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Innovative Materials Development and Testing

Volume 5: Partial Depth Spall Repair in Jointed Concrete Pavements

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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.

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- SikaPronto is a trademark of Sika Corporation
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Contents

List of Figures

List of Tables

Abstract

The partial-depth spall-repair experiment, conducted as part of the Strategic Highway Research Program (SHRP) H-106 project, is one of the most extensive attempts to date to evaluate the performance of various rapid-setting materials and procedures used in the repair of partial-depth spalls in PCC pavements. Four test installations, consisting of a total of 1,607 patches, were constructed in the four SHRP climatic zones: wet-freeze, wet-nonfreeze, dry-freeze, and dry-nonfreeze. The experiment investigated the performance of several cementitious, polymeric, and bituminous patching materials, and procedures used in repairing jointed concrete pavements. The materials evaluated include Type III Portland Cement (PCC), Duracal®, Set-45®, Five Star® HP, MC-64, SikaPronto® 11, Percol FL, UPM High Performance Cold Mix, Pyrament® 505, Penatron® R/M-3003, and spray-injection bituminous cold mix (e.g., AMZ, Rosco). The repair techniques evaluated include saw and patch, chip and patch, mill and patch, waterblast and patch, and minimal preparation clean and patch under adverse conditions. Overall, patch performance has been good; only 2.3 percent of all patches have failed. Although some significant differences in distress and overall ratings have been found, for the most part, distinct rankings of materials and repair techniques cannot be made at this time.

Executive Summary

Beginning in March 1991, 1,607 spalls were repaired with partial-depth patches in four climatic regions. The patches were placed using different combinations of 11 rapid-setting materials and five patch-preparation procedures. Field performance was monitored five times over 18 months. To date, only 2.3 percent of the patches have failed. Based on statistically significant correlations and differences (at $\alpha = 0.05$) found during the analysis of the installation, laboratory testing, and short-term field performance data, several preliminary observations can be made:

- Significant differences in the overall patch rating and various distress ratings among material-procedure combinations have been found at all sites.
- The only significant effect of the installation temperature was on the longitudinal cracking rating of cementitious and polymer materials placed in the dry-freeze region.
- 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.
- Cementitious and polymer patches had a significantly higher overall patch rating when placed with the chip-and-patch procedure than when placed with the saw-and-patch procedure only in the dry-nonfreeze region.
- For cementitious and polymer patches in the dry-nonfreeze and wet-freeze regions, no significant difference was found between the overall patch rating when the milling-and-patching procedure was contrasted with the sawing-and-patching and chipping-and-patching procedures as a group.
- In the dry-nonfreeze region, Type III PCC, Five Star® HP, MC-64, SikaPronto® 11, and Pyrament® 505 patches had significantly better overall patch ratings than Penatron® R/M-3003 patches.
- In the wet-freeze region, no significant difference in the overall patch rating was found between bituminous 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 at the same site.

1

Introduction

Objectives

The Strategic Highway Research Program (SHRP) H-106 partial-depth spall repair experiment represents one of the most extensive partial-depth patching experiments ever undertaken. The primary aim of this experiment was to determine the most cost-effective materials and procedures for placing quality, long-lasting partial-depth patches in jointed concrete pavements. Maintenance crews spend a large amount of time and money annually to repair partial-depth spalls. The ability to place long-lasting patches quickly reduces the amount of time that crews are exposed to traffic by decreasing the amount of time spent repatching the same areas, and increases the serviceability of the highway.

The best way to compare repair performance is on the basis of the overall cost-effectiveness of each material-procedure treatment. The calculation of overall cost-effectiveness depends on an accurate assessment of the expected life of the repairs, among other things. However, because of low failure rates, it is not yet possible to estimate the life expectancy of the repairs. In the absence of this information, attempts have been made to compare repairs based on installation cost, individual distress ratings, and survival ratings.

A secondary objective of the H-106 project was to identify material tests related to patch performance. An extensive laboratory testing program and subsequent statistical analysis were undertaken to attempt to find these correlations. However, because the patches have performed so well, it has not yet been possible to identify performance-related material tests. Continued monitoring of the patches eventually should provide useful correlations between patch performance and material properties.

Scope

This report presents a summary of all aspects of the partial-depth spall repair experiment of the H-106 project, including test site installation, material testing, field performance, and data analysis. Chapter 2, details the installation process, including test-site arrangements, test-site layout and preparation, patching materials and procedures, documentation of the installation process, and the collection of productivity and cost. Chapter 3 details the material tests performed and their results. In chapter 4, field performance data collection is described and a summary of performance data is presented. Chapter 5 details the statistical methodology used to analyze the data, and the analysis of field performance, laboratory-performance correlations, productivity, and cost-effectiveness. In chapter 6, the preliminary findings of the experiment are outlined. The appendixes include the detailed test site layouts; summaries of installation, material testing, and performance data; and detailed guidelines for calculating cost-effectiveness.

Project Overview

Beginning in March 1991, over 1,600 partial-depth patches were placed at four test sites located across the United States. The repairs were made using materials supplied by SHRP and were placed under SHRP supervision by local maintenance forces from two different state departments of transportation (DOTs) and two contractors working for the state DOTs. The test sites are located on moderate- to high-volume four-lane highways in four climatic regions. The locations of the test sites and the four climatic regions (originally defined for the SHRP Long-Term Pavement Performance (LTPP) projects and subsequently adopted for this project) are shown in figure 1 and listed below:

• Rte 28	Kittanning, PA	Wet-freeze region
• I-15	Ogden, UT	Dry-freeze region
• I-20	Columbia, SC	Wet-nonfreeze region
• I-17	Phoenix, AZ	Dry-nonfreeze region

The original testing plan for the partial-depth spall repair project was developed during the SHRP H-105 project.[1] The original plan is presented in Volume I–Project Overview. The materials and procedures included in the actual test site installations were somewhat different from those originally proposed, as various state agencies requested that additional materials and procedures be included in accordance with the provisions of the SHRP H-106 contract.

Repair Materials

Originally, nine materials and four testing procedures were selected for study. However, the states in which the test sites were constructed were allowed to add an additional material or procedure of their choice to the experiment. As a result, two additional materials and one repair procedure were incorporated into the experiment. The following eleven materials are included:

- Type III PCC
- Duracal®, a gypsum-based concrete
- Set-45®, a magnesium phosphate concrete (powder-based)

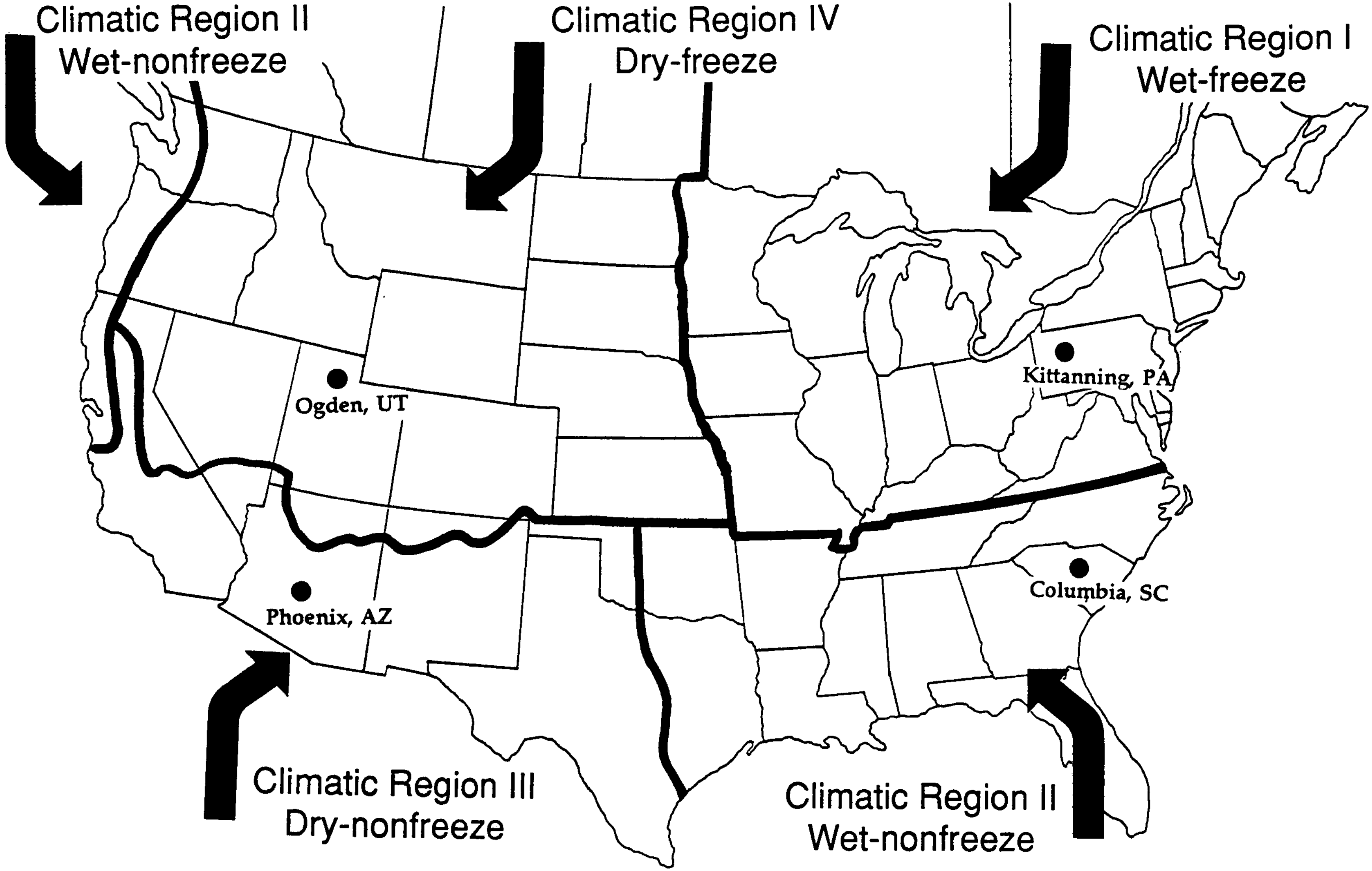

Figure 1. Spall repair test site locations and climatic regions

- Five Star® Highway Patch, a modified, high-alumina concrete
- MC-64, an epoxy concrete
- SikaPronto® 11, a high-molecular-weight methacrylate concrete
- Percol FL, a flexible polyurethane concrete
- UPM High Performance Cold Mix, a bituminous cold mix
- Pyrament® 505, a blended hydraulic cement concrete
- Penatron® R/M-3003, a flexible epoxy-urethane concrete
- Spray-injected bituminous mix (AMZ and Rosco)

Repair Procedures

The five procedures being evaluated vary mainly in the method used to remove the deteriorated concrete. The procedures are:

- Saw and patch
- Chip and patch
- Mill and patch
- Waterblast and patch
- Clean and patch under adverse conditions

Most of these procedures were evaluated under normal conditions. Normal conditions are defined as conditions corresponding to an ambient air temperature above 50°F (10°C) at the time of patching and a substrate that is dry prior to preparation. However, distresses must sometimes be patched under adverse conditions. To determine whether a cost-effective material could be found for this situation, three materials were tested under adverse conditions using the clean-and-patch procedure. Adverse conditions are defined as an ambient air temperature below 40°F (4.5°C) at the time of patching and a substrate that is surface saturated.

Table 1 contains the actual material-procedure combinations that were installed. Not all of the material-procedure combinations were placed at all of the test sites. Some materials (e.g., spray-injection Rosco and AMZ, Penatron R/M-3000) were placed at the request of the participating highway agency that provided the site. South Carolina and Pennsylvania requested the spray-injection materials, and Arizona requested the addition of Penatron R/M-3003. Arizona also requested the addition of the waterblast-and-patch procedure. Because equipment was not available, the mill-and-patch procedure was not installed in Utah. Equipment operational difficulties prevented installation of the waterblast-and-patch procedure in Arizona.

Test Site Characteristics

This section briefly describes the characteristics of the test sites. Table 2 presents a summary of the location, route, number of lanes, annual daily traffic (ADT), annual precipitation, and annual number of days less than 32°F (0°C) for each test site.

Table 1. Matrix for spall repair experiment (number of patches)

REGION	Wet-freeze (PA)				Dry-freeze (UT)			Wet-nonfreeze (SC)		Dry-nonfreeze (AZ)			TOTAL
PATCHING PROCEDURE	S&P	CH&P	M&P	ADV	S&P	CH&P	W&P	S&P	CH&P	S&P	CH&P	M&P	
Type III PCC	22	24	20		25	35	37	20	20	20	20		243
Duracal					22	25		20	20	20	20		127
Set-45	20	20	20		25	23		20	20	20	20		188
Five Star HP	20	20	20		19	34		20	20	20	20		193
MC-64	20	20			25	28		19	20	20	20	20	192
SikaPronto 11	21	20			26	28		20	20	20	20		175
Percol FL	20	20	29	20	29	29		20	20	20	20	20	238
Pyrament 505	20	20		19								20	79
UPM High Perf. Cold Mix		20		20		31			20		20		111
Penatron R/M-3003										20			20
Spray injection (AMZ)									20				20
Spray injection (Rosco)		21											21
TOTAL	143	185	80	59	171	233	37	139	180	160	160	60	1,607
	467				441			319		380			

Note: S&P = saw and patch, CH&P = chip and patch, M&P = mill and patch, W&P = waterblast and patch, ADV = adverse-condition clean and patch.

Table 2. Test-site characteristics for the spall repair project

Test Site	Route	No. of Lanes 2 dir	2-way ADT (vpd)	Annual Precipitation[1] (in)	Annual Days < 32°F[1] (days)
Kittanning, PA	Rte 28	4	3,400	42	120
Ogden, UT	I-15	4	20,000	16	180
Columbia, SC	I-20	4	24,000	46	31
Phoenix, AZ	I-17	6	125,000	7	17

[1] Historical averages from the 1983 Climatic Atlas of the United States; 1 in = 25.4 mm, °C = (°F - 32) x 5/9.

Rte 28–Kittanning, Pennsylvania

The test site in the wet-freeze region is located in Pennsylvania on Route 28, northeast of Pittsburgh between Freeport and Kittanning, as shown in figure 2. The adverse-condition test sections are located in both the northbound and southbound driving lanes, with the experiment replicated once in each direction. The normal-condition test sections were placed in all four lanes of the route, with a majority of the test sections located in the driving lanes. The topography is hilly with two interchanges and several bridges. The pavement was constructed in 1971 as a 9-in (229-mm) jointed reinforced concrete pavement (JRCP) on a 14-in (356-mm) cement-stabilized subbase. At the time of installation, the transverse joints, spaced at 46.5 ft (14.2 m), were sealed with a bituminous sealant and the sealant was in fair condition. The shoulders are asphalt concrete.

There was extensive spalling in parts of the test section, often with more than one spall per joint. When the test site was first inspected, the spalls were judged to be limited to the upper one-third of the pavement (coring was not performed). This was confirmed during the installation of the adverse-condition test sections. However, when the remainder of this test site was installed and more rigorous concrete removal techniques were employed, the spalls appeared to extend deeper into the pavement, and dowels often were exposed. Due to limited resources and other constraints, there were no departures from the procedures outlined for the experiment. This site is in the SHRP region that experiences the most severe climatic conditions, both significant precipitation and freezing temperatures. The climate and the fair amount of salt deposited on this route each year may have contributed to the depth of the spalling found there.

I-15–Ogden, Utah

The test site in the dry-freeze region is located in Utah on I-15 in the passing lane, north of Ogden between exits 357 and 360, as shown in figure 3. The pavement was built in 1971 and consists of an 8-in (164-mm) jointed plain concrete pavement (JPCP) on a concrete

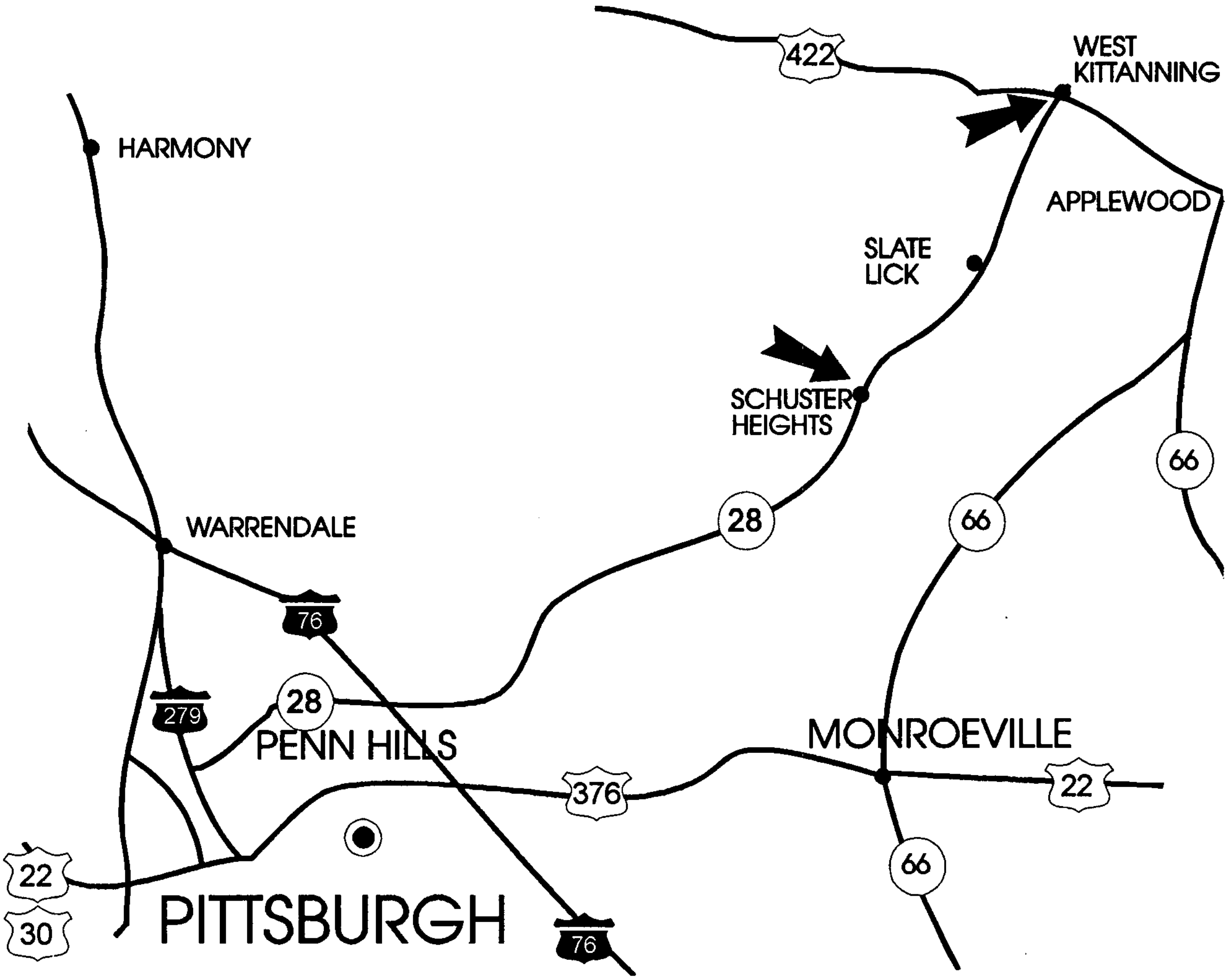

Figure 2. Pennsylvania test site location

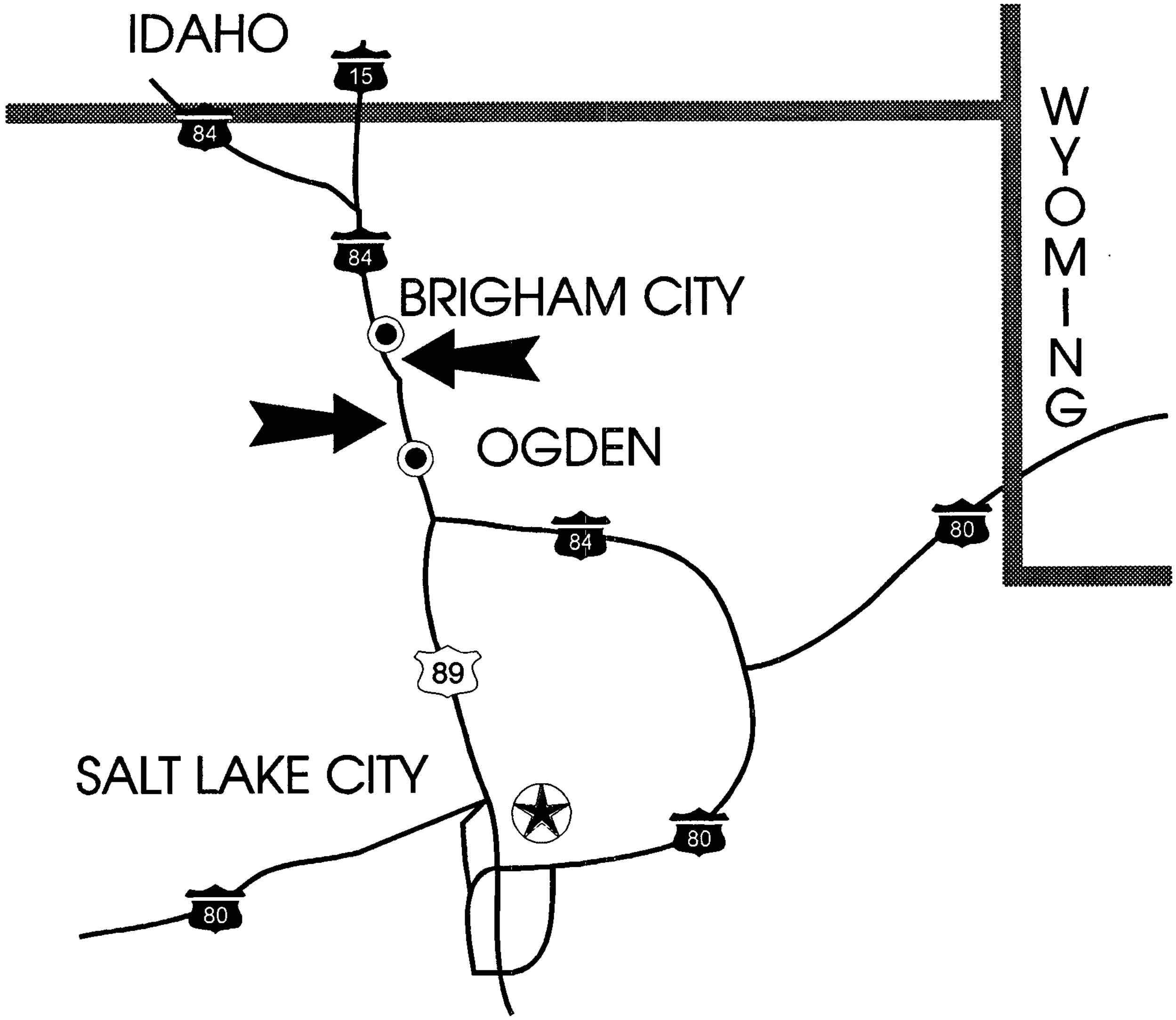

Figure 3. Utah test site location

subbase. The joints are randomly spaced between 12 ft and 18 ft (3.6 m to 5.5 m), and were sealed with silicone sealant at the time of the installation of the test site. The shoulders are concrete. There were spalls on a majority of the joints, but they were fairly small in size. The topography is very flat and no structures are located within the test site boundaries. The test site is surrounded by a lake on the west side and mountains on the east side. This test site was installed in April and the temperature range during installation was 42° to 70°F (6° to 21°C). This area is subject to rapid fluctuations in temperature and large amounts of snowfall. The use of studded tires on this route has caused some wearing of the pavement. This route receives a fair amount of salt each year.

I-20–Columbia, South Carolina

The test site for the wet-nonfreeze region is located in Columbia, South Carolina, on the westbound driving lane of I-20, as shown in figure 4, between mile markers 58 and 61. The pavement was constructed in 1966 and consists of a 9-in (229-mm) JRCP or jointed plain concrete pavement (JPCP) on a 6-in (152-mm) stabilized aggregate subbase. The joints are spaced at 30 ft (9.15 m) and were sealed with a bituminous sealant at the time of installation of the test site. The shoulders are asphalt concrete. There were spalls or existing patches of AMZ spray-injection mix at almost every joint. The terrain for the majority of the site is flat. There is one structure over a railroad crossing.

I-17–Phoenix, Arizona

The test site in the dry-nonfreeze region is located in the northbound and southbound passing lanes of I-17 in Phoenix, Arizona, between the Camelback and Thomas Road exits (mileposts 202 to 204), as shown in figure 5. The pavement was constructed in 1961 and consists of a 9-in (229-mm) JPCP over a 3-in (76-mm) granular base and a 6-in (152-mm) granular subbase. The joints are spaced 15 ft (4.58 m) apart. At the time of installation of the test site, the joints were not sealed and there was a great deal of joint debris infiltration. The joints were constructed using metal joint inserts. The pavement was grooved to remove faulting and restore friction. The section contained many existing patches, and many of the spalls were full-lane width. The shoulders are JPCP also.

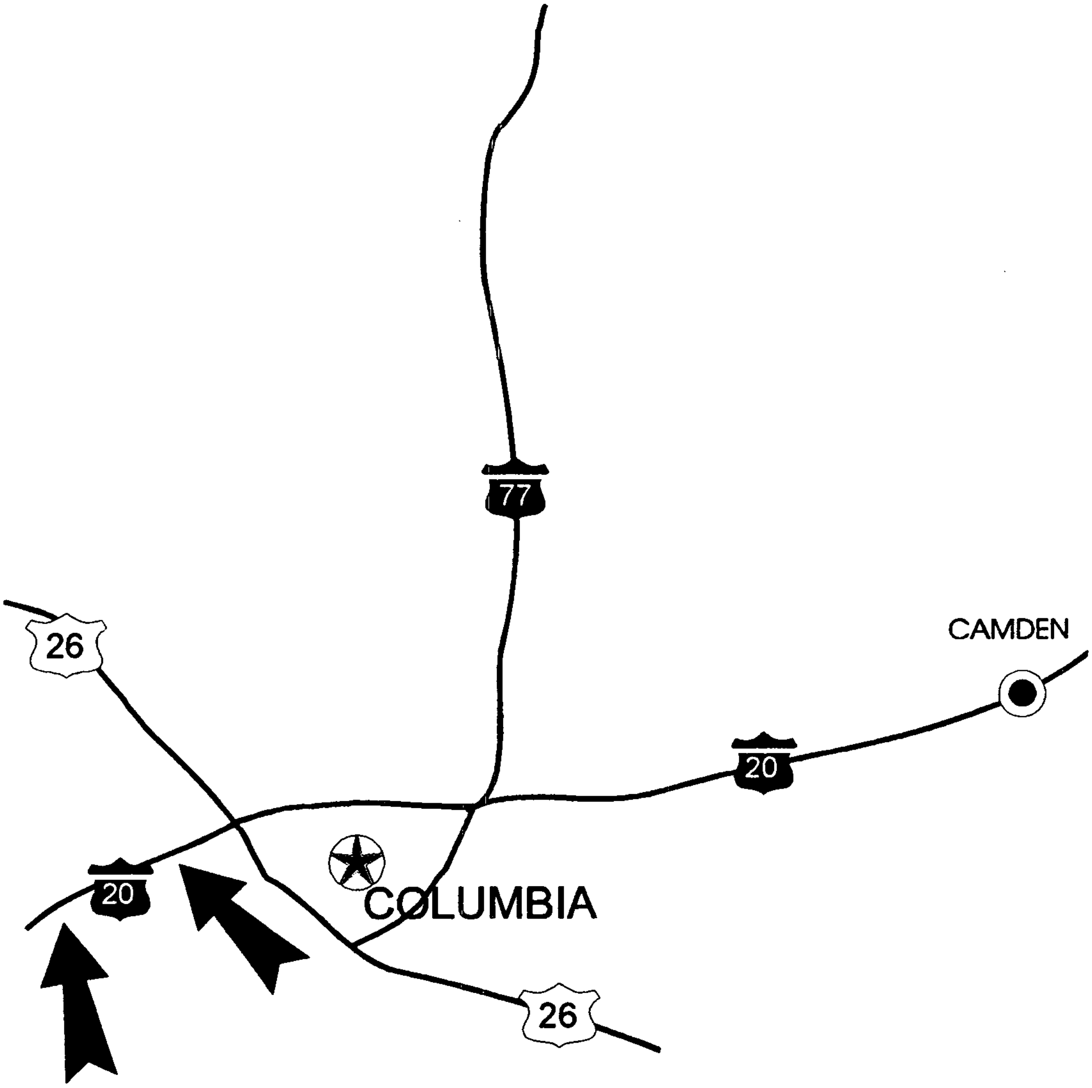

Figure 4. South Carolina test site location

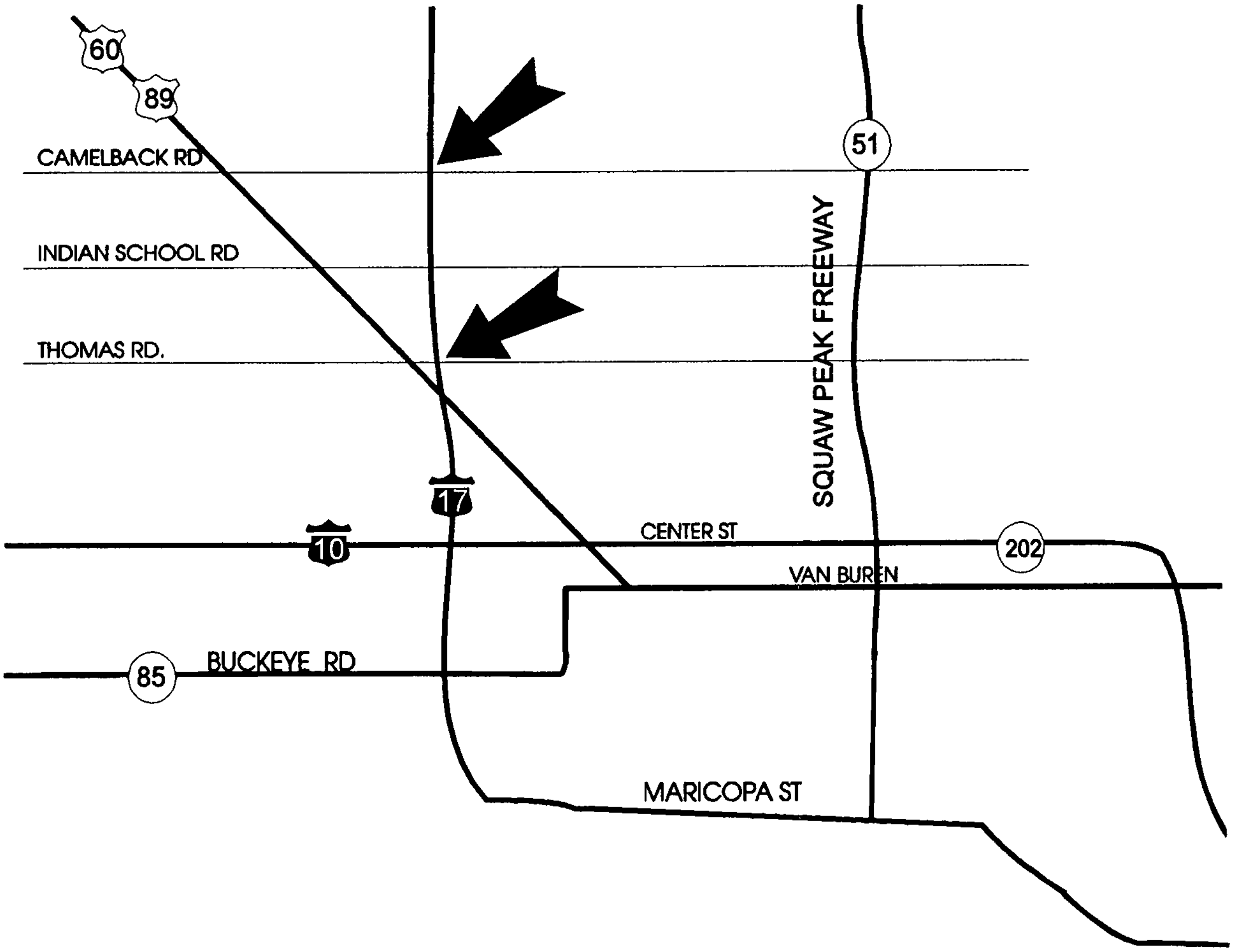

Figure 5. Arizona test site location

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Test Site Installation

Site selection began in November 1990, and installation of the test sites began in March 1991 and continued through August 1991. Installation of the test sites was regulated and monitored by project engineers, together with representatives from the manufacturers of repair materials and state DOTs. This chapter presents an overview of the installation process, material costs, productivity rates, equipment requirements, problems encountered during installation, and comments on the materials and procedures used.

Test Site Arrangements

The first step in the site installation process was to find test sites that met the requirements outlined in *Innovative Materials and Procedures to Perform Spall Repair in Jointed Concrete Pavement–Experimental Design and Research Plan.*[2] Once the test sites were selected, close coordination among the H-106 project team, the state DOTs and contractors, and the material manufacturers was critical to the smooth and efficient installation of the test sites.

Based on estimations of patch size, product yield, and material waste factors, the repair materials were ordered and shipped to the test site. Each repair material was obtained from a single production batch when possible, to minimize variability, and was shipped to the four test sites. A separate shipment from each batch was sent to the laboratory for independent testing.

Because it was considered critical that the materials be placed correctly and in accordance with manufacturers' recommendations, representatives of repair material manufacturers were requested to observe and participate in the installation of their material. In addition, a recognized expert in the field of patching attended the first installation in Utah to provide advice on quality control and material performance evaluation. Overall, the interest among the material manufacturers was high; almost all sent representatives to at least one test site. The presence of a representative for the Type III PCC was not requested because it was felt that most agencies would be familiar with the use of Type III PCC as a patching material. Because South Carolina and Pennsylvania regularly use AMZ and Rosco spray-injection machines for patching, representatives of these manufacturers also were not requested to attend. Table 3 indicates which material manufacturers were represented at the test sites.

The installation dates for each test site are shown in table 4. Specific construction schedules are given in *Innovative Materials and Procedures to Perform Spall Repair in Jointed Concrete Pavement–Experimental Design and Research Plan.*[2] It was originally planned that all the installations would be performed by state maintenance crews; however, private contractors were used for the installations at two of the test sites.

Installation Process

The installation process encompasses selection and marking of the repair areas; removal of the deteriorated concrete; and mixing, placement, and finishing of the repair materials. This section presents the details of the installation process.

Layout

The original experimental plan called for 10 patches to be placed for every material-procedure treatment in each test section. These test sections were placed in random order consecutively along the test site pavement. After the placement of the first block of treatments, the sequence was repeated randomly for the second replicate. A typical test section layout is shown in figure 6. Detailed test site layouts are presented in appendix A. At two of the test sites, more than 10 patches were included in some of the test sections. In Pennsylvania, this occurred as a result of additional distress development between test section layout and actual repair placement. In Utah, additional patches were included as the result of a misunderstanding.

A few days before installation was begun, the spalls to be repaired were selected. The perimeter of each repair location was determined by sounding the pavement with a hammer or steel rod. Only deteriorated areas at joints were selected. The area for removal was marked 2 in to 3 in (51 mm to 76 mm) beyond the sound area on all nonjoint sides. Deteriorated or unsound areas smaller than 6 in (152 mm) long and 3 in (76 mm) wide were not repaired.

Spalls within the test section that previously had been patched with an asphalt patching mix were included for repair in all sections. These spalls were repaired using the chip-and-patch, saw-and-patch, waterblast-and-patch, and mill-and-patch procedures. Repair areas closer than 1 ft (0.3 m) to each other were marked as one repair area. Each repair area was marked with a painted code that indicated the patching procedure and material to be used.

Preparation

After the repair areas were marked, the existing transverse and longitudinal joints bordering repair areas to be patched with a rigid material (i.e., Type III PCC, Duracal, Five Star HP,

Table 3. Manufacturers' representative present at test site

	Test site			
Material	Pennsylvania	Utah	South Carolina	Arizona
Type III PCC	no	no	no	no
Duracal	---	yes	yes	yes
Set-45	yes	yes	yes	yes
Five Star HP	no	yes	yes	yes
MC-64	yes	yes	yes	yes
SikaPronto 11	no	yes	yes	yes
Percol FL	yes	yes	yes	yes
Pyrament 505	yes	---	---	yes
UPM	no	yes	no	no
Penatron	---	---	---	yes
AMZ	---	---	no	---
Rosco	no	---	---	---

--- Material not installed at this location.

Table 4. Summary of spall repair installation schedule

Spall-Repair Project Site	Participating Agency	Installation Start Date	Installation Completion Date	Number of Construction Days
Rte. 28, Kittanning, PA	Commonwealth of Pennsylvania DOT–Armstrong County	Adverse: 3/11/91	Adverse: 3/27/91	4
		Normal: 6/4/91	Normal: 7/22/91	22
I-20, Columbia, SC	South Carolina Dept. of Highways and Public Transportation–Lexington County	5/6/91	5/29/91	13
I-15, Ogden, UT	Utah DOT–Research and Development/Wadsworth Construction Co.	4/22/91	5/1/91	5
I-17, Phoenix, AZ	Arizona DOT–Research/Bentson Contractors	5/29/91	6/9/91	8

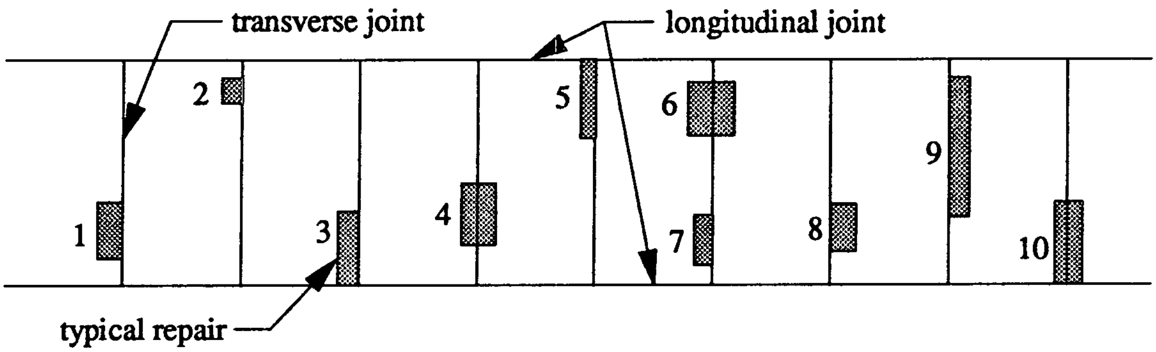


Figure 6. Layout of a typical test section

Set-45, SikaPronto 11, and Pyrament 505) were sawed using a double-bladed concrete saw. The depth of the saw cut was generally deeper than the depth of the repair. In most cases, a depth of 4 in to 5 in (102 mm to 127 mm) proved to be sufficient. The saw cut extended 2 in to 3 in (51 mm to 76 mm) beyond the repair area in each direction. The saw cut to reestablish the joint was eliminated for the repair areas that were to be patched with flexible materials (i.e., Percol FL, MC-64, Penatron R/M-3003, UPM High Performance Cold Mix, and spray-injection mix), as well as for the patches to be installed under adverse conditions.

The joints were sawed a minimum of one day in advance of the removal and replacement operations so that the spall would be sufficiently dry for those patching materials requiring a dry substrate.

Procedures

The deteriorated concrete was removed using one of five procedures: saw and patch, chip and patch, mill and patch, waterblast and patch, and adverse-condition clean and patch. This section describes the concrete-removal procedures included in the experiment.

After the removal of the deteriorated concrete was complete, the remaining concrete was again tested for soundness. If further unsound concrete was observed, the unsound material was removed to a sufficient depth using the same procedure used for the initial removal.

If the depth of removal of unsound material using the saw-and-patch, chip-and-patch, mill-and-patch, or waterblast-and-patch procedure exceeded one-half the nominal pavement thickness, or if dowel bars were encountered, a full-depth repair was recommended. However, because of the constraints of traffic, labor, and equipment, the construction of full-depth repairs was not feasible, and partial-depth repairs were installed. This was particularly true during construction of the Pennsylvania test site, where dowel bars were often encountered.

Saw-and-Patch Procedure

Using a diamond-bladed concrete saw, the rectangular marked areas were sawed with neat vertical faces 1.5 in to 2 in (38 mm to 51 mm) deep. The saw cut extended 2 in to 3 in (51 mm to 76 mm) beyond the limits of the repair area in each direction. A pneumatic hammer with a maximum weight of 30 lb (13.6 kg) was used for the initial removal. The operation started in the center of the patch area and worked toward, but not all the way to, the patch boundaries. A light pneumatic hammer with a maximum weight of 15 lb (6.8 kg) and hand tools were used near the patch boundaries.

Chip-and-Patch Procedure

All loose and unsound concrete within the repair area was removed using a pneumatic hammer of up to 15 lb (6.8 kg) and hand tools, and swept away using a stiff broom. Fresh concrete faces at least 1 in (25 mm) deep were exposed on all sides.

Mill-and-Patch Procedure

All unsound concrete within the marked area was removed to a minimum depth of 1.5 in (38 mm) using an approved carbide-tipped milling machine. The milling machine had a drum diameter of 3 ft (0.9 m) or less and was capable of making a cut 12 in (305 mm) wide or narrower. A carbide-tipped, cold-milling machine is shown in figure 7. Milling proceeded in such a manner as to produce vertical edges at the patch boundaries. A small amount of sound material at patch corners could not be removed by milling from any direction. This material was removed by light chipping hammers, as shown in figure 8. Care was exercised to minimize spalling the sound concrete at the patch boundaries.

Waterblast-and-Patch Procedure

All unsound concrete within the marked area was removed to a minimum depth of 1.5 in (38 mm) with neat vertical faces, using an approved waterblasting machine. The waterblasting equipment produced a water jet under a minimum pressure of 30,000 psi (207,000 kPa), and was controlled by a mobile robot, as shown in figure 9. The maximum depth of concrete removal was determined by the waterblasting pressure and speed of the water jet. Care was exercised to remove only the unsound concrete.

