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Innovative Materials Development and Testing

Volume 1: Project Overview

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Preface

The results of the experiment described in this volume are confined to the materials, procedures, and equipment used in this SHRP study. Omission of other materials, procedures, and equipment should not be construed as an indication of non- or poor performance due to their not being selected for inclusion in the study. It was not feasible for SHRP to test all materials, procedures, and equipment available in all regions and in all localities. Many agencies are successfully placing repairs using materials, procedures, and equipment that were not included in the SHRP study. Highway agencies are encouraged to evaluate and select materials, procedures, and equipment that provide the most cost-effective repairs.

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987. Special thanks go to the H-106 project management team at SHRP and to the following agencies that provided traffic control throughout the installations and the subsequent evaluations, and in many cases also provided crews to perform the repairs:

- Arizona Department of Transportation
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- Illinois Department of Transportation
- Iowa Department of Transportation
- Kansas Department of Transportation
- Kentucky Transportation Cabinet
- New Mexico Highway and Transportation Department
- Ontario Ministry of Transportation
- Oregon Department of Transportation
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- Texas Department of Transportation
- Utah Department of Transportation
- Vermont Agency of Transportation
- Washington State Department of Transportation

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Abstract

The Strategic Highway Research Program (SHRP) project H-106 has initiated an investigation of the cost-effectiveness of materials, equipment, and procedures used to perform several routine pavement maintenance activities: pothole repair in asphalt pavement, crack treatment (sealing and filling) in asphalt pavement, joint resealing in portland cement concrete (PCC) pavement, and partial-depth spall repair in PCC pavement. The project provided for test site installations of all four maintenance activities at locations across the United States and Canada. Data collected during the installation procedures, as well as survival and distress development data collected during subsequent evaluations, have been compiled into one of the most comprehensive data bases on these pavement maintenance topics.

While performance evaluations will continue to accumulate data under a future Federal Highway Administration (FHWA) project, this report presents the results of the analyses to date. This volume provides an overview of all four repair projects, including the development of the initial testing and evaluation plans; volumes II through V present each of the individual experiments in greater detail.

Executive Summary

The Strategic Highway Research Program (SHRP) project H-106 has begun to evaluate the effectiveness of many different materials, procedures, and pieces of equipment used for performing routine maintenance activities. Four main areas are being investigated: pothole repair in asphalt pavement, crack treatment (sealing and filling) in asphalt pavements, joint resealing in PCC pavements, and spall repair in PCC pavements. In three of the four repair areas–crack treatment, joint resealing, and spall repair–the repairs were installed with the understanding that a majority of the repairs would be in service from 5 to 10 years or beyond. Although this type of performance speaks well of the materials and repair methods used and of the crews who performed the actual work, it does decrease the amount of useful information available now, less than 18 months after the completion of the test site installations.

The fourth area of repair–pothole repair–has seen the greatest number of failures to date. Although these repairs were anticipated to fail before the other repairs, the rate of failure has been less than was anticipated. To date, almost 70 percent of these repairs are still in service.

Pothole Repair

Using the data collected during the test site installations, laboratory testing, and the limited field performance of the different patch types over an 18-month period, several preliminary findings have been drawn from this study.

- When the two procedures have been compared directly, the throw-and-roll technique has proved just as effective as the semipermanent procedure for the three materials.
- Spray injection devices are a viable way to repair potholes in asphalt pavements, although the procedure depends on the skill of the operator.
- Preliminary testing should be done to ensure the compatibility of the aggregate and binder that will be used to avoid premature failures and repatching operations.
- The patches in the wet-freeze region are exhibiting a lower rate of success than those placed in the dry-freeze region (48 versus 93 percent). The lowest rate of survival has been observed at the Ontario test site.

- Either the throw-and-roll or spray-injection technique should be used when patching during winter conditions; this reduces the time crews spend in traffic and improves safety for both the workers and the traveling public.

Crack Treatment

Approximately 18 months after installation, most of the crack treatments are performing very well. Of 82 total treatments (sealant and filler), 64 are exhibiting less than 10 percent failure: furthermore, 73 of the 82 treatments are exhibiting less than 20 percent failure. Using the information available to date, the following general observations have been made:

- Polyester fiberized asphalt placed in a simple band-aid configuration has not provided good short-term performance in transverse cracks undergoing significant amounts of movement (> 0.05 in [1.3 mm]).
- Polypropylene fiberized asphalt placed in a simple band-aid configuration has shown very good short-term performance in longitudinal cracks that did not experience significant movement.
- Hot-applied, rubber-modified asphalts and cold-applied, self-leveling silicone are generally showing good to very good short-term performance as transverse crack sealants.
- Low-modulus rubberized asphalt sealants have experienced higher rates of overband wear than standard rubberized asphalt sealants. Consequently, the thinner bands have often resulted in more cohesion and adhesion losses in cracks undergoing significant movement.
- Crack sealants in the wet- and dry-freeze climatic regions have generally exhibited a much higher rate of failure than those in the wet- and dry-nonfreeze regions, most likely due to the larger crack movements.
- Two proprietary emulsions have provided satisfactory short-term performance as longitudinal crack fillers. A third proprietary emulsion has exhibited 100 percent failure as a transverse crack sealant after the first winter.
- Reservoir-and-flush and recessed band-aid configurations provide better short-term sealant performance than the simple band-aid configuration.

Joint Resealing

Analysis of test site installation records, field performance evaluation data over an 18-month period, and extensive laboratory testing results have led to the formulation of several observations and preliminary findings from the joint resealing project.

- Most joint seals from which old sealant was removed by plowing and in which rubberized sealant was installed in an overbanded configuration are functioning as well as seals in joints that were sawed and sandblasted.

- The success of seals in plowed joints is dependent on the amount and condition of sealant remaining in the joint following the plowing operation.

- Most sealants installed in sawed and sandblasted joints using an overband configuration developed statistically less partial-depth adhesion loss than the same sealants installed in a standard recessed configuration.

- The overbanded segment of most rubberized asphalt sealants remains effective (less than 80 percent worn) for 12 to 18 months in the wheelpath of 20,000 to 40,000 vpd concrete interstates.

- Although the rubberized asphalt sealants have not developed significantly more full-depth adhesion failure than silicone sealants, most rubberized asphalts used in this study exhibit significantly more partial-depth adhesion loss than silicone sealants.

Spall Repair

More than 1,600 spalls were repaired with partial-depth patches in four climatic regions. The patches were placed using different combinations of 11 rapid-setting materials and 5 patch preparation procedures. Field performance was monitored five times over 18 months. To date, only 2.3 percent of the patches have failed. Using statistically significant correlations and differences (at $\alpha = 0.05$) found during the analysis of installation, laboratory, and field performance data, several preliminary observations can be made:

- Significant differences in the overall patch rating and various distress ratings between material-procedure combinations have been found at all sites.

- At all sites, no significant difference in the overall patch rating was found between Type III PCC and the more expensive proprietary cementitious materials as a group.

- In the dry-nonfreeze region, Type III PCC, FiveStar HP, MC-64, SikaPronto 11, and Pyrament patches had significantly better overall patch ratings than Penetron patches.

- In the wet-nonfreeze region, UPM High Performance Cold Mix patches placed with the chip-and-patch procedure had a significantly higher overall patch rating than spray-injection patches placed with the clean-and-patch procedure under "normal" conditions.

- Of the 74 sets of repair types placed at all sites, 3 have shown significantly poorer performance in the survival analysis than those repair types with no failures.

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Introduction

Hundreds of millions of dollars are spent in the United States every year on the maintenance and upkeep of almost 4 million miles of roadways. These maintenance activities may be performed to maintain the serviceability and structural integrity of the pavement or to reduce or prevent future pavement deterioration. Often these activities may be performed as a stopgap measure until funds become available for rehabilitation of the roadway. To improve the effectiveness of these activities, maintenance crews are constantly searching for improved maintenance materials and procedures.

The Strategic Highway Research Program (SHRP) initiated a study (SHRP H-105) to identify the materials, procedures, and equipment that had the most potential to improve the state of the practice of everyday maintenance activities.[1] The objective of the study documented here (SHRP H-106) was to take the materials, procedures, and equipment identified in the H-105 study and evaluate the performance and cost-effectiveness of the various activities under actual field conditions.[2]

This volume presents an overall view of SHRP H-106. Additional volumes contain detailed information concerning each of the four individual experiments: Pothole Repair (Volume II); Crack Treatment (Volume III); Joint Resealing (Volume IV); and Spall Repair (Volume V).

Background

In a time of limited funding, numerous conflicting time demands, downsizing and attrition, and an increasing number of maintenance products of unknown value, it is not surprising that the most cost-effective maintenance activities are seldom performed at the optimal times. In order to address this problem, the SHRP H-105 study collected information on the types of maintenance activities routinely performed by maintenance crews.

