietary materials are used.
- Spray injection repairs can be placed as quickly as the throw-and-roll repairs and have been observed to perform as well in most instances. Use of the spray injection procedure requires more effort for the maintenance of the device, and a high skill level for the operator, but can be used effectively by most agencies.
- For situations where patching must be done in adverse climatic conditions, the throw-and-roll and spray injection procedures are recommended to reduce the amount of time crews must spend in traffic and still provide quality repairs.
- Repairs that survived the first month and achieved a higher degree of "set" had a much better chance of surviving as long as the surrounding pavement.

Crack Sealing and Filling

Test Site Installation

Four transverse crack seal and one longitudinal crack fill test sites were installed between March and August 1991. The test site locations are Abilene, Texas; Wichita, Kansas

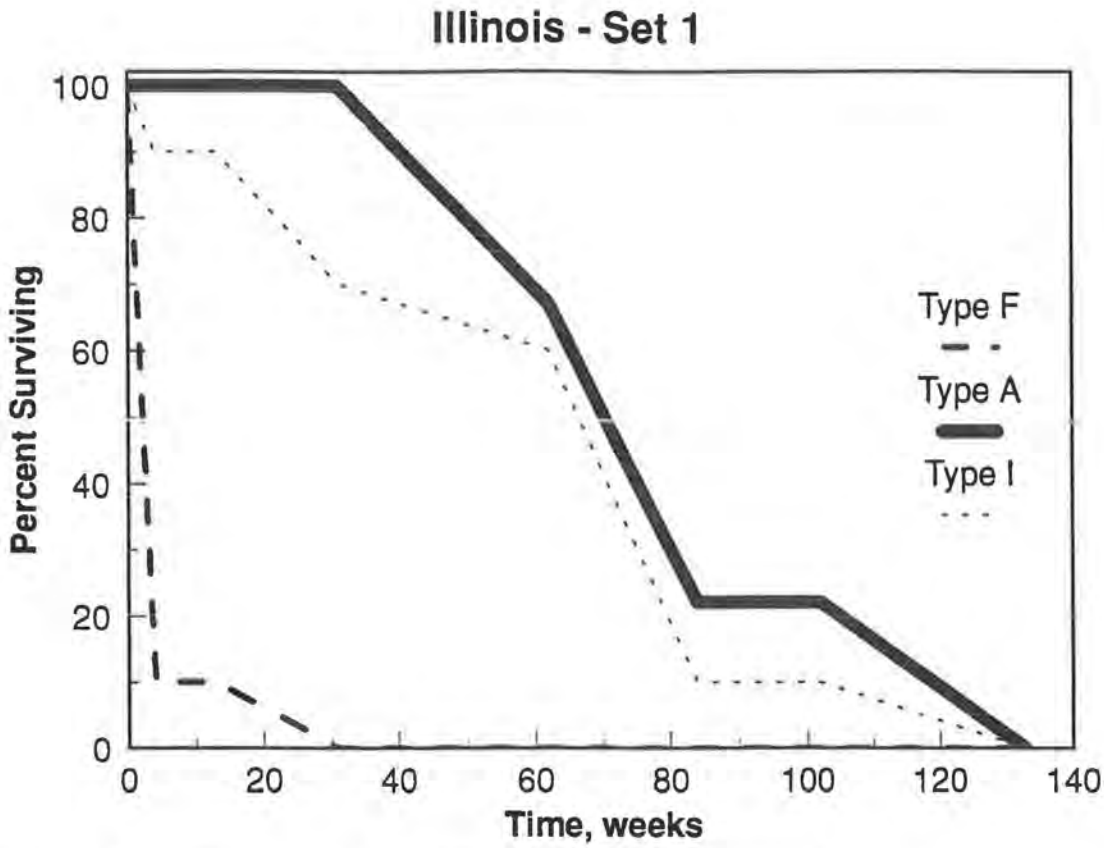

FIGURE 2 Example of various survival plots for pothole repair experiment.

TABLE 2 Summary of Survival Differences

Test Site	Significant Comparisons (at alpha = 0.10)	
	Better Type	Poorer Type (Material/Procedure)
California	Control[1]	Spray Injection
Illinois	Control	Local/Throw-and-roll
	Control	Local/Surface seal[2]
	Control	PennDOT 486/Throw-and-roll
New Mexico	Control	HFMS-2/Throw-and-roll
	UPM/Edge seal	Control
Oregon	Control	Local/Throw-and-roll
Texas	Control	Local/Throw-and-roll
Vermont	Perma-Patch	Control
Ontario	Control	QPR 2000/Throw-and-roll
	Control	HFMS-2/Throw-and-roll

(ideal and adverse conditions); Elma, Washington; Des Moines, Iowa; and Prescott, Ontario (crack fill site).