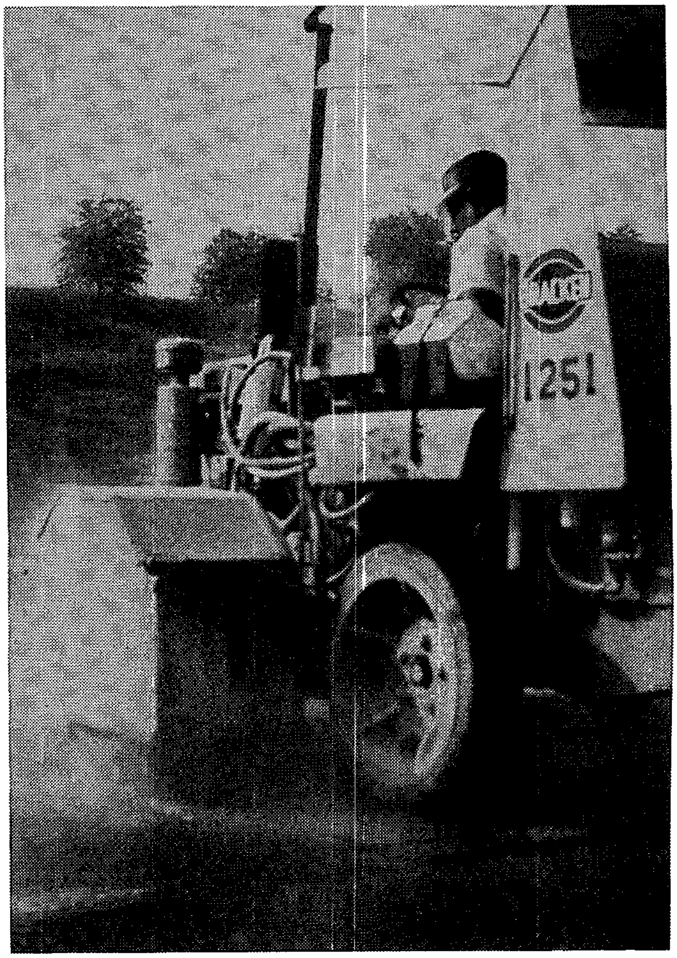


Figure 7. Carbide-tipped, cold-milling machine

Clean-and-Patch Procedure

This procedure was used only with the bituminous spray-injection materials. Due to the manufacturer's recommendations, only the deteriorated concrete that could be removed using shovels and or handpicks was removed.

Clean-and-Patch Procedure–Adverse Conditions

Deteriorated and loose concrete within the repair area was removed primarily using hand tools. Occasionally, a light pneumatic hammer was allowed if the spalled area was large or if the cracked concrete was held tightly in place.

Figure 8. Corners of patch being removed after milling

Cleaning and Preparing the Repair Area

The remaining steps of the patching procedures are similar for all but the clean-and-patch procedure. When cleaning and patching, sandblasting was eliminated, as was joint preparation and the installation of the bond-breaker for the bituminous materials. When a spray-injection machine was used with the clean-and-patch procedure under good conditions, the repair area was not sandblasted. Instead, it was airblown with the equipment used to place the asphalt cement and aggregate. For the adverse-condition clean-and-patch procedure, if moisture was not present in the repair hole at the time of material placement, water was lightly sprayed in the open hole. Furthermore, immediate sealing of the joint adjacent to the patch was not required.

For the other procedures, after removal of the deteriorated concrete was completed, the surfaces within the repair area were thoroughly cleaned by sandblasting. Oil-less airblasting was then used to remove any dust that remained. The air compressor was checked for moisture and oil by placing a piece of clean cloth over the air jet nozzle and checking for residue. The cleanliness of the surfaces was checked by using a black glove or black cloth.

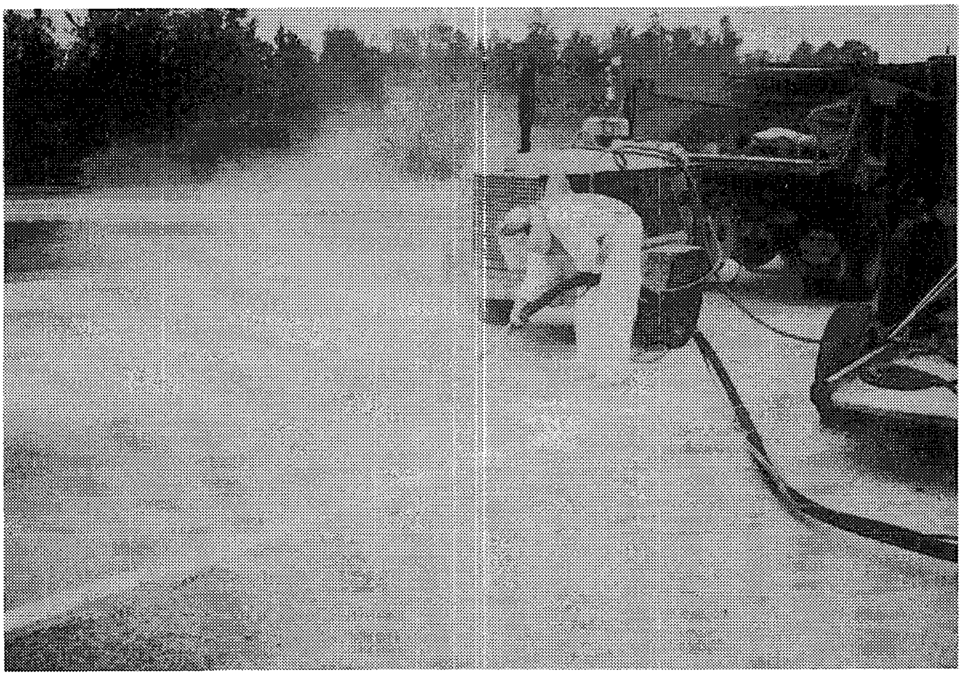


Figure 9. Waterblasting equipment with mobile robot

Following the cleaning operation, a joint bond-breaker was placed full-depth in the joints adjacent to repair areas that were to be patched with nonflexible repair materials (i.e., Type III PCC, Duracal, Set-45, Five Star HP, MC-64, SikaPronto 11, and Pyrament 505). The joint bond-breaker consisted of a 4-in (102-mm) high, 0.5-in (13-mm) wide, closed-cell, polystyrene foam board, slightly wider than the saw cut. In back-to-back repair areas at a joint, difficulty was encountered in maintaining a true, straight joint line. In locations deeper than 4 in (102 mm), it was also difficult to stack the joint bond-breaker to the desired height. Latex caulking was used occasionally to seal any irregularities or gaps between the joint bond-breaker and joint opening, to prevent repair material from flowing into the joint or crack opening below the bottom of the patch. A joint bond-breaker was not installed in repair areas that would be patched with Percol FL, Penatron R/M-3003, UPM High Performance Cold Mix, AMZ, or Rosco.

After the surface of the existing concrete was cleaned and the joint bond-breaker installed as needed, the repair surfaces were prepared as required by the manufacturers of the individual repair materials. This preparation, which included such activities as application of a bonding agent or a light spray of water, is detailed in the following sections.

Materials

Instructions on the proper mixing, placing, finishing, curing, and handling of the individual patching materials were obtained from the manufacturer of each product. Furthermore, most manufacturers were asked to send a representative to each of the test sites for at least the first day that their product was being installed. The purpose was to provide a brief training session and general guidance to ensure that their product was properly installed.

The cementitious products were prepackaged in easy-to-handle 35-lb to 50-lb (16-kg to 23-kg) bags; the aggregate was provided in 100-lb (45-kg) bags. The aggregate was proportioned in the field using precalibrated buckets.

Type III PCC

The Type III PCC mix was prepared in a mobile 3-yd^3 (2.3-m^3) drum mixer. First the water (3 gal [11.4 L]) was added to the mixer, followed by the coarse aggregate (220 lb [100 kg]), the air-entraining agent (1 oz [30 mL]), and the fine aggregate (110 lb [50 kg]). This combination was allowed to mix for 3 minutes. The Type III portland cement (94 lb [43 kg]) was added next, and allowed to mix for another 3 minutes. The accelerating agent (0.5 gal [1.9 L]) was added and mixed for 1 minute, followed by the superplasticizer (12 oz [355 mL]). The combination was mixed for 2 minutes. If the mix looked stiff at this time, up to 0.125 gal (0.5 L) of water was added as needed. The water-cement ratio for the mix varied from 0.30 to 0.33.

The Type III PCC repair material required that the bottom and sides of the repair area be primed with a medium-viscosity epoxy bonding agent. The bonding agent was prepared by mixing part B with part A for 3 minutes, using an electric drill with a Jiffy mixer. A paint brush was used to apply the epoxy evenly to the repair surfaces. While the epoxy was still tacky, the prepared Type III PCC mix was shoveled into the repair area and vibrated using a pencil vibrator.

After vibration, the surface of the patch was troweled level with the surface of the pavement and finished with a float. The mix was sometimes stiff to work with and vibration was essential to make the work finishable. A curing compound was applied after 1 to 2 minutes and, if necessary, the patch was covered with an insulating blanket.

The working time for the Type III PCC mix was 20 minutes, and the opening time was 4 hours at 80°F (27°C). Insulating blankets were used during cooler temperatures to achieve the same opening time.

Duracal

Duracal was mixed using a drum mixer. The water was added first (1.75 gal [6.62 L] per bag of Duracal), followed by the pea gravel (50 lb [23 kg] per bag of Duracal), the Duracal (50 lb

[23 kg] per bag), and the sand (50 lb [23 kg] per bag of Duracal). The cement and aggregate were mixed for a minimum of 2 to 3 minutes. If the mix looked stiff or dry, up to an additional 0.125 gal (0.47 L) of water was added, as needed. Generally, only one bag of Duracal per batch was used. The area to be patched was sprayed with water, and then the concrete was shoveled into the repair area. The mix was vibrated by moving a trowel up and down throughout the patch. A curing compound was used only if the air temperature was above 90°F (32°C) and it was windy. The working time for the Duracal concrete was approximately 10 minutes, and the opening time was 1 hour at 80°F (27°C) and 1.5 hours at 50°F (10°C).

Five Star HP

The mixing of Five Star HP was accomplished using a mortar mixer. Generally, two to three bags of Five Star HP per batch were mixed at one time. With the mixer running, the water was added to the mixer (0.75 gal [2.8 L] per bag of Five Star HP). The cement was then added to the mixer (50 lb [23 kg] per bag), followed by the pea gravel (30 lb [14 kg] per bag of Five Star HP). This combination was mixed for 5 to 6 minutes. As is common with this material, the mix looked very dry until it had been mixed for almost 4 minutes. However, additional water was not added, as the mix is very sensitive to water content.

Before the mix was shoveled into the repair hole, the hole was sprayed with water. The mix was vibrated by moving a trowel up and down throughout the patch. The manufacturer recommends that the surface of the patch be kept moist for at least 30 minutes after the mix has stiffened. This was accomplished by spraying water onto the patch every 5 to 10 minutes, for a total of 30 minutes. The working time for the Five Star HP concrete was approximately 10 minutes, and the opening time was 1 hour at 80°F (27°C) and 2 hours at 50°F (10°C).

Set-45

The mixing of Set-45 was accomplished using a mortar mixer. With the mixer running, the water was added to the mixer (0.5 gal [1.9 L] per bag of Set-45). Then the cement was added (50 lb [23 kg] per bag), followed by the pea gravel (30 lb [14 kg] per bag of Set-45). This combination was mixed for 2 to 3 minutes. The mix was shoveled into a dry hole, worked with a trowel, and air cured. The working time was approximately 10 minutes, and the opening time was 1 hour at 80°F (27°C) and 3 hours at 50°F (10°C).

Pyrament 505

A mortar mixer was used for mixing Pyrament 505. With the mixer running, the water was added to the mixer (0.58 gal [2.2 L] per bag of Pyrament 505). The pea gravel was then added to the mixer (30 lb [14 kg] per bag of Pyrament 505), followed by the cement (50 lb

[23 kg] per bag). This combination was mixed for 6 to 7 minutes. Before the mix was shoveled into the hole, the hole was sprayed with water. Then the mix was worked and leveled with a trowel and finished with a float. Approximately 5 minutes after finishing, a curing compound was sprayed on the surface. The working time was approximately 10 minutes, and the opening time was 1.5 hours at 80°F (27°C) and 2 hours at 50°F (10°C).

SikaPronto 11

Preparation of SikaPronto 11 involves mixing component A, a liquid set initiator, with the cement and then adding the aggregate. Two different methods of mixing SikaPronto 11 were used. The first method involved using electric drills with Jiffy mixers to mix the three components; the second method used the standard mortar mixer. It was believed that the first method would provide more uniform mixing; however, because of the size of the batches mixed, this method proved inefficient. The mortar mixer seemed to provide satisfactory results and was more convenient to use.

Before the SikaPronto 11 mix was poured into the dry hole, the hole was primed with the methylmethacrylate primer, SikaPronto 19, as specified by the manufacturer. The SikaPronto 19 primer was prepared by combining component B with component A and mixing for 3 minutes, using a low-speed electric drill and a "Sika" paddle provided by the manufacturer. The primer was brushed onto the surfaces of the repair area.

The mix was placed in the prepared hole while the primer was still tacky and was vibrated with a mechanical vibrator. The manufacturer recommends that the SikaPronto 11 be placed in lifts with sufficient cure time between lifts if the thickness of the repair is greater than 1.5 in (38 mm). However, because of the nature of this project, it was not practical to place the material in lifts and the material was placed in one lift only. Following placement, the patches were air cured. The SikaPronto 19 primer has a pot life of 20 minutes and will remain tacky for 20 minutes at 70°F (21°C). The SikaPronto 11 mix has a working time of 20 minutes and an opening time of 2 hours at 80°F (27°C).

Percol FL

After the spall area was cleaned, the repair area was filled to grade with 0.75 in (19 mm) washed and oven-dried crushed stone. Percol FL, a flexible two-component polyurethane resin, was pumped directly over the preplaced aggregate and allowed to percolate through the voids around the aggregate until it was flush with the pavement surface. Immediately following the flooding of the repair area with the resin, 0.25-in (6.4-mm) aggregate was broadcast over the top of the repair as a friction layer, as shown in figure 10. An air-powered Percat 500 pump drove equal amounts of each resin thorough an impingement mixer to the discharge nozzle. The resin was pumped from two 55-gal (208-L) tanks. The initial set time for the Percol FL was 60 seconds, and the opening time was 2 to 3 minutes at 80°F (27°C), as well as at 40°F (4.5°C).

Figure 10. Placement of Percol FL

MC-64

MC-64, a two-component epoxy, comes prepackaged with long-grain rubber aggregate in two 5-gallon (19-L) buckets. One bucket contains a premeasured amount of resin A; the other contains a premeasured amount of resin B. These two components were first mixed individually for 3 minutes, then part B was added to part A, and the combination was mixed for 5 more minutes. Timers were used to keep track of mixing times. Stainless steel 21-in-long (533-mm) Jiffy mixers, powered with 0.75-in (19-mm) drill motors, were used for mixing the components, as shown in figure 11. After mixing the two components, the material was poured into the prepared spall. Although the manufacturer states that the material may be placed in one lift, under the supervision of the manufacturer's representative the material was placed in 2-in (51-mm) lifts with as little as 4 to 5 minutes between lifts. A stiff asphalt-impregnated styrofoam board was used to work the material to the patch corners and level with the pavement. The working time was 10 minutes, and the opening time was 2 hours at 80°F (27°C), as well as at 40°F (4.5°C).

Penatron R/M-3003

Before Penatron R/M-3003 was mixed, the repair hole was filled to grade with 0.75-in × 1-in (19-mm × 25-mm), washed and dried, crushed granite rock. The Penatron R/M-3003 4-Gallon (15-L) Kit comes with two parts of component A and two parts of component B.

Figure 11. Mixing of MC-64

First part A was poured into a clean, 5-gal (19-L) mixing bucket. Jiffy mixers were used for mixing. While mixing part A, part B was slowly and carefully poured into the same bucket. The mixture must be continuously agitated during the addition of part B. After the two components were added to the mixing bucket, mixing was continued for another minute. Immediately following mixing, the product was poured into the repair hole and allowed to encapsulate the pre-placed rock until the patch was level with the surrounding surface, as shown in figure 12. A cardboard trowel was used to finish the surface. The working time for Penatron R/M-3003 was approximately 5 minutes, and the opening time was 45 minutes.

UPM High Performance Cold Mix

UPM High Performance Cold Mix is a premixed bituminous material. It was shoveled directly from 55-gal (208-L) drums into the repair areas with no additional preplacement preparation. The repair areas were overfilled and then compacted using a vibratory roller or plate until the patches were level with the pavement.

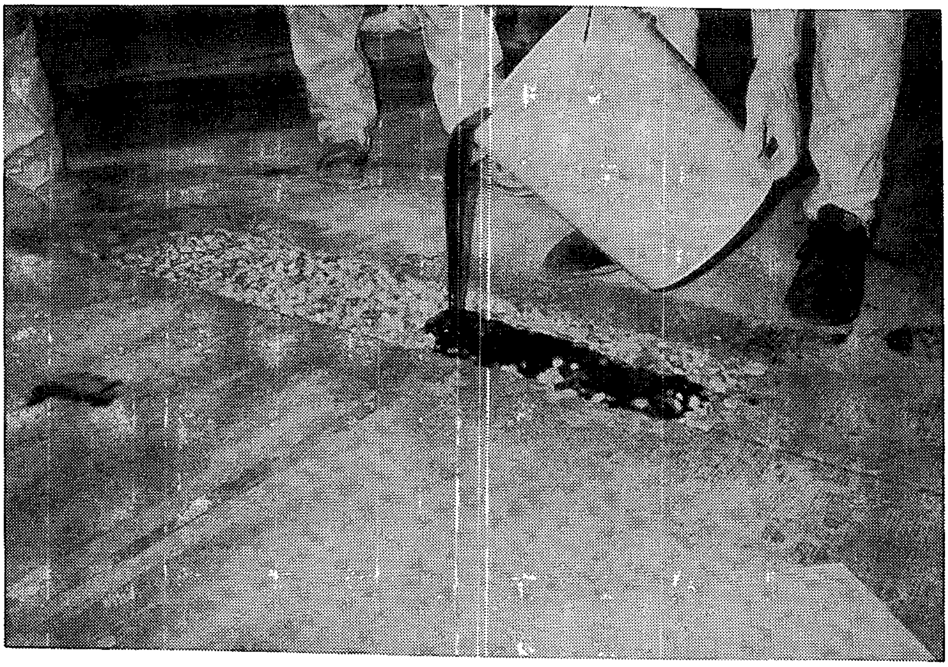


Figure 12. Placement of Penatron R/M-3003

Spray-Injection Mix

This bituminous mix was placed using a Rosco or AMZ spray-injection machine. As soon as the hole had been cleaned with the machine's blower, the operator sprayed a tack coat into the hole and also onto the edges of the pavement surface surrounding the repair area. Then a mixture of liquid asphalt and aggregate was sprayed directly into the prepared hole. When the repair was filled level with the surface of the pavement, a coating of chip stone was sprayed onto the patch to prevent tracking.

Joint Sealing

After a cure time of at least one week, the transverse joints bordering the partial-depth patches were sealed, using each state's joint or crack sealing specification and materials at the time of installation. There were considerable differences in these specifications and standards. In South Carolina, a soft, bituminous joint sealant was applied heavily at the joint location. In Pennsylvania, a soft, bituminous sealant was applied around the entire perimeter of the patch. In Utah, a silicone joint sealant was applied. The test site in Arizona was not sealed because of the high traffic volume at the site and the need to minimize the disruption of traffic.

Equipment

The mixing, placing, and patch-preparation procedures used in this experiment required some equipment commonly used by maintenance crews everywhere, such as jackhammers, concrete saws, and mechanical vibrators, as well as some less commonly used equipment, including spray-injection machines and waterblasting equipment. Table 5 shows the equipment typically used to prepare patches using each of the five procedures that were included in the project. Table 6 shows the mixing and placement equipment and supplies typically used with the rapid-setting spall repair materials that were included in the project. In all cases, the manufacturer's material specifications were consulted for mixing and placing equipment requirements.

Documentation

To effectively evaluate the performance and cost-effectiveness of the repair procedures and materials, detailed information regarding the installation of the test sites was collected. The forms used during installation are shown in appendix B. The information collected includes:

- Patch length, width, and depth
- Degree of faulting at the joint
- Whether reinforcing steel or dowels were visible during patch preparation
- Date of patch placement
- Patch area preparation procedure used
- Patching material used
- Bonding material used
- Climatic conditions at time of construction
- Time before opening to traffic
- Time required for construction
- Workability of the material

Productivity and Cost Data

Productivity and cost data are necessary to determine the overall cost-effectiveness of the materials and procedures being evaluated. Productivity data were collected at each of the test sites during installation of the test site. Material cost data were obtained from the manufacturers of the repair materials.

Productivity

Three factors seemed to affect the efficiency of the patching operations: personnel, equipment, and traffic control. As mentioned earlier, two of the spall repair test sites, Utah and Arizona, were constructed by private contractors. The contractors at both of these sites had more personnel and more and better equipment available than the participating state agencies. A

Table 5. Typical equipment used for the five patch-preparation procedures

Equipment	Preparation Procedure[1]				
	S	C	M	W	A
Sounding equipment: rod, chain, or ball-peen hammer	✓	✓	✓	✓	✓[2]
Double-bladed concrete saw for joint sawing	✓	✓	✓	✓	
Single-bladed concrete saw for sawing patch boundaries	✓				
15-lb (6.8-kg) jackhammer with air compressor	✓	✓	✓[3]		✓[2]
30-lb (13.7-kg) jackhammer with air compressor	✓[4]	✓[4]			
Stiff brooms for debris removal	✓	✓	✓	✓	✓
Hand tools (pick axe, etc.)	✓	✓			✓
Truck for hauling removed material	✓	✓	✓		✓
Waterblasting machine				✓	
Carbide-tipped, cold-milling machine			✓		
Sandblasting equipment with directional nozzle, sand, air compressor	✓	✓	✓	✓	✓[2]
Airblasting equipment with oil and water filtering capability, air compressor	✓	✓	✓	✓	✓[2]

[1] S = saw and patch, C = chip and patch, M = mill and patch, W = waterblast and patch, and A = clean and patch (adverse conditions).

[2] Jackhammers were used for large areas, or when the deteriorated concrete could not be removed using hand tools; sand blasting, airblasting, and sounding were not used under adverse conditions.

[3] To remove rounded edges.

[4] 15-lb (13.7-kg) jackhammers were preferred. 30-lb (13.7-kg) hammers were **never** used at patch boundaries.

major problem encountered at both the South Carolina and Pennsylvania sites was equipment breakdown. The majority of the equipment used by the states was old, poorly maintained, or of insufficient capacity.

Traffic control requirements varied from site to site. In Utah, overnight traffic control was set up for the duration of the construction. In Arizona and South Carolina, temporary traffic control was set up and removed every work day. In Pennsylvania, temporary traffic control was used during the first 3.5 weeks and overnight traffic control was used for the remainder

Table 6. Typical mixing and placement equipment and supplies

Typical equipment and supplies[1]	III	Dur	St45	5HP	MC64	SP11	Pen	Pyr	PFL	UPM	Spr
Potable water/hose/pump	✓	✓	✓	✓		✓		✓			
Drum mixer (6-8 ft^3)[2]	✓	✓						✓			
Mortar mixer (3-4 ft^3)			✓	✓		✓					
0.75-in electric drills and 21-in stainless steel Jiffy mixers	✓[3]				✓[3]	✓[3]	✓				
Bonding agent brush/roller	✓					✓					
Vibrators and/or screeds	✓	✓	✓			✓		✓			
Trowels	✓	✓	✓	✓	✓	✓		✓			
Shovels	✓	✓	✓	✓		✓		✓		✓	
Curing compound, applicator, burlap, or plastic sheeting[4]	✓	✓	✓					✓			
Insulating blankets[5]	✓							✓			
Vibratory roller or plate										✓	
Electric generator[6]	✓	✓	✓	✓	✓	✓	✓	✓	✓		
Grayco Percat 500[7]									✓		
Spray-injection machine[8]											✓
Nonwater cleaning solvent					✓	✓	✓		✓	✓	
Compression cylinders/rod	✓	✓	✓	✓				✓			
Slump cone	✓	✓	✓	✓				✓			
Air meter, rod, water bulb	✓										

[1] III = Type III PCC, Dur = Duracal, St45 = Set-45, 5HP = Five Star HP, MC64 = MC-64, SP11 = SikaPronto 11, Pen = Penatron R/M-3003, Pyr = Pyrament 505, PFL = Percol FL, UPM = UPM High Performance Cold Mix, Spr = Spray-injection Mix. 1 in = 25.4 mm. 1 ft. = 0.31 mm.

[2] Mixers used had at least twice the volume of the amount of material to be mixed.

[3] Capable of 400-600 rpm.

[4] Used in hot (> 85°F [29°C]), windy (>25 mph [41 km]) weather.

[5] Used in weather below 45°F (7°C).

[6] Used as needed; sufficient for demand.

[7] Air-driven, automatic, ration-metering pump.

[8] Capable of delivering chip-size aggregate and asphalt emulsion (e.g., AMZ, Rosco).

of the 2 weeks. Use of temporary traffic control reduced the productive time available in each working day by 1 to 2 hours and resulted in downtime for the personnel not involved with traffic control. There also was significant amount of downtime near the end of the day after placement of the last patch for the day to allow sufficient cure time before opening the roadway to traffic. At the Arizona test site, all construction work was performed at night or on weekends because of the high traffic volume of the roadway. Though not quantifiable in this situation, night work appeared to reduce productivity somewhat. Table 7 shows the number of patches installed at each test site and the approximate time required for the installations. "Productive hours" were determined by subtracting the time necessary for setting up and removing traffic control, scheduled breaks, and the hour needed for cure time at the end of the day from the scheduled work hours.

Maintenance repairs of this nature usually are performed with the adjacent lane open to traffic. Many of the patching operations, such as sawing or removal of the deteriorated concrete by milling, waterblasting, or chiseling, often require encroachment onto the adjacent lane. This, of course, also affects productivity. More important, it affects the safety of the repair crew. Patching procedures and materials that minimize the time required for repairing the pavement are highly desirable.

Crew Size

The various procedures and materials that were evaluated required different labor for the removal and replacement of the deteriorated concrete. Summaries of the labor requirements for the procedures and materials evaluated in the project are shown in tables 8 and 9, respectively. For the majority of the installations, the patching operations were done sequentially with different crews responsible for different activities. Every operation except sawing was performed within a reasonable time following the preceding operation. For example, a crew would saw the patch boundaries, followed by a crew using jackhammers to remove the concrete, followed by another crew sandblasting and airblasting the patches clean. The sawing was performed at least 1 day before the other operations. Generally, four to five repair areas were prepared for receiving the repair material before the mixing of the repair material was started. This decreased the amount of waste allowing more efficient use of the repair material. At no time was the patching material placed more than 30 minutes after airblasting.

Tables 8 and 9 list the minimum number of personnel used by the participating agencies. In certain cases, such as with the placement of the aggregate with the Percol FL or Penatron R/M-3003 and insertion of the joint bond-breaker, persons could be used for two activities that did not occur simultaneously. A supervisor generally was responsible for overseeing the crews and their operations. Inspection was performed by the SHRP project staff.

Table 7. Time required for placement of spall repairs

Participating Agency	Productive Hours per Day	Number of Patches Installed	Number of Days	Average Number of Patches per Hour
Commonwealth of Pennsylvania DOT - Armstrong County Maintenance Crew	Temporary Traffic Control: 4 to 6	205[1]	13.5	3
	Overnight Traffic Control: 6	175	8.0	4
South Carolina DOH&PT - Lexington County Maintenance Crew	7	320	12.5	4
Utah DOT - Wadsworth Construction Co.	9.5[2]	440[3]	5	9
Arizona DOT - Bentson Contractors	Week night: 6.5	245	5.5	7
	Weekend: 12.5	140	1.5	7

[1] Does not include the patches installed under adverse conditions or the Rosco patches that were installed 1 month after the majority were installed.

[2] Traffic control was left in place during the weekdays and removed during the weekend.

[3] At this test site a test section consisted of ten joints rather than ten patches. All spalls on the joint were repaired.

Material Cost

The costs of the materials evaluated in this experiment varied greatly; they are given in table 10. The costs shown in the table do not include shipping or any discounts that may be realized by buying large quantities. Cementitious materials were readily available through local distributors. However, the newer polymer materials had an additional cost (not shown in the table) because they required shipping from the source of production.

Comments

During the installation process, observations were made regarding the ease and workability of the materials and procedures. The following section describes these observations.

Saw-and-Patch Procedure

The saw-and-patch procedure is generally the most accepted way of patching partial-depth spalls. The advantages of this procedure are that the saw leaves vertical edge faces, the forces experienced by the pavement during removal of the concrete within the sawed boundaries are isolated to within the patch area, and very little spalling of the remaining

Table 8. Labor requirements for the various spall repair procedures

Spall Repair Procedure	Required Labor
reestablishing joint sawing	1 person operating saw 1 person directing saw
saw and patch	1 person directing saw 1 person operating saw 2 persons operating pneumatic hammers 2 persons cleaning repair hole 1 person removing debris
chip and patch	2 persons operating pneumatic hammers 2 persons cleaning repair hole 1 person removing debris
mill and patch	1 person operating milling machine 1 person directing milling machine 2 persons operating pneumatic hammers 2 persons cleaning repair hole 1 person removing debris
waterblast and patch	1 person operating waterblaster 1 person operating water truck 1 person cleaning repair hole
clean and patch	1 person operating pneumatic hammer 1 person cleaning repair hole
inserting joint bond-breaker	1 person installing joint board (available for other activities)

pavement occurs. However, if water is used during the sawing operation, the repair area may be saturated for some time afterward. Some patching materials are very susceptible to the moisture condition of the substrate and will not bond to a wet surface. If such a material is being used, concrete replacement operations may have to be delayed. It was found that no spalling of the edges resulted from allowing traffic onto the repair areas that had been cut 1 to 2 days prior to being replaced. Furthermore, if additional unsound concrete is found beyond the original boundaries after the initial removal, the saw must be brought back to saw new boundaries, which may create a delay. To obtain the depth of cut required for the patch boundaries, the boundaries must be overcut 2 in to 3 in (51 mm to 76 mm) in each direction. These overcuts may create a weak area that may deteriorate in the future unless cleaned and sealed. If the area to be patched is adjacent to the open lane of traffic, the saw must encroach into that lane, creating a somewhat dangerous condition.

Generally, the removal of the deteriorated concrete within the sawed boundaries was much easier and quicker than when the boundaries had not been sawed.

Table 9. Labor requirements for the various spall repair materials

Repair Material	Required Labor
Type III PCC	2 persons mixing and applying epoxy 2 persons proportioning and mixing Type III PCC mix 3 persons placing, compacting, and finishing
Duracal	1 person proportioning and mixing Duracal 2 persons placing, compacting, and finishing
Five Star HP	1 person proportioning and mixing Five Star HP 2 persons placing, compacting, and finishing 1 person spraying curing water
Set-45	1 person proportioning and mixing Set-45 2 persons placing, compacting, and finishing
Pyrament 505	1 person proportioning and mixing Pyrament 505 2 persons placing, compacting, and finishing
SikaPronto 11	2 persons mixing and applying SikaPronto 19 2 persons proportioning and mixing SikaPronto 11 2 persons placing, compacting, and finishing
MC-64	4 persons mixing MC-64 2 persons placing and finishing
Percol FL	1 person placing rock into prepared hole 1 person driving truck with pumps and tanks 1 person applying Percol FL 1 person applying broadcast aggregate
Penatron R/M- 3003	1 person placing rock into prepared hole 2 persons mixing Penatron R/M-3003 3 persons placing and finishing
UPM	2 persons shoveling and placing mix 1 person operating vibratory roller or plate
AMZ/Rosco	1 person driving truck 1 person operating binder/aggregate sprayer

Chip-and-Patch Procedure

The chip-and-patch procedure (without sandblasting) is frequently used by highway agencies when it is perceived that there is not enough time to patch using the more rigorous saw-and-patch procedure. However, this method has merits of its own. Once the joint sawing has

Table 10. Spall repair material cost

Material	Unit[1]	Weight of Aggregate per Unit of Material (lb)	Cost per unit ($)	Cost per yd^3 ($)
Type III PCC	94 lb	340	5.00	132.00[2]
Duracal	50 lb	100	7.50	214.00
Five Star HP	50 lb	30	18.00	840.00
Set-45	50 lb	30	21.50	990.00
SikaPronto 11	68 lb	37.5	113.00	4,340.00[2]
MC-64	4 gal	not applicable	129.00	6,550.00
Percol FL	1 gal	49	29.00	2,680.00
Pyrament 505	50 lb	30 lb	9.00	440.00
Penatron R/M-3003	4 gal	88	188.00	4,760.00
UPM High Performance Cold Mix	1 ton	1880	65.00 to 80.00	140.00 to 180.00
AMZ/Rosco	1 ton	varies	35.00 to 60.00[3]	70.00 to 110.00

[1] 1 lb = 0.454 kg, 1 gal = 3.785 L, 1 yd^3 = 0.765 m^3.

[2] The cost does not include the cost of the bonding agent. Due to the small number of spalls being repaired at one time using this material, a significant amount of waste was encountered. The cost of the epoxy bonding agent used was $49 per gal ($13 per L) and the cost of the methacrylate bonding agent was $110 per gal ($29 per L).

[3] The cost of the spray-injection bituminous patching material represents averages provided by the manufacturers. These costs include the cost of purchasing the equipment (amortized over the life expectancy of the equipment), maintenance, binder, aggregate, and other variable costs.

been completed, the concrete saw is not needed again. It is much easier with this method to remove any additional unsound concrete found after the initial removal. The chisel also leaves a rough vertical edge, thus providing more bonding area for the replacement material. If a light jackhammer is used around the periphery of the patch, the spalling can be controlled. The chip-and-patch procedure also does not leave saw overcuts, which may be a plane of weakness or require sealing. Therefore, including the time required to saw and dry the patching area, resaw, and seal the overcuts, this method may take less time than the more rigorous saw-and-patch method. Unfortunately, because of confounding factors, the analysis of productivity could not determine which of these two procedures is actually faster.

The main objections to the chip-and-patch method are the fact that damage to the remaining concrete can occur when heavy pneumatic hammers are used and that the patch edges may be feather-edged. The transmission of destructive forces may be reduced by allowing a heavy pneumatic hammer only at the center of the area to be removed. A light pneumatic hammer should be used around the edges. Also, the work should progress from the inside of the patch toward the edges and the chisel point should be directed toward the inside of the patch. Feather-edging of the patch edges can be minimized by requiring a minimum 1-in (25-mm) vertical face on all sides. It was also felt that to achieve proper bond, sandblasting is required.

Mill-and-Patch Procedure

The milling machine is very efficient in removing large areas of spalled concrete. With a milling head of 1 ft (0.3 m), the smallest currently available for this use, the repair area will be a minimum of 1.0 ft^2 (0.09 m^2). Therefore, if the area to be repaired is small, the patch may be larger than necessary. The exposed bottom surface of the concrete created by milling is very rough and very level, as shown in figure 13. The hole created by the operation will tend to be concave, rather than vertical, at the boundaries that are perpendicular to the direction of the milling. The milling operation also caused spalling on the edges of the adjacent pavement. The removed concrete becomes a fine slurry that is easy to wash away. The size of the machine and the location of the milling head in relation to the rest of the equipment affects the efficiency of the removal operation.

The orientation of the concave edges was parallel to the direction of traffic where possible. However, because of traffic constraints, the equipment was not always able to maneuver into such an orientation. It may be desirable in such cases to chisel the edges to form a vertical face. This was done on all but one test section in Arizona. Cementitious materials, in particular, may not perform well when feather-edged.

Milling machines are generally readily available in most regions of the United States. However, a suitable machine, at a reasonable cost, could not be located in Utah. The cost of renting a milling machine, including an operator, may vary from $250 per day to $200 per hour. A Caterpillar PR-105 pavement profiler was used in Arizona and a Barcomill 100 milling machine was used in Pennsylvania.

Six to ten teeth were replaced daily in Pennsylvania. In Arizona, 31 teeth were replaced the first day, 13 the second day, and 6 the third day. An average rate of 25 ft^2 (2.3 m^2) per hour was achieved at both test sites. This rate includes the time to travel to each spall repair location and orientation of the machine. The rate was significantly greater when the repair areas were larger and located away from the adjacent lane of traffic. The rate does not

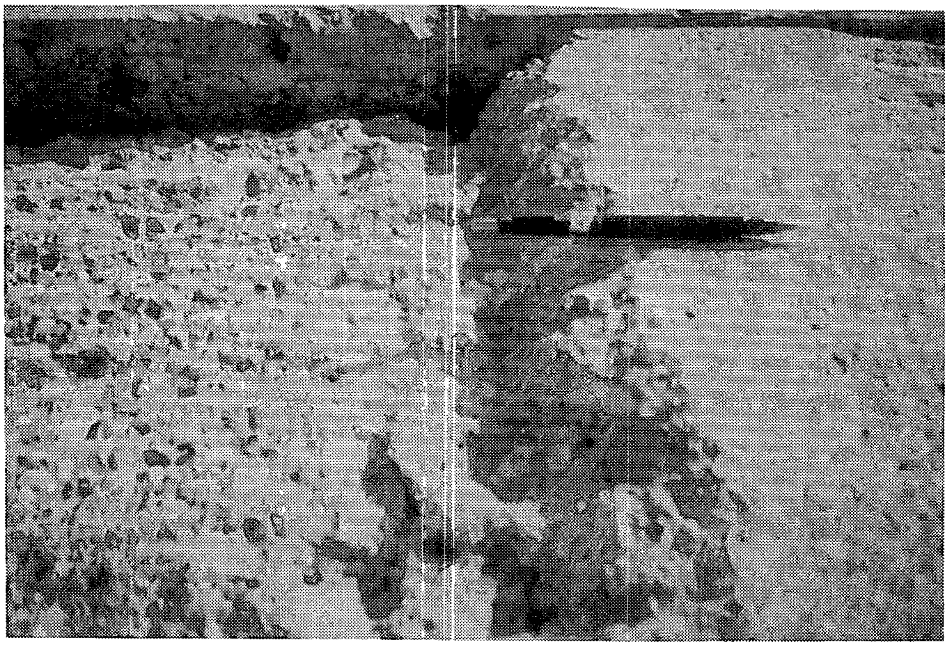


Figure 13. Patch bottom after milling

include the time to straighten the concave edges left by milling. The machine used at both test sites seemed more suited for milling asphalt. More powerful equipment may be more efficient for milling concrete. Less spalling of the adjacent pavement may also result from using a more powerful machine.

Waterblast-and-Patch Procedure

The use of a high-pressure water jet (30,000 psi [207,000 kPa]) to remove the deteriorated concrete was attempted at the test sites in Arizona and Utah. The main advantage of using a high-pressure water jet is that once the jet nozzle speed and pressure are adjusted, only the weak concrete is removed. The operation also can be done with as few as two people. Another advantage may be the finished condition of the exposed faces of the repair hole. The bottom and sides of the finished area are extremely rough and angular, providing more surface area to which the new replacement material may bond, as shown in figure 14. A disadvantage may be that the finished surfaces are saturated, which may limit possible replacement materials to those that require a wet bonding surface. Otherwise, time is required to allow the area to become dry. Another concern is that the fine slurry laitance left by the removal process requires careful attention in the sandblasting phase of the patching operation.

The waterblasters were originally expected to remove the concrete at a rate of 60 ft^2 (5.4 m^2) per hour; however, problems with equipment at both locations brought this rate down significantly. In Utah, it took 3 days of in-the-field diagnostic work before the operator could get the Jet to work properly. Once the equipment was operational, a production rate of 10 ft^2 to 15 ft^2 (0.9 m^2 to 1.4 m^2) per hour was achieved. A significant amount of time was needed to orient the nozzle at each patch location. The waterblaster broke the concrete down to fine and coarse aggregate and this aggregate was ejected out of the hole. A protective shield was constructed around the area under repair to avoid damage to ongoing traffic. The cost of renting the equipment was $10,000 per month.

In Arizona, the first working day was spent trying to get the waterblasting equipment operational, without success. The subcontractor spent the next day "fixing" the waterblaster. The following working day, another 1.5 hours were spent in the field adjusting the water jet nozzle speed and pressure. When the equipment was working, it was difficult to control the depth of removal. After removing the deteriorated concrete at five spall locations, the equipment again broke down. At the time, a production rate of 7 ft^2 to 8 ft^2 (0.6 m^2 to 0.7 m^2) per hour was being achieved. It was speculated that the aggregate in the original pavement was a very tough granite and was therefore requiring extra demolition time. The cost of subcontracting this work was $4,352 per day, not including mobilization and transportation costs.

Adverse-Condition Patching

When patching under adverse conditions and using a cementitious material, it is very unlikely that a wet saw can be used to reestablish the joint. It will therefore be very difficult to install the joint bond-breaker to the proper depth, slightly below the depth of removal. In cold weather, hot water and insulating blankets are also required. At the adverse-condition test site, a heated water tank was not available. Although the water tank was insulated, it was very difficult to maintain the warm temperature of the water. Insulating blankets also were difficult to keep in place because of wind gusts created by passing trucks in the adjacent lane.

It should also be noted that in one test section involving the installation of UPM, the repair hole was not wetted prior to placement of the material, because no water was available at the job site that morning. Only hand tools were to be used to remove the loose concrete, but only the very loose material was removable with hand tools. Therefore, a small jackhammer was used to remove all of the deteriorated material.

Joint Preparation

Reestablishing the joint with a partial-depth saw cut and removing any point of mechanical conflict is considered critical to the performance of the new patch. If this saw cut is not deep enough or wide enough, inserting the joint bond-breaker is difficult. It was suggested that

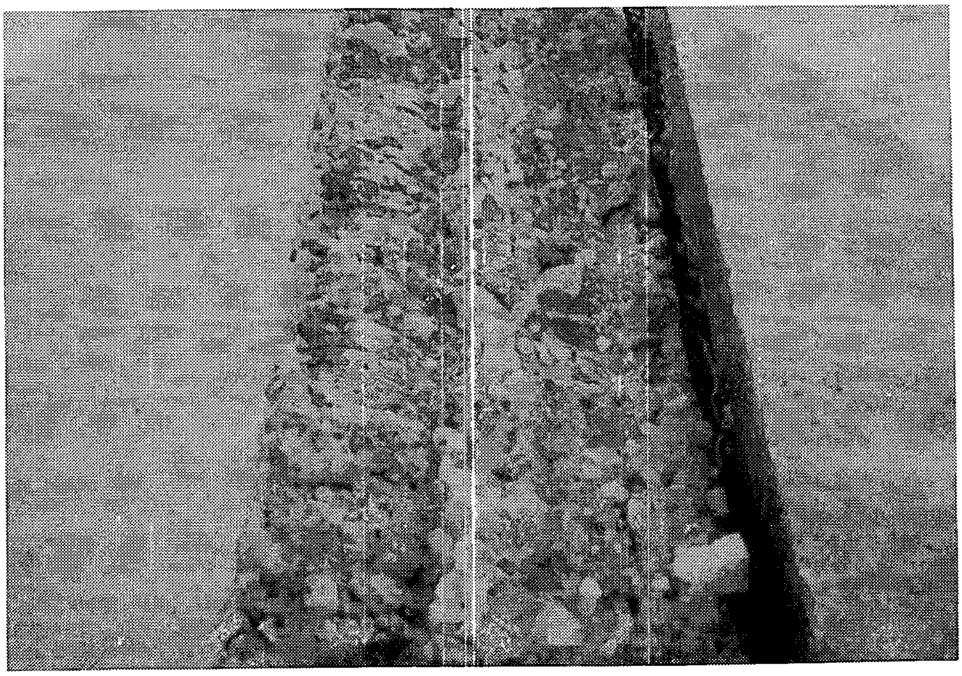


Figure 14. Patch bottom after waterblasting

latex sealant be used to caulk any irregularities or openings between the backer board and the joint. This proved to be extremely difficult and time consuming. Often, the sawed joint was not located directly over the working crack. The performance of patches installed in that situation is highly questionable. On back-to-back repairs at a joint, maintaining the alignment of the backer board is difficult. Stiffer boards may be required for such repairs.