Extensive performance data from questionnaires, literature, and knowledgeable individuals were examined. The performance trends established and reported in the H-105 study were general in nature, due to the inherent weaknesses in the sources of the data–for instance, much of the data collected were found to be subjective. Questionnaire responses and personal interviews consisted essentially of educated guesses from experienced individuals. In addition, many research studies that were examined proved to be incomplete as a result of the limited testing performed or the large number of variables not considered. Despite these shortcomings, the information collected on material performance, properties, and testing was quite comprehensive and representative of the current status of materials and procedures used in pavement surface repairs. This information led to a set of recommended experiments to develop actual data on procedures, materials, and equipment.

The major objective of the H-106 program was to test and evaluate the performance of the repair materials and procedures recognized as promising or innovative by the H-105 study. By conducting carefully designed field experiments, combined with laboratory testing of the materials, a large amount of information has been collected and analyzed. Such information should greatly benefit the pavement surface maintenance programs of many highway agencies.

Test Site Identification

The first step in evaluating different materials and procedures in each of the four experiments was to identify suitable test site locations. This process began in November 1990. Table 1 contains a listing of each of the pavement sections that were visited and evaluated as part of this project. A total of 141 sites across the United States and Canada were visited in order to select the final 22 test site locations.

Initial information concerning the existence of potential test sites was collected by SHRP. Each state department of transportation (DOT) was sent forms for nominating potential test sites in each of the four experiments. Information from these forms led to preliminary telephone contacts at each DOT in an attempt to determine which sites were worthy of inspection.

Through phone contacts and site inspections basic information concerning the location, boundaries, traffic levels, age, cross section, distress, rehabilitation history, uniformity, geometry, and condition were collected for each potential site. This information was used to formulate a site-ranking value between 0 and 100. The site-ranking values were based on weighted means of different sets of site characteristics. The relative weights were determined by surveying engineers as to the importance of each characteristic, and extracting the average significance of each characteristic from the survey. Grouping the average significance factors allowed a ranking system to be developed, as shown in figure 1.

Table 1. Summary of nominated test sites inspected

Climatic Region	Pothole Repair Experiment	Crack-Treatment Experiment
Wet-freeze	Rt. 25 Bradford, VT Rt. 12 Westfield, IA Rt. 970 (old U.S. 75) Salix, IA Rt. 333 Hamburg, IA Rt.13 Higginsville, MO Rt. 140 Westminster, MD U.S. 206 Belle Meade, NJ I-57 Rantoul, IL I-74 Morton, IL I-74 Farmer City, IL I-70 Vandalia, IL Rt. 225 Corning, NY Rt. 226 Steuben County, NY U.S. 9 Saratoga Springs, NY U.S. 15 Lindley, NY Rt. 2 Prescott, ON	Rt. 7 Perth, ON[1] Rt. 16 Ottawa, ON I-25 Des Moines, IA Rt. 8 Cooperstown, PA Rt. 225 Caton, NY I-76 Philadelphia, PA I-91 St. Johnsbury, VT I-70 Boonville, MO I-83 Herford, MD US 9 Saratoga Springs, NY US 15 Lindley, NY Rt. 130/US 150 Urbana, IL US 45 Savoy, IL Rt. 116 Peoria, IL[1] Iron Works Pike - Fayette County, KY I-70 Montrose, IL Rt. 1 Allandale, IL Rt. 1 Mt. Carmel, IL Rt. 37 Mt. Vernon, IL I-57 Ina, IL Rt. 401 Prescott, ON[1] I-35 Des Moines, IA[1] I-80 Adair, IA[1]
Wet-nonfreeze	I-30 Dallas, TX FM 1570 Greenville, TX U.S. 69 Greenville, TX FM 35 West Tawakoni, TX Rt. 34 Cash, TX FM 36 Quinlan, TX U.S. 78 Jefferson County, AL U.S. 431 Etowah County, AL Rt. 24/Rt. 50 Campbell, AL	Rt. 8 Elma, WA L 178 Commerce, TX FM 36/Rt. 66 Caddo Mills, TX Stonewall Street Greenville, TX U.S. 78 Jefferson County, AL Rt. 269 Walker County, AL Rt. 109 Grays Harbor County, WA I-40 Memphis, TN U.S. 76 Columbia, SC
Dry-freeze	U.S. 395 Alturas, CA Rt. 139 Alturas, CA Rt. 299 Modoc County, CA Rt. 139 Lassen County, CA Rt. 9 Silverthorne, CO I-15 Frontage Draper, UT I-70 Richfield, UT I-70 Agate, UT Rt. 40 Craig, CO Rt. 394 Craig, CO Rt. 86 Franktown, CO U.S. 285 Bailey, CO Rt. 59 Yuma, CO U.S. 97 Modoc Point, OR	Rt. 30 Union County, OR Rt. 254 Wichita, KS U.S. 97 Siskiyou County, CA
Dry-nonfreeze	Rt. 1 Santa Barbara, CA Rt. 518 Las Vegas, NM	Rt. 246 Santa Barbara, CA U.S. 84 Abilene, TX U.S. 83 Hawley, TX I-20 Abilene, TX U.S. 395 Bishop, CA U.S. 101 San Mateo, CA

[1] Crack-filling site

Table 1. Summary of nominated test sites inspected (continued)

Climatic Region	Joint Sealant Experiment	Spall Repair Experiment
Wet-freeze	I-787 Albany, NY U.S. 54 Jefferson City, MO I-80 Grinnell, IA Rt. 49 Picton, ON Rt. 133 Millhaven, ON I-78 Ananndale, NJ I-78 Lamington, NJ U.S. 127 Frankfort, KY U.S. 60 Versailles, KY	I-83 Baltimore, MD I-55 Crystal City, MO Rt. 28 Kitanning, PA Rt. 885 Baldwin, PA U.S. 365 Verona, NY I-787 Albany, NY I-80 Newton, IA Rt. 130/U.S. 150 Urbana, IL Rt. 130 Urbana, IL U.S. 45 Pesotum, IL I-80 Stroudsburg, PA Rt. 4 Nilwood, IL Rt. 16 Litchfield, IL I-55 Frontage Litchfield, IL
Wet-nonfreeze	I-30 Dallas, TX I-90 Kittitas County, WA I-77 Fairfield, SC I-10 Tallahassee, FL I-65 Birmingham, AL U.S. 59 Houston, TX	I-65 Birmingham, AL I-240 Memphis, TN I-20 Columbia, SC I-82 Kittitas, WA
Dry-freeze	I-15 Beaver County, UT I-82 Yakima, WA U.S. 81 Menominee, NE I-25 Fort Collins, CO I-15 Salt Lake City, UT U.S. 77 Lincoln, NE I-135 McPherson, KS K-18 Ogden, KS I-90 Hyak, WA I-70 Denver, CO I-25 Loveland, CO	I-15 Ogden, UT Rt. 18 Junction City, KS I-15 Weber County, UT U.S. 81 Menominee, NE U.S. 20 Menominee, NE U.S. 20 Laurel, NE I-82 Yakima, WA I-82 Thrall, WA I-135 McPherson County, KS
Dry-nonfreeze	U.S. 101 Santa Barbara, CA U.S. 101 San Mateo, CA I-17 Phoenix, AZ	U.S. 101 San Mateo, CA U.S. 101 Santa Barbara, CA I-17 Phoenix, AZ

Rated by: ____________________ Date of Site Visit: __________

State/Province: ________ Route: _______ Experiment: Crack Joint Pothole Spall

---

SCALED SITE RATING ________ ("0" if site is inappropriate)

Reason site is inappropriate ______________________

____

VG G F P VP

Section 1 $\text{Mean}_1 =$ _____

4	3	2	1	0	Quantity of Distress (Both existing and anticipated)
4	3	2	1	0	Appropriateness of Distress (Meets EDRP expectations)
4	3	2	1	0	Adequate time before next scheduled rehabilitation

Section 2 $\text{Mean}_2 =$ _____

4	3	2	1	0	Excessive distress (other than experiment-specific distress)
4	3	2	1	0	Good representative for climatic region
4	3	2	1	0	Uniform cross-section throughout test site
4	3	2	1	0	Applicability of traffic levels (ADT and percent trucks)
4	3	2	1	0	Uniformity of traffic levels throughout site

Section 3 $\text{Mean}_3 =$ _____

4	3	2	1	0	Enthusiasm of local agency staff
4	3	2	1	0	Adequate site distance, adequate shoulders, good safety parameters
4	3	2	1	0	Availability of experienced crew
4	3	2	1	0	Length of test site
4	3	2	1	0	Availability of applicable equipment

Section 4 $\text{Mean}_4 =$ _____

4	3	2	1	0	Age of pavement
4	3	2	1	0	Uniformity of drainage throughout site
4	3	2	1	0	Uniformity of subgrade throughout site
4	3	2	1	0	Number of lanes (Total two directions)
4	3	2	1	0	Presence of grades and/or curves along test site

Section 5 $\text{Mean}_5 =$ _____

4	3	2	1	0	Agency has additional experiments to be included at site
4	3	2	1	0	Convenient travel to and from test site
4	3	2	1	0	Potential for obtaining traffic counts at actual test site

---

RAW SITE RATING

$(6.3 \times \text{Mean}_1) + (2.7 \times \text{Mean}_2) + (1.7 \times \text{Mean}_3) + (1.3 \times \text{Mean}_4) + (\text{Mean}_5) =$

(6.3 × _____) + (2.7 × _____) + (1.7 × _____) + (1.3 × _____) + (_____) = ________

SCALED SITE RATING

(Raw Site Rating) ______ × 1.923 = _________ (Scaled Site Rating)

Figure 1. Sample of test site rating form for SHRP H-106

Test Site Installations

Figure 2 shows the test site locations for each of the four experiments. Also indicated in this figure are the borders for the four climatic regions. These regions were initially developed for the SHRP Long-Term Pavement Performance (LTPP) program and were adopted for this project.