A total of 15 different materials were placed at the various test sites:

Crack Seal Materials	*Crack Fill Materials*
Meadows Hi-Spec	Hy-Grade Kold Flo
Crafco RoadSaver 515	AC with Hercules Fiber Pave
Crafco RS 211	Witco CRF
Crafco AR+	Crafco AR2
Koch 9030	85–100 Penetration-graded AC
Meadows XLM	
AC 20 with Kapejo Bonifibers	
Dow Corning 890-SL	
Elf CRS-2P	
Koch 9000-S	

The first four of these materials are rubberized asphalt cements, with the Hy-Grade being a rubberized emulsion. The Koch 9030 and Meadows XLM are termed low-modulus rubberized asphalts. Kapejo Bonifibers and Hercules Fiber Pave are two of the brands of fibers available for adding to asphalt cement. The Dow 890-SL is a self-leveling silicone, whereas the Witco CRF and Elf CRS-2P represent emulsified asphalt products. The Crafco AR2 and Koch 9000-S are asphalt rubber materials. Costs for the various repair materials varied from approximately \$2.00/30 m (100 linear ft) of crack for asphalt cement to \$40.00/30 m (100 linear ft) of crack for self-leveling silicone.

Seven different crack preparations were used at the various sites: none; wire brush and compressed air; hot compressed air; compressed air; light sandblast, compressed air, and backer rod; compressed air and backer rod; and light sandblast, compressed air, and backer tape. Each of these procedures had different labor and equipment requirements and production rates. These factors, in conjunction with the performance of the sealants in the field, will be used in calculating the cost-effectiveness of each type of sealant placed.

Eight different configurations of material placement were also included in the experiment and are shown in Figure 3.

At each test site, two replicate sections of the various combinations of material and method (i.e., preparation, procedure, and materials placement configuration) were placed. For each material and method combination, a series of 10 transverse (crack-seal sites) or longitudinal (crack-fill sites) cracks were repaired within each replicate, with the order of seal combinations identical for both replicates. At all test sites, every effort was made to ensure that the cracks treated in the experiment were as uniform as possible. In some instances, this meant that severely deteriorated cracks or partial-lane width cracks were skipped to establish a series of 10 experimentally treated cracks.

Repair Performance Evaluation

Each of the test sites was evaluated periodically to document the survival of the various treatments. Each of the treatments still performing at the time of the evaluation was evaluated for several different distress types: weathering, pull-outs, overband wear, tracking, extrusion, stone intrusion, adhesion loss, cohesion loss (due to either tensile/shear forces or bubbling), and edge deterioration. Also documented were the inches of "failure," defined as locations where the treatment could no longer keep moisture from entering the pavement. Distress information for transverse cracks was recorded along five crack segments: outer edge, outer wheelpath, center of lane, inner wheelpath, and inner edge. These segments provide a method for analyzing the differences in performance that are observed along the crack length. Crack fill treatments were inspected in 1.5-m (5-ft) segments of the longitudinal centerline crack.

Experimental Analysis

Because crack treatment failure has generally been limited, the primary analysis performed has been multivariate analysis of variance (MANOVA) for each of the distress types collected. Tukey analysis, which involved grouping the different treatment types by distress quantities to show where the various treatments performed similarly and where they did not, was also performed. Data were also collected on the amount of movement experienced across a crack to determine which treatments performed better for different ranges of movement.

Tables 3 and 4 give the overall percentages of failure observed for each type of crack-seal and crack-fill treatment, respectively. Failure rates at Elma are consistently much lower than at the other sites. This is due in large part to the moderate climate and lower traffic levels associated with the Elma site.

Figure 4 reinforces this finding and also shows Wichita to be perhaps the most demanding of the sites. Figure 4 shows the average overall survival rates (opposite of failure rates) of sealants placed at all four sites for each site at different periods following installation. Measured horizontal crack movements have generally been the highest at Wichita (ranging between 0.05 and 0.18 in.), and truck traffic on the two-lane facility there is among the highest of the sites.

The primary modes of failure depend largely on the method of application. For instance, full-depth cohesion