Type III PCC

Type III PCC is the most commonly used rapid-setting cementitious patching material; therefore, the maintenance and construction crews are familiar with the placing, compacting, finishing, and curing techniques necessary to install this product. To achieve the high, early strength desired for this project, many admixtures were incorporated into the mix design. The addition of these admixtures in the proper quantities, in proper sequence, and at the proper time required much attention. The mix was workable at the two test sites where air temperatures at the time of placement were below 80°F (27°C). However, it was stiff and difficult to work with at higher temperatures.

Duracal

Of the products being evaluated, Duracal is most like "regular" concrete to handle. The proportioning, mixing, placing, and finishing of this product were very easy to accomplish. The product is self-leveling and does not require mechanical vibration or a curing compound under normal conditions. Although a bonding agent was not applied before placement of Duracal, the manufacturer suggests that a bonding agent be used on shallow patches. Feather-edging is not recommended. This product is more tolerant of higher ambient air temperatures than the other cementitious products that were evaluated.

Five Star HP

The Five Star HP concrete looks very dry during most of the mixing cycle and appears wet only during the last few minutes of mixing. The temptation to add water must be resisted, as the strength is adversely affected by the addition of water. The concrete is fairly self-leveling and only requires compaction by trowel. The product is temperature-sensitive and will set up quickly at temperatures above 80°F (27°C). A chemical retarding additive is available to lengthen the working time if patching is done in hot weather. One tube of Summerset per bag of material is added during mixing to gain an additional 5 minutes of working time. Summerset was used in South Carolina and Pennsylvania. One major drawback to this product is the requirement for wet curing the material for 30 minutes after placement. This is difficult to ensure and oversee in a moving operation. It is also difficult to determine exactly when the material has set sufficiently to start wetting the surface.

Set-45

Set-45 is very sensitive to ambient air temperatures. When the air temperature is below 80°F (27°C), the working time for the product is approximately 10 minutes and the product is easily placed and finished. However, when the air temperature is above 80°F (27°C), the working time for the product is much less. At the South Carolina, Arizona, and Pennsylvania test sites, the product set in the wheelbarrow or in the patch before it could be compacted. Though the use of ice water to slow the initial set was recommended, and used in South Carolina, it was often impractical to do so. For this reason, Set-45 is available in a "hot weather" formula. It should be noted that the substrate must be dry and that the product should not be used to repair pavement constructed with limestone aggregate. The presence of limestone aggregate can be checked by wetting the freshly exposed concrete face with vinegar. If bubbles appear, the pavement contains limestone aggregate. Set-45 also emits a peculiar, although not harmful, odor.

Pyrament 505

Pyrament 505 was easy to mix, place, and finish when placed under normal conditions during the project (an ambient air temperature above 40°F [4°C]). It behaved very much like regular concrete. This product takes more time for mixing than the other cementitious products being evaluated (except the Type III PCC mix) and appears dry until the last few minutes of the mix cycle. It was less workable under adverse conditions, which are defined in this project as an ambient air temperature below 40°F [4°C] and a repair area saturated with surface moisture. Without hot water and insulating blankets, the material will not set in the time stated. For small maintenance operations, such as the project at the Pennsylvania test site, it may be difficult to keep the water sufficiently hot for the time required for patch preparation. The product's workability under high air temperatures was not evaluated, as it was not installed under this condition.

SikaPronto 11

When properly mixed and under normal conditions during the experiment (40° to 90°F [4° to 32°C), SikaPronto 11 was easy to work with and finished very easily. Even under higher air temperatures (> 90°F [32°C]), the SikaPronto 11 concrete retained its workability. However, the primer required for its placement, SikaPronto 19, gelled very rapidly at these high temperatures and became difficult to apply to the patch substrate. The manufacturer recommended that the product be installed in lifts because of the heat of hydration of this product. However, time and construction constraints made it impractical to do this. No adverse effects have been noted to date from this method of placement.

A major concern with this product may be its toxicity. In particular, masks are recommended to avoid breathing the fumes. However, during mixing and placement, the material looked and finished very much like regular concrete; because of this similarity to a nontoxic repair material, workers may tend to disregard the face mask recommendation.

At three of the four test sites, product representation for SikaPronto 11 was very poor. The local manufacturer's representatives were either not available or not very knowledgeable about the product and its installation. Because its mixing and use are different from normal concretes, it may be difficult to get this product to perform properly.

Percol FL

Use of polyurethanes for pavement patching is fairly new to most maintenance and construction workers. With the proper equipment, the procedure to install the material is simple. The required equipment, the PERCAT 500, may be purchased for $10,000 or rented for $750 per month. A qualified technician is required to adjust the pumps for proper mixing of the two component resins prior to dispensing Percol FL. Once the pumps have been adjusted, the machine is easy to operate. A Percol Polymerics Inc. representative was available at the four test sites to personally operate and adjust the equipment (which took considerable time at some locations). It is also critical that clean, oven-dried aggregate be used with this product; even a small amount of dust or moisture may cause poor bonding or bubbling.

Properly filling the repair hole to grade with the 0.75-in (19-mm) aggregate is critical to achieving a smooth-riding patch. If the hole is overfilled, the resultant patch is very rough. If the hole is underfilled, additional resin will be required, and the cost of the repair will be increased. The product sets very rapidly. If a friction aggregate is to be broadcast over the repair area, it must be done within the critical time period. This critical time period is very short at high ambient air temperatures. At the Arizona and Pennsylvania test sites, to achieve a smoother finish, the repair area was not filled flush with the resin but was underfilled approximately 0.25 in (6 mm). When the resin started to react, the repair area was sprayed with a very fine mist of the resin and the friction aggregate was broadcast. The repairs in Utah and South Carolina are rough and have an uneven finish.

It should be noted that Percol FL has a very low viscosity and is therefore difficult to place on pavements with slopes and grades. A qualified, experienced technician may be able to produce a smooth patch by adjusting the dispensing rate. However, even though they were placed by the manufacturer's representative, many of the patches installed on a grade in this experiment are not level.

A major advantage of this product is its rapid setting time. If Percol FL can be applied to shallow, rapidly cleaned (non-sandblasted) patches, repairs may be performed using a moving traffic control operation.

The disposal of the unused portion of this product may be of concern in certain states.

MC-64

The use of epoxies for pavement patching is unfamiliar to most maintenance and construction workers. As with most epoxies, proportioning and mixing is critical to the performance of MC-64. The manufacturer's representative very carefully ensured that the materials were mixed properly. Using two to three Jiffy mixers at a time is essential for an efficient operation. Each mixer requires one operator, as well as an additional operator to pour part B into part A and clock the mixing time. Part B must always be added to part A, and if using only one mixer, part B must be mixed first. The mixing paddles must not be interchanged, as this may cause the product to set prematurely. The finishing technique for this material is also very different from commonly used techniques and must be carefully observed. An asphalt-impregnated board is used in a repeated up-and-down stroke to work the resin to the surface, as well as to move the material. Both the mixing and finishing required many personnel and much time. An advantage of this product is that very little equipment is required; therefore, mobilization time and cost are minimized. Another advantage is that because the component parts are premeasured, material properties are less variable.

Users should note that this product has a very low viscosity at high temperatures and may require special care in placing it on pavements with slopes and grades when patching in hot weather. The product must be worked against the grade repeatedly until it has set. The disposal of the unused portion of this product may be of concern in certain states.

Penatron R/M-3003

The mixing and placing of Penatron R/M-3003 was relatively easy. However, care was required during mixing because of the requirement that agitation of component A must be ongoing during the addition of component B. Placement of the correct gradation and amount of aggregate in the repair home result in a smooth patch as well as optimal use of materials, thereby reducing cost. As with the epoxy and polyurethane materials, this product has a very low viscosity and is difficult to place on pavements with slopes and grades. The disposal of the unused portion of this product may be of concern in certain states.

UPM High Performance Cold Mix

The placement of the bituminous cold mix is very simple. The only advice on the installation procedure is to leave the patch slightly high (0.125 in to 0.25 in [3 mm to 6 mm]) to allow for additional compaction from traffic.

AMZ/Rosco

The placement of this spray-injection bituminous material is very simple; however, an experienced operator is needed to control the flow of the aggregate and asphalt to the nozzle because these variables are not preset. There is also a significant amount of overspraying, making the patch appear larger than it is and resulting in a rough patch.

Test Site Conditions

Although the test sites were carefully screened for their suitability to the demands of the H-106 project, unexpected pavement conditions were encountered at the Pennsylvania site. Ideally, only spalls that measure less than one-third the pavement thickness in depth are suitable for partial-depth repairs. However, the depth of the deterioration below the spalled area is difficult to determine prior to actually repairing the spall. At the Pennsylvania test site, joint deterioration often was more severe than the surface visual inspection indicated.

Many of the spalled areas were deteriorated to the depth of the dowel bars and below. Because of time constraints and the unavailability of proper equipment to perform full-depth repairs, partial-depth repairs were installed and will be evaluated as a part of this project.

At the Arizona test site, a majority of the work was performed at night. Although floodlights were used, the relative darkness made it difficult to visually determine if the area of deterioration at each repair location had been completely removed and if the repair area was sufficiently clean. Noise from the high traffic volume muted the effectiveness of sounding the pavement.

3

Material Testing

In addition to the data collected during the installation of the experimental patches, the H-106 project also included a series of laboratory tests on the materials used in the project. The laboratory testing was an attempt to define pertinent material characteristics that could be related to the performance of the materials in the field. Once these characteristics were identified, the next step would be to formulate sample specifications regarding the materials, mixing, and placement of rapid-setting, partial-depth spall repair materials that would take advantage of characteristics indicative of good performance while avoiding characteristics indicative of poor performance.

Laboratory Tests Performed

The tests performed on the rapid-setting, partial-depth spall repair materials were intended to characterize the physical properties of the materials. Appropriate tests were run on the various materials according to their classification as cementitious, polymer, or bituminous. However, since the life of the individual spall repairs often is longer than the duration of this project, the ability of this experiment to determine performance-related specifications and to predict spall repair life is limited. Continued monitoring of patches will provide the additional field performance data needed to establish correlations between laboratory data and field performance.

All materials were prepared and cured in the laboratory according to the manufacturers' recommendations. If a product could be extended with aggregate, the maximum percentage recommended by the manufacturer was used to extend the material. All materials for the laboratory evaluation were sampled from the materials being used at one of the test sites. Manufacturers were requested to ship materials to all of the test sites from one manufacturing lot or one day's production to reduce overall material variability. Aggregate for each of the materials also came from a single source and this aggregate was used in making the laboratory specimens.

The tests and test procedures used for the cementitious or polymeric patching materials include the following:

- "Compressive Strength of Hydraulic Cement Mortars," ASTM C 109 and "Compressive Strength of Cylindrical Concrete Specimens," ASTM C 39
- "Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM C 469
- "Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," ASTM C 78
- Bond Strength of Epoxy-Resin Systems Used with Concrete," ASTM C 882 and CALTRANS' "Method of Test of Bonding Strength of Concrete Overlay and Patching Materials to PCC"
- "Resistance of Concrete to Rapid Freezing and Thawing," ASTM C 666A
- "Scaling Resistance of Concrete Surfaces Exposed to Deicing Chemicals," ASTM C 672
- "Method for Determining the Surface Abrasion Resistance of Concrete Specimens," CALTRANS' California Test 550
- "Length Change of Hardened Cement Mortar and Concrete," ASTM C 157
- "Thermal Compatibility between Concrete and an Epoxy-Resin Overlay," ASTM C 884

Laboratory evaluation for the bituminous patching materials included the following:

- Resilient Modulus: ASTM D 4123
- Marshall Stability: ASTM D 1559
- Antistripping: ASTM D 1664
- Workability: Pennsylvania Transportation Institute method
- Extraction: ASTM D 2172
- Sieve Analysis: ASTM C 136

Laboratory Testing Results

Compressive strength often is used for specifying and evaluating cementitious spall repair materials. For rapid repairs, early strength gain is of interest. Figure 15 shows the strength-gain curves for the spall repair materials that were tested. It is interesting to see that materials with the highest early strengths are not necessarily those with the highest ultimate strength. The unusual strength-gain curve for Set-45 cannot be explained at this time. Based on Least Square Difference T test and a confidence level of 95 percent, at 2 hours, Set-45 is significantly stronger than the other materials and Percol FL and Type III PCC are significantly weaker than the others. However, at 28 days, Type III PCC is significantly stronger than all other materials, with Pyrament 505 having the next highest compressive strength. MC-64 and Percol FL are significantly lower in compressive strength than all other materials at 28 days. Set-45, Five Star HP, and Duracal are not significantly different in terms of compressive strength at 28 days.

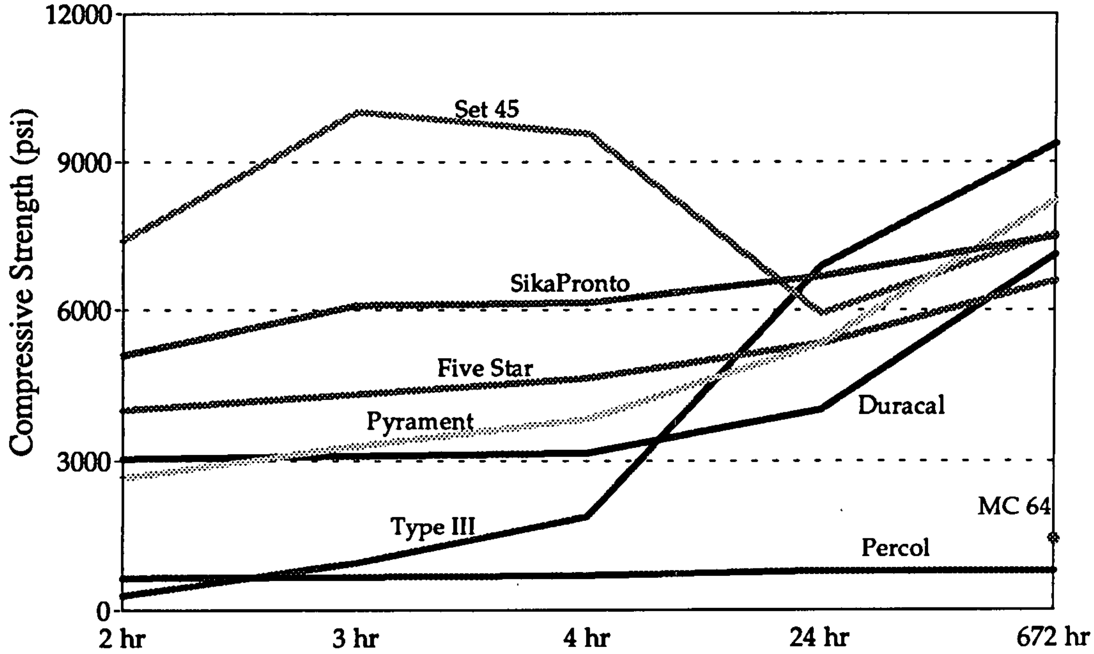


Figure 15. Compressive strength of spall repair materials

Bond strength is thought to be an important factor in determining field performance. The bond strength of the spall repair materials is shown in figures 16 and 17. It is interesting to note that, in general, the bond strength of the materials that are specified to be installed wet decreases when tested using a dry substrate, and materials that are specified to be installed dry lose bond strength when tested using a wet substrate. Several exceptions to that statement should be noted. Percol FL, whose manufacturer claims that the material is moisture tolerant, loses strength significantly when applied to a wet substrate. Also, Five Star HP and Pyrament 505 manufacturers recommend that their materials be applied to a saturated, surface dry (SSD) surface. The slant-shear and center-point bond strength tests indicate that the bond strength is weaker when applied to a wet substrate. It can also be seen that some materials are more tolerant of changed conditions than others.

A partial listing of the results of the tests for the cementitious and polymeric materials is given in table 11. Table 12 gives the results of the tests on the bituminous materials when tested using a wet substrate. Complete details of the material testing results are presented in appendix C.

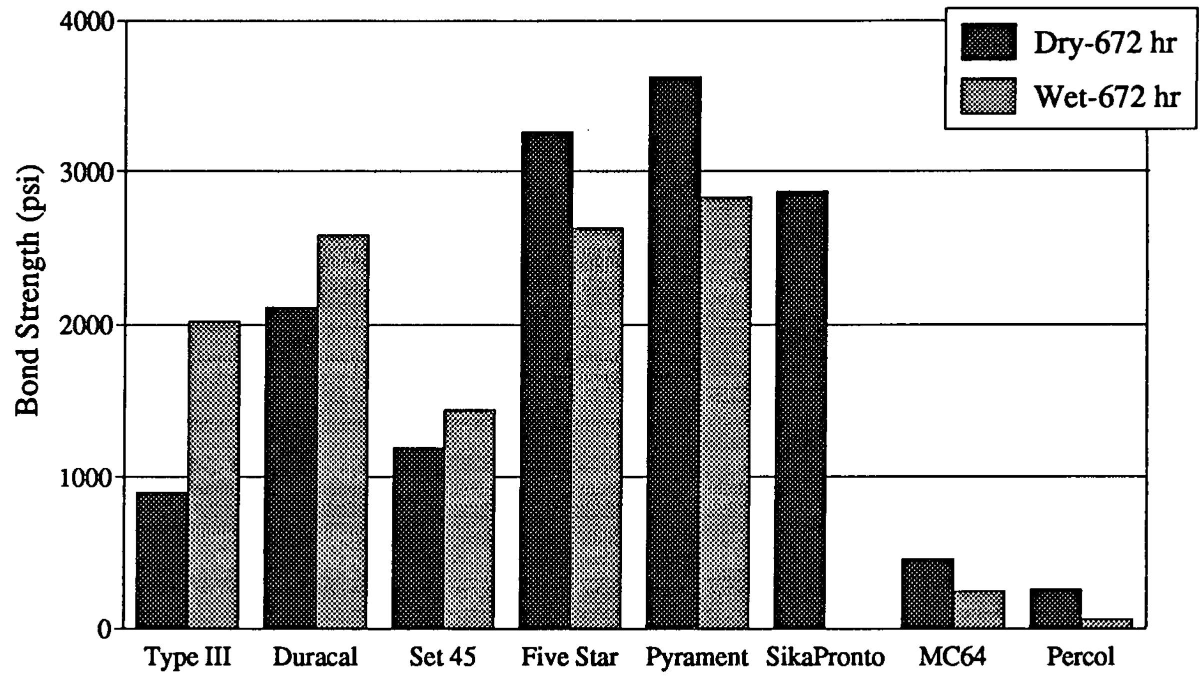


Figure 16. Slant-shear bond strength of spall repair materials

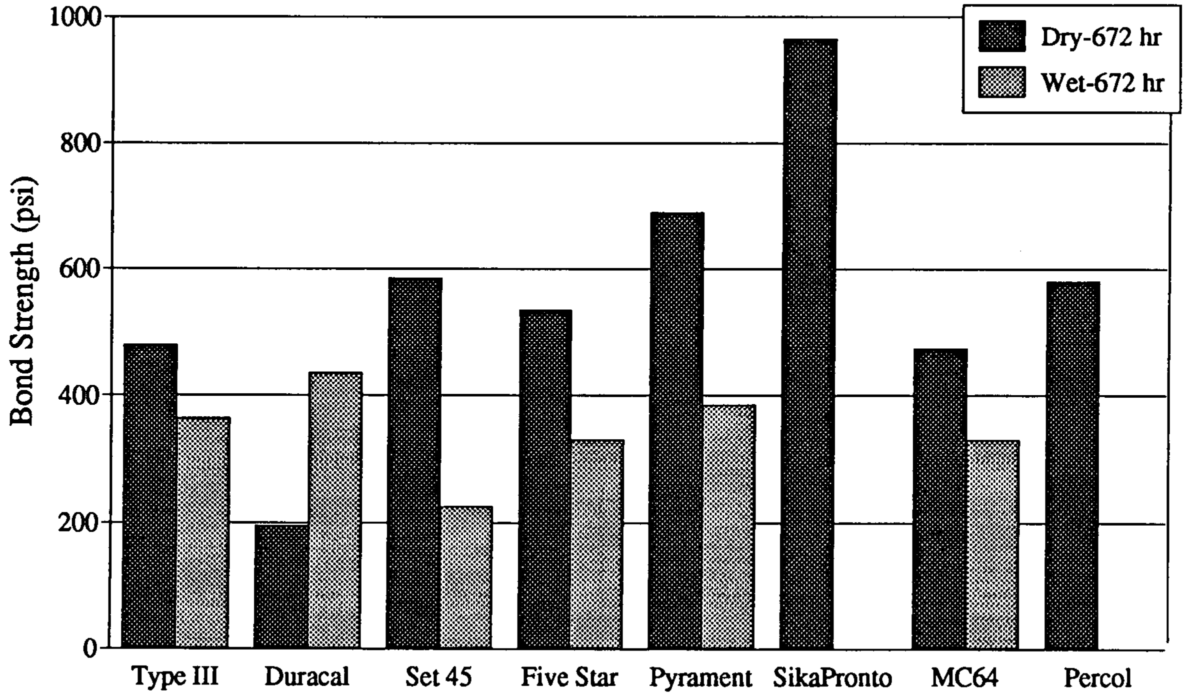


Figure 17. Center-point bond strength of spall repair materials

Table 11. Summary of laboratory test results of cementitious and polymer materials

Material	Modulus of Elasticity (10^6 psi)	Poisson's Ratio	Modulus of Rupture 28 day (psi)	Freeze Thaw Weight Change (g)	Durability Factor	Abrasion Loss (g)	Scaling 100 cycles
Type III	6.95	0.17	1160	-12.3	101.3	18.7	4
Duracal	5.6	0.25	655	-39.4	43	19.8	4
Set-45	6.7	0.2	495	-36	24.9	23.7	5
Five Star	5.6	0.17	675	a	10.1	19.5	3
Pyrament	7.2	0.16	1230	-5.6	124.9	25.5	4
SikaPronto	3.45	0.3	2200	3.5	76.3	12.7	0
MC-64	b	b	b	61.7	96.2	-0.8	0
Percol FL	b	b	b	56.9	57.1	0	0

a Sample was too badly deteriorated to make measurement. b Test is not appropriate. 1 psi =6.89 kPa.

Table 12. Summary of laboratory test results of bituminous materials

Test	Standard		UPM	AMZ
Resilient Modulus	ASTM D 4123	77°F, 0.33 Hz (ksi)	290	
		77°F, 0.50 Hz (ksi)	281	
		77°F, 1.00 Hz (ksi)	292	
Marshall Stability	ASTM D 1559	Stability (lb)	5080	4818
		Flow (0.01 in)	9.7	17.1
Bulk Spec. Grav.	ASTM D 2726		2.26	2.15
Max. Spec. Grav.	ASTM D 2041		2.54	2.45
Air Voids		(percent)	10.9	12.17
Anti Stripping	ASTM D 1664	[Modified] (percent)	+95	
Workability	PTI Method	Ambient Temp.	0.5	
Extraction (percent passing)	ASTM D 2172 ASTM D 136	D_{50}		
		A.C. (percent)	3.5	4.0
Viscosity	ASTM D 2171	140°F (poise)	640	4904
Penetration	ASTM D 5	77°F, 100 g, 5 sec. (dmm)	196	68
Ductility	ASTM D 113	77°F, 5 cm/min (cm)	+150	
Softening Point	ASTM D 36	(°F)	109	128

°C = (°F - 32) × 5 / 9, 1 psi = 6.89 kPa, 1 lb = 0.455 kg.

4

Field Performance

A great deal of data were collected during evaluations of the four test sites to monitor the development of distresses and the occurrence of patch failure. Distresses characteristic of cementitious and polymer patches and of bituminous patches were observed and recorded. These distresses were rated according to the portion of the patch experiencing the distress and the severity of the distress. Individual distress ratings were combined into an overall patch rating intended to reflect the overall performance of the patch. This chapter presents summary performance data; more detailed performance data are presented in appendix D.

Performance Data Collection

Once the patches were placed, they were monitored periodically to assess performance. Five evaluations were conducted, roughly at 1 month, 3 months, 6 months, 12 months, and 18 months from the date of installation, as shown in table 13. The evaluations mainly entailed a visual evaluation of the patches. For the rating system to accurately assess the condition of a patch, the distress type and the severity and density of the distress were recorded. The cementitious and polymer patch distresses and observations include:

- Spalling
- Cracking
- Wearing
- Oxidizing
- Edge fraying
- Patch-adjacent deterioration
- Pavement corner cracking
- Joint sealant condition
- Faulting
- Patch debonding

Table 13. Spall repair site evaluation schedule

Test Site	Evaluation Number					
	1	2	3	4	5	6
PA (adverse)	3-11-91	4-22-91	7-15-91	10-28-91	3-23-92	6-15-92
PA (normal)	6-91 & 7-91	8-5-91	10-28-91	3-9-92	6-15-92	10-6-92
SC	5-91	7-9-91	9-9-91	1-14-92	5-4-92	9-21-92
AZ	6-91	7-13-91	9-2-91	1-25-92	6-6-92	10-16-92
UT	4-91	5-3-91	8-26-91	3-18-92	7-8-92	9-29-92

The bituminous patch distresses and observations include:

- Dishing
- Raveling
- Shoving
- Cracking
- Bleeding
- Edge disintegration
- Missing patch

Each cementitious and polymer patch was sounded using a 1.5 lb to 2 lb (0.68 kg to 0.91 kg) steel hammer to determine whether debonding had occurred. The percentage of area debonded was recorded to the nearest 10 percent. Distress definitions are in appendix D.

An initial inspection was performed within 3 days of patch installation at each site to record the development of drying shrinkage cracks, and any construction-related failures. The data presented in this report represent distresses that were recorded during the initial inspection or any one of the five evaluations that followed (through the eighteenth month of patch life).

At the time of the evaluations, the distress types and their severity and density were observed and recorded in terms of lengths and widths or an estimate of the percentage of the distressed portion of each patch. The percentage of the patch area or perimeter affected by each distress and the severity levels were used to determine a distress rating. A rating scale of 0 to 10 was used, with "10" for "excellent" and "0" for "failed." Details of the rating scheme are in appendix D.

The individual distress ratings were combined to determine an overall patch rating. The rating system developed provides a repeatable method for rating the condition of each patch. The rating scale assists in the evaluation of the comparative performance and cost-effectiveness of the materials and procedures. Overall, distress development and failure have been low, and only 2.3 percent of the patches not lost in rehabilitation during the project have failed (37 of 1,607).

Summary of Performance Data

The percentage of failed patches is shown in figures 18 through 20, grouped by site, material, and procedure, respectively. It is important to note that these charts cannot be used to rank patch performance. The statistical analysis detailed in chapter 5 presents statistically significant differences among the materials and procedures.

Conceptually, a patch is considered failed if it can no longer service traffic safely. At this time, failure is determined subjectively. An unusually high number of patches, 22 out of 467 patches (4.7 percent), have failed at the Pennsylvania test site. The percentage of patch failure in Arizona, South Carolina, and Utah is 2.1 percent (8 of 380 patches), 2.2 percent (7 of 319 patches), and 0 percent (none of 441 patches), respectively.

Pyrament 505 showed the highest percentage of patch failure at 11.4 percent (some patches were placed under adverse conditions), followed by Percol FL at 5 percent (some patches were placed under adverse conditions), Set-45 at 4.3 percent, Five Star HP at 2.6 percent, and Type III PCC at 1.2 percent. The remaining materials, Duracal, MC-64, SikaPronto 11, Penatron R/M-3003, UPM High Performance Cold Mix (some patches were placed under adverse conditions), and spray-injection mix (e.g., AMZ, Rosco), did not experience patch failures at any of the sites.

Of the concrete-removal procedures, the adverse-condition clean-and-patch procedure, not surprisingly, showed the highest percentage of patch failure at 17.9 percent. The procedures conducted under normal conditions experienced percentage patch failure rates as follows: mill and patch at 3.6 percent, saw and patch at 2.1 percent, and chip and patch at 1.9 percent. Neither the waterblast-and-patch procedure nor the normal-condition clean-and-patch procedure showed any failures.

Figure 21 shows a graphical comparison, for all sites, of the average overall patch ratings for the bituminous materials by treatment (i.e., by material-procedure combination). Figures 22 through 25 show a graphical comparison, within each site, of the average overall patch ratings for the cementitious and polymer materials by treatment (i.e., by material-procedure combination). In these figures, "S&P" stands for the saw-and-patch procedure, "CH&P" for the chip-and-patch procedure, "M&P" for the mill-and-patch procedure, "W&P" for the waterblast-and-patch procedure, "AC&P" for the adverse-condition clean-and-patch procedure, and "NC&P" for the normal-condition clean-and-patch procedure. Summary numeric tables of the average distress ratings and overall patch ratings are shown in appendix D. Significant differences among materials, procedures, and treatments are analyzed in chapter 5.

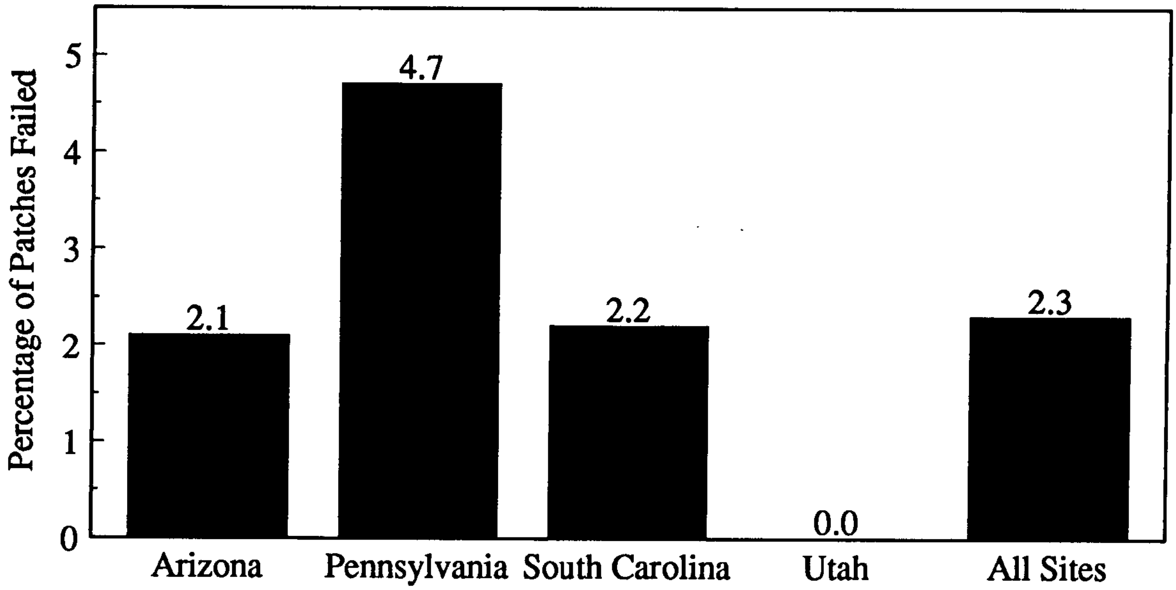


Figure 18. Percentage of patches failed by site

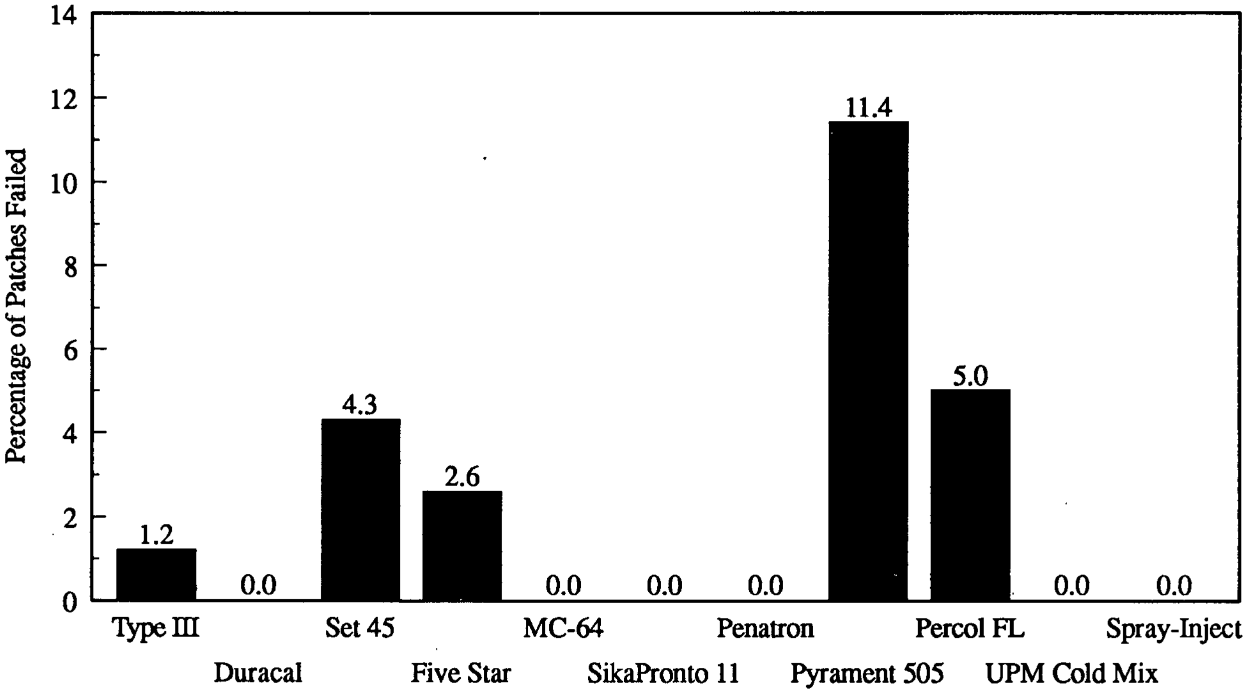


Figure 19. Percentage of patches failed by material

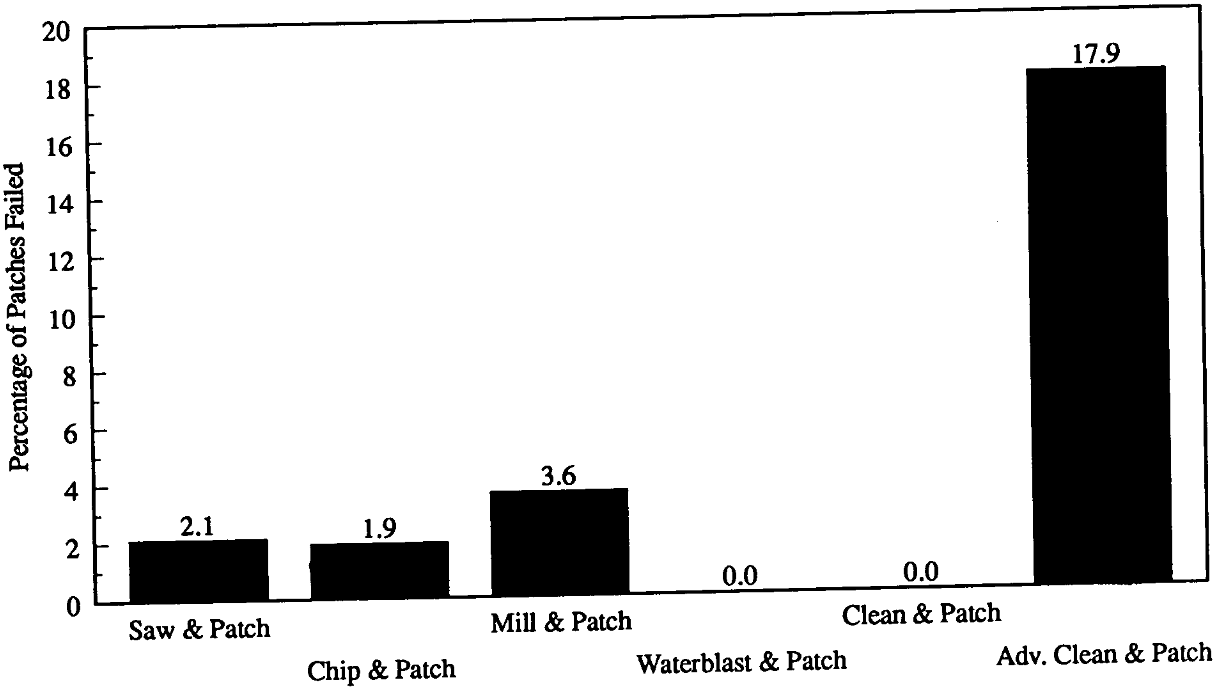


Figure 20. Percentage of patches failed by concrete-removal procedure

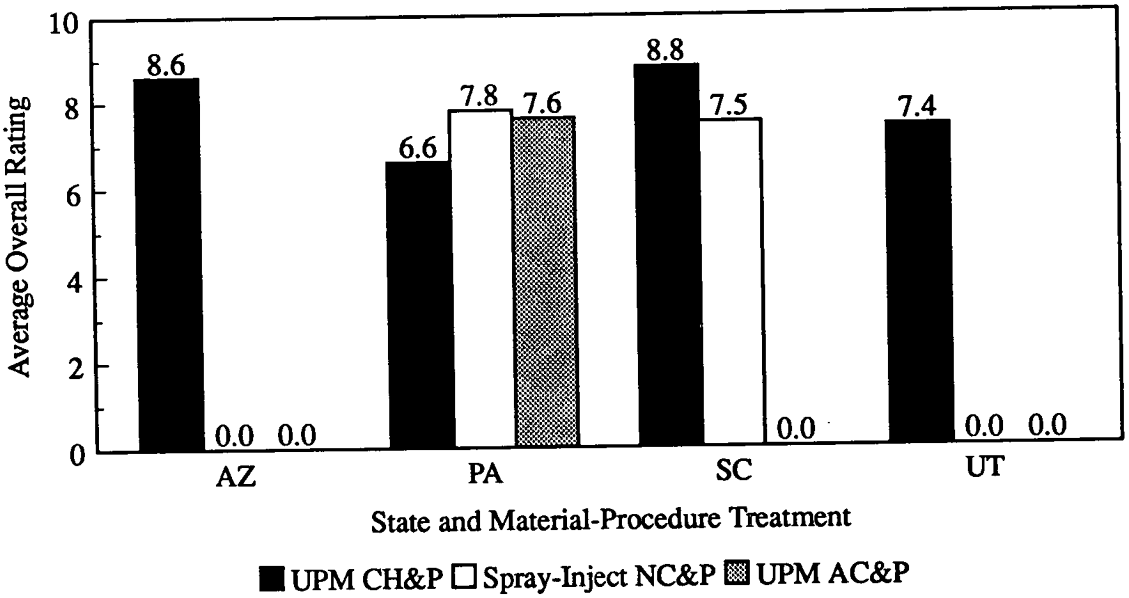


Figure 21. Average overall rating by state and material-procedure treatment for bituminous materials

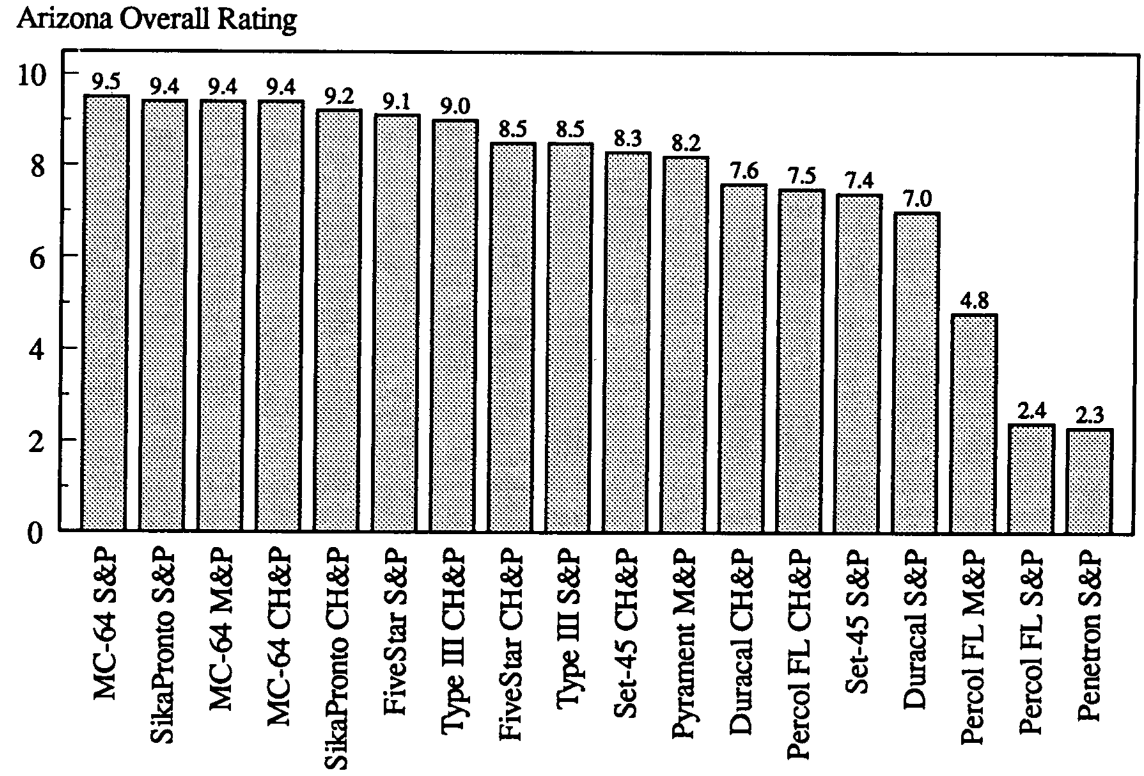


Figure 22. Arizona's average overall ratings by material-procedure treatment for cementitious and polymer materials

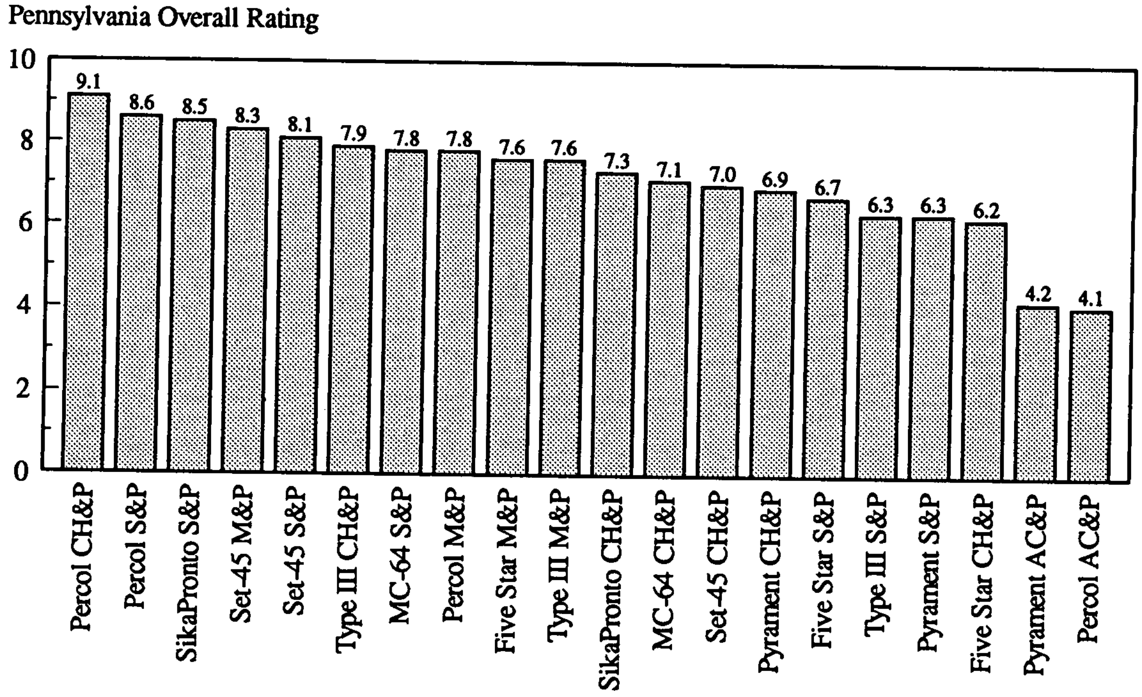


Figure 23. Pennsylvania's average overall ratings by material-procedure treatment for cementitious and polymer materials

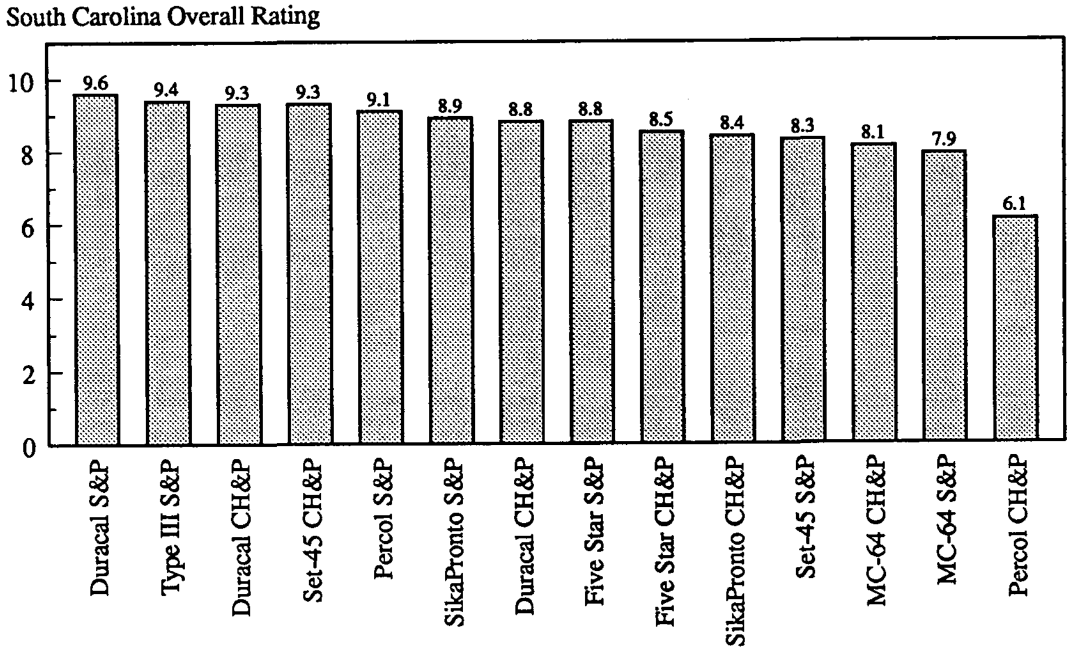


Figure 24. South Carolina's average overall ratings by material-procedure treatment for cementitious and polymer materials

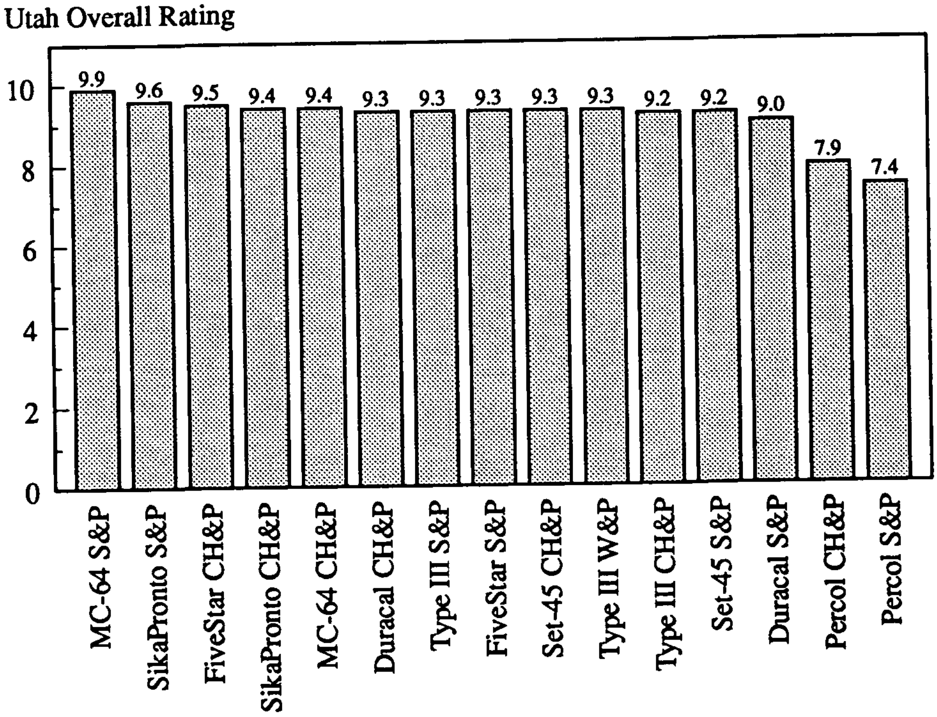


Figure 25. Utah's average overall ratings by material-procedure treatment for cementitious and polymer materials

5

Analysis

This project has attempted to determine the optimum combination of repair material and patching procedure for the effective repair of partial-depth spalls in jointed concrete pavements. Toward this end, an approach for the collection and analysis of data was determined during the early stages of the project.[2] The primary factor used to define "optimum" is the cost-effectiveness of the operations. Cost-effectiveness is a function of several factors, including the productivity of the repair crew; the performance of the repairs; the cost of the labor, materials, and equipment required to perform the repairs; and the number and volume of patches to be placed. This chapter presents the statistical methodology used to analyze the data, as well as a discussion of the analysis of field performance, laboratory-performance correlations, productivity, and cost-effectiveness.