The installation of the test sites was begun in March 1991 at the spall repair site in Kittanning, Pennsylvania, and was completed in February 1992 at the pothole repair test site in Modoc Point, Oregon. During that time, 1,250 pothole patches and 1,600 spall repair patches were placed, and 22,000 ft (6,700 m) of crack-treatments and 18,000 ft (5,500 m) of joint seals were applied. The installation process involved crews from 15 state DOTs, 1 Canadian province, and 1 city department of public works.

Information was collected during each test site installation. The data collected included information on the size and location of the repairs made, the climatic conditions during the repair process, the time needed to make the repairs, the equipment needed to make the repairs, and the size of the crew required to effectively make the repairs. Cost information for each of the materials was also collected so that, combined with equipment and labor rates, total costs for the repair procedures could be calculated.

More detailed information is available concerning the test site installation procedures for each of the four experiments in the corresponding volumes of this final report.

Test Site Evaluation

During the course of this study, 108 performance evaluations were performed at the 22 test sites (4 to 5 evaluations per site). These performance evaluations provided an opportunity to monitor the deterioration of the repairs that had been placed. During these evaluations, information was collected on the development of distress in the repairs that remained in service, while repair failures were also noted where those repairs no longer served their intended purpose.

More detailed information is available on the data collected during the performance evaluations for each of the four experiments in the corresponding volumes.

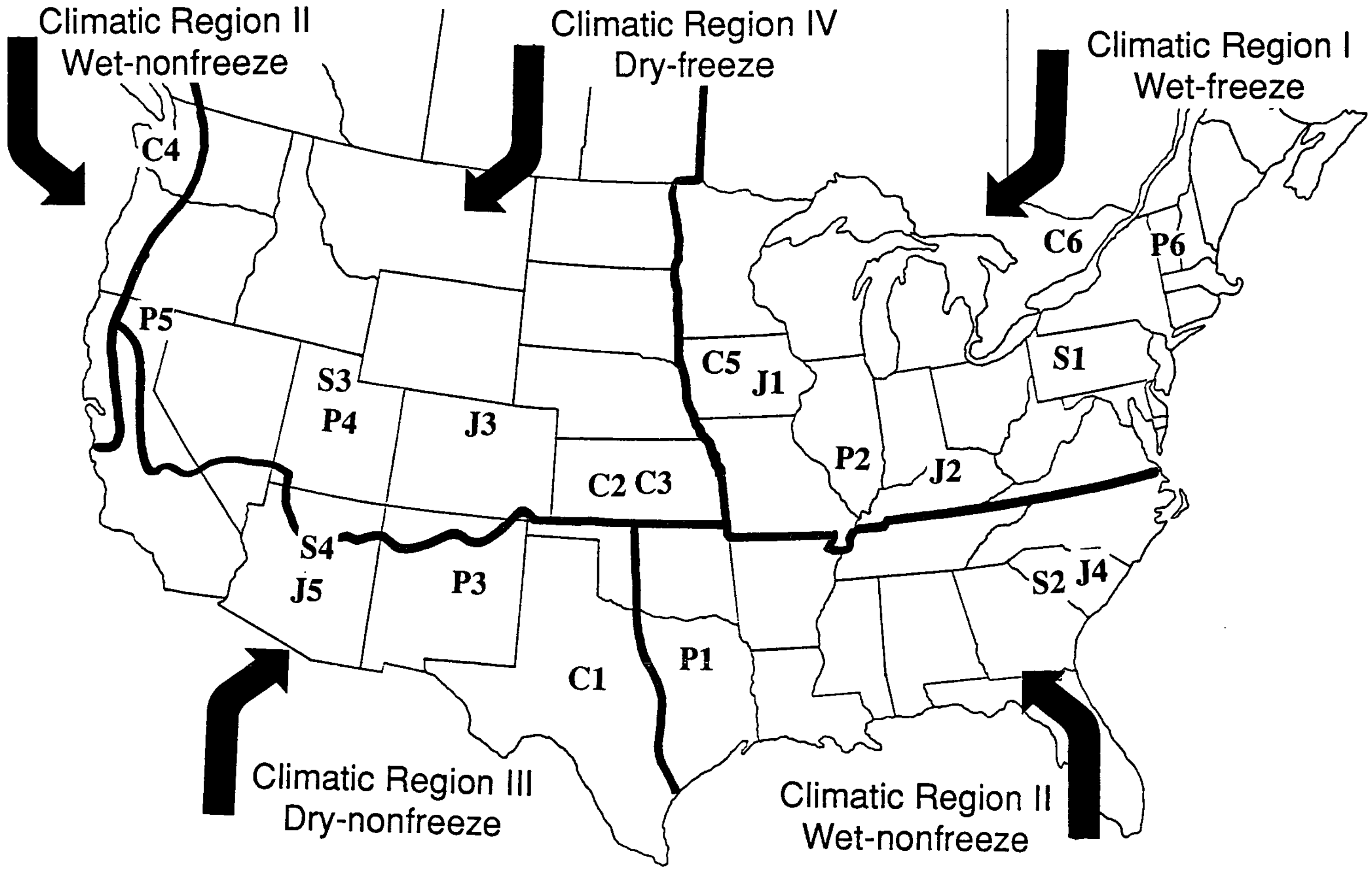

Figure 2. SHRP H-106 test site locations and climatic regions.
(C = Crack, J = Joint, P = Pothole, S = Spall)

2

Experimental Design

This study was designed so that direct comparisons could be made between the different repair types placed at each test section.[2,3,4,5] The following is a summary of the original experimental design for each of the individual experiments.

Pothole Repair

The pothole repair experiment was intended to evaluate the performance of various pothole-patching materials and techniques with regard to many factors, including

- Climate
- Pavement type
- Patching material
- Repair procedure

Test sites were located in each of the four climatic regions so that the effects of climate on repair performance could be investigated. Pavement type was divided into two categories for this project: flexible (full-depth hot-mix asphalt cement [HMAC] over subbase or subgrade material) and composite (HMAC over PCC pavement over the subbase or subgrade material).

Table 2 shows the material-procedure combinations initially included in the H-106 test site installations. Each set listed in table 2 refers to a set of 10 patches placed using the same material-procedure combination.

The UPM High Performance Cold Mix, placed using the rapid placement method, was the "control" at all sites. The placement of these patches, as well as one other patch type (material and procedure), was to be alternated in such a way that each day's production would consist of 10 control and 10 experimental patches placed as shown in figure 3. A direct comparison could then be made between the control and experimental repairs without its being confounded by other factors, such as temperature at the time of placement.

Table 2. Design matrix for pothole repair project

Patch Type	Material	Repair Procedure	Wet-freeze		Wet-nonfreeze	Dry-freeze		Dry-nonfreeze
			Flex.	Comp.	Flex. or Comp.	Flex.	Comp.	Flex. or Comp.
A[1]	UPM High Performance Cold Mix	Rapid	9 sets	9 sets	9 sets	9 sets	9 sets	9 sets
B		Edge seal	1 set	1 set	1 set	1 set	1 set	1 set
C		Semi perm.	1 set	1 set	1 set	1 set	1 set	1 set
D	PennDOT 485	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
E	PennDOT 486	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
F	Local material	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
G	HFMS-2	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
H	Perma-Patch	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
I	QPR 2000	Rapid	1 set	1 set	1 set	1 set	1 set	1 set
J	Spray injection	Spray injection	1 set	1 set	1 set	1 set	1 set	1 set
X	Agency request	Agency request	1 set	1 set	1 set	1 set	1 set	1 set