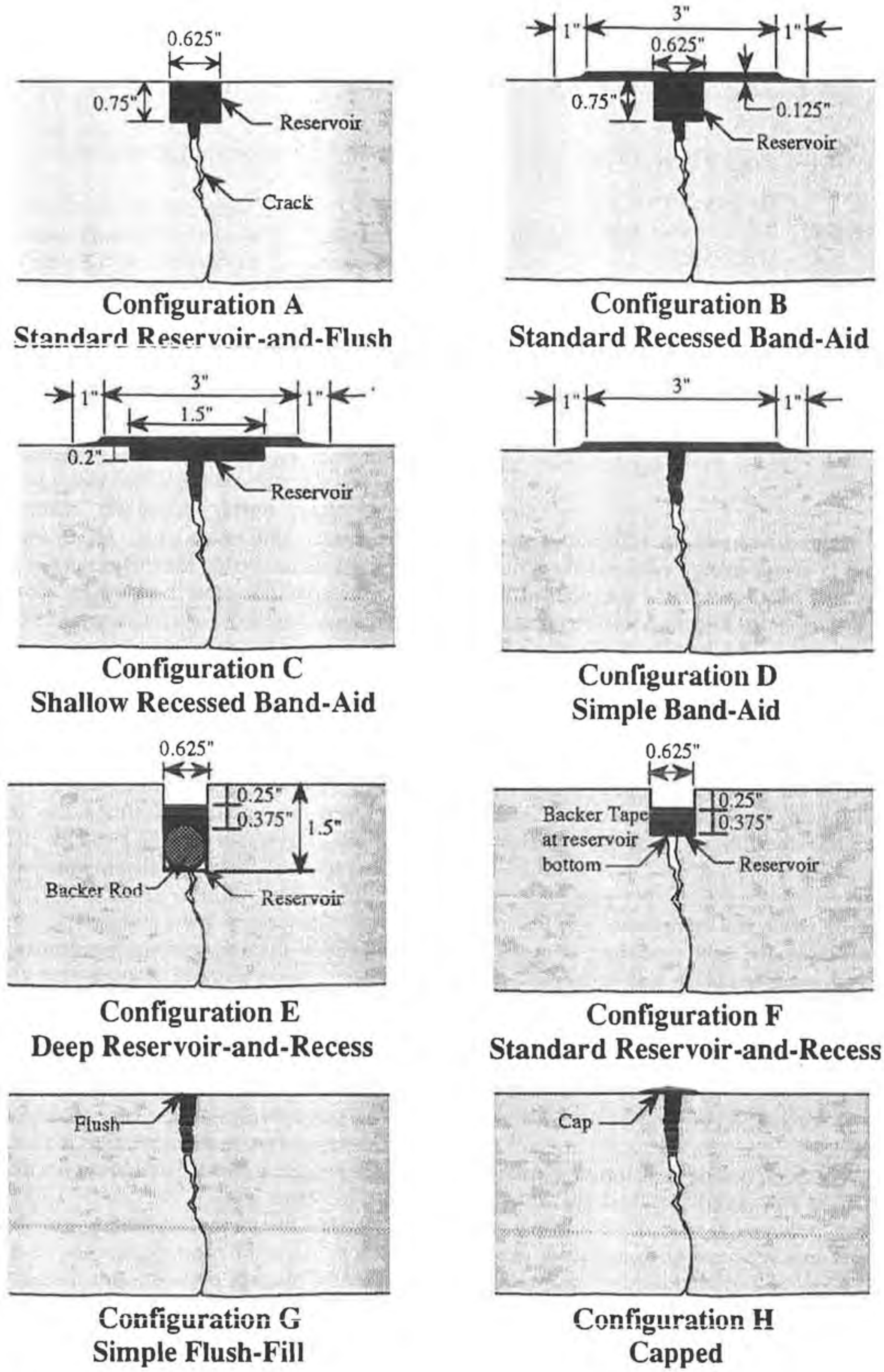

FIGURE 3 Crack seal configurations.

TABLE 3 Percentage of Overall Failure for Various Crack-Seal Treatments at Each Site

Material	Installation Method (Cfg-Prep)	Average Overall Failure, Percent Crack Length				
		Abilene	Wichita (Ideal)*	Wichita (Adverse)*	Elma	Des Moines
Hi-Spec	A-2					6.0
	A-3	2.5	19.9	15.1	0.1	0.6
	B-3	0.1	3.9	1.9	0.0	0.7
	C-3		2.1	2.1		0.3
	D-3	6.5	30.6	21.7	0.0	14.5
	D-4	11.7	27.2	25.7	1.1	7.1
RS 515	B-3	0.3			0.0	0.0
	C-3		1.6	2.3		6.5
	D-3	1.4	22.2	18.8	0.1	12.1
9030	B-3	0.3			0.0	1.4
	C-3		7.7	8.0		0.3
	D-3	11.5	40.6	43.0	0.1	11.2
XLM	B-3	1.8			0.1	0.8
	C-3		10.4	23.6		0.0
	D-3	6.8	26.8	5.8	0.0	1.1
B-Fiber + AC	D-3	53.1	78.6	94.0	0.7	36.9
890-SL	E-5	13.6	18.9		1.8	10.6
	E-6			31.5		
	F-7			NA		
RS 211	B-3				0.0	
AR+	B-3		3.7	2.5		
9000-S	B-3		0.9	1.3		
CRS-2P	G-4					100.0

* Based on data collected from only 1 of 2 replicate sections. NA - Not available.

loss was predominant in the simple band-aid and flush-fill configurations (configurations D and G), whereas full-depth adhesion loss was the main contributor of failure in the reservoir-type configurations (configurations A, B, and C). Self-leveling silicone, placed in reservoir configurations E and F, typically exhibited adhesion failure and edge deterioration failure that stemmed from sawcutting operations.