Statistical Methodology

This section provides a basic description of the statistical approaches and models that were 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 that the input data be in ASCII format. SAS command files were created to read in the input data, perform the analysis, and produce the final output.

Multivariate Analysis of Variance

To compare distress and overall ratings for each of the material-procedure treatments, a multivariate analysis of variance (MANOVA) of the data was performed using the SAS GLM procedure. This procedure used the mean values and associated variability for each rating and identified whether there were any statistically significant differences ($\alpha = 0.05$) between the means of the ratings of the different repair types.

Tukey Analysis

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

Each Tukey analysis resulted in a series of ordered mean values of ratings for the various repair types that were analyzed. The list below shows a sample of the mean values and Tukey groupings for a distress rating:

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 groups of repair types determined by the Tukey analysis to have no significant differences between their mean values ($\alpha = 0.05$). For example, no statistically significant differences exist between the means for the repair types in the "A" group. Likewise, no statistically significant differences exist between the means for the repair types in the "B" group, and no statistically significant differences exist between the means for the repair types in the "C" group. However, some difference does exist between the repair types in group A and the repair types in group C. Unfortunately, the overlap of group B prevents an overall ranking of repair types from being performed.

Contrast Analysis

One goal of the statistical analysis was to determine whether there were statistically significant differences ($\alpha = 0.05$) between the average patch ratings of certain categories of repair types or material types of interest. These categories included proprietary versus nonproprietary cementitious materials, and traditional versus nontraditional concrete-removal methods (i.e., saw-and-patch or chip-and-patch versus mill-and-patch procedures). To accomplish these group comparisons, the SAS CONTRAST statement was used.

Survival Analysis

A patch survival analysis also was conducted in this experiment. To determine which repairs have significantly higher survival rates, a method was needed to compare the survival plots over time. Figure 26 shows a typical survival plot for several different repair types. Through the use of the SAS LIFETEST procedure, the differences between the various plots were calculated and analyzed for statistical significance at $\alpha = 0.05$.

Laboratory-Performance Correlations

During the statistical analysis, attempts also were made to find correlations between laboratory results and field performance. For analysis purposes, average values from a set of laboratory samples were used as representative values for particular material characteristics. These average lab results were then compared to average performance ratings of material-repair treatments in an attempt to identify correlations between them. The absence of differences in field performance in most cases has limited the effectiveness of these comparisons.

Field Performance

One of the major factors in determining the cost-effectiveness of a partial-depth spall repair operation is the performance of the patches. Patches that last a long time and require very little repatching can reduce the labor, equipment, and material cost simply by allowing a crew to patch the developed spalls a single time. The performance of the patches in the partial-depth spall repair experiment was compared in two ways. The first is a comparison of the performance of materials, procedures, and material-procedure treatments based on overall patch ratings and on individual distress ratings. The second is a comparison of the patch survival percentages for each repair type over time. Both analyses are presented in this section.

During the statistical analysis of performance based on the individual distress ratings and overall patch ratings, the materials were divided into two groups: bituminous materials, and cementitious and polymer materials. This grouping is logical because of the different types of distress that occur in the two categories of materials. Bituminous materials can dish, ravel,

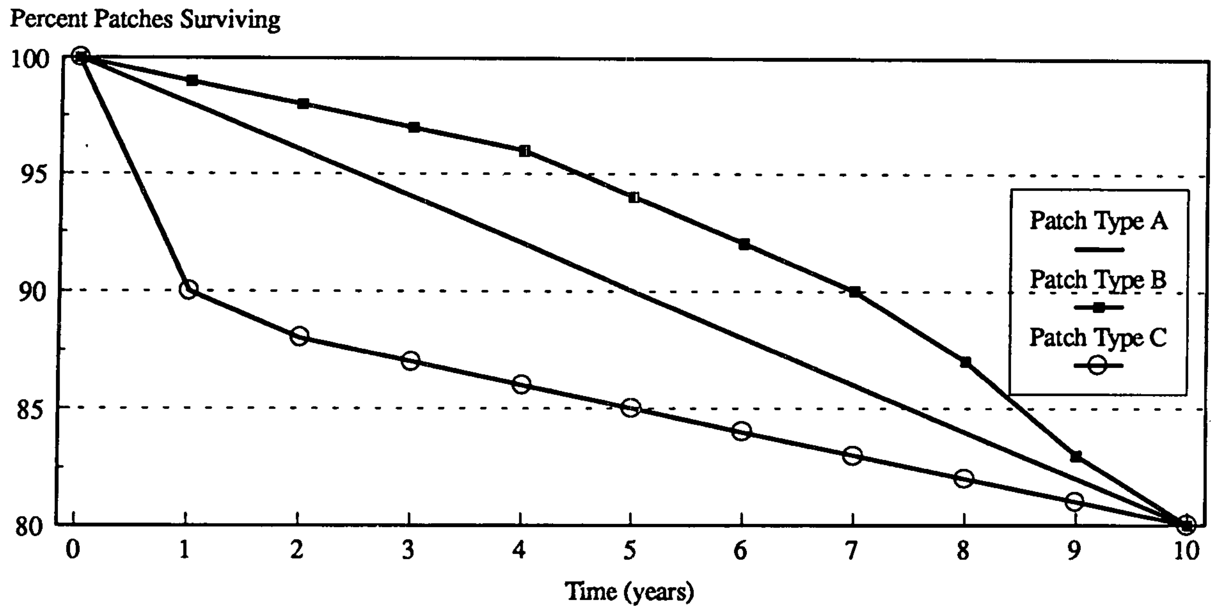


Figure 26. Example patch survival plot

shove, crack, bleed, fray at the patch edges, and develop missing areas of the patch; cementitious and polymer materials can spall, wear or ravel, fray at the patch edges, debond, and develop longitudinal and transverse cracking. Some cementitious and polymer materials also can oxidize. It should be noted that although additional distresses were recorded during the site evaluations, only distresses present to a significant degree were included in the analysis. The remainder of this chapter is divided according to these material groupings.

Bituminous Materials

The bituminous materials were analyzed to determine how the materials, procedures, and material-procedure treatments might differ in significant ways. Table 12 shows a summary of significant variables for ratings of the bituminous materials, as determined in the multivariate analysis of variance. Because a significant amount of variation was contributed to the error term by the position of the patch (wheelpath versus non-wheelpath), position was included as a variable in the analysis. A total of six patch positions were combined into three categories: wheelpath (WP), non-wheelpath (NWP), and both wheelpath and non-wheelpath (BOTH). Because there were so few patches that fell into the BOTH category, it was necessary to drop these patches from the data set to facilitate the statistical analysis.

It can be seen from table 14 that in Pennsylvania, the bleeding rating is significantly different between bituminous patches placed in the wheelpath and those not placed in the wheelpath;

Table 14. Summary of significance for bituminous materials

Site	Variable	Rating	Level of Significance	Significant at	
				.05	.01
AZ[1]	none				
PA[2]	position (WP versus NWP)	bleeding	0.0452	✓	
PA[2]	treatment (material-procedure)	bleeding	0.0063		✓
PA[2]	treatment by position	bleeding	0.0452	✓	
PA[2]	treatment	edge fraying	0.0433	✓	
SC	treatment	dishing	0.0222	✓	
SC	treatment	raveling	0.0368	✓	
SC	treatment	overall	0.0467	✓	
UT[1]	none				

[1] Only one bituminous treatment was constructed in Arizona and Utah.

[2] Treatments installed under adverse conditions were excluded from the analysis so as not to unfairly rank material performance.

the bleeding and edge-fraying ratings are significantly different among material-procedure treatments; and the bleeding rating is significantly different based on the interaction between treatment and position. In South Carolina, the dishing, raveling, and overall ratings are significantly different among material-procedure treatments.

Table 15 shows a comparison of treatments for significant distresses and patch ratings among bituminous materials. The table shows that when the two bituminous treatments in Pennsylvania are compared, UPM High Performance Cold Mix patches placed with the chip-and-patch procedure have a significantly better bleeding rating (i.e., they bled less) than spray-injection patches placed with the normal-condition clean-and-patch procedure. The table also shows that in South Carolina, UPM High Performance Cold Mix patches placed with the chip-and-patch procedure have significantly better dishing, raveling, and overall ratings (i.e., they dished and raveled less and had a higher overall rating) than spray-injection patches placed with the normal-condition clean-and-patch procedure.

The temperature at the time of installation of the bituminous patches was investigated as a covariate with the bituminous distress ratings, as well as the overall bituminous patch rating, and was not found to be a significant factor (at $\alpha = 0.05$) at any of the sites.

Table 15. Comparison of treatments for significant distresses and patch ratings among bituminous materials

Site	Comparison[1]	Rating	Significance	
			.05	.01
PA[2]	UPM CH&P (10.00) > Spray-Inject NC&P (9.69)	bleeding		✓
SC	UPM CH&P (8.64) > Spray-Inject NC&P (7.44)	dishing	✓	
SC	UPM CH&P (9.96) > Spray-Inject NC&P (8.79)	raveling	✓	
SC	UPM CH&P (8.34) > Spray-Inject NC&P (7.55)	overall	✓	

[1] CH&P = the chip-and-patch procedure; NC&P = the clean-and-patch procedure under normal conditions; UPM = UPM High Performance Cold Mix; Spray-Inject = spray-injection (e.g., AMZ, Rosco).

[2] Treatments installed under adverse conditions were excluded from the analysis so as not to unfairly rank material performance.

Cementitious and Polymer Materials

The cementitious and polymer materials also were analyzed to determine how the materials, procedures, and material-procedure treatments might differ from each other in significant ways. The multivariate analysis of variance conducted on the suite of distresses showed treatment to be significant in three of the four sites, with the fourth site, Arizona, the mildest climate, just barely not significant (at $\alpha = 0.06$). Table 16 shows a summary of significant variables for cementitious and polymer material ratings that were then found in the univariate analysis of variance. Because a significant amount of variation was not contributed to the error term by the position of the patch (wheelpath versus non-wheelpath), it was not included as a variable in the analysis. However, in future analyses, position is likely to be significant and should be included.

It can be seen from table 16 that in Arizona, the wearing, fraying, bonding, longitudinal cracking, oxidizing, and overall ratings are significantly different among material-procedure treatments. In Pennsylvania, the spalling, wearing, fraying, bonding, longitudinal cracking, transverse cracking, and overall ratings are significantly different among material-procedure treatments. In South Carolina, the spalling, wearing, fraying, bonding, and overall ratings are significantly different among material-procedure treatments. Table 16 also shows that in Utah, the wearing, fraying, bonding, longitudinal cracking, and overall ratings are significantly different among material-procedure treatments.

The Tukey test was used to order material-procedure treatments by rating value and to group the treatments that were not found to be significantly different from each other. The Tukey groupings can be further analyzed to determine which treatments are significantly different from each other. The Tukey groupings often overlap, preventing a decisive ranking of the

Table 16. Summary of significance for cementitious and polymer materials

Site	Variable	Rating	Level of Significance	Significant at		
				.05	.01	.001
AZ	treatment[1]	wearing	0.0001			✓
AZ	treatment[1]	fraying	0.0001			✓
AZ	treatment[1]	bonding	0.0001			✓
AZ	treatment[1]	longitudinal cracking	0.0001			✓
AZ	treatment[1]	oxidization	0.0001			✓
AZ	treatment[1]	overall	0.0001			✓
PA[2]	treatment	spalling	0.0006			✓
PA[2]	treatment[1]	wearing	0.0001			✓
PA[2]	treatment[1]	fraying	0.0001			✓
PA[2]	treatment	bonding	0.0002			✓
PA[2]	treatment	longitudinal cracking	0.0001			✓
PA[2]	treatment[1]	transverse cracking	0.0001			✓
PA[2]	treatment	overall	0.0005			✓
SC	treatment	spalling	0.0016		✓	
SC	treatment[1]	wearing	0.0001			✓
SC	treatment[1]	fraying	0.0001			✓
SC	treatment	bonding	0.0001			✓
SC	treatment[1]	overall	0.0001			✓
UT	treatment[1]	wearing	0.0001			✓
UT	treatment	fraying	0.0007			✓
UT	treatment	bonding	0.0001			✓
UT	treatment[1]	longitudinal cracking	0.0072		✓	
UT	treatment[1]	overall	0.0001			✓

[1] Replicate and/or treatment by replicate are significant due to the exclusion of position (which was not found to be significant) from the error term.

[2] Treatments installed under adverse conditions were excluded from the analysis so as not to unfairly rank material performance.

material-procedure treatments. However, as the patches develop more distress, future analyses of performance data may result in less overlap, making more decisive rankings possible. The conclusions drawn from Tukey groupings of material-procedure treatments might be useful to an agency if it is not committed to a particular material or procedure and would like to see which material-procedure combinations give a significantly better distress or overall patch rating compared to other material-procedure combinations.

Figures 27 through 29 show the Tukey groupings of cementitious and polymer patch performance differences at a 0.05 significance level, grouped by material-procedure treatment in Arizona. S&P stands for the saw-and-patch procedure, CH&P for the chip-and-patch procedure, and M&P for the mill-and-patch procedure. The Tukey groupings A, B, and C are shown with the overall rating, while the Tukey groupings A, B, C, and D are shown with the wearing and bonding ratings. Material-procedure combinations labeled with the same letter are not significantly different.

Figure 27 shows that the following material-procedure treatments do not have significantly different overall patch ratings from each other: Type III PCC patches prepared with the saw-and-patch or chip-and-patch procedure; Duracal patches prepared with the chip-and-patch procedure; Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedure; Percol FL patches prepared with the chip-and-patch procedure; and Pyrament 505 patches prepared with the mill-and-patch procedure. However, they do have significantly better overall patch ratings than Percol FL patches prepared with the saw-and-patch procedure and Penatron R/M-3003 patches prepared with the saw-and-patch procedure, which do not have significantly different overall patch ratings from each other.

Figure 27 also shows that the following material-procedure treatments do not have significantly different overall patch ratings from each other: Type III PCC patches prepared with the saw-and-patch or chip-and-patch procedure; Set-45 patches prepared with the chip-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedure; Percol FL patches prepared with the chip-and-patch procedure; and Pyrament 505 patches prepared with the mill-and-patch procedure. However, they do have significantly better overall patch ratings than Percol FL patches prepared with the saw-and-patch or mill-and-patch procedure, and Penatron R/M-3003 patches prepared with the saw-and-patch procedure, which do not have significantly different overall patch ratings from each other.

Figure 28 shows that the following material-procedure treatments do not have significantly different wearing ratings from each other: Type III PCC patches placed with the saw-and-patch or chip-and-patch procedures; Duracal patches prepared with the saw-and-patch or chip-and-patch procedures; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedures; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedures; Percol FL patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedures; Pyrament 505 patches prepared with the mill-and-patch

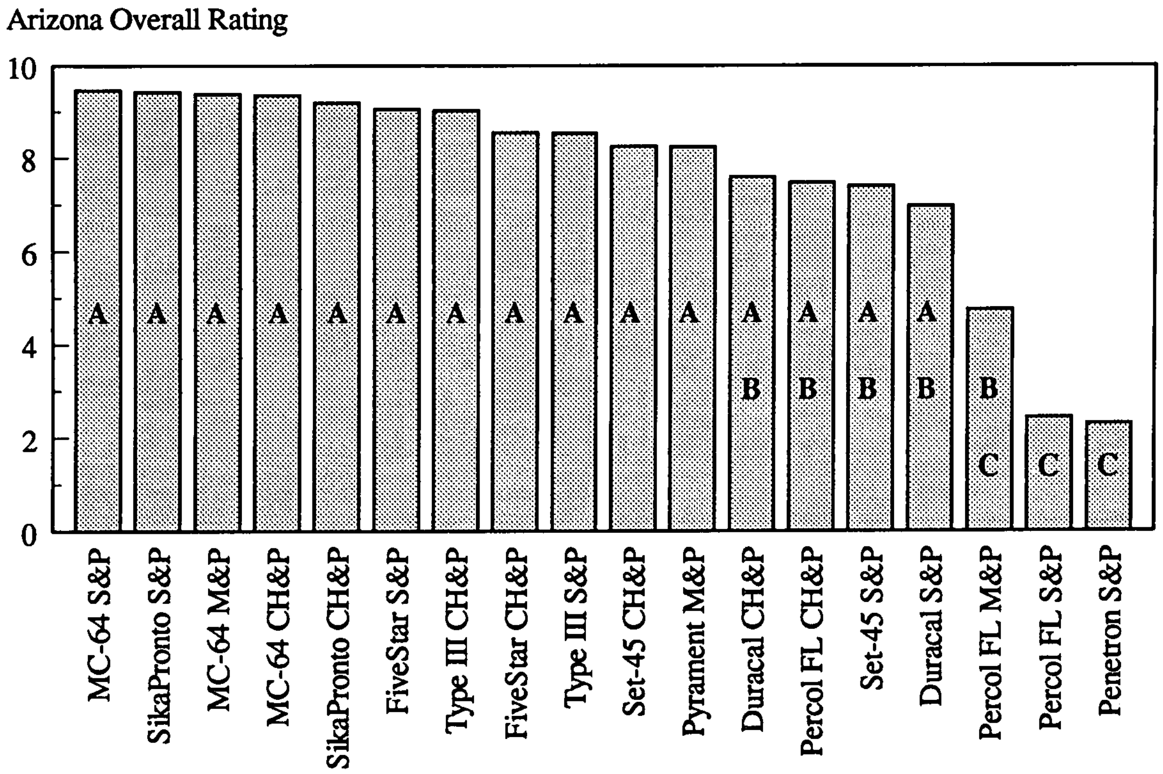


Figure 27. Tukey groupings of Arizona cementitious and polymer overall ratings, grouped by material-procedure treatments

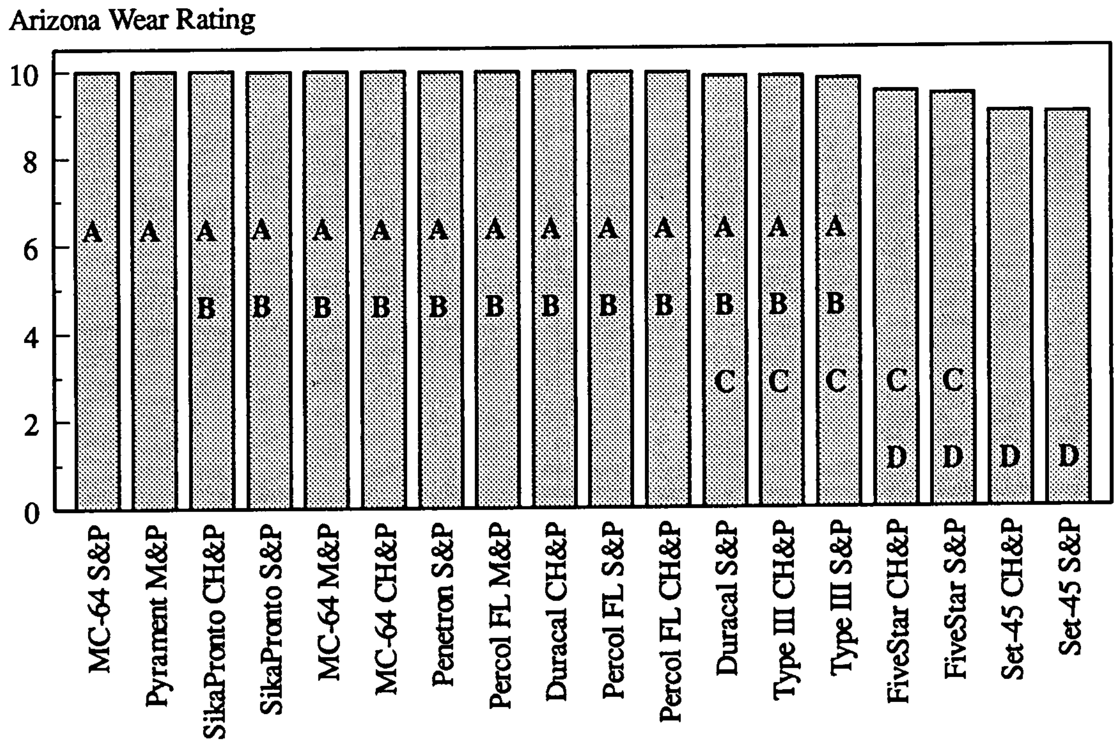


Figure 28. Tukey groupings of Arizona cementitious and polymer wear ratings, grouped by material-procedure treatments

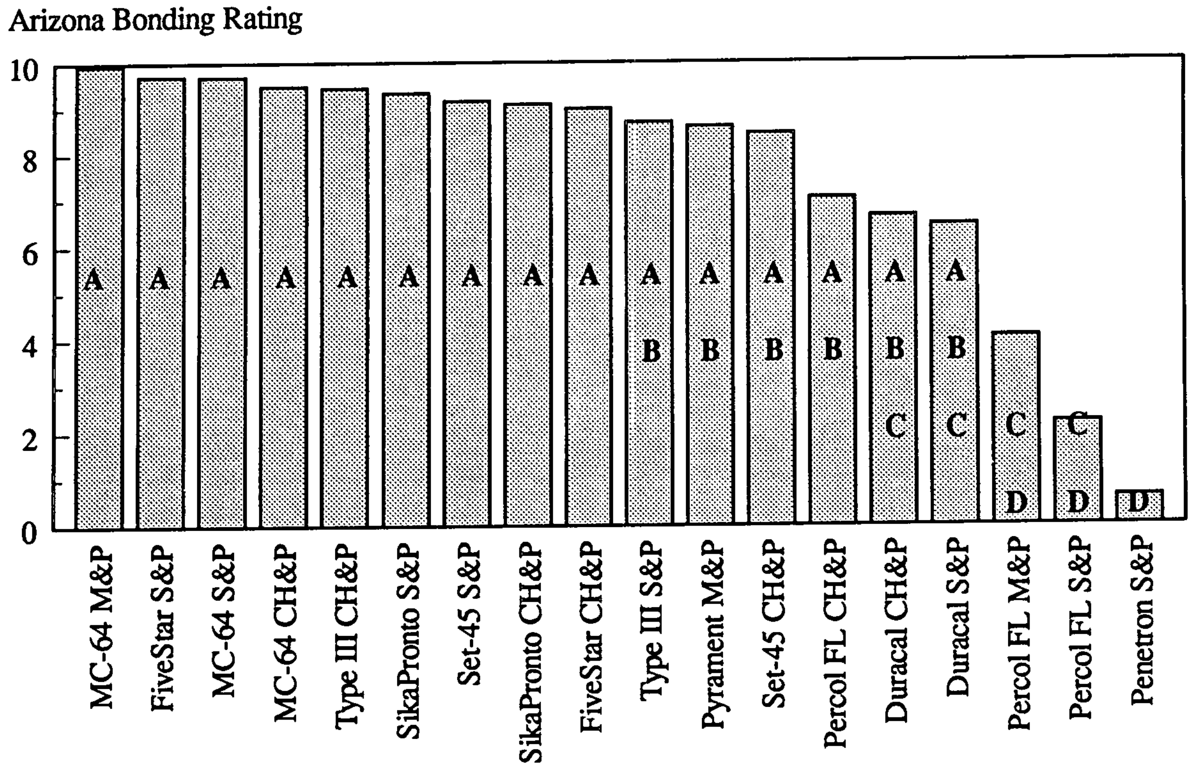


Figure 29. Tukey groupings of Arizona cementitious and polymer bonding ratings, grouped by material-procedure treatments

procedures; and Penatron R/M-3003 patches prepared with the saw-and-patch procedure. However, they do have significantly better wearing ratings than Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure, which do not have significantly different wearing ratings from each other.

Figure 28 also shows that the following material-procedure treatments do not have significantly different wear ratings from each other: Duracal patches prepared with the chip-and-patch procedure; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedure; Percol FL patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; Pyrament 505 patches prepared with the mill-and-patch procedure, and Penatron R/M-3003 patches prepared with the saw-and-patch procedure. However, they do have significantly better wear ratings than Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure; and Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure, which do not have significantly different wear ratings from each other.

Figure 29 shows that the following material-procedure treatments do not have significantly different bonding ratings from each other: Type III PCC patches prepared with the saw-and-patch or chip-and-patch procedure; Duracal patches prepared with the saw-and-patch or chip-and-patch procedure; Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedure; Percol FL patches prepared with the chip-and-patch procedure; and Pyrament 505 patches prepared with the mill-and-patch procedure. However, they do have significantly better bonding ratings than Penatron R/M-3003 patches prepared with the saw-and-patch procedure.

Figure 29 also shows that the following material-procedure treatments do not have significantly different bonding ratings from each other: Type III PCC patches prepared with the saw-and-patch or chip-and-patch procedure; Duracal patches prepared with the saw-and-patch or chip-and-patch procedure; Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedures; MC-64 patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedure; Percol FL patches prepared with the chip-and-patch procedure; and Pyrament 505 patches prepared with the mill-and-patch procedure. However, they do have significantly better bonding ratings than Percol FL patches prepared with the saw-and-patch or mill-and-patch, and Penatron R/M-3003 patches prepared with the saw-and-patch procedure, which do not have significantly different bonding ratings from each other.

Figures 30 and 31 show the Tukey groupings of cementitious-and-polymer-patch performance differences at a 0.05 significance level, grouped by material-procedure treatment and installed under normal conditions in Pennsylvania. As in figures 27 through 29, the material-procedure combinations labeled with the same letter in figures 30 and 31 are not significantly different.

Figure 30 shows no significant difference in spalling ratings among the treatments. Figure 31 shows that MC-64 patches prepared with the saw-and-patch procedure, and Percol FL patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure do not have significantly different transverse cracking ratings from each other. However, they do have significantly better transverse cracking ratings than Type III PCC patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; Five Star HP patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure; SikaPronto 11 patches prepared with the chip-and-patch procedure; and Pyrament 505 patches prepared with the saw-and-patch or chip-and-patch procedure; which do not have significantly different transverse cracking ratings from each other.

Figure 31 also shows that Set-45 patches prepared with the chip-and-patch or mill-and-patch procedure; MC-64 patches prepared with the saw-and-patch or chip-and-patch procedure; and Percol FL patches prepared with the saw-and-patch, chip-and-patch, or mill-and-patch procedure do not have significantly different transverse cracking ratings from each other. However, they do have significantly better transverse cracking ratings than Type III PCC patches prepared with the saw-and-patch procedure and Five Star HP patches prepared with the mill-and-patch procedure, which do not have significantly different transverse cracking ratings from each other.

Figure 32 shows the Tukey groupings of cementitious and polymer patch performance differences at a 0.05 significance level, grouped by material-procedure treatment in South

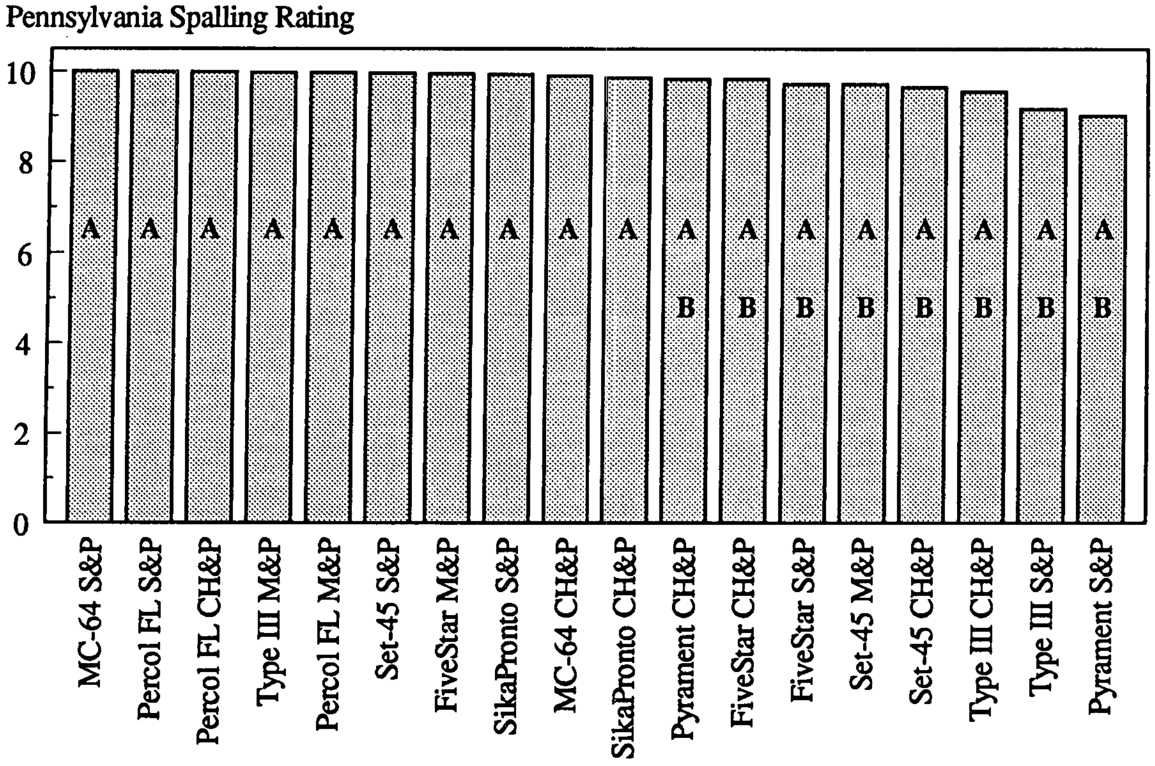


Figure 30. Tukey groupings of Pennsylvania cementitious and polymer spalling ratings, grouped by material-procedure treatments

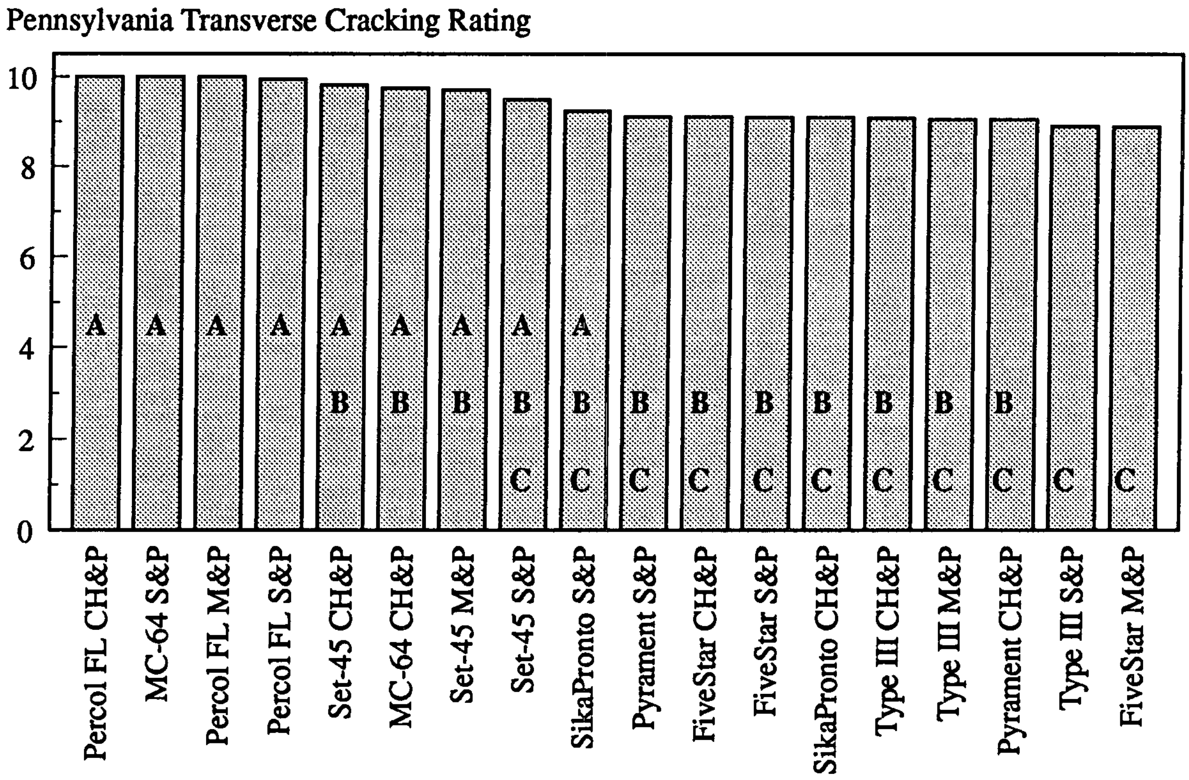


Figure 31. Tukey groupings of Pennsylvania cementitious and polymer transverse cracking ratings, grouped by material-procedure treatments

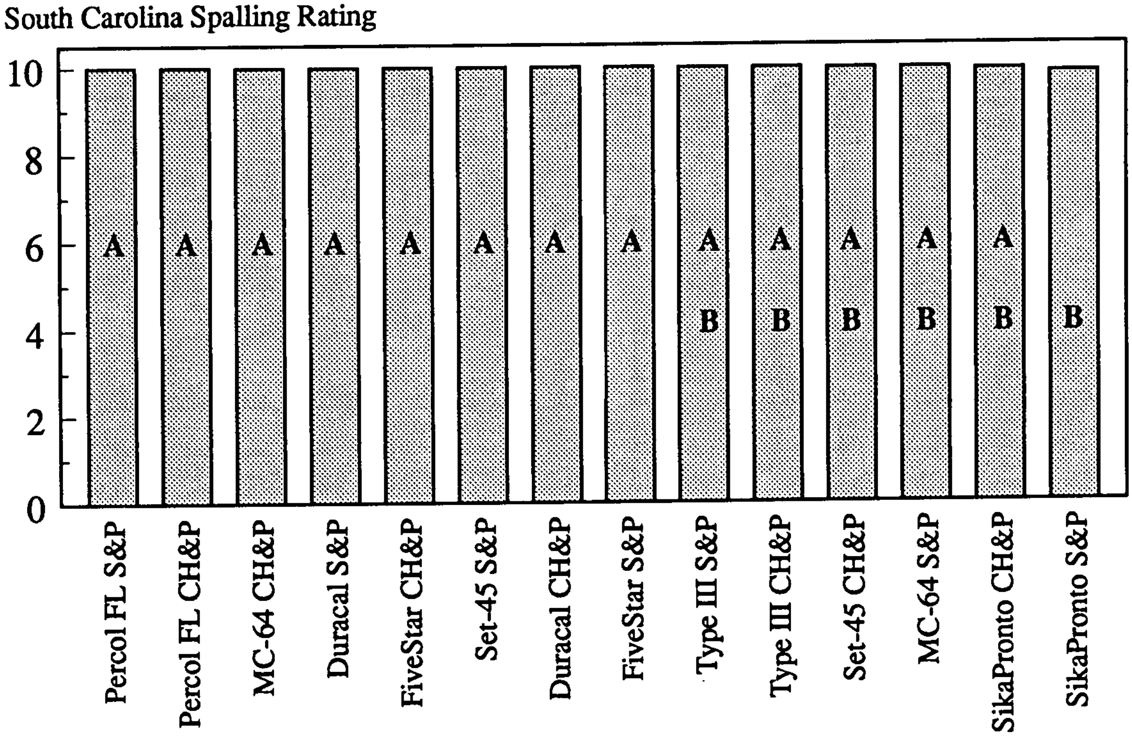


Figure 32. Tukey groupings of South Carolina cementitious and polymer spalling ratings, grouped by material-procedure treatments

Carolina. Figure 32 indicates that Duracal patches prepared with the saw-and-patch or chip-and-patch procedure; Set-45 patches prepared with the saw-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure; MC-64 patches prepared with the chip-and-patch procedure; and Percol FL patches prepared with the saw-and-patch or chip-and-patch procedures do not have significantly different spalling ratings from each other. However, they do have significantly better spalling ratings than SikaPronto 11 patches prepared with the saw-and-patch procedure.

Figures 33 and 34 show the Tukey groupings of cementitious and polymer patch performance differences at a 0.05 significance level, grouped by material-procedure treatment in Utah. Figure 33 shows that the following material-procedure treatments do not have significantly different overall patch ratings: Type III PCC patches prepared with the saw-and-patch or chip-and-patch procedure; Duracal patches prepared with the saw-and-patch or chip-and-patch procedure; Set-45 patches prepared with the saw-and-patch or chip-and-patch procedure; Five Star HP patches prepared with the saw-and-patch or chip-and-patch procedure; MC-64 patches prepared with the saw-and-patch or chip-and-patch procedure; and SikaPronto 11 patches prepared with the saw-and-patch or chip-and-patch procedures. However, they do have significantly better overall patch ratings than Percol FL patches prepared with the saw-and-patch procedure.