[1] Control patch type at all sites

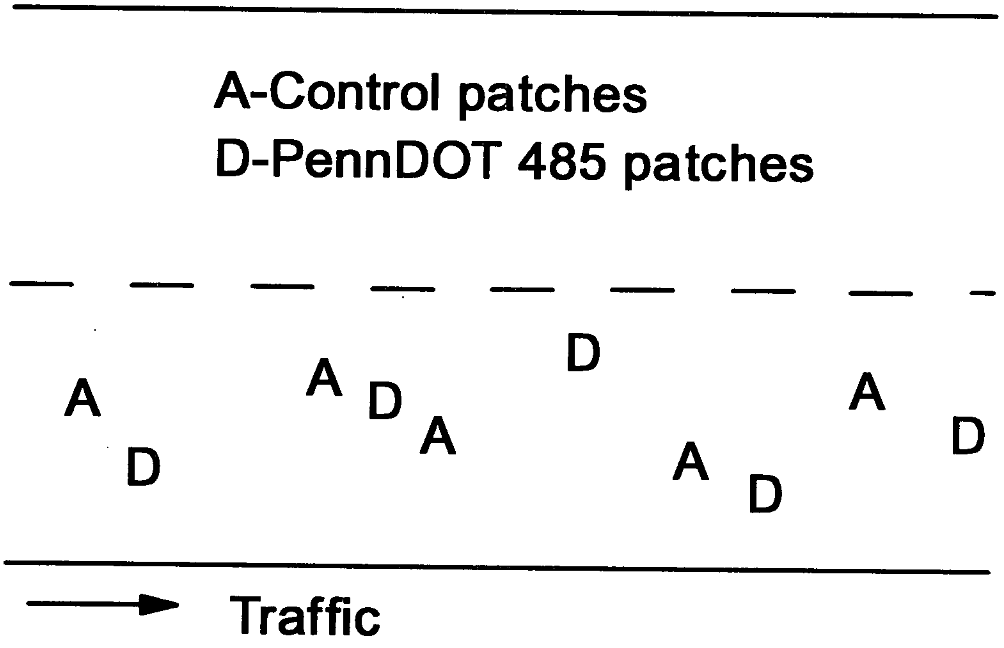

Figure 3. Repair placement order for pothole repair project

Ideally, each of the experimental materials would have been placed using each of the repair procedures. Due to budgetary considerations (and to limit the number of patches needed from the participating agencies) it was decided that only one material, UPM High Performance Cold Mix, would be used with all the procedures. This approach would provide a comparison among the three procedures and would allow for evaluation of all of the materials under the harshest placement procedure, the throw-and-roll.

Crack Treatment

The crack-treatment experiment was intended to evaluate the performance of various crack-sealing and/or filling materials and techniques with regard to many factors, including

- Climate
- Traffic
- Weather during sealing operations
- Material type
- Material configuration
- Crack preparation

Test sites were located in each of the four climatic regions so that the effects of climate on performance could be investigated. The traffic levels were initially divided into three categories: outside lane, passing lane, and shoulder. The weather during the test site installations was categorized as either ideal or adverse.

The six configurations listed in tables 3 through 7 correspond to the following:

A. Rout and flush (0.75 in [19 mm] x 0.75 in [19 mm])
B. Rout and band-aid (0.75 in 19 mm] x 0.75 in [19 mm])
C. Rout and band-aid (1.5 in [38 mm] x 0.2 in [5 mm])
D. Band-aid, no rout
E. Rout/Saw and recess (0.5 in [13 mm] x 0.5 in [13 mm] or 0.75 in [19 mm] x 0.75 in [19 mm])
F. Flush, no rout

The five preparations listed in tables 3 through 7 correspond to the following:

1. Hot, compressed-air lance
2. Wire brush and compressed air
3. Compressed air and backer rod
4. Compressed air
5. None

Table 3. Design matrix for crack-treatment project—wet-freeze

Materials	Config. A		Config. B		Config. C		Config. D		Config. E		
	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 3
Control Material D 3405	2 reps		2 reps		2 reps		2 reps	2 reps	▨	▨	▨
Crafco 34515			2 reps				2 reps		▨	▨	▨
Koch 9030			2 reps				2 reps		▨	▨	▨
Meadows Sof-Seal XLM			2 reps				2 reps		▨	▨	▨
Dow 890 SL	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps
AC + fibers	▨	▨	▨	▨	▨	▨	2 reps		▨	▨	▨

Note: Shaded areas are inappropriate combinations of material and configuration.
(reps = replication of combination)

Table 4. Design matrix for crack-treatment project—wet-nonfreeze

Materials	Config. A		Config. B		Config. C		Config. D		Config. E		
	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 3
Control Material D 3405	2 reps		2 reps				2 reps	2 reps	▨	▨	▨
Crafco 34515			2 reps				2 reps		▨	▨	▨
Koch 9030			2 reps				2 reps		▨	▨	▨
Meadows Sof-Seal XLM			2 reps				2 reps		▨	▨	▨
Dow 890 SL	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps
AC + fibers	▨	▨	▨	▨	▨	▨	2 reps		▨	▨	▨

Note: Shaded areas are inappropriate combinations of material and configuration.

Table 5. Design matrix for crack sealing/filling project–dry-nonfreeze

	Config. A		Config. B		Config. C		Config. D		Config. E		
Materials	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 3
Control Material D 3405	2 reps		2 reps				2 reps	2 reps	▨	▨	▨
Crafco 34515			2 reps				2 reps		▨	▨	▨
Koch 9030			2 reps				2 reps		▨	▨	▨
Meadows Sof-Seal XLM			2 reps				2 reps		▨	▨	▨
Dow 890 SL	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps
AC + fibers	▨	▨	▨	▨	▨	▨	2 reps		▨	▨	▨

Note: Shaded areas are inappropriate combinations of material and configuration.

Table 6. Design matrix for crack-treatment project–ideal conditions–dry-freeze

	Config. A		Config. B		Config. C		Config. D		Config. E		
Materials	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 3
Control Material D 3405	2 reps		2 reps		2 reps		2 reps	2 reps	▨	▨	▨
Crafco 34515					2 reps		2 reps		▨	▨	▨
Koch 9030					2 reps		2 reps		▨	▨	▨
Meadows Sof-Seal XLM					2 reps		2 reps		▨	▨	▨
Dow 890 SL	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps
AC + fibers	▨	▨	▨	▨	▨	▨	2 reps		▨	▨	▨

Note: Shaded areas are inappropriate combinations of material and configuration.

Table 7. Design matrix for crack-treatment project–adverse conditions–dry-freeze

Materials	Configuration A		Configuration B		Configuration C		Configuration D				Configuration E			Configuration F	
	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 1	Prep. 2	Prep. 4	Prep. 5	Prep. 1	Prep. 2	Prep. 3	Prep. 1	Prep. 2
Sealant Materials															
Control Material D 3405	2 reps		2 reps		2 reps		2 reps	2 reps		▨	▨	▨	▨	▨	▨
Crafco 34515			2 reps				2 reps			▨	▨	▨	▨	▨	▨
Koch 9030			2 reps				2 reps			▨	▨	▨	▨	▨	▨
Meadow Sof-Seal XLM			2 reps				2 reps			▨	▨	▨	▨	▨	▨
Dow 890 SL	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps	▨	▨
AC + Fibers	▨	▨	▨	▨	▨	▨	2 reps				▨	▨	▨	▨	▨
Filler Materials															
Asphalt cement	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps	2 reps
Witco CRF	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	2 reps	
Asphalt rubber	▨	▨	▨	▨	▨	▨			2 reps	▨	▨	▨	▨	2 reps	
Fiberized asphalt	▨	▨	▨	▨	▨	▨			2 reps	▨	▨	▨	▨	▨	▨

Note: Shaded areas are inappropriate combinations of material and configuration

Each of the replicates listed in tables 3 through 7 indicate a set of 10 consecutive cracks. At each test site, the layout was in two halves: the first half included one replicate of each combination and the second half consisted of another replicate of each combination in the exact order as the first half.

Joint Resealing

The joint resealing experiment was intended to evaluate the performance of various joint-resealing materials and techniques with regard to many factors, including

- Climate
- Joint spacing
- Sealant material
- Sealant configuration
- Joint preparation

Test sites were located in each of the four climatic regions so that the effects of climate on performance could be investigated. Joint spacing was divided into two categories: short-jointed, which have joint spacings less than 30 ft (9.1 m), and long-jointed, which have joint spacings between 35 and 60 ft (10.7 and 18.3 m). Each of the four climatic regions has a short-jointed section; whereas the wet-freeze regions also has a long-jointed section, resulting in a total of five test sites.

The initial materials and configurations to be installed at the joint-reseal test sites are listed in tables 8 through 11. These tables show the material-configuration combinations planned for each climatic region. The configuration numbers shown in tables 8 through 11 represent the following:

1. Conventional recessed sealant configuration with backer rod (placed to manufacturer's recommended shape factor). Joint preparation includes diamond saw refacing and sandblast cleaning.
2. Overband sealant configuration with backer rod. Joint preparation includes diamond saw refacing and sandblast cleaning.
3. Overband sealant configuration without backer rod. The joint is routed only to remove existing sealant; no refacing or cleaning is done.

Each of the replicates described in tables 8 through 11 consisted of 10 full-width, transverse working joints. At each test site, the layout was in two halves, where the first half included one replicate of each combination and the second half consisted of another replicate of each combination in the exact order as the first half.