Results of the MANOVA and Tukey analysis indicated significant differences in fall 1993 performance among the treatments at Des Moines and Abilene. No significant differences, however, were found to exist among the treatments at Elma and Prescott. A summary of the statistically significant differences in overall failure is given in Table 5. Because of incomplete data collected for the two Wichita subsites during the fall 1993 evaluation, the Tukey groupings given in this table represent those formulated for the fall 1992 evaluation. It is believed that only minor changes in performance rankings would have resulted from the fall 1993 evaluation of the Wichita site.

TABLE 4 Percentage of Overall Failure for Various Crack-Fill Treatments at Prescott, Ontario, Site

Material	Installation Method (Cfg-Prep)	Average Overall Failure, Percent Crack Length
RS 211	H-4	0.9
Asphalt Cement	G-1	2.3
	G-4	2.5
CRF	G-4	6.1
AR2	D-4	0.0
	G-4	0.0
FiberPave	D-4	0.9
Kold.Flo	G-4	3.6

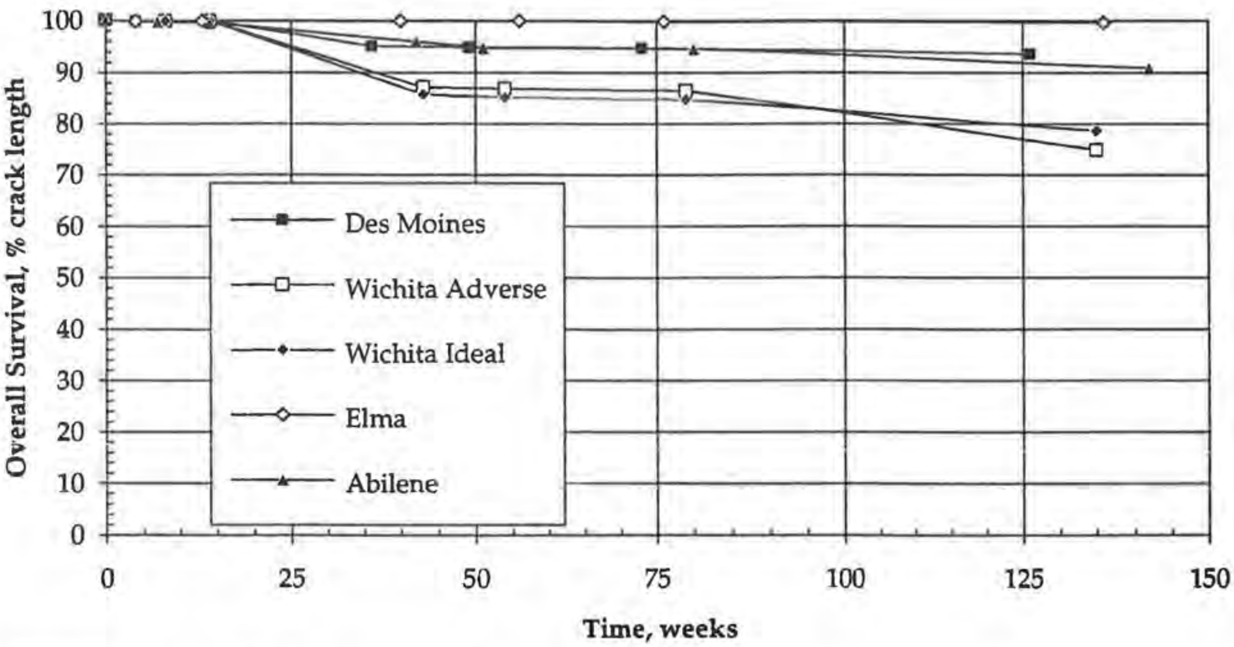

FIGURE 4 Survival of primary crack seal treatments.

In Table 5, treatment performance is categorized by level of performance, with Level 1 representing the best performance, followed by Level 2, Level 3, and so on. On the basis of the results of the Tukey analysis, some treatments were categorized in two or more levels, thereby representing marginal cases. The most notable findings given in this table are the consistently lower performance levels of Bonifiber at each site and the consistently lower performance levels of the simple band-aid material placement configuration (configuration D) for various hot-applied sealants. Also of interest is the low level of performance of CRS-2P emulsion at Des Moines. One may recall from Table 3 that this material has exhibited complete failure.

Preliminary Findings

- In general, good short-term performance can be achieved by both standard and low-modulus rubberized asphalt sealants.
- Barring the creation of secondary cracks during crack-cutting operations, self-leveling silicone can provide