Figure 33 also shows that SikaPronto patches prepared with the following material-procedure treatments do not have significantly different overall patch ratings from each other: chip-and-patch procedure; MC-64 patches prepared with the chip-and-patch procedure; Duracal patches

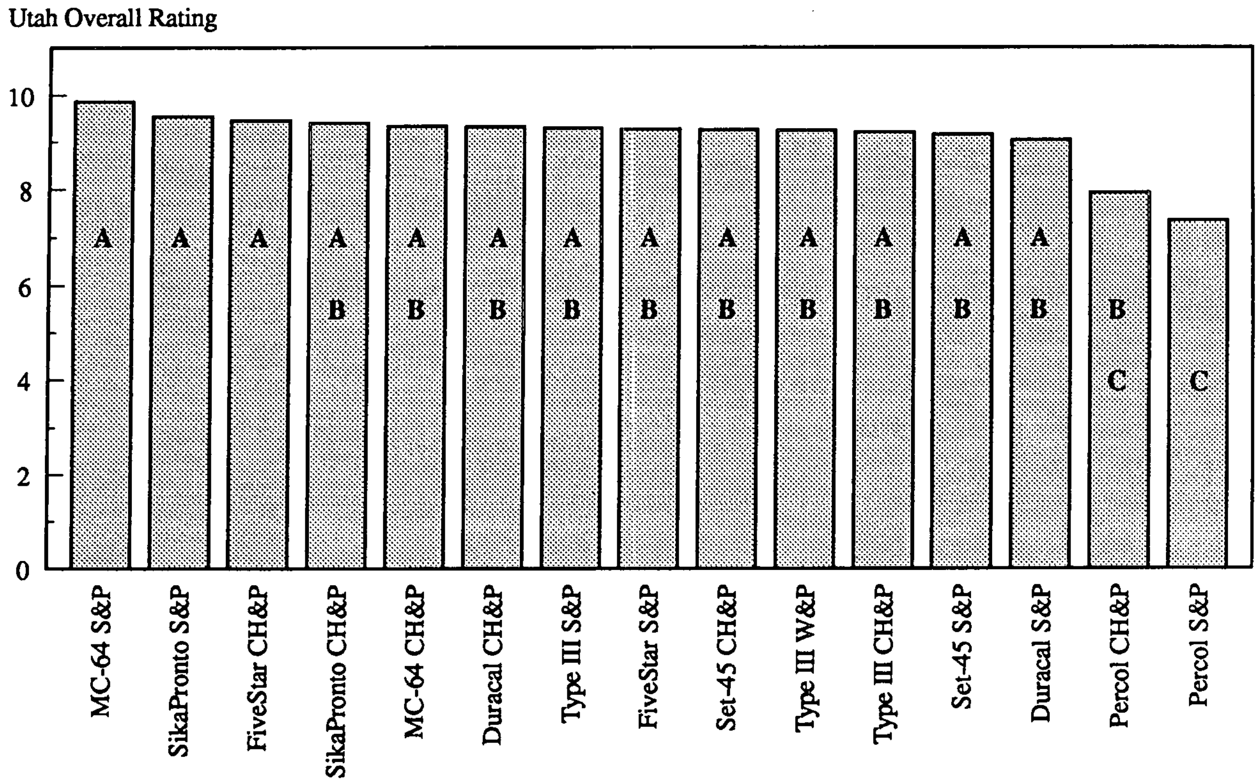


Figure 33. Tukey groupings of Utah cementitious and polymer overall ratings, grouped by material-procedure treatments

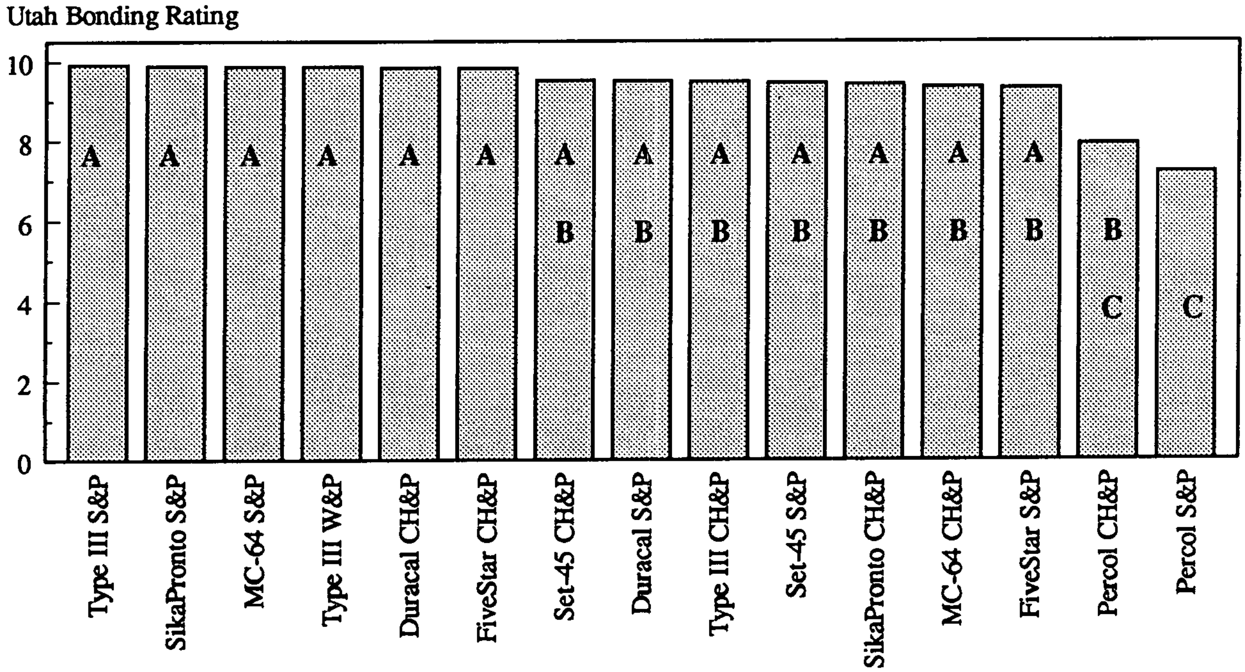


Figure 34. Tukey groupings of Utah cementitious and polymer bonding ratings, grouped by material-procedure treatments

prepared with the chip-and-patch or saw-and-patch procedure; Type III PCC patches prepared with the saw-and-patch, waterblast-and-patch, or chip-and-patch procedures; Five Star HP patches prepared with the saw-and-patch procedure; Set-45 patches prepared with the chip-and-patch or saw-and-patch procedure; and Percol FL patches prepared with the chip-and-patch procedure.

Figure 34 shows that the following material-procedure treatments do not have significantly different bonding ratings from each other: Type III PCC patches prepared with the saw-and-patch or waterblast-and-patch procedure, SikaPronto 11 patches prepared with the saw-and-patch procedure, MC-64 patches prepared with the saw-and-patch procedure, Duracal patches placed with the chip-and-patch procedure, and Five Star HP patches placed with the chip-and-patch procedure. However, they do have significantly better bonding patch ratings than Percol FL patches prepared with the saw-and-patch procedure.

Figure 34 also shows that the following material-procedure treatments do not have significantly different bonding patch ratings from each other: Set-45 patches prepared with the chip-and-patch procedure, Duracal patches prepared with the saw-and-patch procedure, Type III PCC patches prepared with the chip-and-patch procedure, SikaPronto 11 patches prepared with the chip-and-patch procedure, MC-64 patches prepared with the chip-and-patch procedure, Five Star HP patches prepared with the saw-and-patch procedure, and Percol FL patches prepared with the chip-and-patch procedure.

Table 17 shows the results of contrasts of the overall patch rating among materials and procedures in each site. Contrasts that are found to be significant can be investigated further in the Tukey analysis and by comparing the means of the contrasted groups.

For cementitious and polymer patches placed in Arizona, table 17 shows that the overall patch rating for patches installed using the saw-and-patch procedure is significantly different from the overall patch rating for patches installed using the chip-and-patch procedure. However, the overall patch rating for patches installed using the saw-and-patch or chip-and- patch procedure, both well accepted by state agencies, is not significantly different from the overall patch rating for patches installed using the mill-and-patch procedure, considered by many state agencies to be an experimental procedure.

Table 17 also shows that for cementitious and polymer patches placed in Arizona, there are significant differences in the overall patch rating among the various materials. The cementitious materials (Type III PCC, Duracal, Set-45, Five Star HP, and Pyrament 505) have significantly different overall patch ratings than the polymer materials (MC-64 and Percol FL). However, the nonproprietary cementitious material (Type III PCC) does not have a significantly different overall patch rating than the proprietary cementitious materials (Duracal, Set-45, Five Star HP, and Pyrament 505).

The significant differences in the contrasts of overall patch rating for Arizona shown in table 17 can be interpreted by comparing the means for the contrasted groups. The average overall patch rating for patches placed with the saw-and-patch procedure is 6.95; for patches placed with the chip-and-patch procedure it is 8.49. Therefore, the chip-and-patch procedure resulted in a higher overall patch rating than the saw-and-patch procedure when used to place

Table 17. Summary of significance for contrasts of the overall patch rating among materials and procedures, for cementitious and polymer materials

Site	Contrast[1]	Level of Significance	Significant at		
			.05	.01	.001
AZ	CH&P versus S&P	0.0001			✓
AZ	S&P and CH&P versus M&P	0.5613			
AZ	All cementitious and polymer materials	0.0001			✓
AZ	Materials 1, 2, 3, 4, 8 versus 5, 7[3]	0.0001			✓
AZ	Materials 1 versus 2, 3, 4, 8	0.1079			
PA[2]	S&P versus CH&P	0.7222			
PA[2]	S&P and CH&P versus M&P	0.4406			
PA[2]	All cementitious and polymer materials	0.0200	✓		
PA[2]	Materials 1, 3, 4, 8 versus 5, 7[3]	0.0074		✓	
PA[2]	Materials 1 versus 3, 4, 8	0.7312			
SC	S&P versus CH&P	0.2790			
SC	All cementitious and polymer materials	0.4131			
SC	Materials 1, 2, 3, 4 versus 5, 7[3]	0.0385	✓		
UT	S&P versus CH&P	0.8021			
UT	S&P and CH&P versus W&P	0.5198			
UT	Material 1, 2, 3, 4 versus 5, 7[3]	0.0009			✓
UT	Materials 1 versus 2, 3, 4, 8	0.9313			

[1] S&P = the saw-and-patch procedure; CH&P = the chip-and-patch procedure; M&P = the mill-and-patch procedure; W&P = the waterblasting procedure; 1 = Type III PCC; 2 = Duracal; 3 = Set-45; 4 = Five Star HP; 5 = MC-64; 7 = Percol FL; 8 = Pyrament 505.

[2] Treatments installed under adverse conditions were excluded from the analysis so as not to unfairly rank material performance.

[3] SikaPronto was excluded from the contrast analysis because it is neither clearly only a cementitious material nor clearly only a polymer material in nature.

cementitious and polymer patches in Arizona. The average overall patch rating for patches placed with the cementitious materials (Type III PCC, Duracal, Set-45, Five Star HP, and Pyrament 505) is 8.18; for patches placed with the polymer materials (MC-64 and Percol FL) it is 7.14. Therefore, the cementitious materials seem to have significantly better overall patch ratings than the polymer materials. However, the average overall patch rating for MC-64 is 9.4, while for Percol FL it is 4.89. Therefore, almost any material paired with Percol FL would have a mean substantially lower than 8.18 (the mean of Type III PCC, Duracal, Set-45, Five Star HP, and Pyrament 505). Thus, MC-64 and Percol FL, although both polymer materials, do not statistically behave the same, and the statement that the cementitious materials have significantly better overall patch ratings than the polymer materials is not valid.

The statistically significant differences shown in table 17 between all cementitious and polymer materials in Arizona can be further investigated by analyzing the Tukey groupings ($\alpha = 0.05$) shown in figures 35 through 37. Figure 35 shows that Type III PCC, Five Star HP, MC-64, SikaPronto 11, and Pyrament 505 patches do not have significantly different overall ratings from each other. However, they do have significantly better overall patch ratings than the Penatron R/M-3003 patches.

Figure 36 shows that Type III PCC and Duracal patches do not have significantly different wearing ratings from each other. However, they do have significantly better wearing ratings than Set-45 and Five Star HP patches, which do not have significantly different wearing ratings from each other. Figure 36 also shows that Type III PCC, Duracal, MC-64, SikaPronto 11, Percol FL, Pyrament 505, and Penatron R/M-3003 patches do not have significantly different wearing ratings from each other. However, they do have significantly better wearing ratings than Set-45 patches. Furthermore, figure 36 shows that Type III PCC, Duracal, and Pyrament 505 patches do not have significantly different wearing ratings from each other. However, they do have significantly better wearing ratings than Five Star HP patches.

Figure 37 shows that Type III PCC, Duracal, Set-45, Five Star HP, MC-64, SikaPronto 11, and Pyrament 505 patches do not have significantly different bonding ratings from each other. However, they do have significantly better bonding ratings than Penatron R/M-3003 patches.

Figures 38 through 40 show the Tukey groupings by procedure of ratings found to be significant for material-procedure treatment (at $\alpha = 0.05$). Figure 38 supports the significant contrast found between the chip-and-patch procedure and the saw-and-patch procedure, as all materials placed with the chip-and-patch procedure have better overall ratings than two materials placed with the saw-and-patch procedure. Figure 38 also supports the lack of significant difference found in the contrast in the overall rating between the patches placed with the mill-and-patch procedure and the patches placed with the more traditional saw-and-patch and chip-and-patch procedures: the mill-and-patch Tukey groupings completely overlap the chip-and-patch, and saw-and-patch Tukey groupings. Figures 39 and 40, however, do not show any distinct ranking of procedures according to the wear or bonding ratings.

For cementitious and polymer patches placed in Pennsylvania, table 17 shows that the overall patch rating for patches installed using the saw-and-patch procedure is not significantly

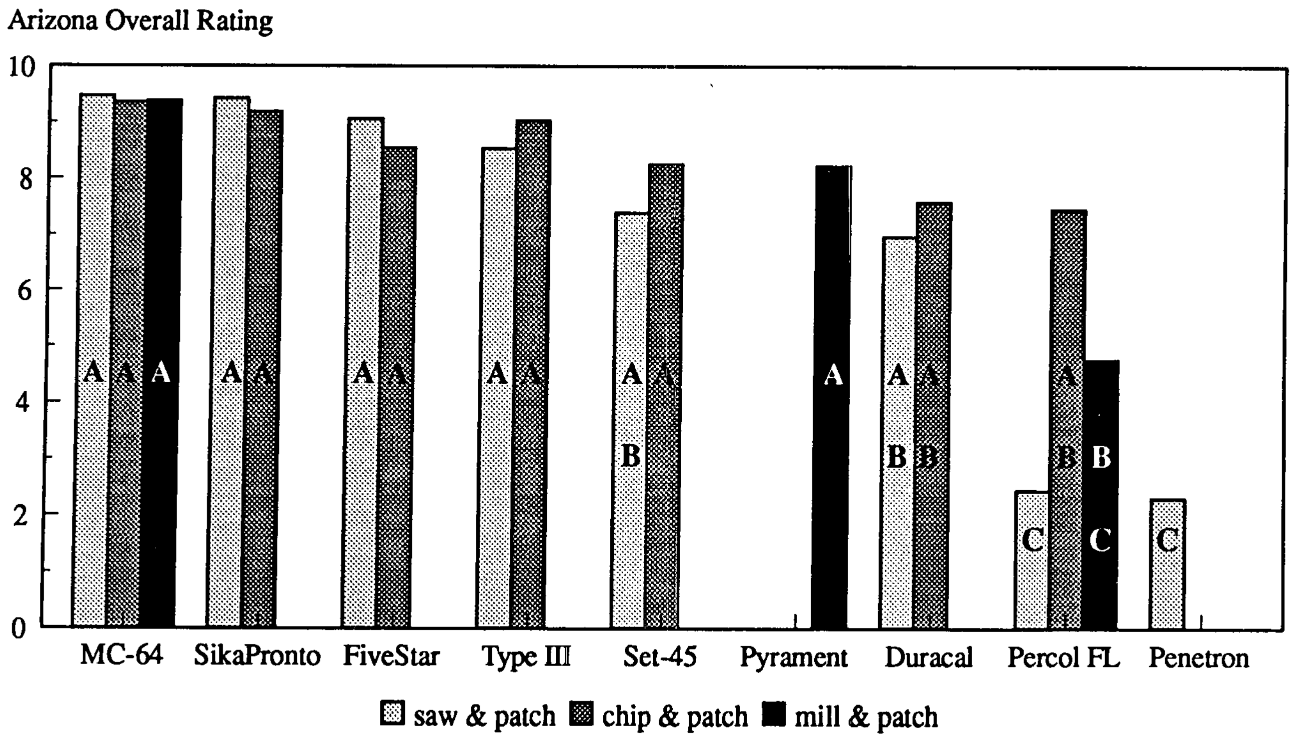


Figure 35. Tukey groupings of Arizona cementitious and polymer overall ratings, grouped by material

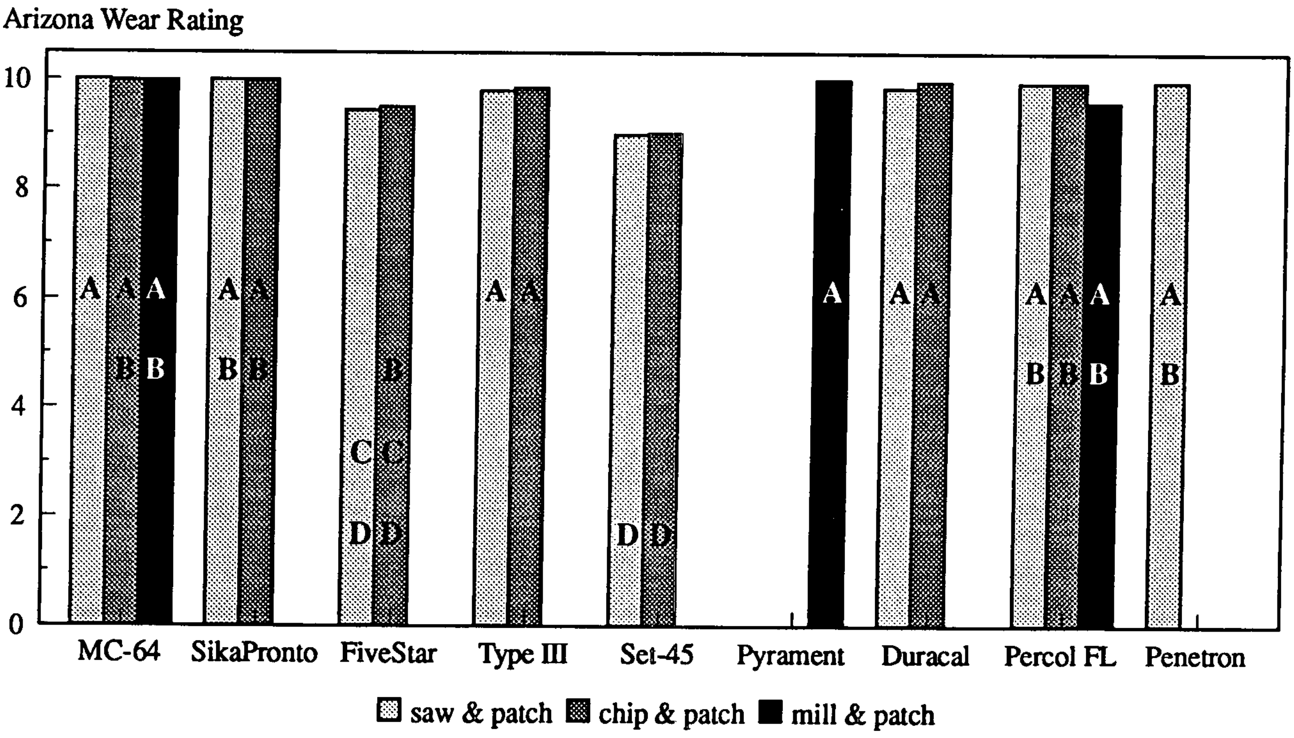


Figure 36. Tukey groupings of Arizona cementitious and polymer wear ratings, grouped by material

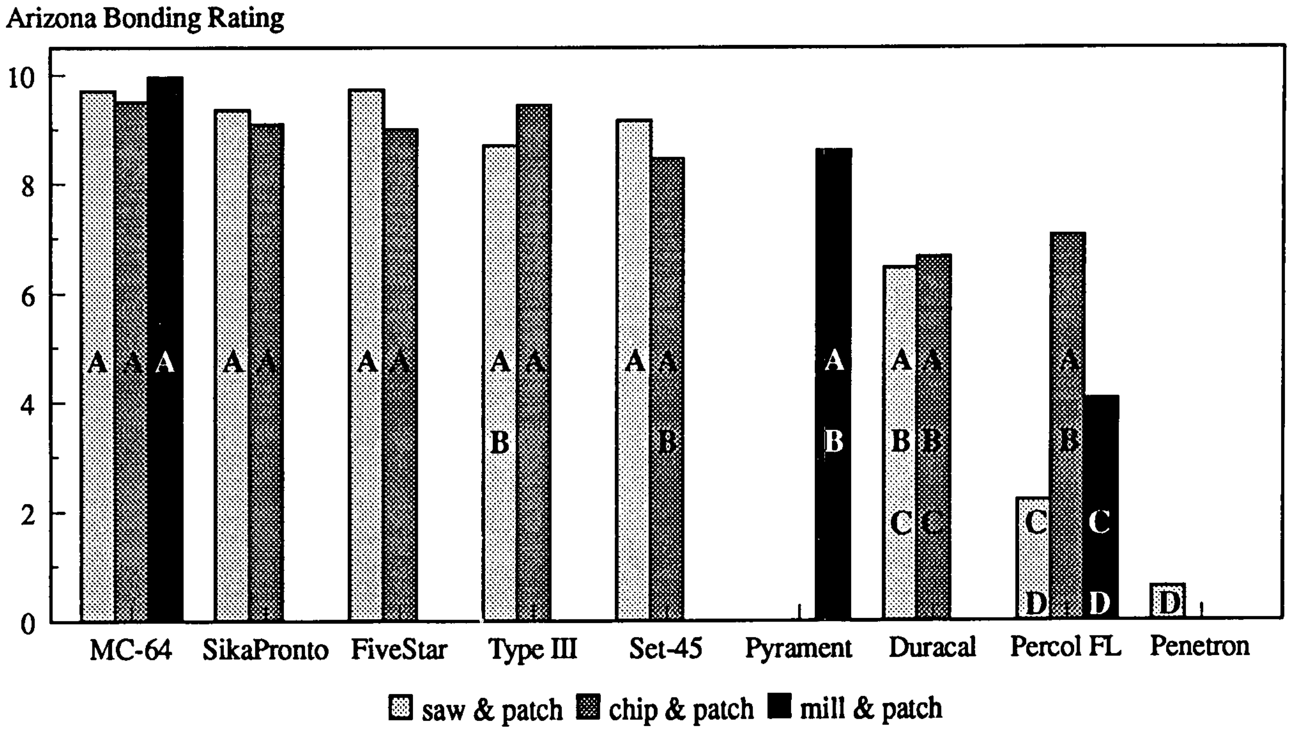


Figure 37. Tukey groupings of Arizona cementitious and polymer bonding ratings, grouped by material

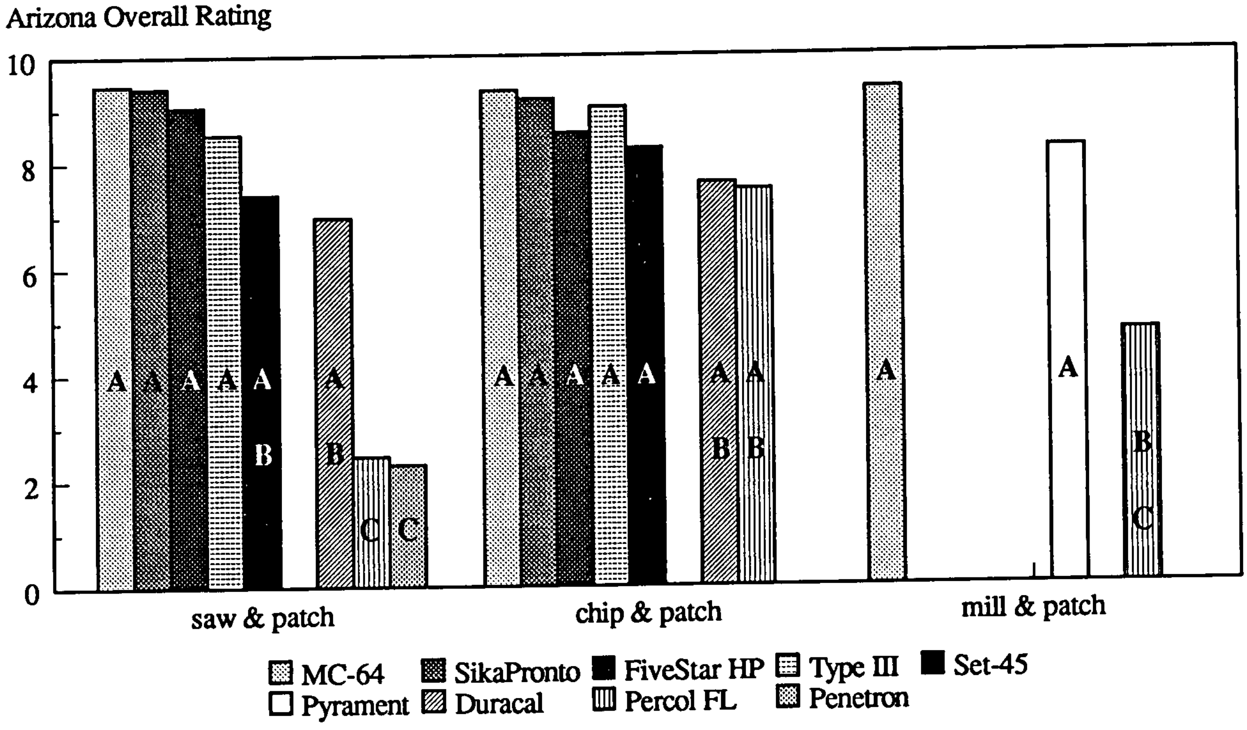


Figure 38. Tukey groupings of Arizona cementitious and polymer overall ratings, grouped by procedure

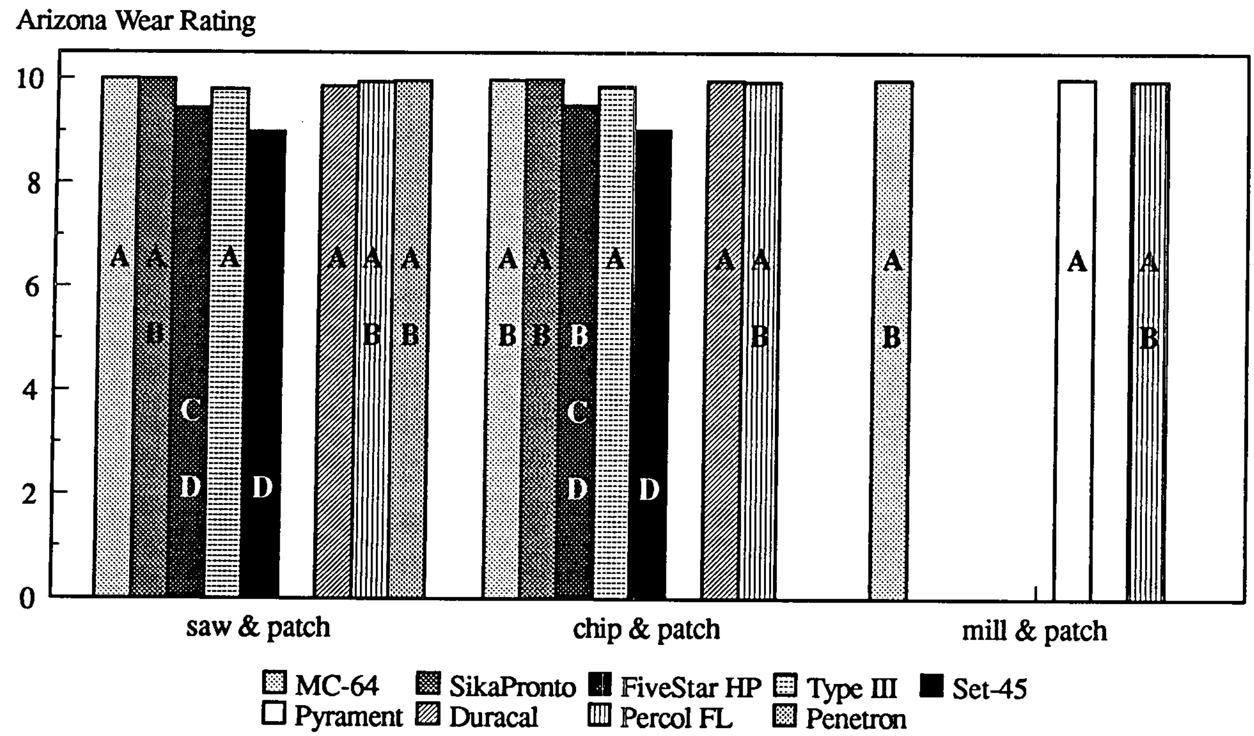


Figure 39. Tukey groupings of Arizona cementitious and polymer wear ratings, grouped by procedure

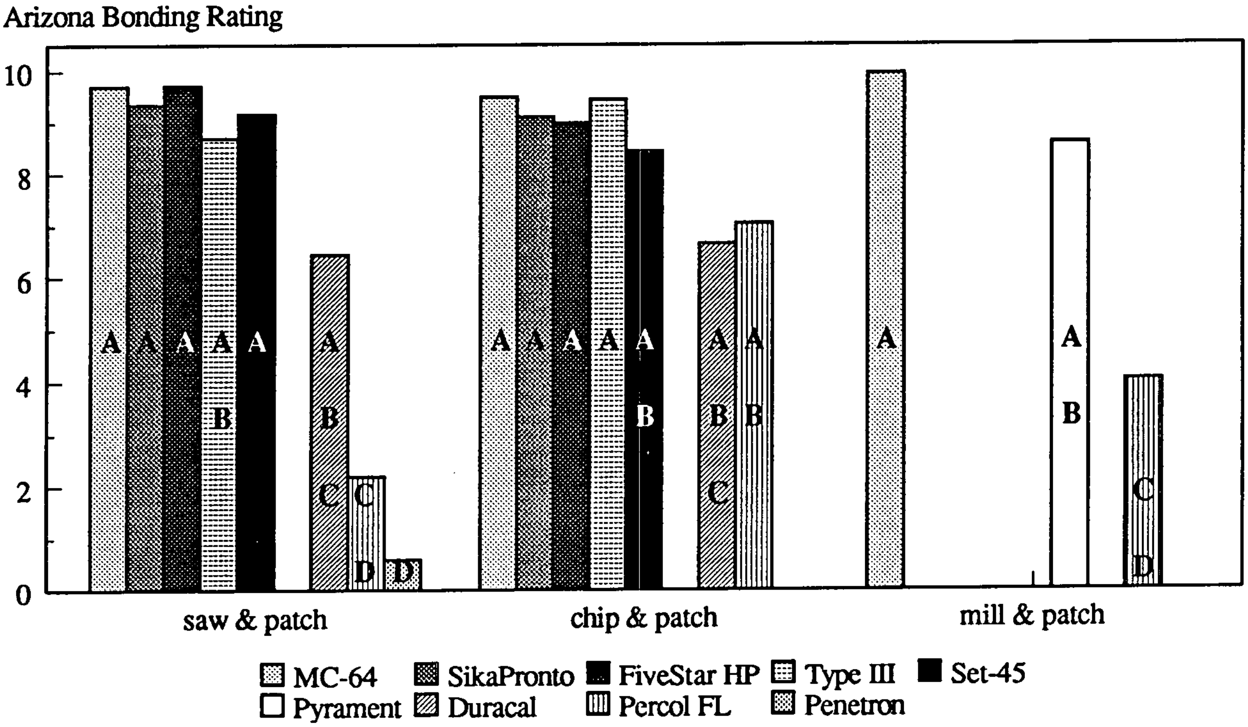


Figure 40. Tukey groupings of Arizona cementitious and polymer bonding ratings, grouped by procedure

different from the overall patch rating for patches installed using the chip-and-patch procedure. In addition, the overall patch ratings for patches installed using the saw-and-patch or chip-and-patch procedure are not significantly different from the overall patch rating for patches installed using the mill-and-patch procedure. Furthermore, for cementitious and polymer patches placed in Arizona, there are significant differences in the overall patch ratings among the various materials: the cementitious materials (Type III PCC, Duracal, Set-45, Five Star HP, and Pyrament 505) have significantly different overall patch ratings than the polymer materials (MC-64 and Percol FL). However, the nonproprietary cementitious material (Type III PCC) does not have a significantly different overall patch rating than the proprietary cementitious materials (Duracal, Set-45, Five Star HP, and Pyrament 505).

The significant differences in the contrasts of overall patch ratings for Pennsylvania can be interpreted by comparing the means for the contrasted groups. The average overall patch rating for patches placed with the cementitious materials (Type III PCC, Duracal, Set-45, Five Star HP, and Pyrament 505) is 7.18; for patches placed with the polymer materials (MC-64 and Percol FL) it is 8.10. Therefore, the polymer materials seem to have significantly better overall patch ratings than the cementitious materials. However, the Tukey analysis showed no statistically significant differences among treatments. A conservative approach to the interpretation of these results would be to assume that there is really only a borderline significantly different overall patch rating between the cementitious materials and the polymer materials that should be watched carefully in the analysis of future performance data.

The statistically significant differences shown in table 17 between all cementitious and polymer materials in Pennsylvania cannot be further investigated by the Tukey analysis for overall ratings by treatment because the analysis did not show any significantly different groupings. This may be interpreted conservatively to mean that in Pennsylvania some individual materials are just beginning to distinguish themselves from each other and should be watched carefully in future analyses of performance data. However, Tukey groupings of material-procedure treatments were found in the analysis of the significant ratings for Pennsylvania: spalling and transverse cracking. Figures 41 and 42 show the Tukey groupings for these ratings based on material.

Figure 41 shows that patches placed with MC-64, SikaPronto 11, and Percol FL do not have significantly different ratings from each other. However, they do have significantly better spalling ratings than Pyrament 505. Figure 42 shows that patches placed with Percol FL had significantly better transverse cracking ratings than patches placed with Type III PCC, Five Star HP, and Pyrament 505.

Figures 43 and 44 show the Tukey groupings of Pennsylvania cementitious and polymer patch performance material-procedure treatment differences at a 0.05 significance level, grouped by procedure. The Tukey groupings for the spalling and transverse cracking ratings support the lack of significant difference found in the contrast statements regarding patch preparation procedure in Pennsylvania, as there is a great deal of overlap among the Tukey groupings.

For cementitious and polymer patches placed in South Carolina, table 17 shows that the overall patch rating for patches installed using the saw-and-patch procedure is significantly different from the overall patch rating for patches installed using the chip-and-patch

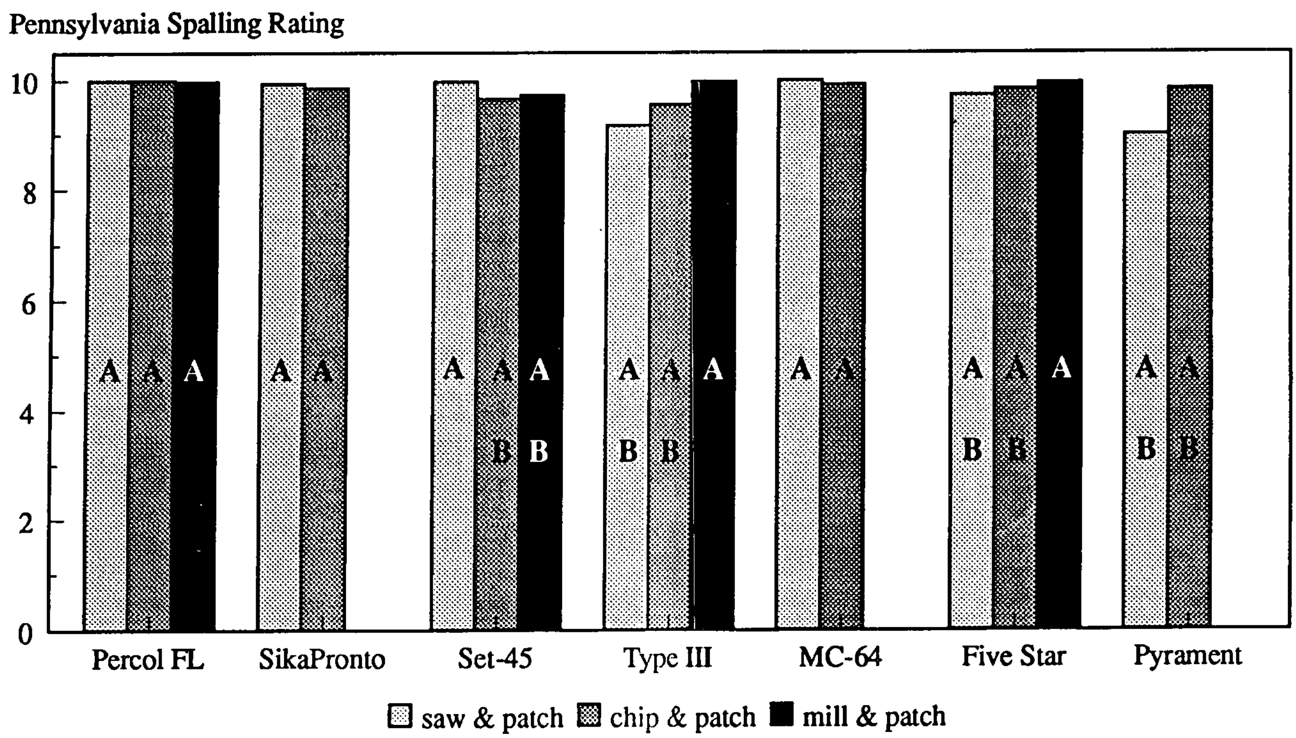


Figure 41. Tukey groupings of Pennsylvania cementitious and polymer spalling ratings, grouped by material

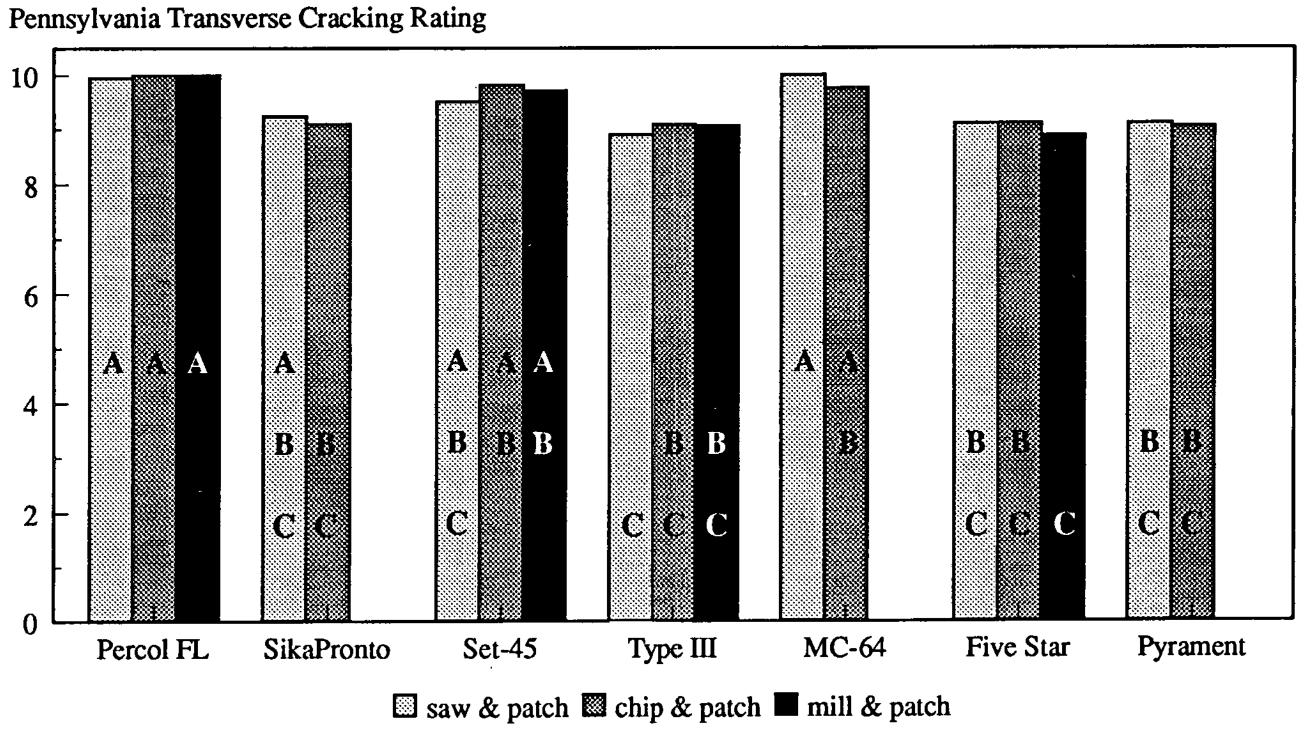


Figure 42. Tukey groupings of Pennsylvania cementitious and polymer transverse cracking ratings, grouped by material

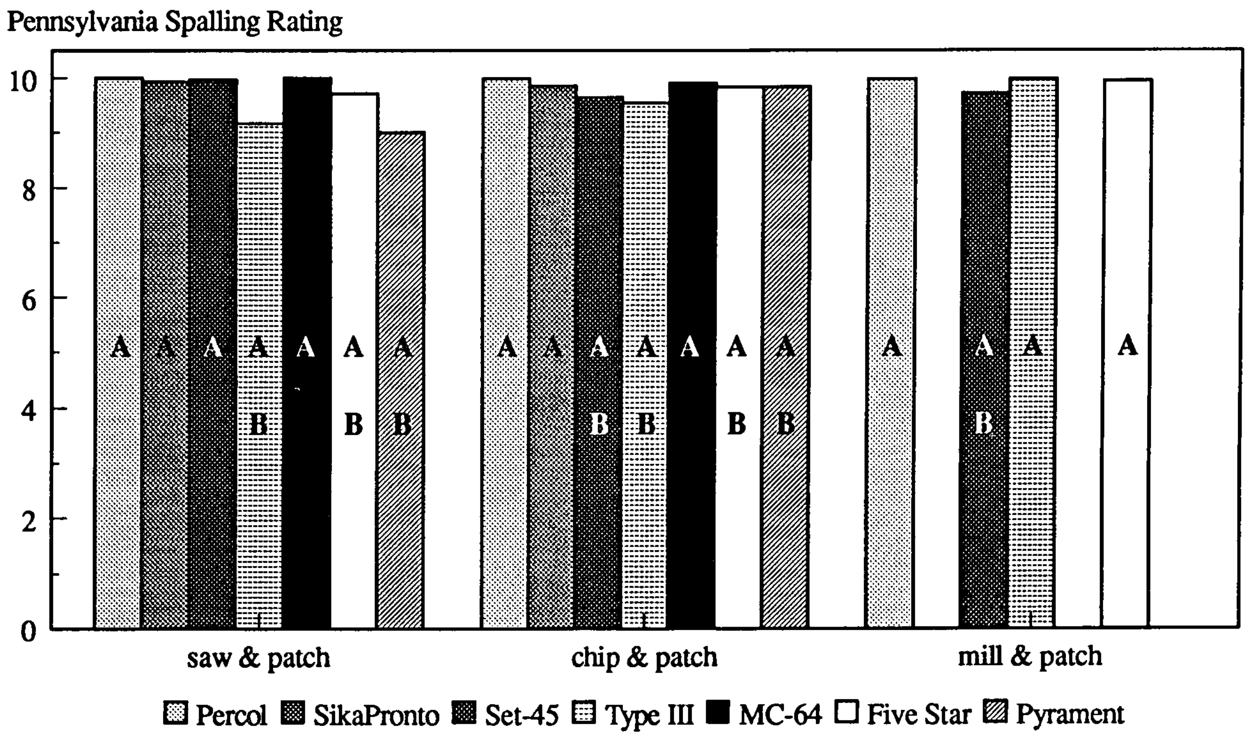


Figure 43. Tukey groupings of Pennsylvania cementitious and polymer spalling ratings, grouped by procedure

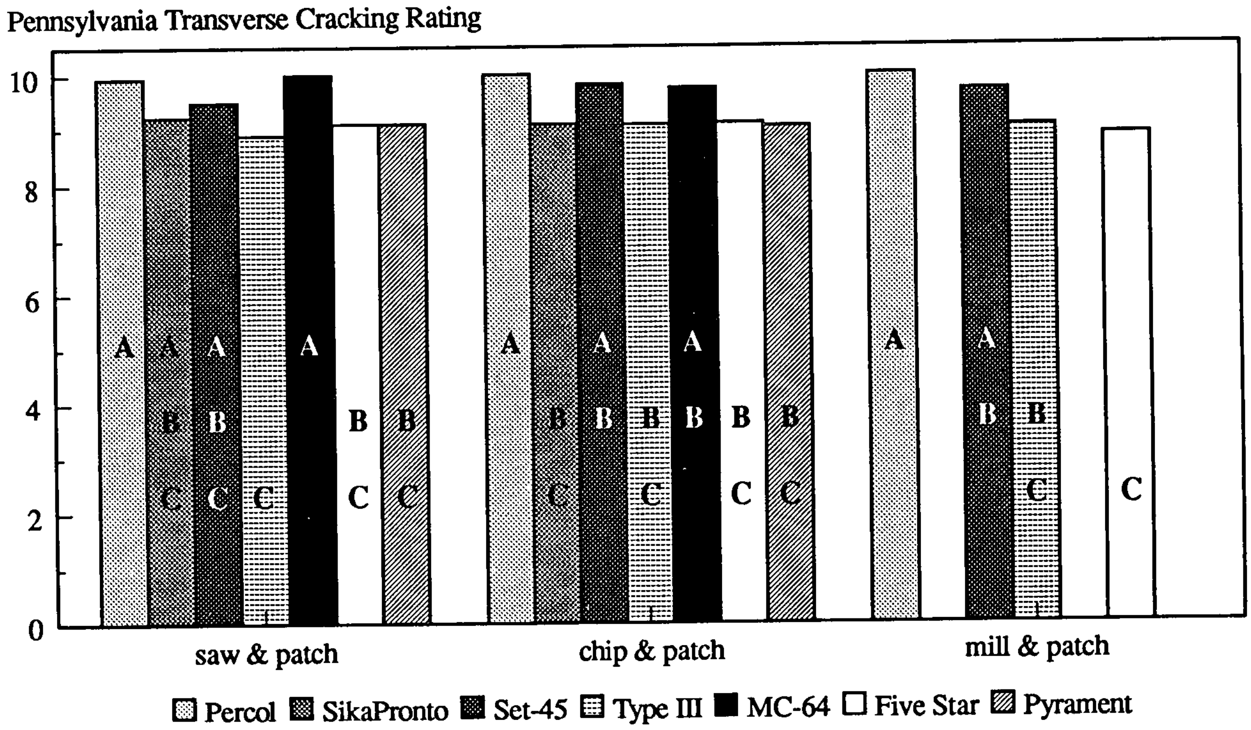


Figure 44. Tukey groupings of Pennsylvania cementitious and polymer transverse cracking ratings, grouped by procedure

procedure. Furthermore, for cementitious and polymer patches placed in Arizona, there are no significant differences in the overall patch rating among the various individual materials, although the cementitious materials (Type III PCC, Duracal, Set-45, and Five Star HP) have significantly different overall patch ratings than the polymer materials (MC-64 and Percol FL).