Table 8. Design matrix for joint-resealing project—wet-freeze

Materials	Short-jointed			Long-jointed		
	Config. 1	Config. 2	Config. 3	Config. 1	Config. 2	Config. 3
Control Material D 3405	3 reps[1]	2 reps	2 reps	2 reps	2 reps	2 reps
Crafco Roadsaver 231	2 reps	2 reps	2 reps	2 reps	2 reps	2 reps
Koch 9030	2 reps	2 reps	2 reps	2 reps	2 reps	2 reps
Meadows Sof-Seal	2 reps	2 reps	2 reps	2 reps	2 reps	2 reps
Dow Corning 888	2 reps	▨	▨	2 reps	▨	▨
Dow Corning 888-SL	2 reps	▨	▨	2 reps	▨	▨
Mobay Baysilone (SL)	2 reps	▨	▨	2 reps	▨	▨

[1] Three reps included for an evaluation of the effectiveness of primer

Table 9. Design matrix for joint-resealing project—dry-freeze

Materials	Short-jointed			Long-jointed		
	Config. 1	Config. 2	Config. 3	Config. 1	Config. 2	Config. 3
Control Material D 3405	2 reps	2 reps	2 reps	▨	▨	▨
Crafco Roadsaver 231	2 reps	2 reps	2 reps	▨	▨	▨
Koch 9030	2 reps	2 reps	2 reps	▨	▨	▨
Meadows Sof-Seal	2 reps	2 reps	2 reps	▨	▨	▨
Dow Corning 888	2 reps	▨	▨	▨	▨	▨
Dow Corning 888-SL	2 reps	▨	▨	▨	▨	▨
Mobay Baysilone (SL)	2 reps	▨	▨	▨	▨	▨

Table 10. Design matrix for joint-resealing project—wet-nonfreeze

Materials	Short-jointed			Long-jointed		
	Config. 1	Config. 2	Config. 3	Config. 1	Config. 2	Config. 3
Control Material D 3405	2 reps	2 reps	2 reps	▨	▨	▨
Crafco Roadsaver 231	2 reps	2 reps	2 reps	▨	▨	▨
Koch 9030	2 reps	2 reps	2 reps	▨	▨	▨
Meadows Sof-Seal	2 reps	2 reps	2 reps	▨	▨	▨
Dow Corning 888	2 reps	▨	▨	▨	▨	▨
Dow Corning 888-SL	2 reps	▨	▨	▨	▨	▨
Mobay Baysilone (SL)	2 reps	▨	▨	▨	▨	▨

Table 11. Design matrix for joint-resealing project—dry-nonfreeze

Materials	Short-jointed			Long-jointed		
	Config. 1	Config. 2	Config. 3	Config. 1	Config. 2	Config. 3
Control Material D 3405	2 reps	2 reps	2 reps	▨	▨	▨
Crafco Roadsaver 231	2 reps	2 reps	2 reps	▨	▨	▨
Koch 9030	2 reps	2 reps	2 reps	▨	▨	▨
Meadows Sof-Seal	2 reps	2 reps	2 reps	▨	▨	▨
Dow Corning 888	2 reps	▨	▨	▨	▨	▨
Dow Corning 888-SL	2 reps	▨	▨	▨	▨	▨
Mobay Baysilone (SL)	2 reps	▨	▨	▨	▨	▨

Spall Repair

The spall repair experiment was intended to evaluate the performance of various spall repair materials and repair procedures with regard to the following factors:

- Climate
- Repair materials
- Repair procedures
- Weather conditions during repair

Test sites were located in each of the four climatic regions so that the effects of climate on performance could be investigated. Out of the four planned test sites, only the site in the wet-freeze region had patches placed under adverse weather conditions.

Tables 12 through 14 show the different combinations of material and placement method planned for each of the four test sites. The procedures listed in tables 12 through 14 correspond to the following activities:

- The rigorous patching procedure includes saw-cutting the boundaries of the distress, removing the deteriorated concrete with a pneumatic hammer, installing a joint block, sandblasting the hole, and applying a bonding agent.
- The clean-and-patch procedure includes removing the deteriorated concrete by hand, installing a joint block, sandblasting the hole, and applying a bonding agent.
- The mill-and-patch procedure includes removing the deteriorated concrete with a milling device, installing a joint block, sandblasting the hole, and applying a bonding agent.
- The adverse procedure includes removing the deteriorated concrete and cleaning the hole by sweeping out the loose material and water and placing the repair materials.

At each test site the layout was to be in two halves, where the first half included one replicate of each combination and the second half consisted of another replicate of each combination. In the spall repair experiment, it was not required that the order in each half be exactly the same.

Table 12. Design matrix for spall repair project–wet-freeze

Material	Rigorous Patching Procedure	Clean-and-Patch Procedure	Mill-and-Patch Procedure	Adverse Procedure
Type III PCC	2 reps	2 reps	2 reps	
Duracal	2 reps	2 reps		
Set-45	2 reps	2 reps	2 reps	
Five-Star H.P.	2 reps	2 reps	2 reps	
MC 64	2 reps	2 reps		
SikaPronto 12	2 reps	2 reps		
Percol	2 reps	2 reps	2 reps	2 reps
Pyrament				2 reps
UPM High Performance Cold Mix				2 reps

Table 13. Design matrix for spall repair project–dry-freeze

Material	Rigorous Patching Procedure	Clean-and-Patch Procedure	Mill-and-Patch Procedure	Adverse Procedure
Type III PCC	2 reps	2 reps	2 reps	
Duracal	2 reps	2 reps		
Set-45	2 reps	2 reps		
Five-Star H.P.	2 reps	2 reps		
MC 64	2 reps	2 reps		
SikaPronto 12	2 reps	2 reps		
Percol	2 reps	2 reps		

Table 14. Design matrix for spall repair project–wet- and dry-nonfreeze

Material	Rigorous Patching Procedure	Clean-and-Patch Procedure	Mill-and-Patch Procedure	Adverse Procedure
Type III PCC	2 reps	2 reps	▨	▨
Duracal	2 reps	2 reps	▨	▨
Set-45	2 reps	2 reps	▨	▨
Five-Star H.P.	2 reps	2 reps	▨	▨
MC 64	2 reps	2 reps	▨	▨
SikaPronto 12	2 reps	2 reps	▨	▨
Percol	2 reps	2 reps	▨	▨

3

Evaluation Plan

Once a test site was installed, the process of evaluating the performance began almost immediately. There were two main areas of evaluation planned: field performance and laboratory testing. Field performance data were divided into two main areas: repair survival and distress development. The repair survival data were intended to determine the cost-effectiveness of each combination of material and repair method under different circumstances, so that some guidelines could be developed as to which are the most cost-effective combinations for a particular agency's needs.

The distress development data, along with the laboratory test data, were intended to determine which material properties had the most influence over the performance of the repairs in the field. By analyzing the distress data before to the failure of repairs, there could be an indication as to which distress types are the most critical for cost-effective performance of the repair in the field. By analyzing the laboratory data corresponding to the critical distresses the critical material properties could be identified. By knowing which material properties are critical, steps can be taken to develop materials that emphasize those properties to provide even better performance from the repairs.

The SHRP H-105 study identified initial distress types and definitions for each of the four experiments. The following section presents the original evaluation plans, including proposed scheduling of the evaluations and possible causes of distress. Volumes II through V present evaluation plans for each of the individual experiments that reflect the way the projects have evolved.

Field Performance

For each of the four experiments distress types and severities have been determined, for which observations were made in the field. These distresses are intended to encompass all possible deterioration modes the repairs could develop during the course of their service life.

Descriptions of the distress types and severities for each of the four experiments are provided in the following sections.

The original testing plan called for a series of five performance evaluations to be performed at each of the test sites for each of the four experiments. Table 15 shows the proposed timing of evaluations for each experiment. The times listed are from the completion dates of the test site installations.

Table 15. Schedule of field performance evaluations for all experiments

	Experiment Type			
	Pothole Repair	Crack Treatment	Joint Resealing	Spall Repair
First evaluation	1 month	1 month	1 month	3 months
Second evaluation	3 months	3 months	4 months	6 months
Third evaluation	6 months	8 months	7 months	12 months
Fourth evaluation	12 months	12 months	13 months	18 months
Fifth evaluation	24 months	20 months	19 months	24 months

Pothole Repair

The four distresses originally defined for the evaluation of the pothole repair patches are: shoving, raveling, dishing, and debonding. They are defined as follows:

- Shoving. A permanent upward displacement of repair material due to the action of traffic. Shoving may be the result of excess binder material or a binder material too soft to be used in very warm climates.

- Raveling. The loss of aggregate from the surface of the repair due to inadequate cohesion the mix. Raveling may be caused by excess fines in the binder, stripping of the binder from the aggregate, inadequate aggregate interlock, or poor compaction.

- Dishing. The formation of a depression within the repair due to compaction by traffic. Dishing is caused by inadequate compaction during placement or instability of the mix.

- Debonding. The loosening of the patch material from the surrounding pavement. Debonding may occur from stripping due to moisture or debris being present in the pothole at the time of patching.

In addition to the distresses present in the surviving patches, failures of patches will be noted. For this project, failures have been defined as whenever a hole reappears in a location where a patch has been placed. Failed patches are those that necessitate "repatching" due to the development of a new pothole.

Crack Treatment

The distresses to be observed for the crack-treatment test sites can be broken down into four major areas: material failures, pavement failures, stone intrusion, and other failures. These distresses are described below.