TABLE 5 Tukey Analysis of Overall Failure at Abilene, Wichita, and Des Moines

	Level 1	Level 2	Level 3	Level 4	Level 5
Abilene	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (B-3) RS 515 (D-3) 9030 (B-3) 9030 (D-3) XLM (B-3) XLM (D-3) 890-SL (E-5)	B-Fiber (D-3)			
Wichita (Ideal Subsite)*	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) RS 515 (C-3) 9030 (C-3) XLM (C-3) 890-SL (E-5) AR+ (B-3) 9000-S (B-3)	Hi-Spec (A-3) Hi-Spec (D-3) RS 515 (D-3) 9030 (C-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) 9030 (D-3) XLM (D-3)	B-Fiber (D-3)
Wichita (Adverse Subsite)*	Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) Hi-Spec (D-3) RS 515 (C-3) RS 515 (D-3) 9030 (C-3) XLM (C-3) XLM (D-3) 890-SL (E-6) 890-SL (F-7) AR+ (B-3) 9000-S (B-3)	Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (D-3) XLM (C-3) 890-SL (E-6) 890-SL (F-7)	9030 (D-3)	B-Fiber (D-3)	
Des Moines	Hi-Spec (A-2) Hi-Spec (A-3) Hi-Spec (B-3) Hi-Spec (C-3) Hi-Spec (D-3) Hi-Spec (D-4) RS 515 (B-3) RS 515 (C-3) RS 515 (D-3) 9030 (B-3) 9030 (C-3) 9030 (D-3) XLM (B-3) XLM (C-3) XLM (D-3) 890-SL (E-5)	Hi-Spec (D-3) RS 515 (D-3) 9030 (D-3) B-Fiber (D-3) 890-SL (E-5)	CRS-2P (G-4)		

* Tukey groupings based on performance data collected in Fall 1992.

similar, if not better, shorter-term performance than hot-applied materials.

• The emulsion CRS-2P is inadequate as a sealant for cracks exhibiting moderate to large horizontal movements.

• Bonifiberized asphalt placed in a simple band-aid configuration does not provide good long-term performance in cracks that undergo significant amounts of movement or are exposed to significant levels of traffic.

• Reservoir-type configurations provide better short-term performance than the simple band-aid configuration.

• The standard recessed band-aid configuration shows slightly better short-term performance than the wide recessed band-aid configuration.

JOINT RESEALING

Test Site Installation

The five joint resealing sites were installed between April and June 1991. The test site locations are Phoenix, Arizona; Columbia, South Carolina; Ft. Collins, Colorado; Grinnell, Iowa; and Frankfort, Kentucky. A total of 12 different materials were placed at the various test sites: Crafco RoadSaver 231, Koch 9030, Meadows Sof-Seal, Koch 9005, Crafco RoadSaver 221, Meadows Hi-Spec, Dow Corning 888, Dow Corning 888-SL, Mobay Baysilone 960-SL, Crafco RoadSaver 903-SL, Mobay Baysilone 960, and Koch 9050. The first three materials are low-modulus ASTM D 3405 sealants, whereas the next three are regular ASTM D 3405 materials. The next five materials are all silicones, with the Dow Corning 888 and Mobay Baysilone 960 being the only ones that are not self-leveling. The final material, Koch 9050, is a self-leveling one-part polysulfide.

Four different configurations, or methods of installation, were used for placing the sealant materials, and they are shown in Figure 5.

Two sets of 10 joints were installed at random locations along the test site for each material-configuration combination used at the five test sites. Each of the joints was inspected before installation to ensure a high degree of uniformity among the joints included in the experiment.

Repair Performance Evaluation

All experimental resealed joints have been periodically inspected to check for survival and the development of distress. The distress types that have been documented include partial- and full-depth adhesion loss, partial- and full-depth spall distress, overband wear, stone intrusion, and partial- and full-depth cohesive failure. During each field inspection, distress quantities were recorded at 1-ft increments across the joint, providing a joint position variable that can be used for identifying differences occurring within the wheelpaths or along the lane edges.

Experimental Analysis

Since less than 9 percent of the sealed joint lengths has failed at this time, the primary analysis performed has consisted of multivariate analysis of variance (ANOVA) for each of the distress types collected. Additional analysis was performed involving correlation of field performance with the results of laboratory tests on the sealant materials. Data were also collected on the amount of movement experienced across a joint to determine which repairs performed better for different ranges of movement.

After 30 months, the predominant failure type at all sites is adhesion loss, with spall and cohesive failure also occurring in varying amounts. New spalls are more prevalent at test sites in the colder regions, although adhesive and cohesive failure was observed in both cold and warm regions. The overall seal failure, defined as the percentage of joint length in which moisture and debris can penetrate below the seal material, is given for each material in Table 6. Overall failure includes adhesion, spall, and cohesion failure.

A comparison by state of the primary seals, shown in Figure 6, indicates that the rate of failure has increased now that the seals have passed two winters and three summers. The seals in South Carolina, a wet-nonfreeze region state, are not surviving as well as in other states. This is primarily due to the adhesion failure in the configuration 3 joints, where unfailed silicone sealant was partially removed by the plowing operation. The silicone that remained on the joint walls inhibited bonding of the new sealants and has led to significant adhesion loss.

Preliminary Findings

• The silicone sealants have developed significantly less partial- and full-depth adhesion failure than most rubberized-asphalt sealants. When installed in identically prepared joints using the standard, recessed configuration, the silicone sealants averaged 0.3 percent full-depth adhesion failure, whereas the hot-applied sealants averaged 10.7 percent adhesion failure.