The significant differences in the contrasts of overall patch rating for South Carolina can be interpreted by comparing the means for the contrasted groups. The average overall patch rating for patches placed with the saw-and-patch procedure is 8.84; for patches placed with the chip-and-patch procedure, it is 8.34. However, the Tukey analysis showed no statistically significant differences among treatments. A conservative approach to the interpretation of these results is to assume that there is really only a borderline significant difference in the overall patch rating between the saw-and-patch procedure and the chip-and-patch procedure.

The average overall patch rating for patches placed with the cementitious materials (Type III PCC, Duracal, Set-45, and Five Star HP) is 8.97; for patches placed with the polymer materials (MC-64 and Percol FL), it is 7.81. Therefore, the cementitious materials seem to have significantly better overall patch ratings than the polymer materials. However, the Tukey analysis showed no statistically significant differences in the overall rating among treatments. A conservative approach to the interpretation of these results is to assume that there is really only a borderline significant difference in the overall patch rating between the cementitious materials and the polymer materials. Therefore, it cannot yet be determined which of these two contrasted groups have better overall patch ratings.

Figure 45 shows the Tukey groupings of South Carolina cementitious and polymer patch performance differences in treatments at a 0.05 significance level, grouped by procedure. Although significant by treatment, the spalling rating Tukey groups show no identifiable difference between the saw-and-patch procedure and the chip-and-patch procedure, when grouped by procedure.

Figure 46 shows the Tukey groupings of South Carolina cementitious and polymer patch performance differences in treatments at a 0.05 significance level, grouped by material. Although spalling is significant by treatment, figure 46 shows no identifiably different materials, as all Tukey groups overlap.

For cementitious and polymer patches placed in Utah, table 17 shows that the overall patch rating for patches installed using the saw-and-patch procedure is not significantly different from the overall patch rating for patches installed using the chip-and-patch procedure. Table 17 also shows that the overall patch ratings for patches installed using the traditional saw-and-patch or chip-and-patch procedure are not significantly different from the overall patch rating for patches installed using the waterblast-and-patch procedure, which many state agencies consider to be an experimental procedure. Furthermore, for cementitious and polymer patches placed in Arizona, the cementitious materials (Type III PCC, Duracal, Set-45, and Five Star HP) have significantly different overall patch ratings than the polymer materials (MC-64 and Percol FL). However, the nonproprietary cementitious material (Type III PCC) does not have a significantly different overall patch rating than the proprietary cementitious materials (Duracal, Set-45, Five Star HP, and Pyrament 505).

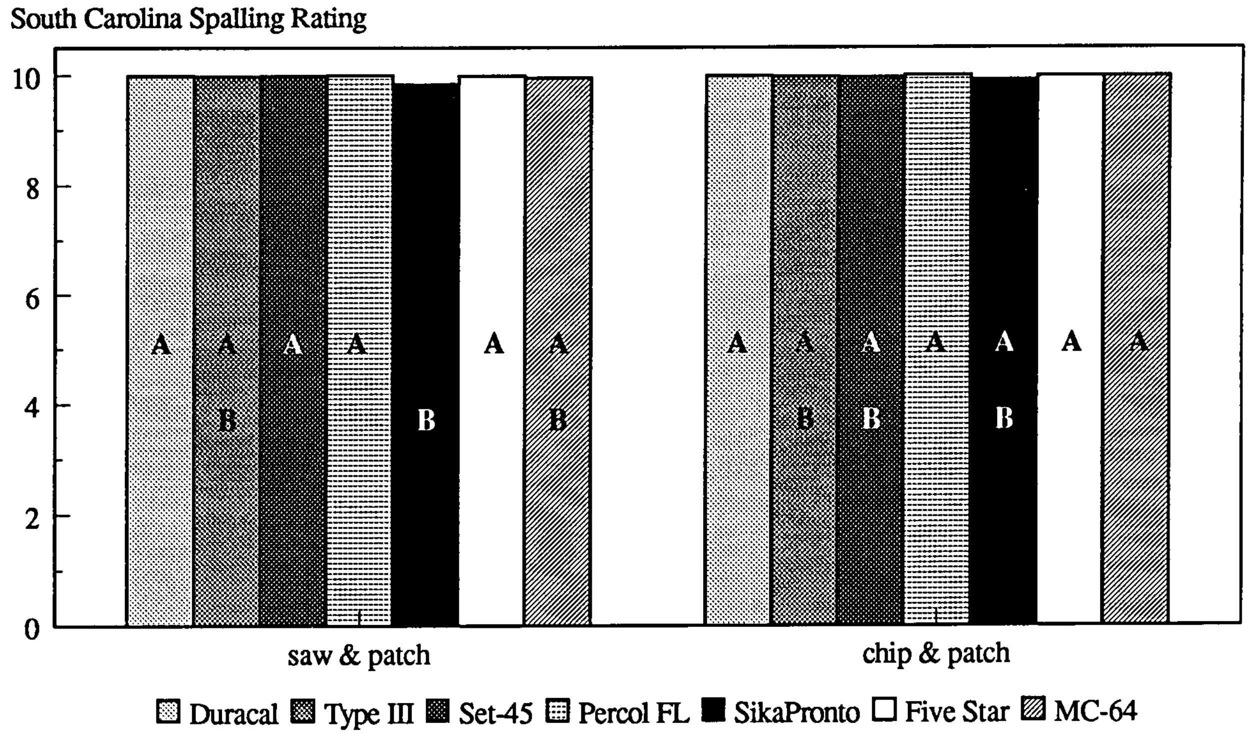


Figure 45. Tukey groupings of South Carolina cementitious and polymer spalling ratings, grouped by procedure

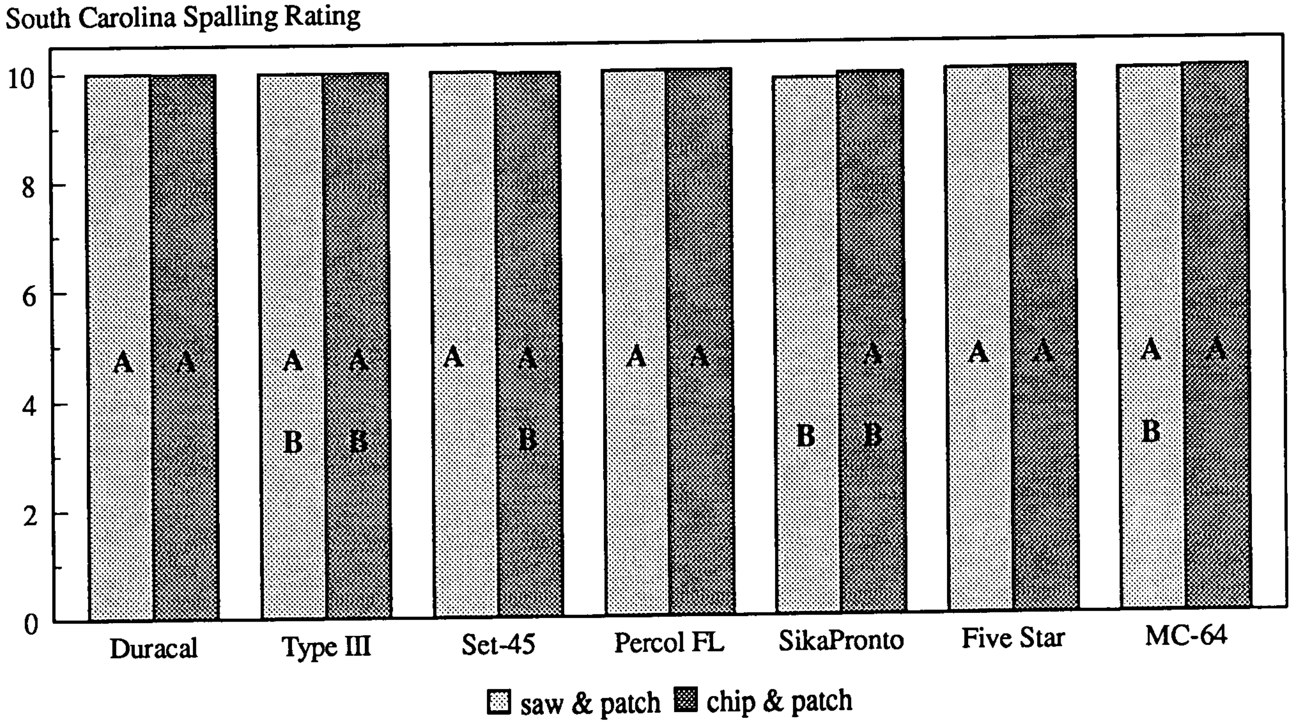


Figure 46. Tukey groupings of South Carolina cementitious and polymer spalling ratings, grouped by material

The significant differences in the contrasts of overall patch rating for Utah can be interpreted by comparing the means for the contrasted groups. The average overall patch rating for patches placed with the cementitious materials (Type III PCC, Duracal, Set-45, and Five Star HP) is 9.26; for patches placed with the polymer materials (MC-64 and Percol FL), it is 8.63. Therefore, the cementitious materials seem to have significantly better overall patch ratings than the polymer materials. However, the average overall patch rating for MC-64 is 9.61, while for Percol FL it is 7.65. Therefore, almost any material paired with Percol FL would have a mean substantially lower than 8.63 (the mean of the cementitious materials). Thus, MC-64 and Percol FL, although both polymer materials, are not a statistically appropriate grouping.

The Tukey groupings of Utah cementitious and polymer patch performance differences in the overall and bonding ratings at a 0.05 significance level are shown in figures 47 and 48, grouped by procedure. Figure 47 supports the lack of significant difference in overall rating found in the contrast between the saw-and-patch procedure and the chip-and-patch procedure, as the Tukey groupings of the two procedures overlap. Figure 48 also fails to distinguish among procedures, even though the bonding rating was significant by treatment.

The Tukey groupings of Utah cementitious and polymer patch performance differences in the overall and bonding ratings at a 0.05 significance level are shown in figures 49 and 50, grouped by material. Although significant by treatment, both figure 49 and figure 50 fail to show significantly different Tukey groupings among the materials, as there is a great deal of overlap.

A summary of patch survival percentages for each material-procedure treatment at the time of the final evaluation is shown in table 18. Survival curve plots for each material-procedure treatment are shown in figures 51 through 54. A statistical analysis was conducted on the patch survival percentages over time to determine whether there are significant differences among the repair types in each site. However, such an analysis and comparison of patch survival percentages is most effective when there is a high number of failures. As of the last evaluation, only 2.3 percent of all patches have failed. Because of the low number of failures, most patch types with failures showed no statistically significant difference in patch survival from patches with no failures. As failures continue over time, an analysis of performance based on survival rate will become more effective.

In Arizona, the early analysis of patch survival indicates that patches placed with the saw-and-patch procedure had a significantly lower patch survival percentage than the patches that had no failures. Under normal conditions in Pennsylvania, patches placed with the chip-and-patch procedure had a significantly lower patch survival percentage than the patches that had no failures. Under adverse conditions in Pennsylvania, no material-procedure combinations with failures showed a significantly different survival percentage than patches with no failures. In South Carolina, Percol FL patches placed with the chip-and-patch procedure showed a significantly lower patch survival percentage than the patches that had no failures. In Utah, there were no failures.

It is important to note that the survival analysis was conducted very early in the life of the patches. This analysis cannot be used to predict the expected life of the patches or even to

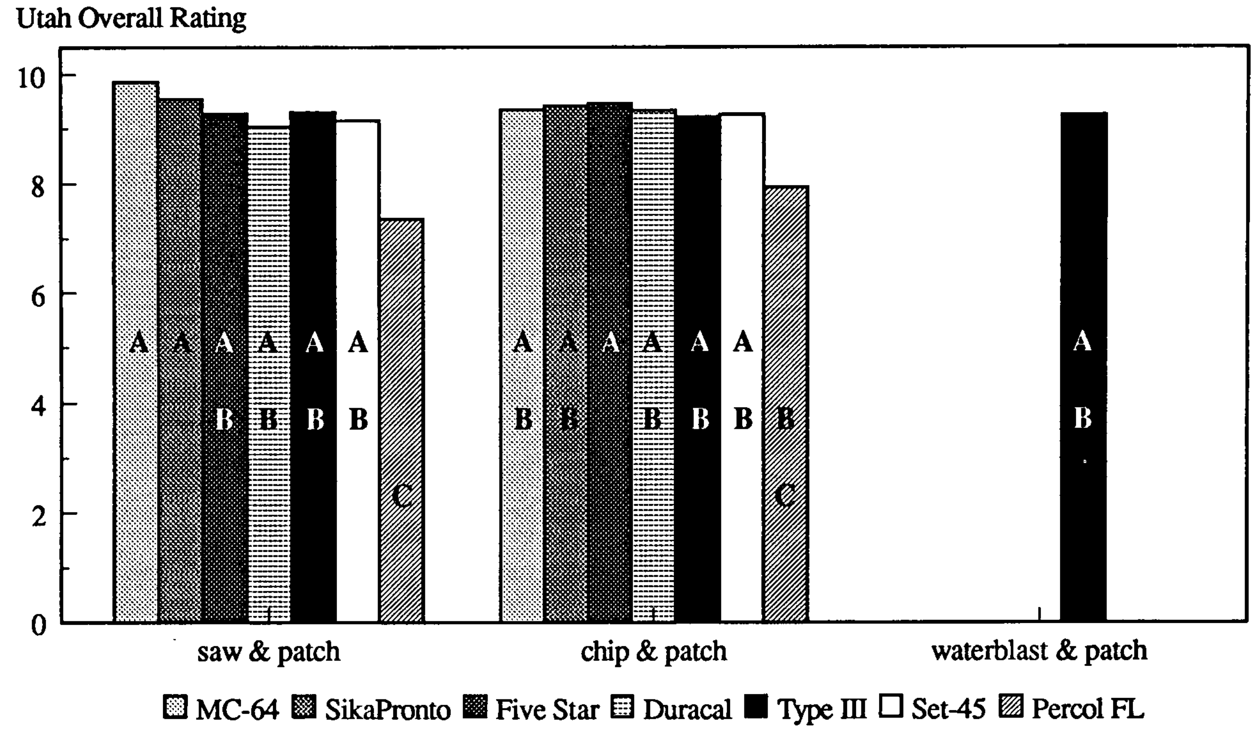


Figure 47. Tukey groupings of Utah cementitious and polymer overall ratings, grouped by procedure

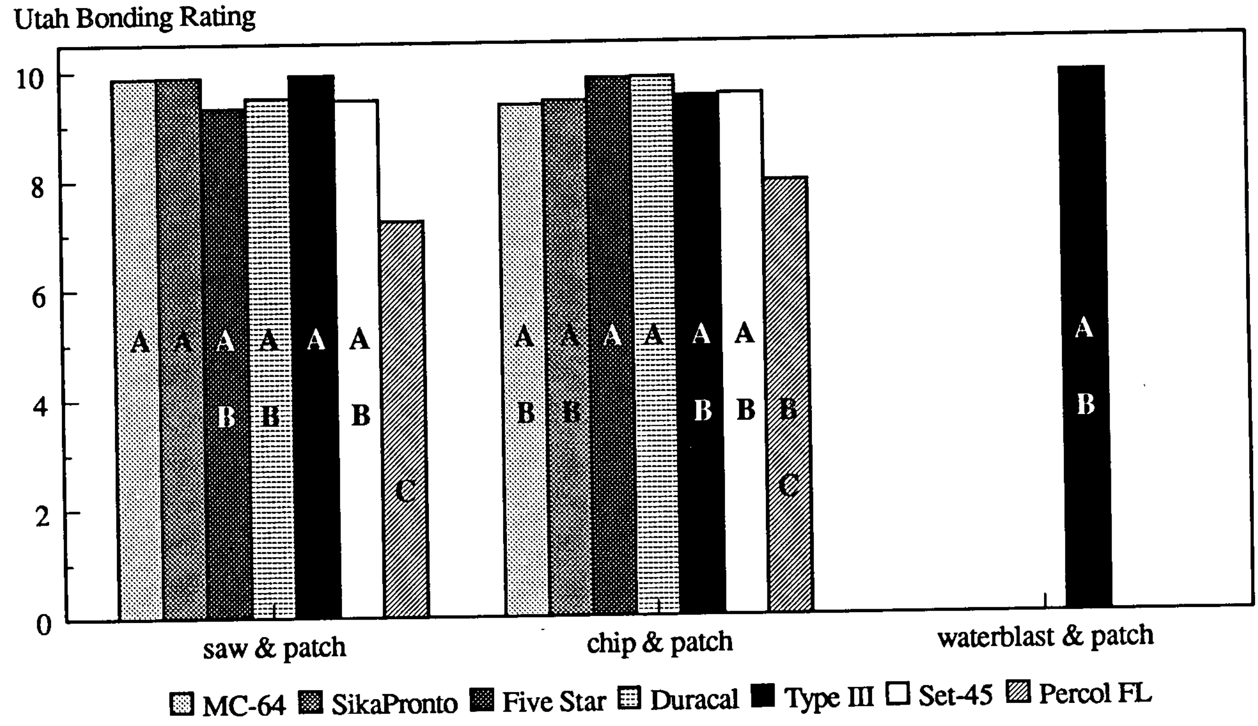


Figure 48. Tukey groupings of Utah cementitious and polymer bonding ratings, grouped by procedure

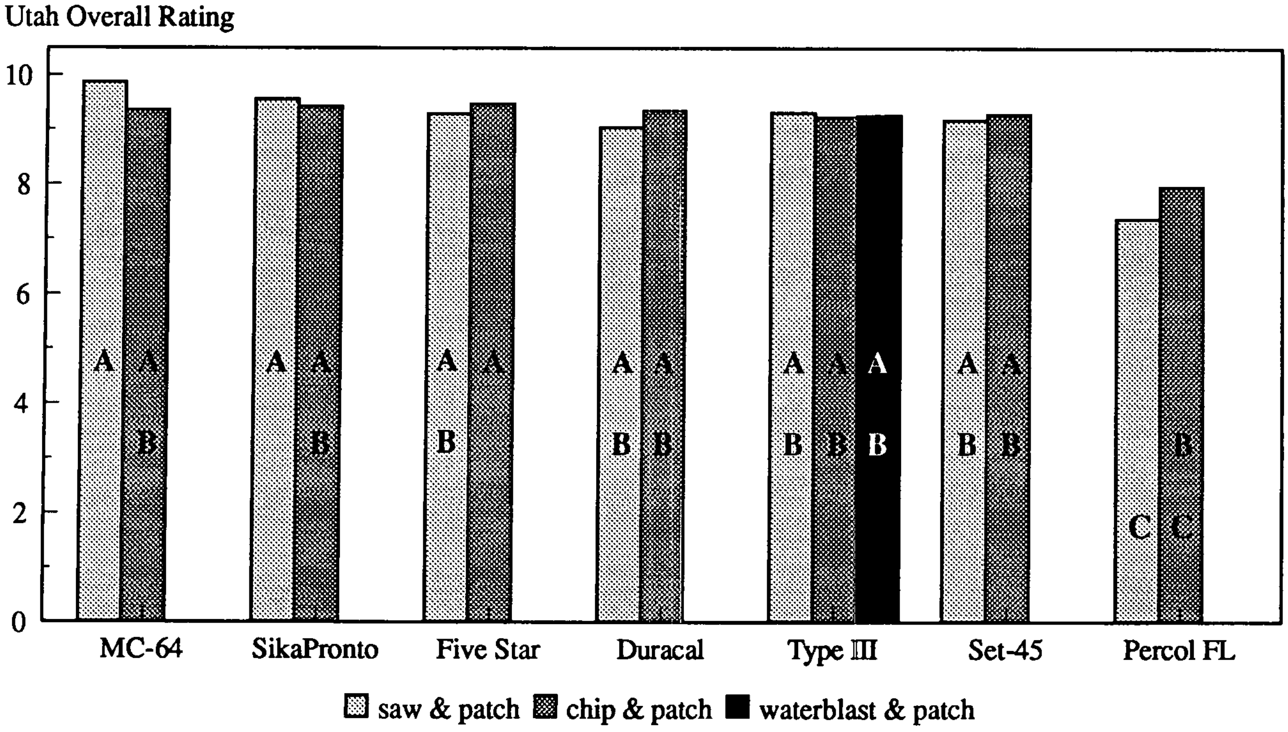


Figure 49. Tukey groupings of Utah cementitious and polymer overall ratings, grouped by material

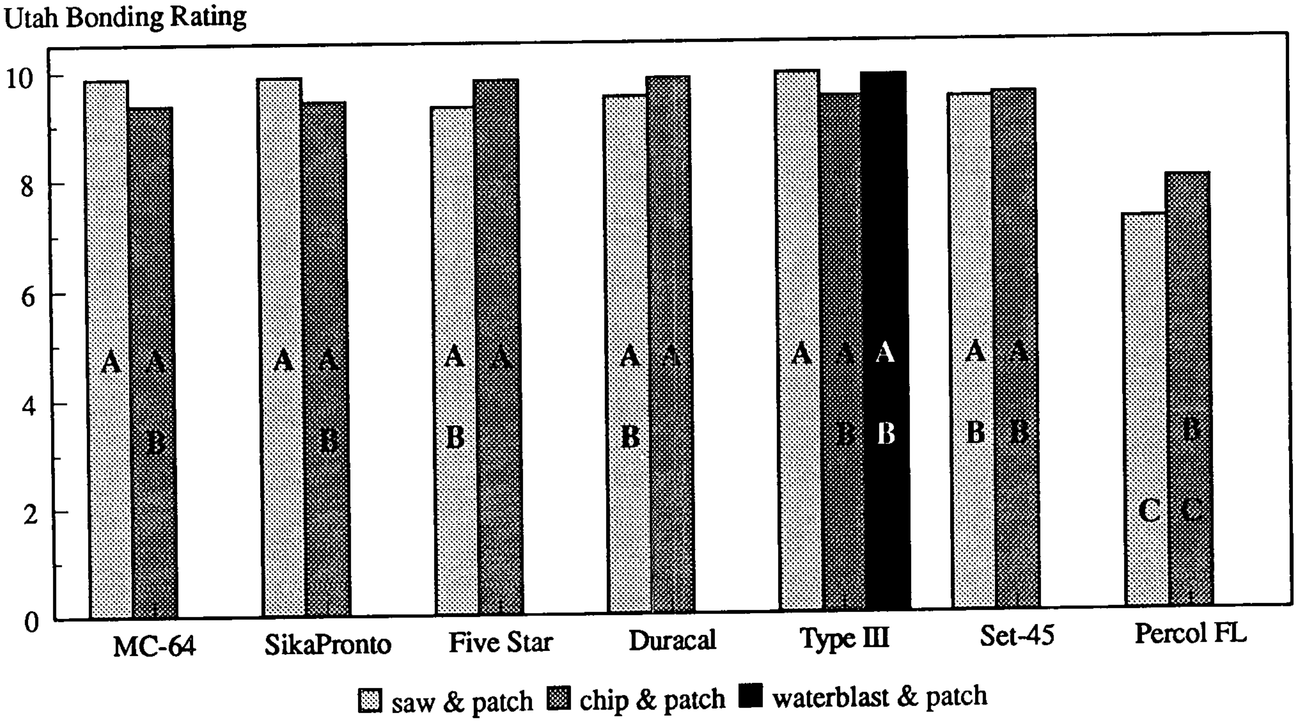
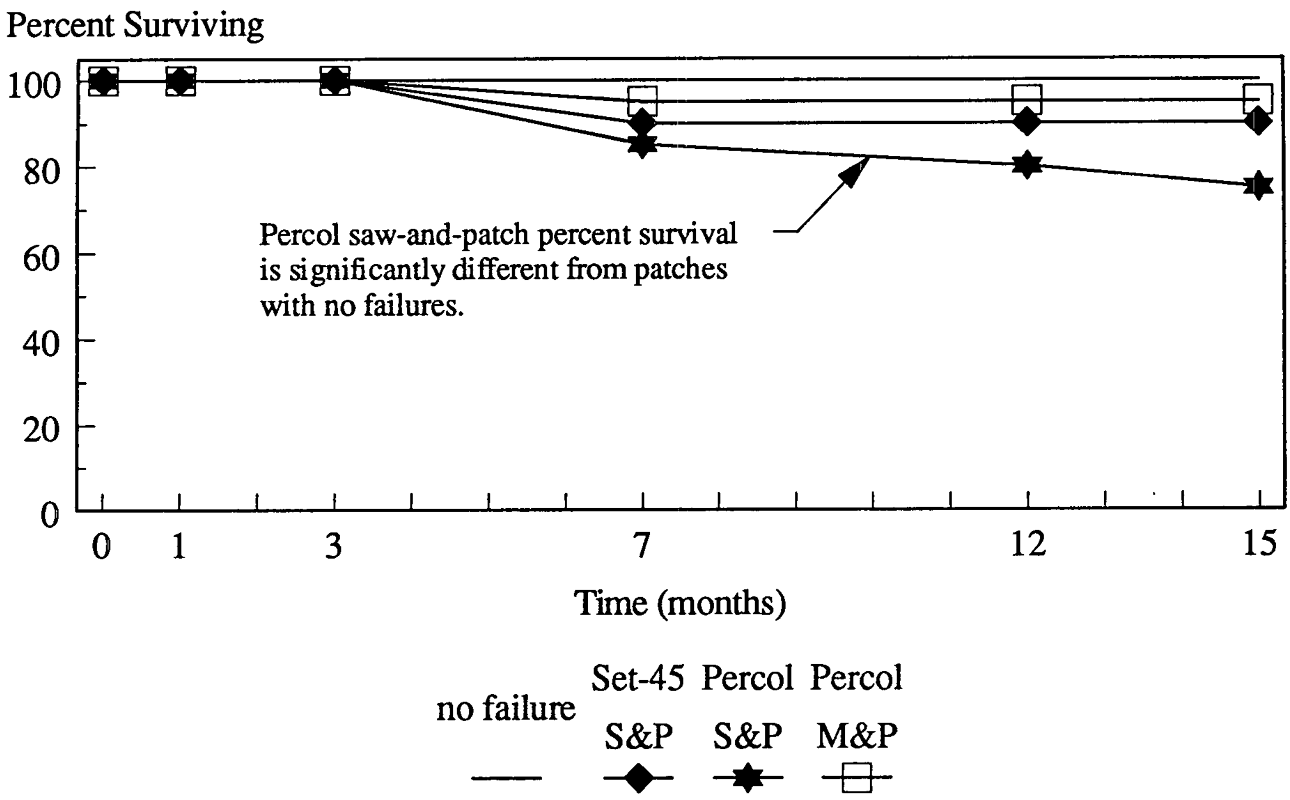


Figure 50. Tukey groupings of Utah cementitious and polymer bonding ratings, grouped by material

Table 18. Percent survival of patches at the time of the last evaluation

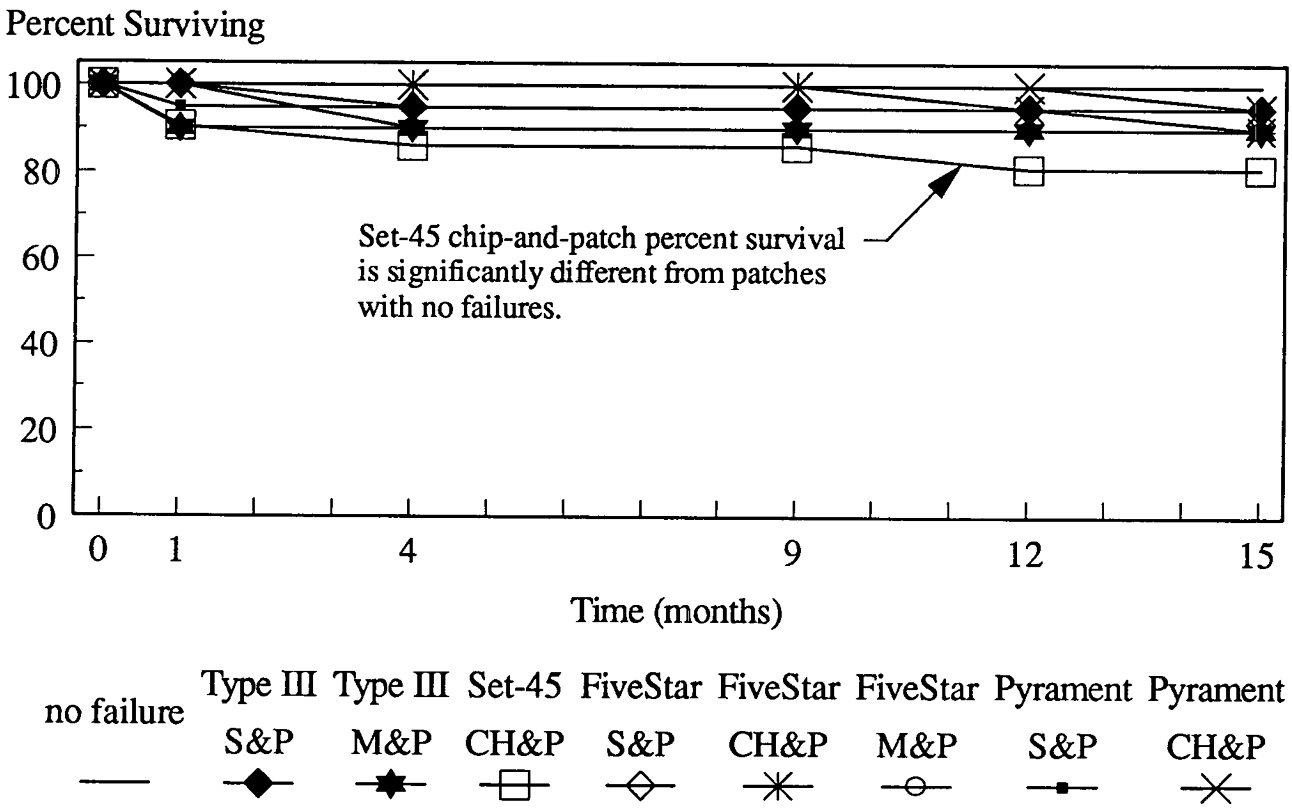
REGION	Wet-freeze (PA)				Dry-freeze (UT)			Wet-nonfreeze (SC)		Dry-nonfreeze (AZ)		
PATCHING PROCEDURE	S&P	CH&P	M&P	ADV	S&P	CH&P	W&P	S&P	CH&P	S&P	CH&P	M&P
Type III PCC	95	100	90		100	100	100	100	100	100	100	
Duracal					100	100		100	100	100	100	
Set-45	100	81	100		100	100		90	100	90	100	
Five Star HP	95	90	90		100	100		100	100	100	100	
MC-64	100	100			100	100		100	100	100	100	100
SikaPronto 11	100	100			100	100		100	100	100	100	
Percol FL	100	100	100	95	100	100		100	75	75	100	95
Pyrament 505	90	95		74								100
UPM High Perf. Cold Mix		100		100		100			100		100	
Penatron R/M-3003										100		
Spray-injection (AMZ)									100			
Spray-injection (Rosco)		100										

Note: S&P = saw and patch, CH&P = chip and patch, M&P = mill and patch, W&P = waterblast and patch, ADV = adverse-condition clean and patch.



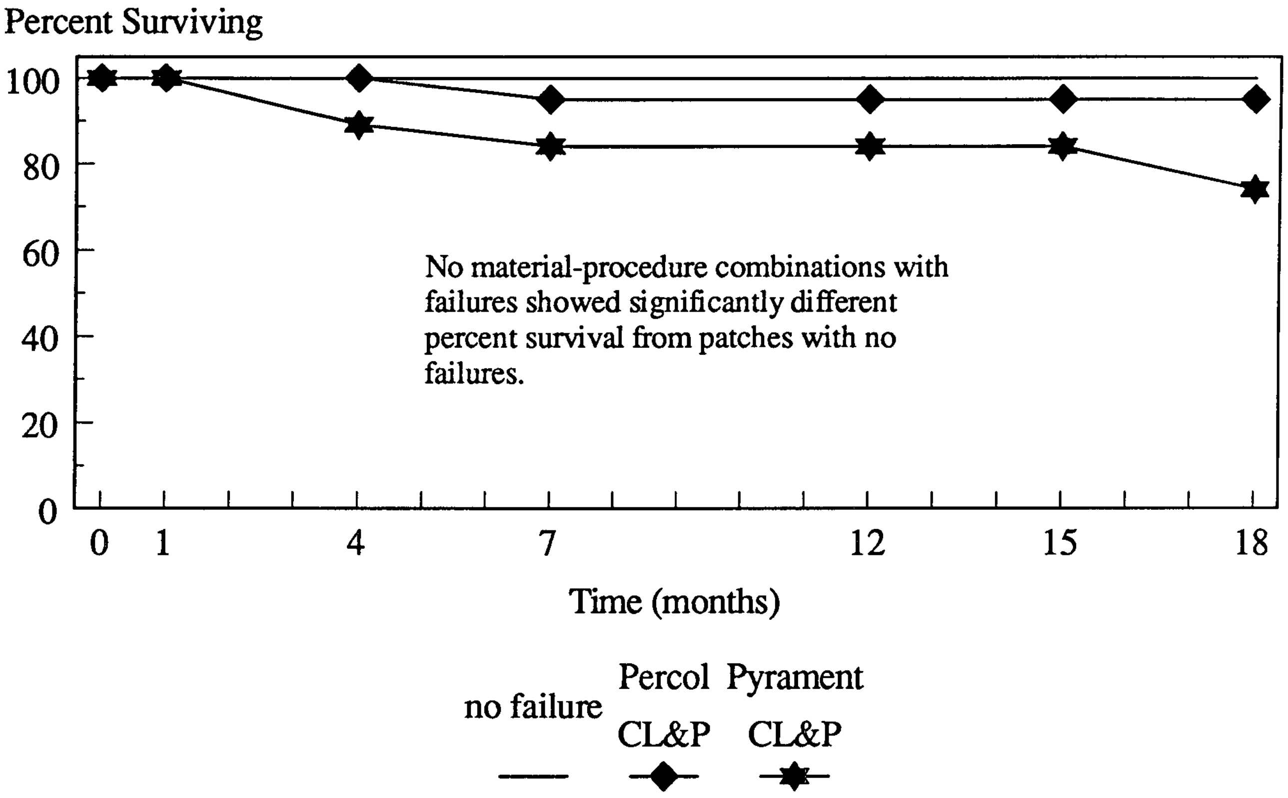
Percol saw-and-patch percent survival is significantly different from patches with no failures.

Figure 51. Arizona patch survival



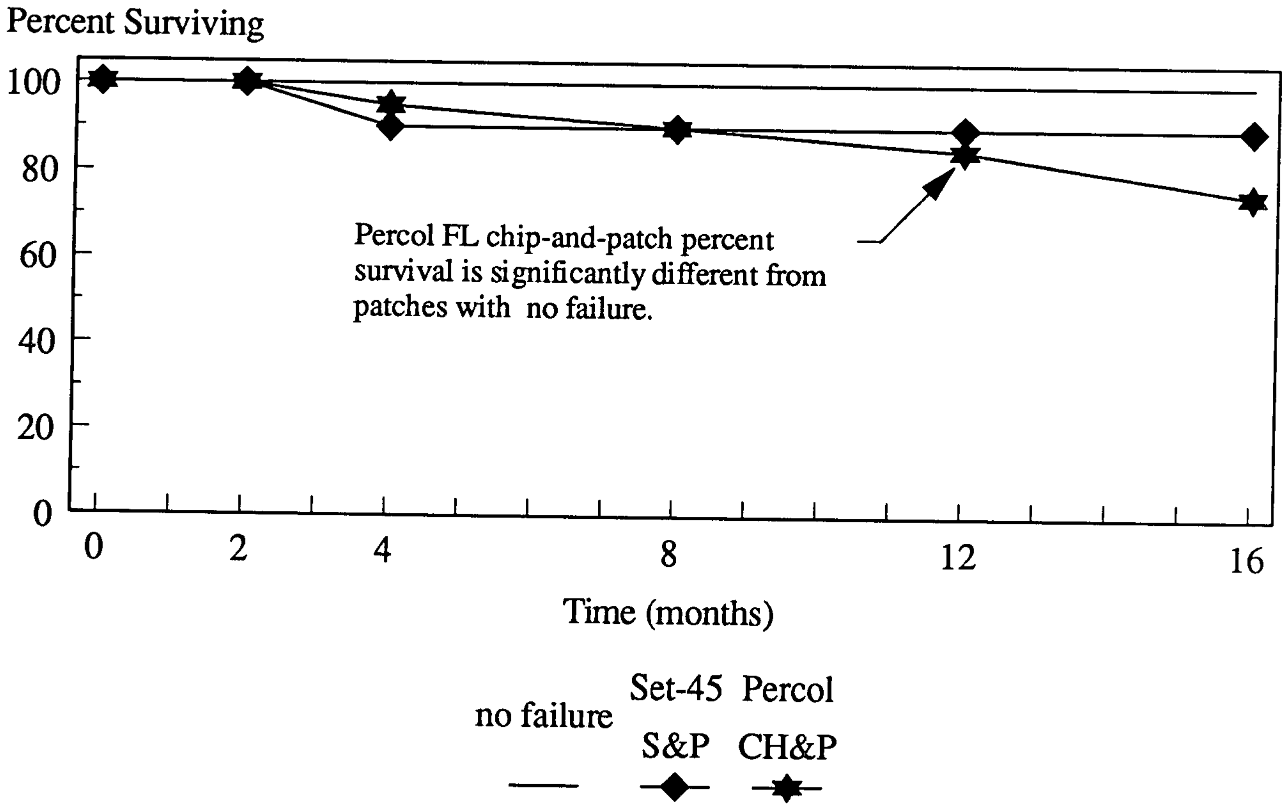
Set-45 chip-and-patch percent survival is significantly different from patches with no failures.

Figure 52. Pennsylvania patch survival (normal conditions)



No material-procedure combinations with failures showed significantly different percent survival from patches with no failures.

Figure 53. Pennsylvania patch survival (adverse conditions)



Percol FL chip-and-patch percent survival is significantly different from patches with no failure.

Figure 54. South Carolina patch survival

predict which patch type will show the best or worst long-term performance. The analysis only indicates how well the patches have survived throughout the short duration of the H-106 project.

The temperature at the time of installation of the cementitious patches placed under normal conditions was investigated as a covariate with the cementitious and polymer distress ratings, as well as the overall patch rating, and was found to be a significant factor (at $\alpha = 0.05$) with respect to the longitudinal cracking rating in Utah; temperature was not found to be a significant factor with respect to any ratings in Arizona, Pennsylvania, or South Carolina. Of the patches placed under normal conditions, table 19 shows that Utah did experience the lowest installation temperature of all the sites. This suggests that the severity of the cold temperature in Utah may have had an effect on the longitudinal cracking of the patching materials placed there. Covariation between the installation temperature and the various ratings should be investigated carefully in future analyses of performance data.