- Sealant material failures. Failures in the material can be divided into adhesion and cohesion. Adhesion failure occurs when the material loses its bond to the adjoining pavement. Cohesion failure occurs when the internal strength of the material is not great enough to handle the expansion that occurs as the crack widens.

- Pavement failures. Failures in the adjacent pavements can be divided into cracking and spalling. Cracking of the adjacent pavement is usually parallel to the direction of the crack. Spalling occurs when pieces break off the edges of the adjacent pavement.

- Stone intrusion. Stone intrusion occurs when stones or other incompressibles are allowed to penetrate into the crack channel. Intrusion usually occurs during colder weather when the crack opening is greatest, but the damage from intrusion does not occur until the crack tries to close during warmer weather and the intruded material creates spalls and cracks at the edges of the asphalt pavement.

- Other failures. Some other failure modes that are being noted include tracking, bubbling, and aging. Tracking refers to the phenomenon that occurs as sealant material is picked up by passing tires and wears onto the pavement as the tire moves away from the crack. Bubbling can occur when hot-applied material is placed in the rain and raindrops form bubbles along the surface, or when material is placed too hot and pockets of hot air form and "pop" on the surface, leaving bubbles. Aging refers to the natural process in which exposure to climatic factors, most notably ultraviolet radiation, hardens the material, making it more likely to develop adhesion and cohesion problems.

In addition to the distresses noted, overall failures of the treatment as a system were also noted. Failures were defined as occurring when the treatment was no longer keeping water from infiltrating down into the pavement.

Joint Resealing

The distresses to be noted for the joint-resealing test sites can be grouped into four major areas, similar to those in the crack-sealing and filling experiment. The four areas are sealant material failure, concrete system failure, intrusion of incompressibles, and other failures. These failures are similar to but not the same as those for crack sealing/filling.

- Sealant material failure. Failures in the material can be divided into adhesion and cohesion. Adhesion failure occurs when the sealant loses its bond to the adjoining pavement. Cohesion failure occurs when the internal strength of the material is not great enough to handle the expansion that occurs as the joint widens.

- Concrete system failure. Concrete system failure generally refers to either saw/tine-related problems or spalling of the concrete. Saw/tine problems occur when sawcuts to reform the joint approach a tine depression, leaving a weakened plane of PCC material. Spalling along the edges of the concrete pavement can result in pieces that extend below the level of the sealant.

- Intrusion of incompressibles. Stones or other incompressibles that get into a joint during cold weather, when the joint is widest, will cause large stresses in the PCC when the joint closes in warmer weather. These stresses can lead to spalling or even blowups if conditions allow.

- Other failures. Other failure modes to be noted include tracking, bubbling, and weathering/aging. Tracking refers to the phenomenon that occurs as sealant material is picked up by passing tires and wears onto the pavement as the tire moves away from the joint. Bubbling can occur when sealant is placed in the rain and raindrops form bubbles along the surface, or when sealant is placed hot and pockets of hot air form and "pop" on the surface, leaving bubbles. Weathering/aging refers to the natural process in which exposure to climatic factors, most notably ultraviolet radiation, hardens the material, making it more likely to develop adhesion and cohesion problems.

In addition to the distresses noted, failures of the sealant as a system were also noted. Sealant failures were defined as occurring when the sealant was no longer keeping water from infiltrating into the pavement.

Spall Repair

The distresses to be noted for the spall repair test sites can be grouped into five major areas. These areas are spalling, surface cracking, wearing/raveling, patch surround deterioration, and debonding.

- Spalling. Spalling occurs when the edges of the patch begin to deteriorate. This can be the result of a thin layer of material cracking and debonding along the patch boundary or stress applied by the surrounding pavement as it expands.

- Surface cracking. Cracking of the patches commonly occurs on the surface as a result of material shrinkage during hydration. Cracks can also occur as a result of high tensile stresses developing in the material.

- Wearing/Raveling. Wearing occurs when the abrasive forces of traffic causes deterioration along the surface of the patch. Raveling of the patch surface is the result of deterioration brought on by exposure to freeze-thaw conditions and deicing chemicals.

- Patch surround deterioration. This distress attempts to characterize the failure of the pavement material around the patch to remain in place. The distress may be in the form of spalling at the slab/patch corner, a corner break in the adjacent slab, or the need for additional patching adjacent to the original patch.

- Debonding. Debonding occurs when the patch material no longer is bonded to the slab material. Bond strength between patch and pavement is influenced by chemical and mechanical interactions between the two materials, and a breakdown of either of these can lead to a debonded patch.

In addition to the distresses noted, failures of the spall repairs were also noted. Spall failures were defined as occurring when the original repair needed to be repatched due to the formation of another spall at the same location.

Laboratory Testing

For each of the four experiments, a battery of laboratory tests was planned to help characterize the materials used in placing the repairs. Table 16 contains all the laboratory tests planned for each of the four experiments. Along with the tests, the properties that are of interest are also listed.

Laboratory testing results were used in conjunction with the performance data to determine which properties are the most critical to good field performance. By identifying these desirable material characteristics, new, more effective specifications will be formulated to help ensure that the best materials are for repairs. Material properties corresponding to poor performance will also prove useful. In these cases, specifications will prevent these materials from being used.

Table 16. Summary of laboratory tests for H-106 materials

Exp.	Desired Property	Lab Test	Standard
POTHOLE	Stability	Resilient modulus Marshall stability Density	ASTM D 4123 ASTM D 1559 ASTM D 2950
	Resistance to water	Anti-stripping	ASTM D 1664
	Workability (mix)	Workability	Penn. Trans. Inst. (Report FHWA-RD-88-001)
	Workability (binder)	Viscosity Penetration	ASTM D 2171 ASTM D 5
	Durability	Softening point	ASTM D 36
	Adhesion/cohesion	Ductility	ASTM D 113
	Stability, durability	Sieve analysis	ASTM C 136
CRACK	Tracking	Flow Softening point	ASTM D 3407-78 ASTM D 36-86
	Ease of placement	Brookfield viscosity	ASTM D 3236
	Adhesion	Bond Asphalt compatibility	ASTM D 3407-78 ASTM D 3407-78
	Elasticity	Resilience	ASTM D 3407-78
	Extensibility	Elongation Ductility @ 39.2 °F (4.0 °C)	ASTM D 412-87 ASTM D 113-86 Modified
	Flexibility	Cold bend	Utah Test
	Internal stress	Force ductility Tensile stress @ 150% elongation	Utah Test ASTM D 412-87
	Elongation at adhesive or cohesive failure	Tensile strength adhesion	ASTM D 3583-85
	Weathering	Artificial weathering	ASTM G 53-88
	Wear	Abrasion	ASTM D 3910-84
JOINT[1]	Resistance to tracking	Flow Tack-Free time	ASTM D 2202-88 ASTM C 679-87
	Adhesion/cohesion	Adhesion/cohesion under cyclic movement	ASTM C 719-86
	Extensibility	Elongation	ASTM D 412-87
	Internal stress	Tensile stress @ 150% elongation	ASTM D 412-87
	Elongation at adhesive or cohesive failure	Tensile strength adhesion	ASTM D 3583-85
	Weathering	Artificial weathering	ASTM G 53-88 or ASTM D 3583-85

Table 16. Summary of laboratory tests for H-106 materials (continued)

Exp.	Desired Property	Lab Test	Standard
JOINT[2]	Resistance to tracking	Flow Softening point	ASTM D 3407-78 ASTM C 36-86
	Adhesion	Bond	ASTM C 3407-78
	Extensibility	Elongation ductility @ 39.2°F (4.0 °C)	ASTM D 412-87 ASTM D 113-86 Modified
	Internal stress	Tensile stress @ 150% elongation force ductility	ASTM D 412-87 Utah Test
	Elongation at adhesive or cohesive failure	Tensile strength adhesion	ASTM D 3583-85
	Weathering	Artificial weathering	ASTM G 53-88 or ASTM D 3583-85
	Ease of placement	Brookfield viscosity	ASTM D 3236
	Elasticity	Resilience	ASTM D 3407-78
	Wear	Abrasion	ASTM D 3910-84
	Flexibility	Cold bend	Utah Test
SPALL	Initial setting time	Workability	
	Strength	Compressive strength Flexural strength	ASTM C 109 or C 39 ASTM C 78
	Stiffness	Modulus of elasticity	ASTM C 469
	Adhesion	Bond strength	ASTM C 882 or California Method
	Freeze/thaw	Resistance to rapid freezing and thawing	ASTM C 666A
	Scaling	Scaling resistance to deicing chemicals	ASTM C 672
	Abrasion/wear	Resistance to surface abrasion	California Test 550
	Shrinkage	Length change	ASTM C 157
	Compatibility	Thermal expansion coefficient	ASTM C 884

[1] Laboratory tests for silicone materials

[2] Laboratory tests for polymerized asphalt rubber materials

4

Analysis

The primary objective of this project was to determine which of the material-procedure combinations in each of the four experiments provided the best results under different traffic and climatic conditions. During the early stages of this project, documents were created that outlined the basic approach for each experiment in terms of collecting and analyzing the data.[3] These plans were developed with the assistance of statistical experts to ensure that the data collection and analysis efforts would result in a meaningful product at the conclusion of the project.