• In states where large amounts of spalling occurred, significantly larger amounts of partial- and full-depth spalls developed in the lane wheelpaths. This verifies the effect of traffic loads on the formation of thin joint-edge spalls.

• The 0.125-in.-thick rubberized asphalt overbanded material remained effective in the pavement wheelpaths

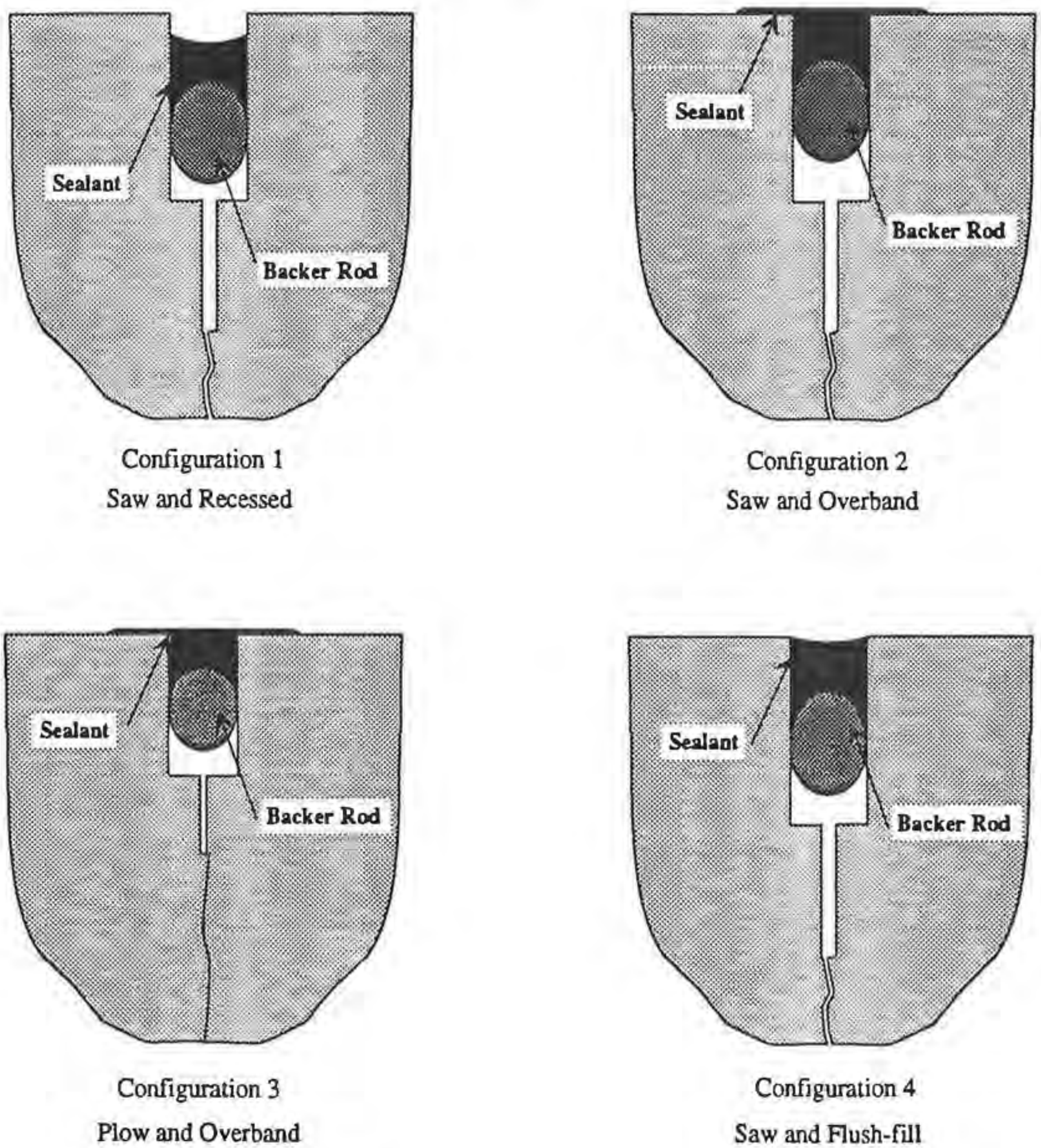

FIGURE 5 Joint seal configurations.

for 9 to 18 months, depending on the material. After 30 months, the overbanded material is completely worn from 90 percent of the joint lengths on all sealants except Crafco RoadSaver 231, where sealant remains along the joint length except in the wheelpath.

- No significant relations ($r^2 = 0.01$ to 0.21) have been observed between adhesive/cohesive failure in each material and the maximum extension experienced by joint seals at the test sites.
- Bubbling has occurred in one of the Mobay 960-SL self-leveling silicone sealants at the Colorado site, which has led to some partial- and full-depth adhesive distress. This material is being reformulated.

Partial-Depth Spall Repair

Test Site Installation

The four partial-depth spall repair sites were installed between March and July 1991. The test site locations are Phoenix, Arizona; Columbia, South Carolina; Ogden, Utah; and Kittanning, Pennsylvania.