Laboratory-Performance Correlations

Comparisons between field performance and laboratory test measures were made to determine whether laboratory test results may be used as performance indicators. Table 20 shows the significant (at 0.05) correlations found between laboratory test measures and performance ratings. Figures 55 through 57 show that for Arizona the significant correlations are weak to moderate. Figures 58 through 60 show that for Pennsylvania the significant correlations that; are moderate to strong. Figures 61 through 63 show that for South Carolina the significant correlations are moderate to strong. Figures 64 through 66 show that for Utah the significant correlations are weak to moderate. Figures 67 through 71 show the significant correlations found when data from all sites are combined; the correlations are extremely low to weak. The strongest significant correlations were found between the overall rating in South Carolina and the 28-day compressive strength (0.92); the spalling rating in Pennsylvania and the 28-day compressive strength (-0.82); the overall rating in Pennsylvania and the 28-day slant-shear bond strength (-0.75); and the overall rating in South Carolina and the 28-day slant-shear bond strength (0.70). However, since there is no consistent sign (positive-negative) to the correlations, conclusions on which laboratory properties are good indicators of field performance are not possible at this time. Because of the higher correlations found, future analyses of performance data should definitely include the 28-day compressive strength and the 28-day slant-shear bond strength.

Productivity

Observations of the installation process were made to help determine the productivity of different partial-depth patching operations. During the four installations, data were collected on the installation productivity of the different crews; two were state agency crews and two were contracted crews. The crews were observed during various patching operations. The times for the operations were recorded, along with information on the volume of repair materials placed. There was a great deal of variation in the productivity data as a result of

Table 19. Maximum and minimum installation temperature by site and conditions

Site	Installation Conditions	Maximum Temperature (°F)[1]	Minimum Temperature (°F)[1]
Arizona	normal	88	63
Pennsylvania	normal	102	61
Pennsylvania	adverse	68	25
South Carolina	normal	100	62
Utah	normal	70	42

[1] °C = (°F - 32) × 5 / 9

Table 20. Correlations between lab properties and distress ratings

Laboratory property	Rating	AZ[1]	PA[1]	SC[1]	UT[1]	All
28-day compressive strength	Overall	0.53	-0.54	0.92	0.54	0.28
	Spalling	-0.36	-0.82	0.58	0.68	0.32
28-day slant-shear bond strength	Overall	0.46	-0.75	0.70	0.53	0.17
	Bonding	▨	▨	▨	▨	0.18
28-day center-point bond strength	Overall	▨	▨	▨	▨	0.04
	Bonding	▨	▨	▨	▨	-0.10

[1] Shaded cells indicate no significant correlation at 0.05.

variation in the number of workers in the crews, type of traffic control, and quantity and quality of equipment at each of the four test sites. There was also variation in these parameters in each test site over the duration of the installation. These variations statistically confound the productivity data, making it impossible to statistically analyze the productivity of various segments of the partial-depth spall repair process for the purpose of comparing the cost-effectiveness of procedures and materials. Consider this simple example: If procedure A takes longer to perform than procedure B, but the equipment used in procedure A suffered numerous breakdowns, it cannot be concluded that procedure B is faster to use than procedure A. Furthermore, although material performance may be expected to vary between sites because of site-specific characteristics such as climate, drainage, and pavement cross-section, patch preparation time and material placement time would not be expected to vary between

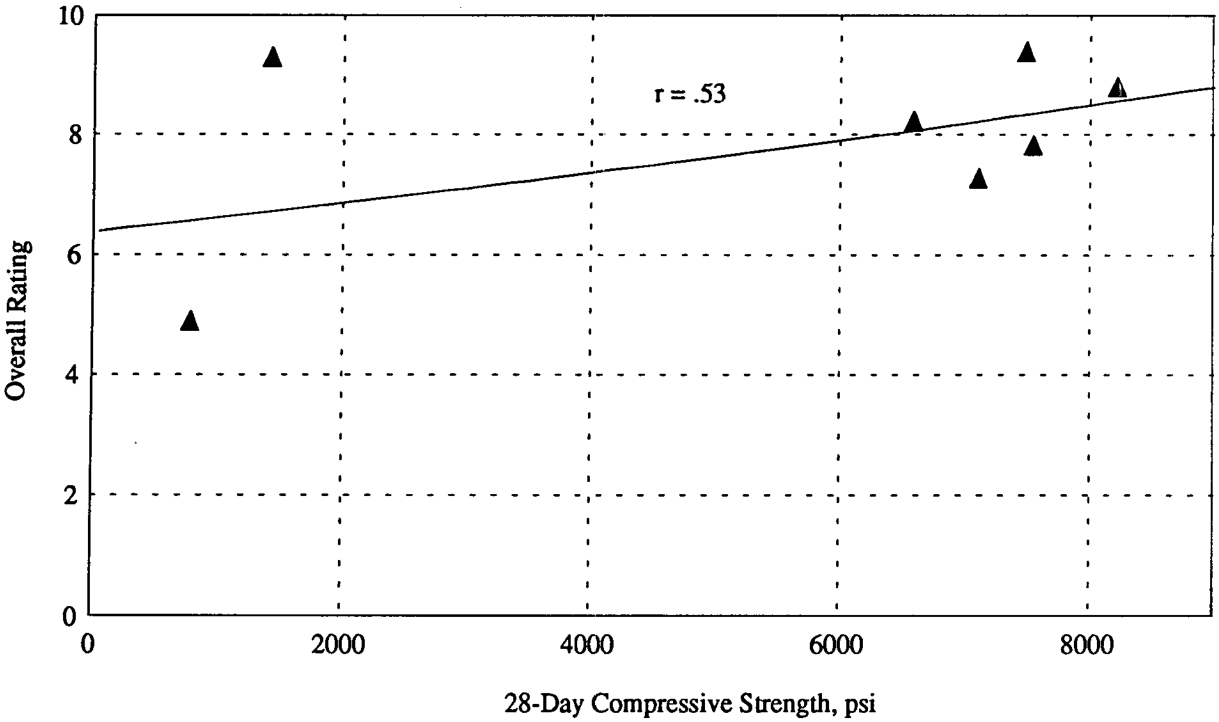


Figure 55. Arizona overall rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

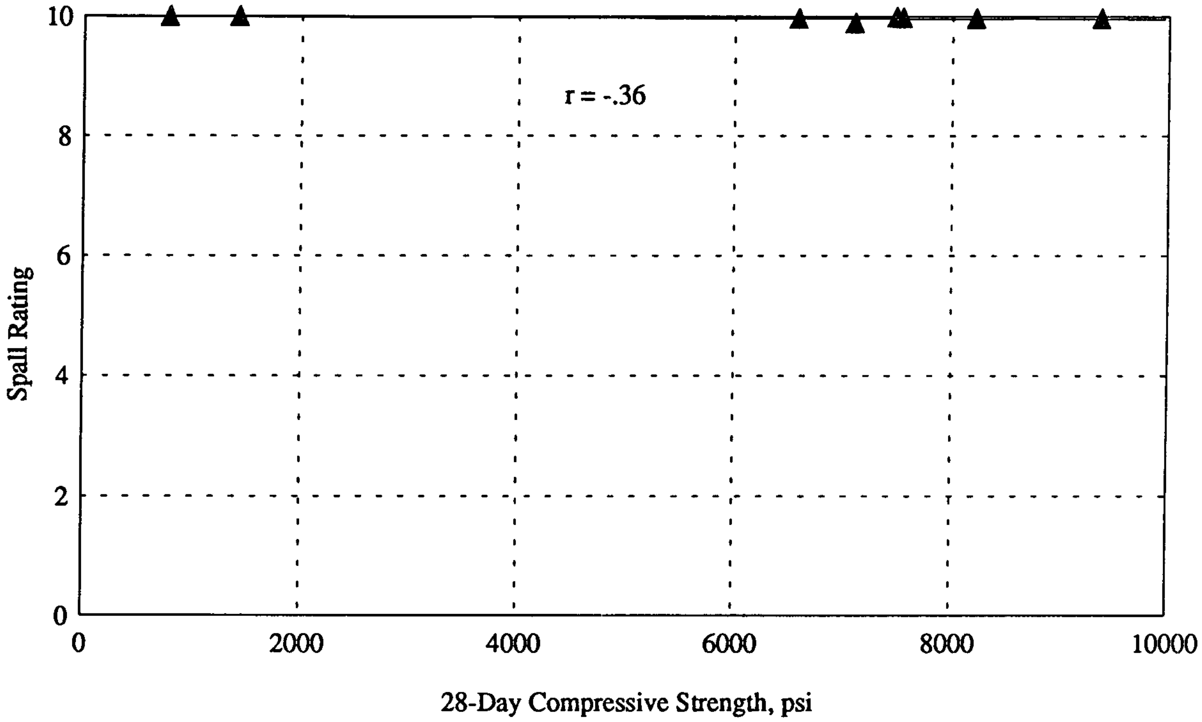


Figure 56. Arizona spalling rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

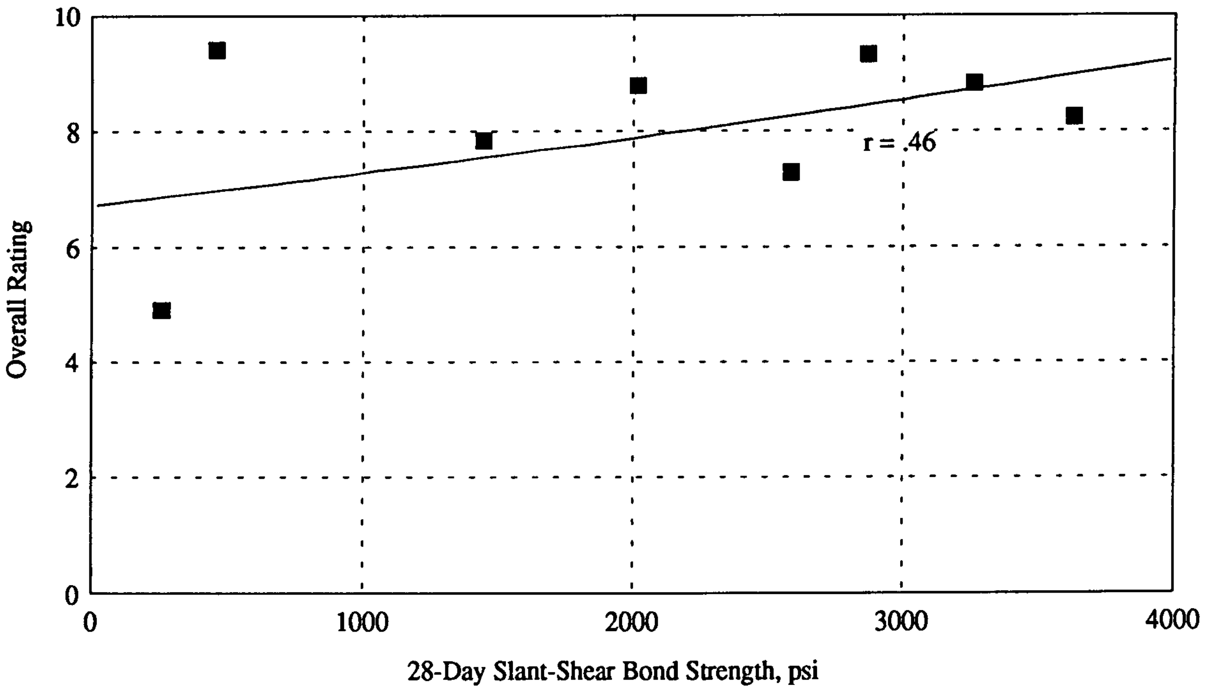


Figure 57. Arizona overall rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

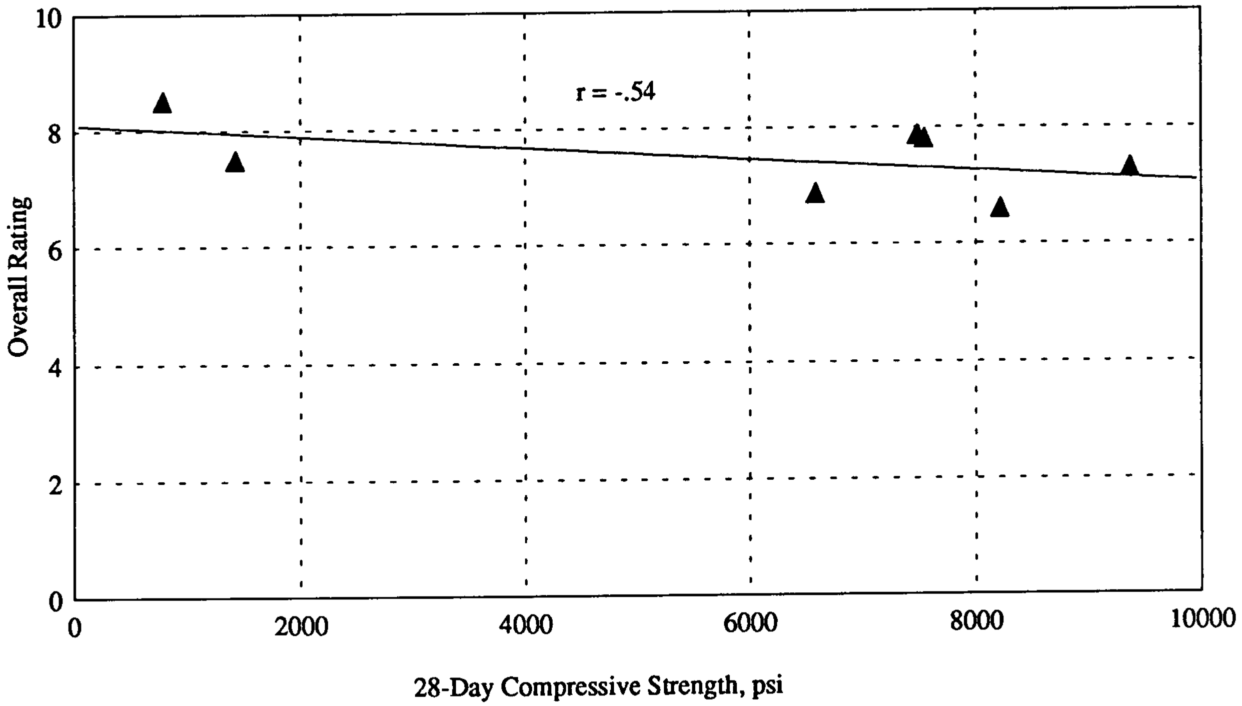


Figure 58. Pennsylvania overall rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

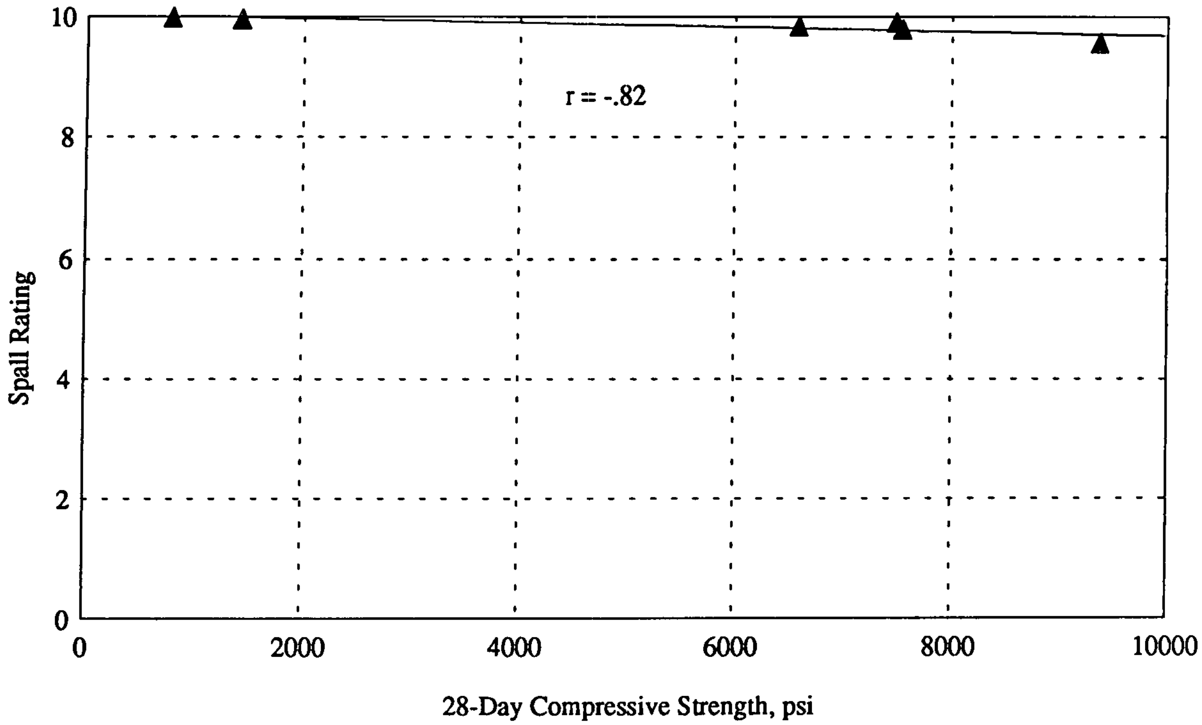


Figure 59. Pennsylvania spalling rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

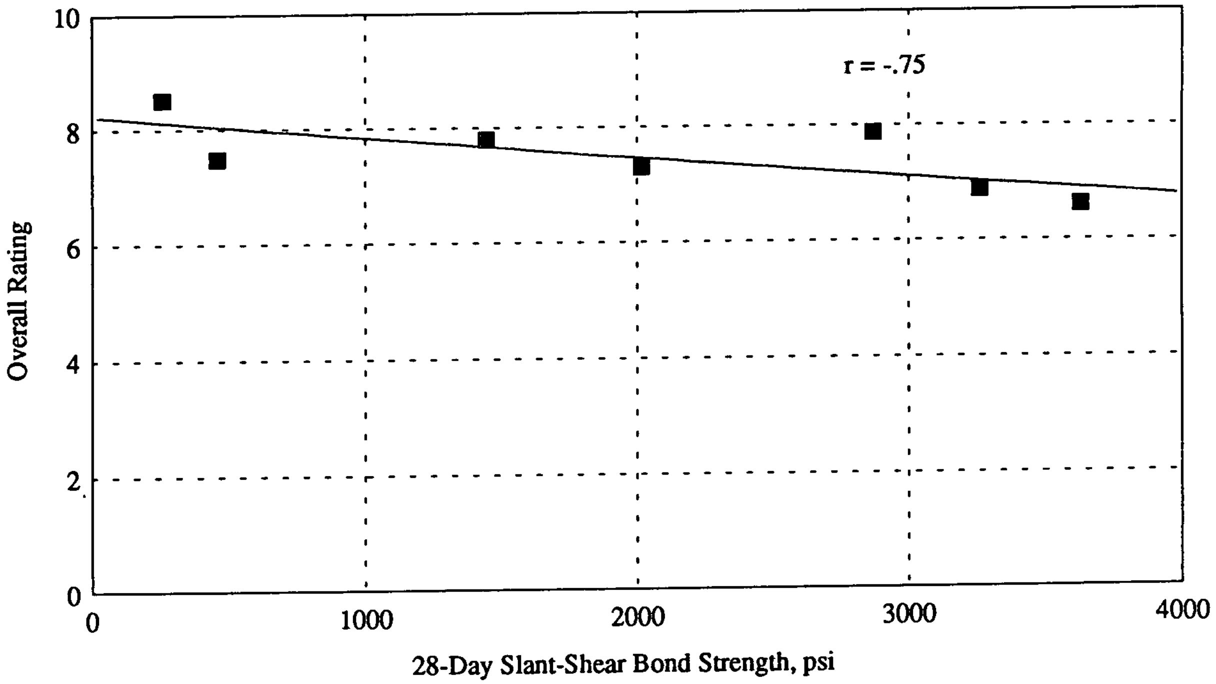


Figure 60. Pennsylvania overall rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

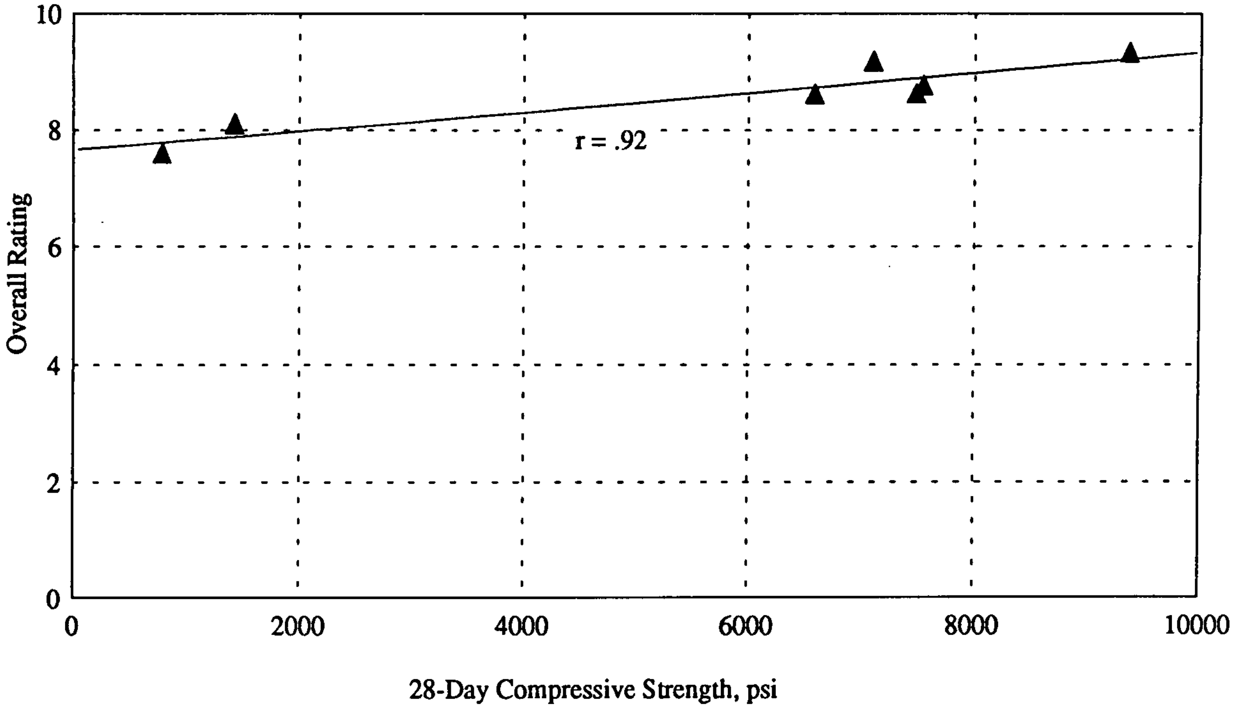


Figure 61. South Carolina overall rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

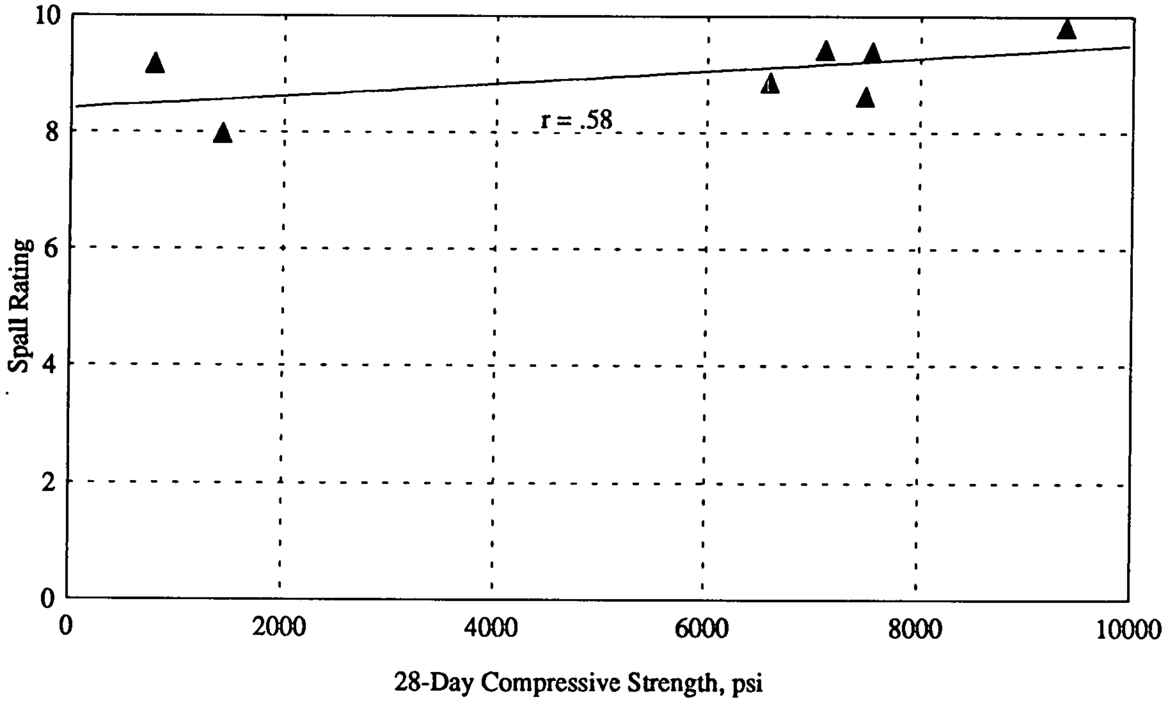


Figure 62. South Carolina spalling rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

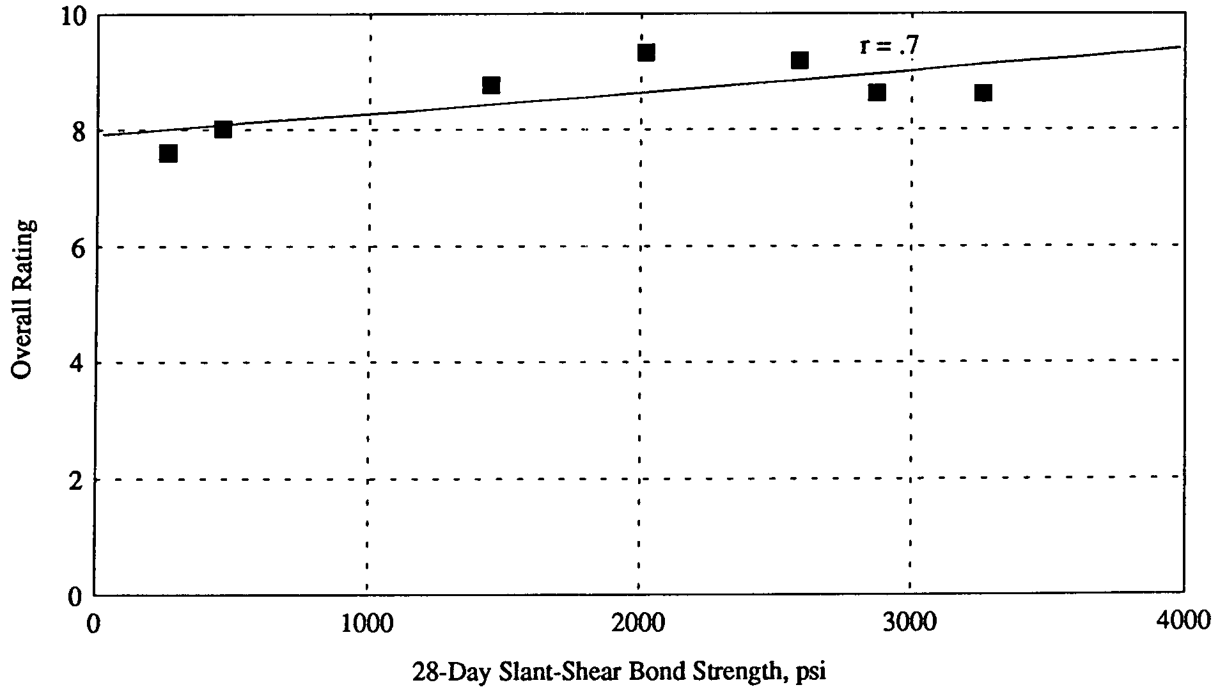


Figure 63. South Carolina overall rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

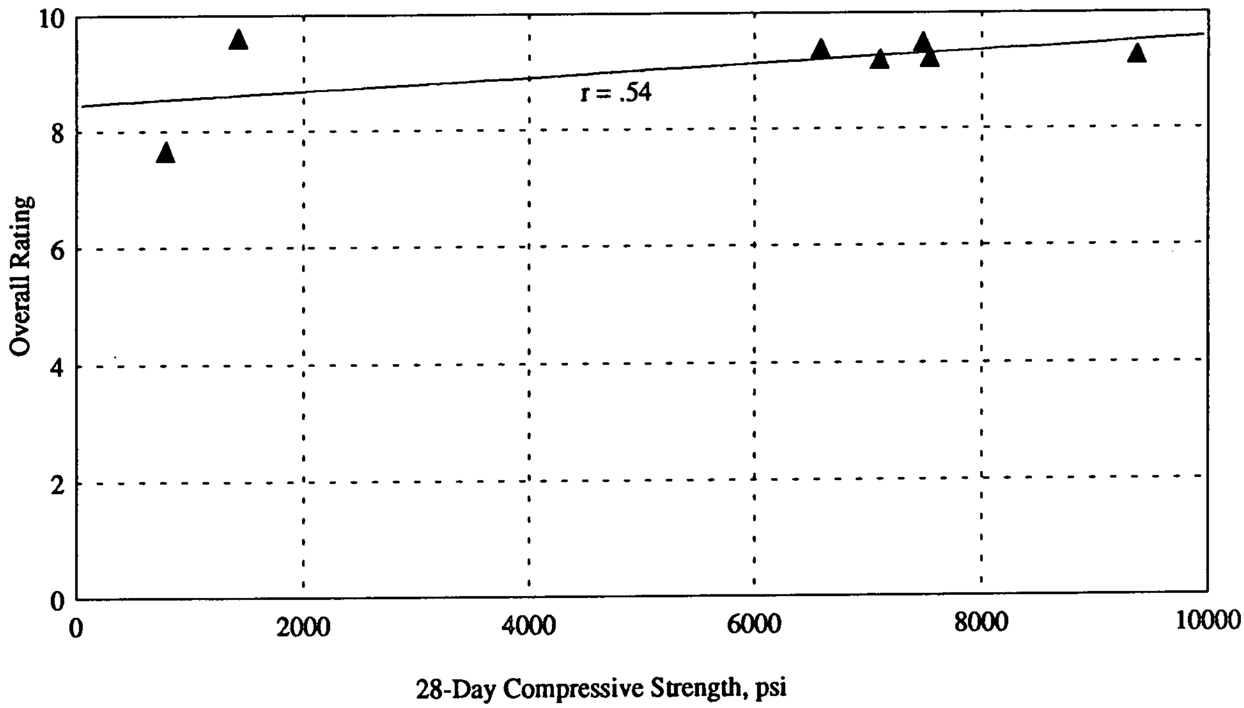


Figure 64. Utah overall rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

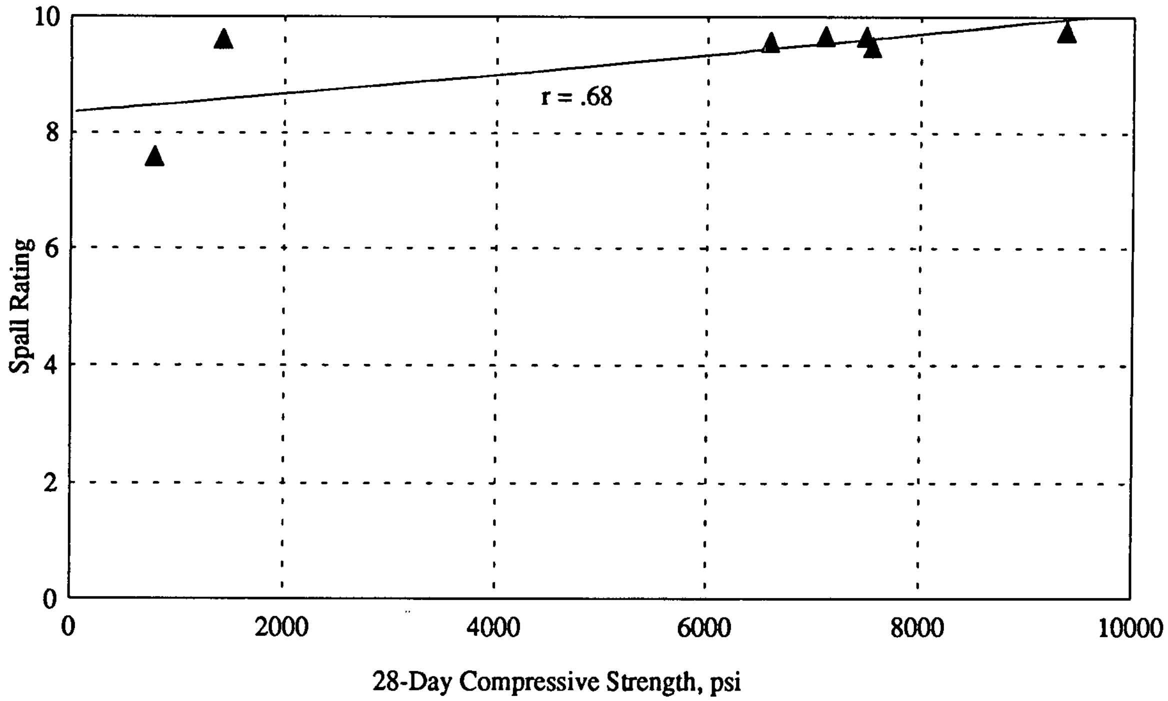


Figure 65. Utah spalling rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

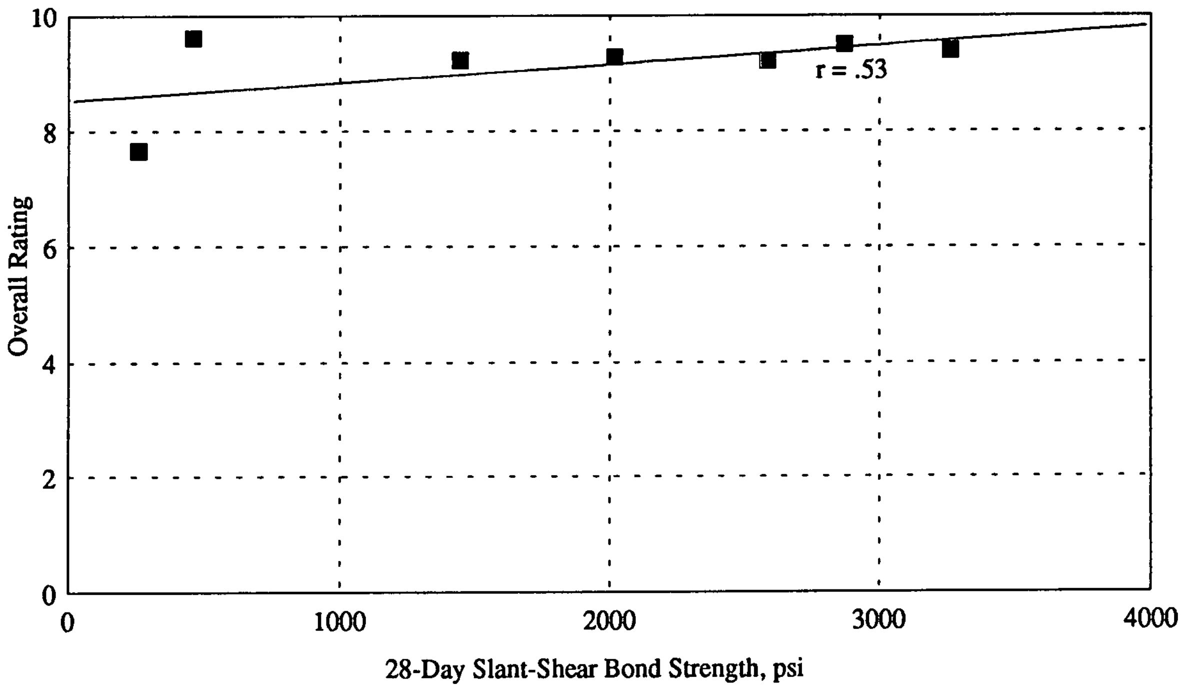


Figure 66. Utah overall rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

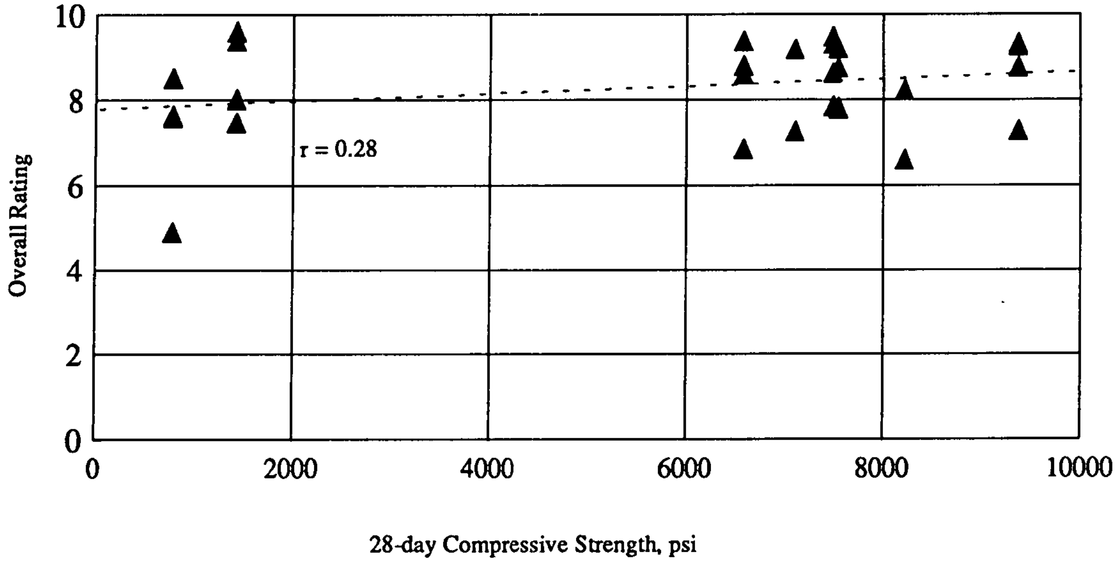


Figure 67. All sites overall rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

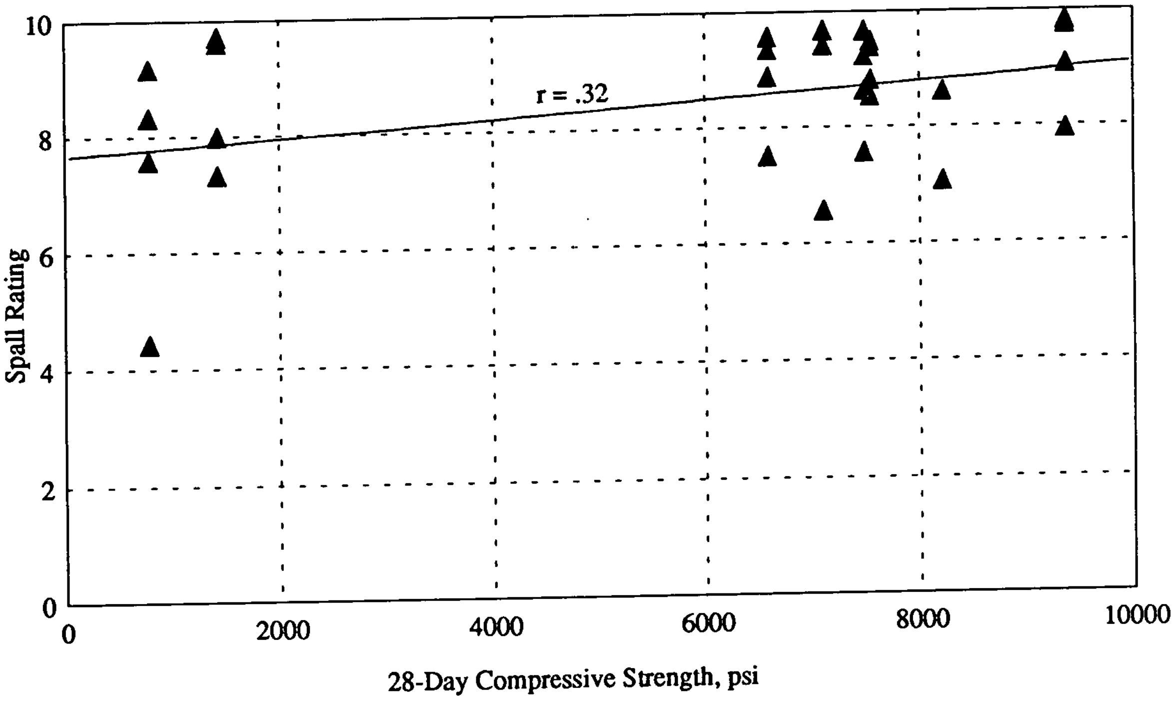


Figure 68. All sites spalling rating vs. 28-day compressive strength (1 psi = 6.89 kPa)

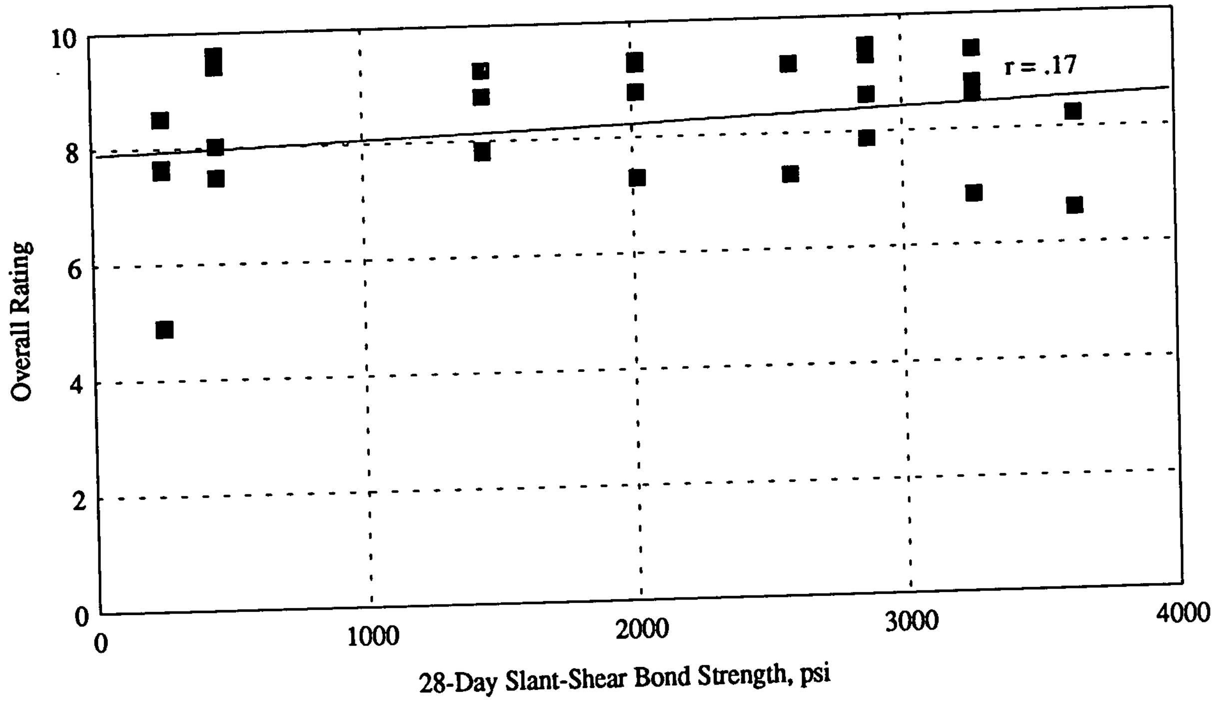


Figure 69. All sites overall rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

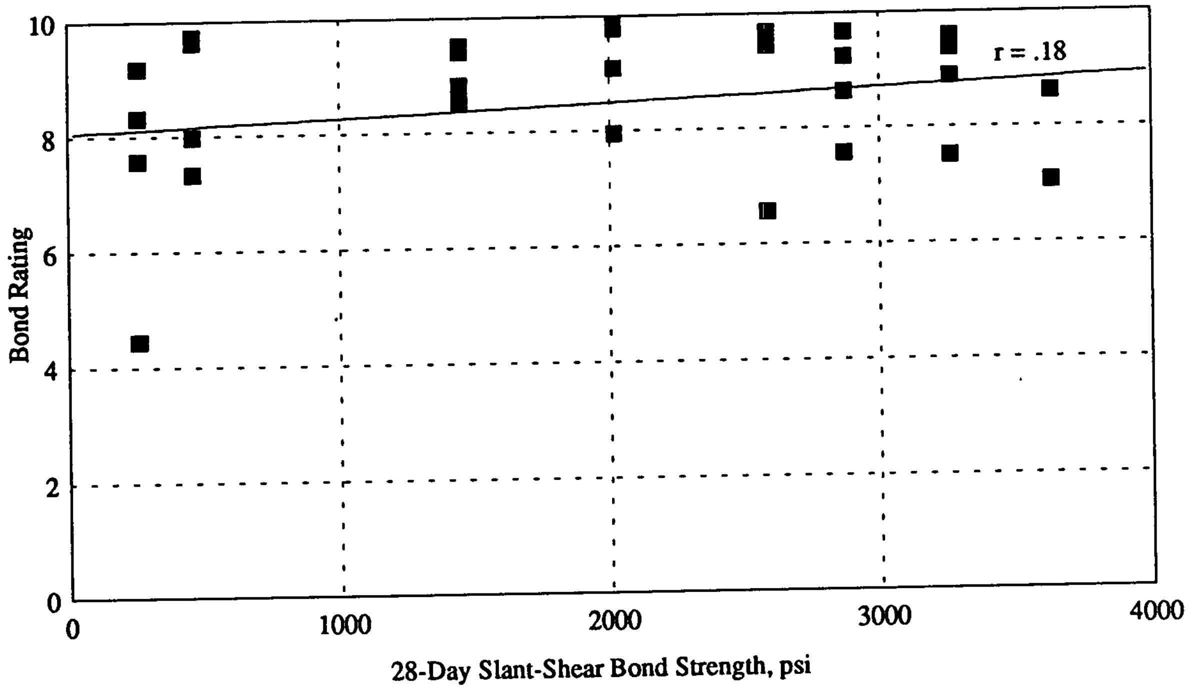


Figure 70. All sites bonding rating vs. 28-day slant-shear bond strength (1 psi = 6.89 kPa)

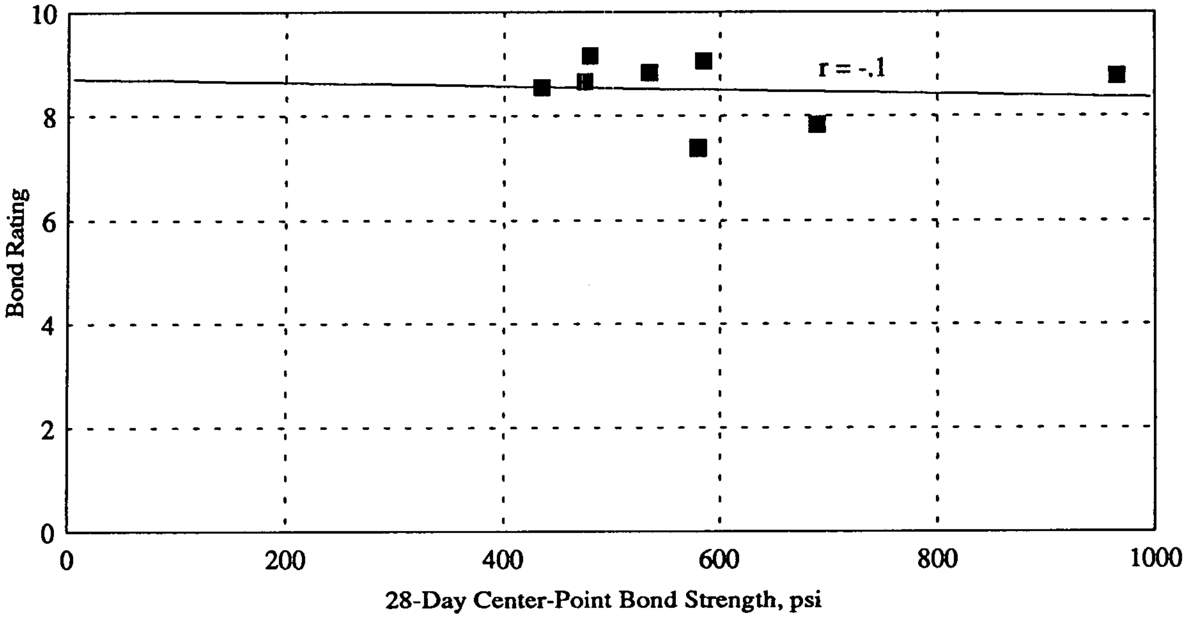


Figure 71. All sites bonding rating vs. 28-day center-point bond strength (1 psi = 6.89 kPa)

sites because of site-specific characteristics, although they would be expected to vary because of differences in crew and equipment. In short, there are too many confounding variables that obscure significant differences in productivity among the various partial-depth spall repair operations and render a statistical analysis of the productivity data impossible.