Statistical Methodology

For each of the four experiments, different statistical tools were used analyze the data. The following sections provide a basic description of the statistical approaches and models used in the various stages of the analysis effort. In most cases, the SAS® statistical package was used to perform the actual statistical analysis. Use of the SAS package required the raw data in ASCII form and also required the creation of "command" files. These filed consisted of SAS statements to read in the raw data, perform the analysis, and produce the final output.

Field Performance

Two main aspects of field performance were being monitored for each experiment: survival rates and distress development. Each of these types of data is being used in analysis efforts to determine which material-procedure combinations should be used under different conditions.

Survival Analysis

For the pothole and spall experiments, the analysis of the survival rates of each of the materials was of major importance. To be able to determine which repairs have significantly higher survival rates, a method was needed to compare the survival plots over time. Figure 4 illustrates a typical survival plot for several different repair types. Through the use of the SAS LIFETEST procedure, the differences between the various plots can be calculated and checked for statistical significance. For this project, a reliability level (α) of 0.05 was used as the threshold of statistical significance in all cases.

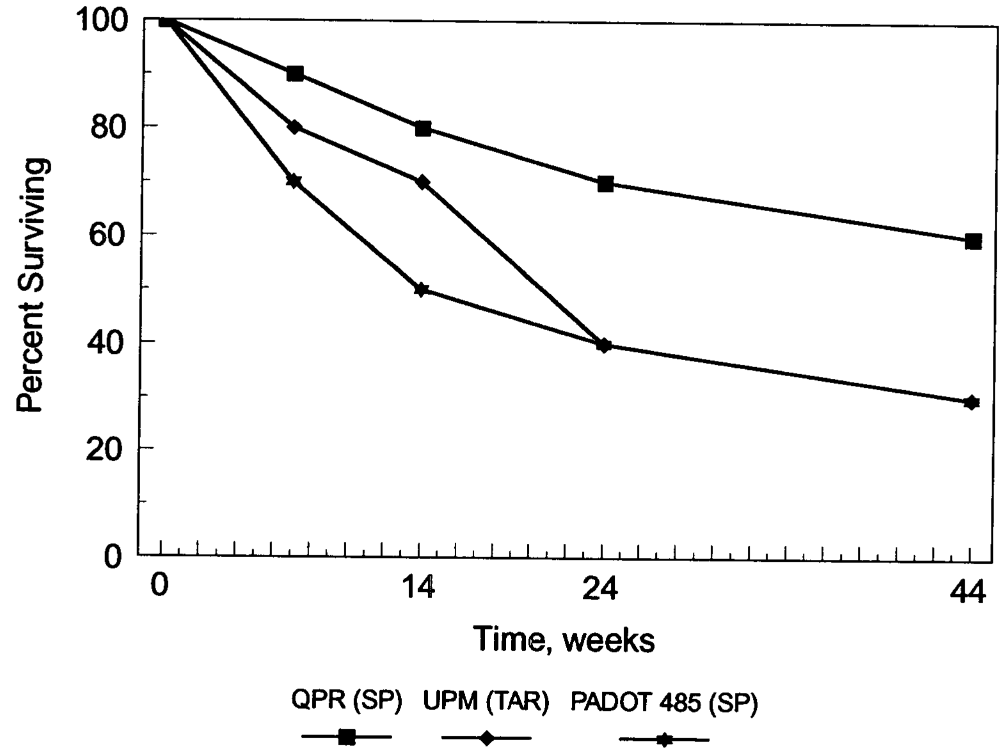

Figure 4. Example of survival plots for different repair types

Distress Development

The distress development data for all of the experiments consists of a record of each distress and corresponding severity that have been observed for the surviving repairs. Discussion on the general distress types can be found in chapter 3 of this volume. More detailed accounts of the distresses and severity levels, along with summaries of the actual distress data, can be found in the volumes detailing each experiment.

For the crack-treatment joint-reseal, and spall repair experiments, many sets of repair types are being compared to each other using the distress data. A multivariate analysis of variance (MANOVA) was performed using the SAS GLM procedure. This procedure uses the mean values and associated variability for each distress and identifies whether there are any statistically significant differences between the means of the different repair types.

When the MANOVA analysis conducted for the different distress values indicated that there was a significant difference between the various repair types, further analysis was needed to determine which repair types were different. To do this, a Tukey analysis of ordered means was used to differentiate those repair types whose means were significantly different at α=0.05. This step also used the SAS GLM procedure.

Each Tukey analysis resulted in a series of ordered mean values for the various repair types for the distress being analyzed. The following shows the mean values and Tukey groupings for the overall patch rating from the spall repair test site in the dry-nonfreeze region:

Type	Mean	Groupings		
51	9.46	A		
61	9.42	A		
53	9.38	A		
52	9.35	A		
62	9.18	A		
41	9.05	A		
12	9.02	A		
42	8.54	A		
11	8.53	A		
32	8.25	A		
83	8.23	A		
22	7.59	A	B	
72	7.47	A	B	
31	7.40	A	B	
21	6.97	A	B	
73	4.76		B	C
71	2.45			C
B1	2.30			C

A, B, and C indicate repair types determined by the Tukey analysis that have significant differences between the mean values (α=0.05). For this particular set of values, no statistically significant difference exists for repair types in the A, B, or C groups. Some difference does exist between group A and group C, though the overlap of group B prevents an overall ranking of repair types from being performed.

Laboratory-Performance Correlations

For analysis purposes, average values from a set of laboratory samples were used as representative values for particular material characteristics. These average laboratory results were then compared to the average survival rates and average distress values in an attempt to identify correlations between the material properties and field performance. The lack of differences in field performance in most cases has limited the effectiveness of these comparisons. Detailed descriptions of the correlation analysis performed in each experiment can be found in the respective volumes.

Productivity

One of the objectives of this project was to arrive at productivity values for each of the repair operations included at the test sites. Data collected during installation of the test sites have been used to calculate average productivity values for each repair operation. More detailed information can be found in the corresponding volumes for each of the four experiments.

Cost-Effectiveness

The ultimate criteria for judging the performance of any of these repair types is the cost-effectiveness of the repair operations. In order to calculate the overall cost-effectiveness of a repair operation, two pieces of information are necessary: the cost of installation for the material-procedure combination and the expected life of the repairs. Information collected during test site installations is able to provide material cost, equipment cost, labor requirements, and time for preparation and placement of the various repair types. Productivity information can also be used to determine the time required to make repairs, which will affect the labor costs, as well as the traffic control and user delay costs.

The second piece of information needed to calculate overall cost-effectiveness is not yet available from this project. With the very high survival rates experienced to date in all the experiments, and the short duration of the project, reliable estimates of the expected life are not available for most repair types. Each experiment volume contains sample cost-effectiveness calculations to provide an indication of what effect each input will have on the overall cost-effectiveness of the repair operations.

5

Preliminary Findings

The SHRP H-106 project is the most extensive maintenance experiment ever conducted. The potential benefits from timely, cost-effective maintenance operations to both the agencies performing the repair operations and the traveling public are immeasurable. The information collected during this project, when completed, will advance the state of the practice of everyday maintenance activities for agencies of all sizes.

This section presents some of the more important conclusions available at this time for each of the four experiments. The conclusions presented here are interim, and will be updated as more data become available in the future. For the crack-treatment, joint-resealing, and spall repair experiments, much more time will be needed to monitor the repairs until they come to the end of their service life. For the pothole repair experiment, the 18 months of performance observed to date constitute a greater percentage of expected life for these "temporary" repairs, so not as much additional monitoring time should be needed.

The low number of failures after 18 months for each experiment may be due to many factors. One of the most important may be in the way that materials and procedures were selected for this project. The SHRP H-105 study produced a list of materials and procedures that were being used for the different maintenance activities included in this project. The materials and procedures used during the test site installations represent those repairs that were felt to have a good chance of performing well. Simply being included in this project meant that a material or procedure had performed well for someone, and the overall good survival of the repairs would indicate that the H-105 project was successful in identifying good materials and procedures.

One other factor that may have improved the quality of the repairs placed during this project was the fact that for the most part, good construction procedures were employed and some amount of quality control was enforced through the presence of the SHRP contractor during the installation process. Major efforts were made by the participating agencies and the H-106 research team to ensure good quality of construction throughout the project, though no information was collected to determine how well these repairs would perform if they had been placed during everyday activities rather than as part of a national research effort.

Observations

The following section contains a brief summary of observations that have been made in each of the four experiments based on the data available to date.