A total of 12 different materials were placed at the various test sites (the number or letter in parentheses after the material denotes the symbol used to refer to it in Table 7): Type III PCC (1), Duracal (2), Set-45 (3), Five Star HP (4), SikaPronto 11 (5), Pyrament 505 (6), MC-64

TABLE 6 Summary of Overall Failure for All Joint Reseal Test Sites

Sealant Material	Config.	Total Joints Installed	Overall failure, percent joint length				
			Arizona	South Carolina	Colorado	Iowa	Kentucky
Koch 9005	1	100	6.3	0.1	7.9	5.2	1.0
	2	100	0.1	1.2	3.5	3.0	0.9
	3	60		8.2		1.3	0.5
	4	40	6.4		21.6		
Crafco RoadSaver 231	1	100	26.5	23.2	2.3	1.1	1.9
	2	100	2.7	12.9	4.0	0.6	1.1
	3	60		30.2		2.9	0.3
	4	40	2.2		1.9		
Meadows Sof-Seal	1	80		19.8	9.7	13.5	19.0
	2	80		25.7	8.9	4.3	6.1
	3	60		32.4		8.4	2.6
	4	20			5.9		
Koch 9030	1	80		34.3	19.7	4.2	12.1
	2	80		16.5	19.7	6.6	16.6
	3	60		62.3		13.2	0.7
	4	20			15.5		
Meadows Hi-Spec	1	20	25.9				
	2	20	4.0				
	4	20	1.0				
Crafco RoadSaver 221	1	20	9.1				
	2	20	1.2				
	4	20	8.0				
Dow 888	1	100	0.1	0.3	2.0	1.4	6.5
Dow 888-SL	1	100	0.2	1.0	2.7	2.0	0.3
Mobay 960-SL	1	100	0.1	0.9	4.3	6.4	2.3
Mobay 960	1	20				0.4	
Crafco 903-SL	1	20	0.4				
Koch 9050	1	30			47.4		0.1
Dow 888 w/ Primer	1	10				1.3	
Dow 888-SL w/ Primer	1	10				1.0	
Koch 9005 w/ Primer	1	10					0.8

(7), Percol FL (8), UPM High-Performance Cold Mix (9), Rosco (A), Penetron (B), and AMZ (C). The first six of these materials are rigid repair materials; the remainder represent flexible repair materials. The UPM is the same proprietary cold mix used in the pothole repair experiment, whereas the AMZ and Rosco are types of spray injection devices. The Penetron is a two-part polymer material put into the study at the request of the Arizona Department of Transportation.

Five different procedures were used for preparing the spalled areas and placing the repair materials (the number in parentheses after the procedure denotes the symbol used to refer to it in Table 7): saw and patch (1), chip and patch (2), mill and patch (3), clean and patch (adverse conditions only) (4), and waterblast and patch (5).

A minimum of 10 partial-depth spall repairs were placed for various material-procedure combinations to make a single test set. Two replicates of the test sets were

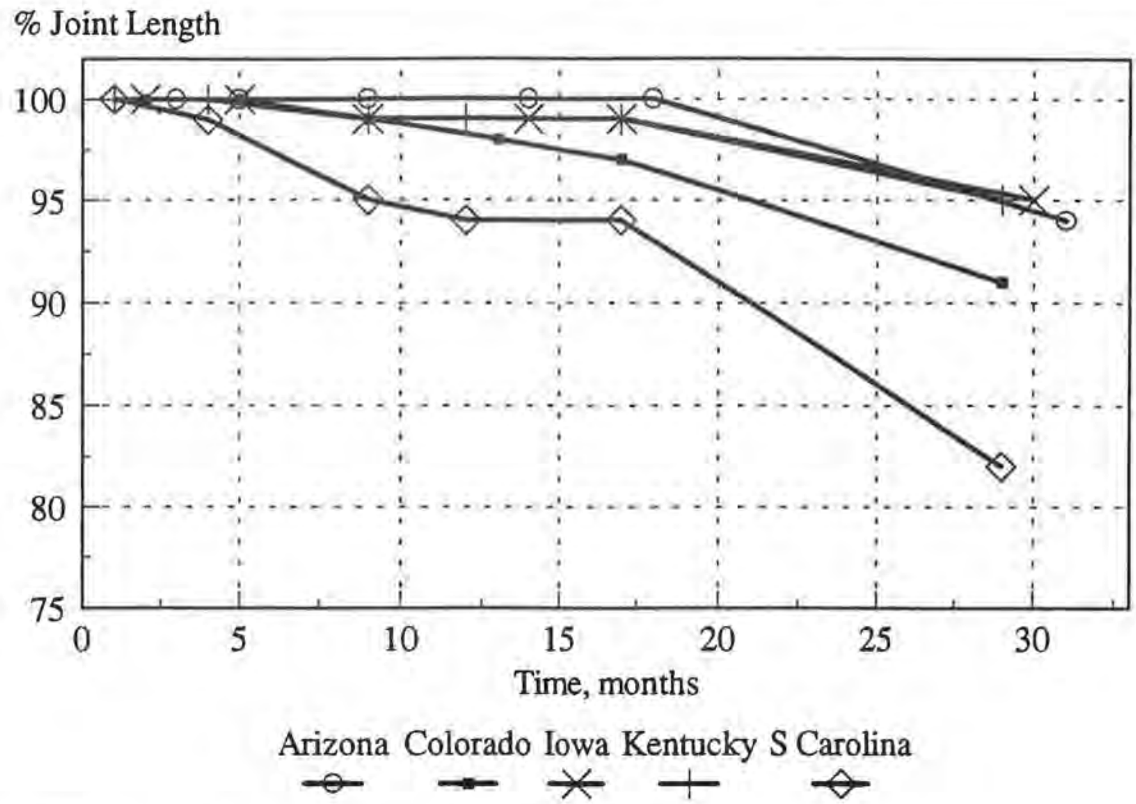

FIGURE 6 Survival of primary joint sealant materials by test site.

placed, with a random order being used to determine each set's position within a replicate.

Repair Performance Evaluation

Each of the partial-depth spall repairs has been evaluated periodically since installation to document its survival and the development of distresses. Distresses that have been documented for the cementitious repairs include spalling, cracking, wearing/ravelling, oxidizing, edge fraying, adjacent pavement deterioration, pavement corner cracking, joint sealant condition, faulting, and patch debonding. Distress types for the bituminous repairs include dishing, raveling, shoving, cracking, bleeding, edge disintegration, and missing patch.

Experimental Analysis

Early analysis efforts for the partial-depth spall repair experiment have concentrated on the distress types and quantities because of the high survival rates that have been observed. Since the failure rates have begun to increase with the latest evaluation, more emphasis has been placed on the survival analysis, similar to that performed for the pothole repair experiment described earlier.

One important difference between the pothole repair and partial-depth spall repair experiments is the lack of a "control" repair for direct comparison with the experimental patches. As a result, a method of comparing each set of material-procedure combinations has been developed that essentially results in the comparison of each set with all other sets of experimental repairs. The result is a series of grouped values similar to the Tukey groupings calculated for the crack seal and joint reseal experiments. Table 7 contains the results of the survival analysis for the partial-depth spall repair experiment. The treatments given in Table 7 use the material and procedure characters given previously in this section to identify the individual treatments.

Findings

Some of the observations and findings which have come from the partial-depth spall repair experiment to date are as follows:

• For the first 2 years, there has been basically no difference in the survival of the Type III PCC repairs and the

TABLE 7 Summary of Partial-Depth Spall Repair Survival Analysis

Test Site	Treatment	Number of Surviving Repairs	Groups with statistically similar survival plots (alpha = 0.10)		
PA	12, 33, 61, 71, 72, 73	20	*		
	31, 41, 51, 62, 92, A2	19	*	*	
	13, 42, 43, 74, 81, 82	18	*	*	*
	11	17		*	*
	32	16		*	*
	84	14			*
SC	11, 12, 21, 41, 42, 51, 71, 92, C2	20	*		
	22, 32, 52, 61	19	*		
	31, 62	18	*	*	
	72	15		*	
AZ	11, 12, 21, 22, 32, 41, 42, 51, 52, 53, 61, 62, 72	20	*		
	B1	17	*	*	
	31	16	*	*	
	73, 92	13		*	*
	71	12			*

NOTE: In the "Treatment" column, the first character of each two-character item indicates the material used from the list of 12 materials applied in the tests. The second character indicates the treatment method from among the five used at the four test sites. No failures had been observed at the Utah test site as of the latest evaluation.

survival of the more expensive proprietary cementitious materials, though some difference began to appear at the Pennsylvania test site.

- The survival of the bituminous patches (cold mix and spray injection) is no different from that of the cementitious and polymer materials, with the exception of the Arizona test site. As with the Type III PCC in Pennsylvania, this difference has only become apparent after the most recent inspection.

FUTURE EFFORTS

The FHWA-LTPP contract for continued monitoring of the H-106 test sites will continue through 1998, and performance data will continue to be collected and analyzed until that point. In the case of the pothole repair experiment, six of the original eight sites have been lost to overlays by the participating agencies, and in every case the condition of the pavements definitely merited the improvements.

For the six "completed" pothole sites, final analyses of the installation and performance data will be completed and sections for a revised final report will be created. Modifications to the *Manual of Practice for Pothole Repair* will also be made on the basis of the results of the final analyses. Once the remaining two sites are lost to overlay, which should be before spring 1995, a revised final report and manual of practice will be produced, which will encompass all of the findings for the project.

For the remaining three experiments, data collection will continue as long as possible with the cooperation of the participating agencies. Modifications to the final reports and manuals of practice will be made as described for the pothole repair experiment.

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