Pothole Repair

The pothole repair project has been very successful in avoiding losses of experimental patches to sealcoats and overlays. This fact has allowed for a very complete set of data, with very few "missing" entries, which has been used to formulate the following findings:

- The throw-and-roll placement method is a viable option for repairing potholes, particularly in adverse weather conditions. This procedure should only be considered if good-quality cold mixes, similar to those used in this project, are used.
- When comparing costs of patching operations the performance or service life should also be considered. In almost all cases, the initial cost per ton of purchasing a material is insignificant when compared to the labor, equipment, and user delay costs incurred by patching operations. Poorly performing materials can further increase the labor, equipment, and user delay costs by requiring a great deal of repatching.
- Spray-injection patching devices are capable of producing good patches when good-quality, compatible aggregate and binder are used. Spray-injection devices are limited by the quality of the materials used and by the skill of the operator using the device. Poor-quality and incompatible materials will not be improved simply by the use of a spray-injection device.
- Patches placed under severe winter conditions should not be expected to perform as well as those placed in more temperate, spring-like conditions. The most critical period in the service life of a pothole patch appears to be the first few weeks, when the material is setting. Excessive moisture and cold temperatures can impede the setting of the repair materials, providing more opportunity for the repairs to fail.
- Winter patching operations should be limited to either throw-and-roll or spray injection to reduce the amount of time that workers need to be in traffic, thereby reducing the risk to both the maintenance crew and the traveling public.
- For three of the eight test sites, the local materials that was used performed very poorly when compared with the experimental materials. In all three cases, the failure mode was raveling of the material out of the pothole and it occurred within days of the installation.
- To date, only three experimental materials have exhibited significantly poorer survival than the respective control patches. This lack of stratification in field performance has resulted in no significant correlations between the laboratory data on material

properties and performance. It is anticipated that future data collection will show more differences in the field performance and will result in a more meaningful analysis of the laboratory data.

Crack Treatment

Using the information that has been collected and analyzed to date, the following observations have been made:

- Roughly 18 months after installation, most of the crack treatments are performing very well. Of 82 total treatments (sealant and filler), 64 are exhibiting less than 10 percent failure. Furthermore, 73 of the 82 treatments are exhibiting less than 20 percent failure. All eight crack fill treatments are showing less than 2 percent failure.

- Reservoir-type configurations, in which sealant is placed flush or in a band-aid, permit better short-term performance than simple band-aid configurations. However, it is essential that cutting equipment (i.e., routers and saws) be capable of closely following the existing crack and cause little, if any, pavement spalling or fracturing.

- The standard recessed band-aid (configuration B) shows slightly better short-term performance than the wide recessed band-aid (configuration C). However, the wider cut associated with configuration C allows cutting equipment to more closely follow cracks, resulting in fewer "weakened" segments.

- Dow 890-SL self-leveling silicone should be recessed no shallower than 0.25 in (6.4 mm) so that traffic does not pull it out during curing.

- Emulsified asphalts can provide satisfactory performance as fillers in cracks that undergo little movement. Sanding after application is recommended, particularly for moderate and wide cracks, to prevent tracking and pullouts by traffic during curing.

- Fiberized asphalt placed in a simple band-aid configuration does not provide good long-term performance in cracks that undergo significant amounts of movement (> 0.05 in [1.3 mm]). In addition, a higher rate of overband wear, which can thereby affect service life, can be expected with this material than with rubber-modified materials.

- Transverse crack seal performance, as related to overband wear, cohesion loss, and edge deterioration, is significantly poorer in the wheelpaths of a lane than the center or edges. This does not hold true for adhesion loss.

- Low-modulus, rubberized asphalt sealants experience higher rates of overband wear than standard rubberized asphalt sealants. Consequently, thinner bands often result in more cohesion and adhesion losses for significant crack movements.

Joint Resealing

The design of the joint seal project has allowed comparison of performance between materials as well as the performance of materials installed using different methods and configurations. Field evaluation in the 18 months following installation and laboratory material-testing results have led to the following findings and observations:

- The silicone sealants used in the project have developed significantly less partial-depth failure than the rubberized asphalt sealants. When installed in identically prepared joints using the standard recessed configuration, the silicone sealants averaged 0.2 percent adhesion loss, whereas the rubberized asphalt sealants averaged 30.7 percent across all sites.

- In full-depth adhesion, no significant performance difference has developed between silicone and rubberized asphalt sealant materials.

- Larger amounts of partial-depth spalling have generally occurred in colder regions in joints containing silicone sealant than in joints containing standard recessed, rubberized asphalt sealant. Joints filled with silicone sealant at the Colorado and Iowa sites averaged 9.9 percent partial-depth spalling of the joint length, whereas joints sealed with rubberized asphalt sealants developed partial-depth spalls on 5.0 percent of their length. However, these amounts are not in many cases statistically different.

- Most rubberized sealants installed in sawed and sandblasted joints using an overband configuration have developed significantly less partial-depth adhesion loss than sealants installed in identically prepared joints using a standard recessed configuration. Overall, overbanded rubberized asphalt sealants have developed partial-depth adhesion loss on 3.2 percent of their joint length, and rubberized asphalt sealants installed in a recessed configuration exhibit 30.7 percent adhesion loss.

- At one of the five sites, the sealants installed using a plow-and-overband configuration developed significantly more full-depth adhesion loss than the same sealants installed in joints that had been sawed and sandblasted. The small amount of failure at the remaining sites does not allow conclusions to be drawn about the configuration in which sealant materials develop the best adhesion.

- The rubberized asphalt, overbanded material in the pavement wheelpath remained effective, with more than 20 percent of its original thickness, for 9 to 18 months. Crafco RoadSaver 231 exhibited the best wear resistance.

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

- The penetration, resilience, stress at 150 percent elongation, immersed elongation, and ultimate elongation tests may slightly correlate with adhesion loss in the field.

Spall Repair

The partial-depth spall repair project has been very successful in monitoring the patches and keeping them from being lost to additional rehabilitations. Only a few patches have been lost to slab replacement. Using the information available to date, the following conclusions can be drawn:

- For cementitious and polymer materials, significant differences were found in wearing, fraying, bonding, and the overall ratings at all sites. In addition, significant differences were found in longitudinal crack ratings in all regions except the wet-nonfreeze, in oxidization ratings in the dry-nonfreeze region, and in spall ratings in the wet-nonfreeze region.

- The only significant effect that the installation temperature was found to have was on the longitudinal cracking rating of cementitious and polymer materials placed in the dry-freeze region. This site had the lowest minimum installation temperature of all sites for patches placed under "normal conditions."

- At all sites, Type III PCC performed the same as the more expensive proprietary cementitious materials as a group when compared using the overall patch rating.

- Cementitious and polymer patches placed with the chip-and-patch procedure had a significantly higher overall patch rating (8.49) than those placed with the saw-and-patch procedure (6.95) for the dry-nonfreeze region.

- For cementitious and polymer patches in the dry-nonfreeze and wet-freeze regions, no significant difference was found in the overall patch rating among milling and patching, sawing and patching, or chipping and patching as a group.

- In the dry-nonfreeze region, Type III PCC, Five Star HP, MC-64, SikaPronto 11, and Pyrament patches had significantly better overall patch ratings than Penetron patches.

- In the wet-nonfreeze region, UPM High Performance Cold Mix patches placed with the chip-and-patch procedure had a significantly higher overall patch rating (8.34) than spray-injection patches placed with the clean-and-patch procedure under "normal" conditions (7.55).

- Of the 74 sets of repair types placed at all sites, 3 have shown significantly poorer performance in the survival analysis when compared with repair types with no failures at the same site. These repair types are Percol FL patches placed with the saw-and-patch procedure in the dry-nonfreeze region, Set-45 patches placed with the chip-and-patch procedure in the wet-freeze region, and Percol FL patches placed with the saw-and-patch procedure in the dry-nonfreeze region.

Recommendations

The SHRP H-106 project has taken a major first step toward improving the state of the practice of everyday maintenance operations. Even though some progress has been made, more room for improvement exists. Some general recommendations for further improving the progress made by H-106 are listed below:

- **Continue monitoring repairs.** The investment made in the installation of these test sites will continue to grow if monitoring is continued, and more answers will be able to be found from these test sites.

- **Set up regional testing centers for continued testing.** Although the SHRP H-105 study attempted to identify those materials and procedures that had the most promise, many materials and procedures that may have been deserving were not tested. The ability to continually evaluate new materials and equipment that come on the market would be invaluable to those agencies involved daily in pavement maintenance. Continued testing would also improve the criteria for determining which repair materials and procedures are actually the most cost-effective.

- **Communicate the findings.** The information gathered by the SHRP program will only benefit the highway community if persons making decisions at a local level are informed of the results. Disseminating the findings to state DOTs, as well as county and municipal highway agencies, could save hundreds of millions of dollars a year.

Additional recommendations for each of the specific experiments can be found in the corresponding individual volumes.

References

1. Smith, K. L. et al. "Innovative Materials and Equipment for Pavement Surface Repairs–Final Report." Strategic Highway Research Program, Contract No. SHRP-M/UFR-91-504, February 1991.

2. Evans, L. D. et al. "SHRP H-106–Experimental Design and Research Plan." Strategic Highway Research Program, Contract No. SHRP-89-H-106, February 1991, revised October 1991.

3. Evans, L. D. et al. "SHRP H-106–Evaluation and Analysis Plan." Strategic Highway Research Program, Contract No. SHRP-89-H-106, February 1991, revised September 1991 and February 1992.

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