Although an analysis of the comparative placement productivity per material cannot be done, the average cubic feet of patching material placed per hour and the average number of patches placed per hour are presented for illustrative purposes in table 21 for two of the test sites: a contracted site (Arizona) and a site installed by a state agency (South Carolina). Many factors should be considered when interpreting table 21. The confounding factors include the temperature during placement, the size and power of the equipment, the distance between repairs, and the number of personnel allocated for material placement. For example, table 21 indicates that the placement rate in South Carolina for Five Star and Set-45 is much higher than the placement rate for Type III PCC and Duracal. However, this higher rate was strongly influenced by the set time for these materials; in order to prevent Five Star and Set-45 from quick-setting at the high temperatures experienced during placement, up to five crew members were required to work very quickly. Even then, the materials occasionally set before they could be properly consolidated. Another example of a confounding factor would be the use of three Jiffy mixers in Arizona compared to the use of two Jiffy mixers in South Carolina for mixing MC-64. Furthermore, the cleanliness of the aggregates used in Percol FL influenced the placement rate for this material. In Arizona, a great deal of time was required to increase the cleanliness of the aggregate prior to placement, whereas in South Carolina the aggregate was cleaner and this additional time was not needed. These are just a few of the confounding factors regarding the productivity rates shown in this table.

Table 21. Comparison of patching material placement rates between a contracted site (Arizona) and a site installed by a state agency (South Carolina)

Material	Average cubic feet placed per hour[1]		Average number of patches placed per hour	
	Arizona	South Carolina	Arizona	South Carolina
Type III PCC	71	60	13	7
Duracal	160	87	20	9
Set-45	113	125	13	17
Five Star HP	147	173	15	25
MC-64	76	45	9	5
SikaPronto 11	119	89	22	11
Percol FL	86	113	11	15
Pyrament 505	106		11	
UPM High Performance Cold Mix	87	96	14	14
Spray-injection (e.g., AMZ, Rosco)		198		27
Penatron R/M-3003	114		16	

[1] 1 ft^3 = 0.28 m^3.

Cost-Effectiveness

Some of the major elements that influence the cost-effectiveness of a partial-depth spall repair operation include:

- Labor rates
- Material purchase cost
- Material shipping cost
- Productivity of the maintenance crew
- Total volume of partial-depth patches to be filled
- Equipment cost
- Performance characteristics of the patches (based on material-procedure combination)

These factors are used to calculate the cost-effectiveness of the repair operation for a specific time frame. A convenient time frame may be 1 year because of the existence of yearly budgets for most agencies involved in maintenance and because so few partial-depth patches have failed in this experiment that the performance characteristics, in particular the survival rate, has yet to be determined. However, once survival rates become known and because partial-depth patches generally have a life of at least several years, the use of longer time frames will allow the performance characteristics of the patches to affect the calculation of cost-effectiveness. A method of calculating patch survival rates is shown in appendix E.

The cost-effectiveness of various partial-depth patching operations can be calculated and compared using the cost-effectiveness worksheet included in appendix E. The following section contains an overview of the inputs necessary to complete the calculation of cost-effectiveness.

Labor Rates

The cost of labor for a partial-depth patching operation is usually determined by the experience and seniority of the crew members, and by the number of crew members who are actually involved in the patching operation. For a calculation of cost-effectiveness, the information on labor rates should be available on a per-day basis. The value of labor rates should be determined for the entire patching crew, including supervisors, so that the labor rate can be multiplied by the number of days anticipated for patching during the selected time frame. This calculation will result in a total cost for the patching operation over the duration of the selected time frame.

Material Purchase and Shipping Cost

For each type of repair material available to an agency, there will be a purchase cost associated with it that can be expressed in dollars per unit weight or volume. In addition to the purchase cost, there may be some cost associated with shipping the material from the source of its production to the agency's maintenance yard. The total cost of purchasing and shipping the repair materials should be used in the calculation of cost-effectiveness.

Productivity of the Patching Operation

Every partial-depth patching crew has a different average productivity rate. One way to estimate the average productivity rate is by dividing the total volume or number of partial-depth patches placed per season by the total days spent patching. The value can be expressed in terms of number of patches placed per day.

Total Quantity of Patches to be Repaired

This value is intended to represent only the new spalls that develop during the given time frame and should not include repeat patching. For calculating total patching costs, this value should be in total volume of finished patches of material.

Equipment Cost

Depending on the type of patching operation performed, different types of equipment are needed. The use of trucks, air compressors, hand tools, diamond-blade saws, jackhammers, sand- and airblasters, spray-injection machines, milling machines, and waterblasting machines all have associated costs. For calculating patching costs, the dollar-per-day rate for all necessary equipment should be used.

Performance Characteristics of the Patches

To calculate the performance of partial-depth patches, survival data and curves are required. The number of surviving patches for each material-procedure combination of interest is plotted against time over a given time frame. The survival percentage for each material procedure combination is the area under each survival plot divided by the area under a 100 percent survival plot. The areas can be calculated for any time span, as long as the actual survival plot and the 100 percent survival plot use the same time frame.

However, so few patches have failed that the survival curves for the material-procedure combinations are virtually identical. The failure rate now will not necessarily be indicative of the failure rate throughout the next several years. Until additional failures occur, agency experience must be applied.

Comments

A final factor to consider is that the Pennsylvania site differed from the other three sites in a few notable ways. One way it differed is that it was the only site at which patches were installed under adverse conditions several months before the normal-condition installations were completed. However, a factor that affects the patches installed in Pennsylvania under both normal and adverse conditions is the number of partial-depth patches that were used to repair spalls in which dowel bars were showing.

The original intent of the experiment was to conduct research on true partial-depth spalls, as this is what theory suggests is appropriate. However, it is common knowledge that partial-depth patches often are placed when theory would prescribe the placement of full-depth patches. One reason for this practice is that maintenance crews seldom arrive on a stretch of highway prepared to place both partial-depth and full-depth patches; the two procedures require different materials and procedures and it is usually impractical to be prepared to do both. This was exactly the case at all sites: the crews were prepared to do partial-depth spall repair only. However, Pennsylvania had a much higher number of spalls that required full-depth patches than the other sites; 70 percent of the spalls in Pennsylvania had dowels visible by the time all the unsound concrete had been removed, whereas Arizona had only 0.5 percent, and South Carolina and Utah each had 0 percent.

It is worth noting that the Pennsylvania site had the highest failure rate percentage of the four sites: 4.7 percent, compared with Arizona's 2.1 percent, South Carolina's 2.2 percent, and Utah's 0 percent of patches failed. However, a 4.7 percent failure rate is still low, considering that the adverse-condition patches placed only in Pennsylvania increased the failure rate there, as would be expected. Although it is still very early in the life of the Pennsylvania patches, this low failure rate suggests that the practice of placing partial-depth patches, when theory recommends full-depth patches, may not be as detrimental to patch performance as has been thought previously. Unfortunately, it was not possible to conduct an analysis of significant differences in patch performance for patches that were placed with dowels showing and patches that were placed in true partial-depth spalls, because of the imbalanced number and distribution of the true partial-depth spalls among the material-procedure treatments. Continued observation is recommended to determine the long-term performance of the Pennsylvania patches placed with dowels visible. Future research investigating a comparison of performance of partial-depth patches placed according to common practice versus those placed according to theoretical recommendations may be advisable, as the cost of full-depth spall repair is much higher than the cost of partial-depth spall repair.

6

Preliminary Findings

The observations and recommendations presented in this chapter are based on the short-term performance of the partial-depth patches placed during the H-106 project. When drawing conclusions, it is important to remember that the last evaluation was conducted only 18 months into the possibly 5- to 10-year life of the patches. Continued monitoring of the patches is necessary.

Observations

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. Based on 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 overall ratings at all sites; in longitudinal cracking ratings at all sites except the wet-nonfreeze region; in oxidization ratings in the dry-nonfreeze region; and in spalling ratings in the wet-nonfreeze region.

- For bituminous materials, significant differences were found in bleeding and edge-fraying ratings in the wet-freeze region, and in dishing, raveling, and overall 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.

- With the exception of the dry-nonfreeze region, the cementitious materials as a group had a significantly higher overall patch rating than the polymer materials as a group when analyzed using MANOVA. However, additional statistical analyses indicated that the difference is only borderline in the wet-freeze and wet-nonfreeze regions. The grouping together of the two polymer materials was shown to be statistically inappropriate in the dry-freeze region. Therefore, decisive conclusions on differences between these two groups will have to await analyses of future performance data.

- 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), only in the dry-nonfreeze region.
- For cementitious and polymer patches in the dry-nonfreeze and wet-freeze regions, no significant difference was found between the overall patch rating when the mill-and-patch procedure was contrasted with the saw-and-patch and chip-and-patch procedures as a group.
- In the dry-nonfreeze region, Type III PCC, Five Star HP, MC-64, SikaPronto 11, and Pyrament 505 patches had significantly better overall patch ratings than Penatron R/M-3003 patches.
- In the wet-freeze region, no significant difference in the overall patch rating was found between spray-injection patches placed with the clean-and-patch procedure under normal conditions and UPM High Performance Cold Mix patches placed with the chip-and-patch procedure.
- 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 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.
- No clear performance trends were consistently found across the four climatic regions.
- Complete ranking of patch types, materials, and procedures is not yet possible because of the good overall performance of the patches.

Recommendations

The SHRP H-106 project has taken a first step toward improving the state-of-the-practice of everyday maintenance operations. To make use of the information gained in the partial-depth spall repair experiment, the following suggestions for research and practice are recommended:

Continue to monitor the repairs. The investment made in the installation of the four test sites will continue to grow if monitoring is continued. It is crucial that the repairs be protected from destruction by future rehabilitations so that enough data is collected over time to allow the construction of survival curves for each of the material-procedure combinations.

Expand the scope of materials tested. While the SHRP H-105 project attempted to identify the materials and procedures with the most promise, many materials and procedures were not included in the SHRP H-106 project that may have been deserving. The evaluation of new materials as they enter the market would be invaluable to agencies that are involved in pavement maintenance activities on a year-round basis.

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

Install a greater number of patches within each material-procedure combination. The absence of significant differences in the distress and overall ratings, both indicators of performance, suggests that a greater number of each material-procedure combination is needed to reduce the variability and would result in an increased finding of significant differences.

Investigate the long-term performance of partial-depth patches used to repair spalls with dowel bars visible. The early performance of such patches in Pennsylvania suggests this common practice may deserve further research.

Appendix A

Test Site Layouts

The order of placement of the test sections within each test site was randomly determined. In Arizona, 40 test sections were installed and evaluated. The test sections consisted of combinations of 10 materials and 4 patching procedures. Tables A-1 and A-2 show the test section layouts for Arizona replicates 1 and 2, respectively. In Pennsylvania, 46 test sections of ten different materials in combination with four different patching procedures were installed and evaluated. The test site layouts for Pennsylvania are shown in tables A-3 and A-4. In South Carolina, the 32 test sections consisted of combinations of eight materials and two patching procedures, as shown in tables A-5 and A-6. In Utah, 34 test sections of nine materials in combination with four patching procedures were installed and evaluated, as shown in tables A-7 and A-8.

Table A-1. Test section layout for Arizona replicate 1 (dry-nonfreeze)

Test Section Number	Procedure	Material
1	clean and patch	Duracal
2	clean and patch	UPM High Performance Cold Mix
3	saw and patch	Set-45
4	clean and patch	Set-45
5	mill and patch	Percol FL
6	saw and patch	Duracal
7	clean and patch	SikaPronto 11
8	saw and patch	SikaPronto 11
9	mill and patch	Pyrament 505
10	mill and patch	MC-64
11	saw and patch	Percol FL
12	clean and patch	Percol FL
13	waterblast and patch	Pyrament 505
14	clean and patch	Five Star HP
15	clean and patch	MC-64
16	saw and patch	MC-64
17	saw and patch	Type III PCC
18	clean and patch	Type III PCC
19	saw and patch	Five Star HP
20	clean and patch	Penatron R/M-3003

Table A-2. Test section layout for Arizona replicate 2 (dry-nonfreeze)

Test Section Number	Procedure	Material
1	mill and patch	Percol FL
2	saw and patch	Set-45
3	mill and patch	Pyrament 505
4	clean and patch	Percol FL
5	saw and patch	Duracal
6	clean and patch	UPM High Performance Cold Mix
7	saw and patch	SikaPronto 11
8	clean and patch	Duracal
9	clean and patch	Set-45
10	saw and patch	MC-64
11	mill and patch	MC-64
12	clean and patch	MC-64
13	clean and patch	Type III PCC
14	clean and patch	Five Star HP
15	saw and patch	Five Star HP
16	waterblast and patch	Pyrament 505
17	saw and patch	Percol FL
18	saw and patch	Type III PCC
19	clean and patch	SikaPronto 11
20	clean and patch	Penatron R/M-3003

Table A-3. Test section layout for Pennsylvania replicate 1 (wet-freeze)

Test Section Number	Procedure	Material
1	clean and patch	UPM High Performance Cold Mix
2	saw and patch	Pyrament 505
3	clean and patch	SikaPronto 11
4	clean and patch	Set-45
5	clean and patch	MC-64
6	clean and patch	Percol FL
7	saw and patch	Percol FL
8	saw and patch	Five Star HP
9	saw and patch	Set-45
10	saw and patch	Type III PCC
11	clean and patch	Five Star HP
12	adverse clean and patch	Percol FL
13	saw and patch	SikaPronto 11
14	mill and patch	Percol FL
15	saw and patch	MC-64
16	mill and patch	Type III PCC
17	clean and patch	Type III PCC
18	mill and patch	Set-45
19	adverse clean and patch	Pyrament 505
20	mill and patch	Five Star HP
21	clean and patch	Pyrament 505
22	adverse clean and patch	UPM High Performance Cold Mix
23	clean and patch	Penatron R/M-3003

Table A-4. Test section layout for Pennsylvania replicate 2 (wet-freeze)

Test Section Number	Procedure	Material
1	adverse clean and patch	Pyrament 505
2	clean and patch	Pyrament 505
3	clean and patch	UPM High Performance Cold Mix
4	saw and patch	Pyrament 505
5	saw and patch	Five Star HP
6	clean and patch	Five Star HP
7	clean and patch	Type III PCC
8	clean and patch	MC-64
9	saw and patch	Type III PCC
10	clean and patch	SikaPronto 11
11	adverse clean and patch	Percol FL
12	saw and patch	Set-45
13	mill and patch	Type III PCC
14	mill and patch	Five Star HP
15	clean and patch	Percol FL
16	mill and patch	Percol FL
17	saw and patch	Percol FL
18	saw and patch	MC-64
19	saw and patch	SikaPronto 11
20	clean and patch	Set-45
21	adverse clean and patch	UPM High Performance Cold Mix
22	mill and patch	Set-45
23	clean and patch	Spray-Injection Mix

Table A-5. Test section layout for South Carolina replicate 1 (wet-nonfreeze)

Test Section Number	Procedure	Material
1	saw and patch	SikaPronto 11
2	clean and patch	SikaPronto 11
3	saw and patch	Percol FL
4	saw and patch	MC-64
5	saw and patch	Duracal
6	clean and patch	Duracal
7	clean and patch	Type III PCC
8	saw and patch	Type III PCC
9	clean and patch	Set-45
10	saw and patch	Set-45
11	clean and patch	MC-64
12	clean and patch	Percol FL
13	clean and patch	Five Star HP
14	clean and patch	UPM High Performance Cold Mix
15	saw and patch	Five Star HP
16	clean and patch	Spray-Injection Mix

Table A-6. Test section layout for South Carolina replicate 2 (wet-nonfreeze)

Test Section Number	Procedure	Material
1	saw and patch	MC-64
2	clean and patch	Five Star HP
3	saw and patch	Five Star HP
4	clean and patch	SikaPronto 11
5	clean and patch	Set-45
6	saw and patch	SikaPronto 11
7	clean and patch	Type III PCC
8	saw and patch	Percol FL
9	clean and patch	Percol FL
10	clean and patch	Duracal
11	saw and patch	Duracal
12	saw and patch	Type III PCC
13	clean and patch	UPM High Performance Cold Mix
14	clean and patch	MC-64
15	saw and patch	Set-45
16	clean and patch	Spray-Injection Mix

Table A-7. Test section layout for Utah replicate 1 (dry-freeze)

Test Section Number	Procedure	Material
1	clean and patch	UPM High Performance Cold Mix
2	clean and patch	Duracal
3	clean and patch	Set-45
4	clean and patch	MC-64
5	mill and patch	Type III PCC
6	clean and patch	Five Star HP
7	saw and patch	Set-45
8	saw and patch	Percol FL
9	saw and patch	Five Star HP
10	saw and patch	Duracal
11	clean and patch	SikaPronto 11
12	saw and patch	Type III PCC
13	saw and patch	MC-64
14	waterblast and patch	Type III PCC
15	clean and patch	Percol FL
16	saw and patch	SikaPronto 11
17	clean and patch	Type III PCC

Table A-8. Test section layout for Utah replicate 2 (dry-freeze)

Test Section Number	Procedure	Material
1	saw and patch	Set-45
2	clean and patch	MC-64
3	clean and patch	Duracal
4	saw and patch	Percol FL
5	clean and patch	Percol FL
6	clean and patch	Set-45
7	clean and patch	Type III PCC
8	saw and patch	Duracal
9	waterblast and patch	Type III PCC
10	clean and patch	Five Star HP
11	mill and patch	Type III PCC
12	saw and patch	SikaPronto 11
13	saw and patch	Five Star HP
14	saw and patch	MC-64
15	clean and patch	UPM High Performance Cold Mix
16	saw and patch	Type III PCC
17	clean and patch	SikaPronto 11

Appendix B

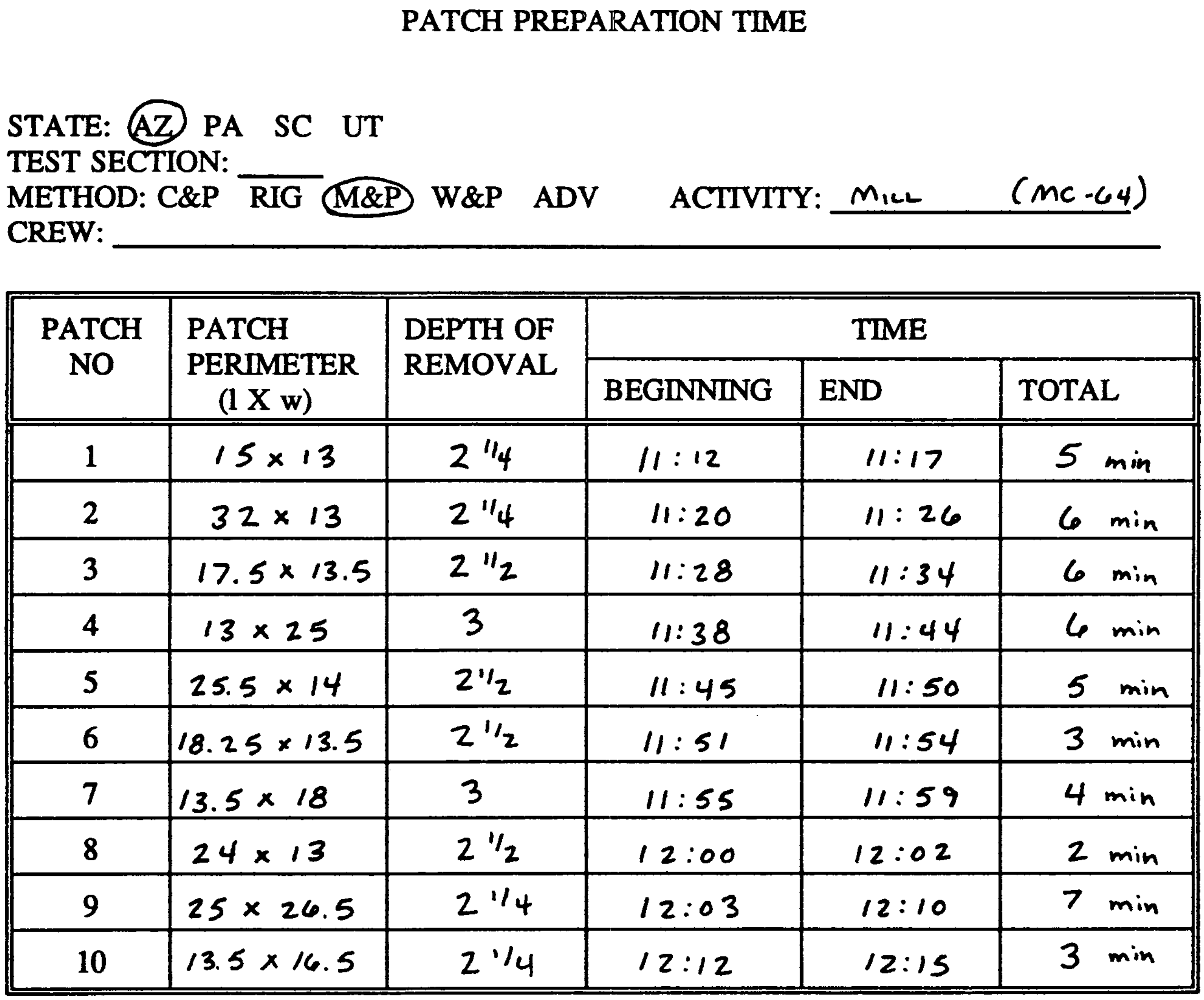
Installation Data

Forms

The forms used to record installation data are shown in figures B-1 and B-2. Figure B-1 shows the form used to monitor productivity of the patching operation. Figure B-2 shows the form used to record information regarding each specific partial-depth spall repair. Both forms show data collected in the field.

Summary Data

Selected summary installation data are shown in tables B-1 through B-4. The data shown for each section identification number (SECTION ID) represent averages or typical values for the approximately 10 partial-depth patches that were installed in that section. The first two digits of the section identification number indicate the site (04 = Arizona, 42 = Pennsylvania, 45 = South Carolina, 49 = Utah). The third character represents the spall repair experiment (S). The fourth character represents the climatic region (1 = wet-freeze, 2 = dry-freeze, 3 = wet-nonfreeze, 4 = dry-nonfreeze). The fifth character is the material code and the seventh character is the procedure code, as shown in table B-5. The sixth character of the section identification number is the dummy variable, "0".



PATCH PREPARATION TIME

STATE: [✓ AZ] PA SC UT
TEST SECTION: _____
METHOD: C&P RIG [✓ M&P] W&P ADV ACTIVITY: Mill (MC-64)
CREW: ____________

PATCH NO	PATCH PERIMETER (l X w)	DEPTH OF REMOVAL	TIME		
			BEGINNING	END	TOTAL
1	15 x 13	2 1/4	11:12	11:17	5 min
2	32 x 13	2 1/4	11:20	11:26	6 min
3	17.5 x 13.5	2 1/2	11:28	11:34	6 min
4	13 x 25	3	11:38	11:44	6 min
5	25.5 x 14	2 1/2	11:45	11:50	5 min
6	18.25 x 13.5	2 1/2	11:51	11:54	3 min
7	13.5 x 18	3	11:55	11:59	4 min
8	24 x 13	2 1/2	12:00	12:02	2 min
9	25 x 26.5	2 1/4	12:03	12:10	7 min
10	13.5 x 16.5	2 1/4	12:12	12:15	3 min

Figure B-1. Patch preparation-time form

PCC SPALL REPAIR INSTALLATION FORM

GENERAL INFORMATION

Date: 5 / 1 / 91
Survey Performed By: A J P (initials)

10-digit experiment ID: 4 9 5 2 6 0 8 0 1 A
1 2 3 4 5 6 7 8 9 10
Ambient Conditions: temp 68 °F humidity 34

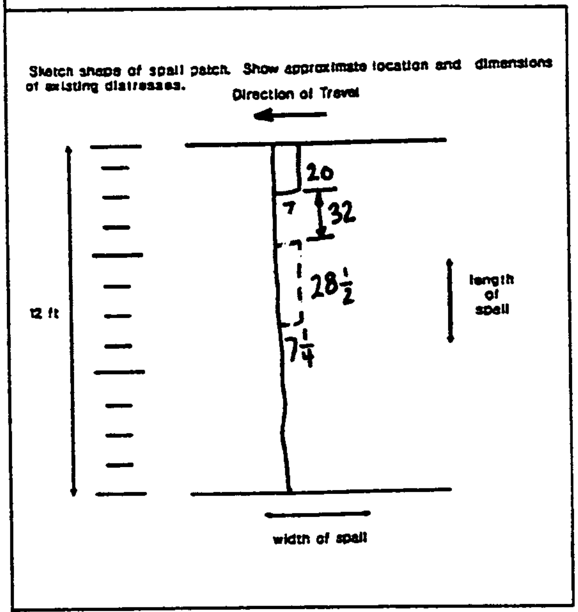
LOCATION

State: AZ PA SC [✓ UT]
Climatic Region: WF [✓ DF] WNF DNF
Material: Type III PCC Duracal Set-45 Five Star HP MC-64 [✓ SikaPronto] Percol Pyrament Sylvax AMZ Rosco Penetron
Highway: I-15

Direction: [✓ N] S E W
No. of Lanes (per direction): 1 [✓ 2] 3 4
Lane: ____
Spall Number: [✓ 1] 2 3 4 5 6 7 8 9 10
Spall Location: Milepost ____
Station 1334 + 26

Repair Procedure: RIG - 1st rep C&P - 1st rep M&P - 1st rep
RIG - 2nd rep [✓ C&P - 2nd rep] M&P - 2nd rep
Adverse - 1st rep W&P - 1st rep
Adverse - 2nd rep W&P - 2nd rep

INSTALLATION



Number of crew members (excluding traffic control): ____
Crew composition : (excluding traffic control) ....
Number of traffic control crew members: ____
Traffic control crew composition: ....

Spall Condition:

Avg. spall length: ___ ft ___ in
Avg. spall width: ___ ft ___ in
Spall area: ___ sf
Avg. spall depth: ___ & ___ / ___ in
Max. spall depth: ___ & ___ / ___ in
Previous bit. patch: Yes [✓ No]
Reinforcement visible: Yes [✓ No]
Dowel visible: Yes [✓ No]
Joint sealant condition: [✓ None] Good Poor

Patch Condition:

Avg. patch length: 1 ft 8 in
Avg. patch width: ___ ft 7 in
Avg. patch depth: 2 & 3 / 4 in
Max. patch depth: 4 & 3 / 4 in

Construction:

Sandblasting: [✓ Yes] No
Airblowing: [✓ Yes] No
Moisture condition prior to placement: Wet SSD [✓ Dry]
Bonding Epoxy: [✓ Yes] No
Internal vibration: [✓ Yes] No
Curing Condition: Curing compound [✓ Air] Water Other ____

CONSTRUCTION OBSERVATIONS

Time for patch preparation: begin __:__ am pm end __:__ am pm

Batch #: 1 Time for mixing: begin 3:56 am [✓ pm] end 3:59 am [✓ pm]
A
Quantity mixed: ____ (cf) 1 gal ~~water~~
1 bags ____ lb CA ____ lb FA

Time for placement and finishing: begin 4:01 am [✓ pm] end 4:02 am [✓ pm]

Workability: slump ____ in air ____ %

Initial set time: __:__ am pm
Cylinders cast: Yes No

Time for curing: begin __:__ am pm end __:__ am pm

Time open to traffic: 12:30 am pm 5/2

INITIAL SHRINKAGE CRACKING SURVEY

Date surveyed: 5 /06 91
Draw diagram:

Time surveyed: 11:59 [✓ am] pm

Crack width: ____ & ____ / ____ in

Crack length: ____ ft ____ in

No cracks
No delam.

COMMENTS PRIME BEGIN 3:42 pm
END 3:55 pm

Figure B-2. Spall repair installation form

Table B-1. Selected summary installation data for Arizona (dry-nonfreeze)

SECTION ID	DATE	TEMP (F)	HUMIDITY	LANE	DIRECT	AVG PATCH DEPTH (in)	AVG PATCH WIDTH (in)	AVG PATCH LENGTH (in)	AVG PATCH AREA (sf)
04S4101	6/1/91	77	10	3	N	3.00	10.00	144.00	10.00
04S4102	6/3/91	70	53	3	N	2.50	13.50	12.00	1.12
04S410A	6/6/91	75	32	3	S	3.00	19.50	27.00	3.65
04S410B	6/5/91	82	10	3	S	2.50	8.50	14.00	0.82
04S4201	5/30/91	77	7	3	N	2.00	28.50	15.00	2.96
04S4202	5/30/91	77	7	3	N	2.50	15.00	14.00	1.45
04S420A	6/7/91	66	44	3	N	2.50	15.50	15.50	1.66
04S420B	6/7/91	64	44	3	N		10.00	15.00	1.04
04S4301	5/31/91	78	20	3	N	2.75	10.50	38.00	2.77
04S4302	5/31/91	69	10	3	N	2.50	20.00	12.00	1.66
04S430A	6/4/91	80	10	3	N	2.50	14.50	10.00	1.00
04S430B	6/5/91	74	27	3	N		12.00	24.00	2.00
04S4401	6/5/91	75	32	3	N	2.50	4.50	9.50	0.29
04S4402	6/2/91	64	51	3	N	2.25	8.50	33.50	1.97
04S440A	6/9/91	78	20	3	S	2.75	8.00	77.00	4.27
04S440B	6/9/91	76	11	3	S	2.50	12.00	30.00	2.50
04S4501	6/2/91	84	25	3	N	3.25	14.00	23.00	2.23
04S4502	6/2/91	63	50	3	N	2.00	16.00	40.00	4.44
04S4503	6/4/91	70	51	3	N	2.25	15.00	13.00	1.35
04S450A	6/8/91	88	20	3	S	3.25	19.00	32.00	4.22
04S450B	6/9/91	74	20	3	S	2.00	14.00	7.50	0.72
04S450C	6/5/91	67	49	3	N	2.00	13.00	48.00	4.33
04S4601	5/30/91	79	10	3	N	2.75	8.00	144.00	8.00
04S4602	5/31/91	74	10	3	N	2.50	12.00	33.00	2.75
04S460A	6/6/91	70	40	3	N	3.00	5.50	9.00	0.34
04S460B	6/7/91	68	41	3	N	2.50	25.00	13.50	2.34
04S4701	6/1/91	71	35	3	N	2.50	9.50	144.00	9.50
04S4702	6/5/91	69	45	3	N	3.00	16.50	144.00	16.50
04S4703	6/2/91	77	34	3	N	3.25	12.00	22.00	1.83
04S470A	6/6/91	75	20	3	S	2.75	10.50	13.00	0.94
04S470B	6/6/91	75	20	3	S	3.00	16.50	17.50	2.00
04S470C	6/2/91	80	20	3	N	2.75	12.00	28.00	2.33
04S4803	6/2/91	68	47	3	N	3.50	13.00	50.00	4.51
04S4807	6/4/91	67	49	3	N	2.50	15.50	32.00	3.44
04S4902	5/30/91	87	7	3	N	2.00	11.00	26.00	1.98
04S490B	5/30/91	74	20	3	N	2.00	17.00	11.00	1.29
04S4B01	6/9/91	78	20	3	S	2.50	10.51	46.00	3.35
04S4B0A	6/9/91	78	11	3	S	3.00	11.00	32.00	2.44

Table B-2. Selected summary installation data for Pennsylvania (wet-freeze)

SECTION ID	DATE	TEMP (F)	HUMIDITY	LANE	DIRECT	AVG PATCH DEPTH (in)	AVG PATCH WIDTH (in)	AVG PATCH LENGTH (in)	AVG PATCH AREA (sf)
42S1101	7/10/91	71	70	1	N	3.50	12.00	54.00	4.50
42S1102	7/16/91	91	34	1	N	3.00	6.50	49.00	2.21
42S1103	7/16/91	86	46	1	N	2.62	16.00	31.00	3.44
42S110A	7/15/91	71	61	1	N	3.50	4.50	33.00	1.03
42S110B	7/18/91	87	52	1	S	4.00	5.00	61.00	2.11
42S110C	6/17/91	74	30	1	S	2.00	17.00	39.50	4.66
42S1301	7/11/91	84	36	1	N	2.50	24.00	15.00	2.50
42S1302	7/9/91	78	51	1	N	3.00	24.00	12.00	2.00
42S1303	6/20/91	80	50	1	N	2.00	17.50	48.00	5.83
42S130A	7/17/91	82	53	1	N	3.00	4.00	31.00	0.86
42S130B	7/2/91	80	90	1	S	3.50	53.00	12.00	4.41
42S130C	6/18/91	75	40	1	S	2.25	18.50	23.00	2.95
42S1401	7/1/91	88	40	1	S	3.00	6.25	54.00	2.34
42S1402	7/17/91	86	49	1	N	2.00	4.50	30.00	0.93
42S1403	6/20/91	94	25	1	N	2.50	17.00	31.00	3.65
42S140A	6/13/91	67	40	1	S	2.00	21.50	32.00	4.77
42S140B	7/10/91	88	38	1	N	4.00	6.00	56.00	2.33
42S140C	6/17/91	90	34	1	S	2.50	16.00	52.00	5.77
42S1501	6/24/91	81	50	1	S	2.25	6.25	17.00	0.73
42S1502	6/24/91	65	30	1	S	1.50	24.00	32.00	5.33
42S150A	6/25/91	88	40	1	S	2.50	17.50	24.00	2.91
42S150B	6/25/91	85	50	1	S	2.00	6.50	14.00	0.63
42S1601	7/15/91	90	30	1	N	4.00	6.00	34.00	1.41
42S1602	7/11/91	72	64	1	N	3.00	6.00	29.00	1.20
42S160A	7/18/91	95	35	1	S	2.50	9.00	34.00	2.12
42S160B	7/11/91	78	49	1	N	4.00	9.50	36.00	2.37
42S1701	6/26/91	91	34	1	S	2.00	20.00	23.50	3.26
42S1702	6/26/91	89	32	1	S	2.50	8.00	27.00	1.50
42S1703	6/19/91	90	40	1	N	1.75	16.00	66.00	7.33
42S1704	3/12/91	25	20	1	N	2.00	12.00	20.00	1.66
42S170A	6/27/91	74	20	1	S	2.50	10.00	14.00	0.97
42S170B	6/27/91	80	50	1	S	2.50	41.00	11.00	3.13
42S170C	6/19/91	85	50	1	S	2.50	17.00	56.00	6.61
42S170D	3/11/91	36	20	1	S	4.00	5.00	21.00	0.72
42S1801	7/9/91	70	68	1	N	2.50	7.00	27.00	1.31
42S1802	7/17/91	92	33	1	N	2.00	26.00	11.00	1.98
42S1804	3/27/91	68	56	1	N	1.00	6.00	19.00	0.79
42S180A	7/1/91	80	60	1	S	2.00	5.50	51.00	1.94
42S180B	6/12/91	81	50	1	S	7.00	28.00	13.00	2.52
42S180D	3/12/91	39	53	1	S	2.50	24.00	20.00	3.33
42S1902	7/8/91	80	70	1	N	4.00	19.00	69.00	9.10
42S1904	3/26/91	61	40	1	N	2.00	3.00	12.00	0.25
42S190B	7/9/91	83	36	1	N	2.00	6.00	31.00	1.29
42S190D	3/26/91	66	34	2	S		10.00	36.00	2.50
42S1A02	8/7/91	75	60	1	N	2.00	16.00	16.00	1.77
42S1A0H	8/7/91	70	60	2	N	4.50	16.00	18.00	2.00

Table B-3. Selected summary installation data for South Carolina (wet-nonfreeze)

SECTION ID	DATE	TEMP (F)	HUMIDITY	LANE	DIRECT	AVG PATCH DEPTH (in)	AVG PATCH WIDTH (in)	AVG PATCH LENGTH (in)	AVG PATCH AREA (sf)
45S3101	5/23/91	84	30	1	W	1.75	10.00	32.00	2.22
45S3102	5/21/91	75	60	1	W	3.25	14.00	33.00	3.20
45S310A	5/28/91	88	90	1	W	2.75	12.00	47.00	3.91
45S310B	5/22/91	70	40	1	W	2.25	10.00	22.00	1.52
45S3201	5/21/91	75	60	1	W	2.75	11.00	24.00	1.83
45S3202	5/21/91	75	60	1	W	1.75	10.00	29.00	2.01
45S320A	5/22/91	80	90	1	W	2.50	11.00	45.00	3.43
45S320B	5/22/91	80	80	1	W	2.50	11.00	47.00	3.59
45S3301	5/22/91	0	0	1	W		23.00	30.00	4.79
45S3302	5/23/91	90	0	1	W	2.50	11.00	35.00	2.67
45S330A	5/28/91	94	90	1	W	3.50	13.00	40.50	3.65
45S330B	5/23/91	87	70	1	W	2.50	10.00	42.00	2.91
45S3401	5/29/91	90	90	1	W	2.25	10.00	50.00	3.47
45S3402	5/29/91	94	90	1	W	2.75	11.50	60.00	4.79
45S340A	5/30/91	89	70	1	W	3.25	10.00	36.00	2.50
45S340B	5/30/91	87	70	1	W	3.00	9.50	19.00	1.25
45S3501	5/14/91	97	42	1	W	1.50	13.50	42.00	3.93
45S3502	5/15/91	89	56	1	W	2.25	7.50	23.50	1.22
45S350A	5/17/91	90	44	1	W	3.00	12.00	77.00	6.41
45S350B	5/16/91	77	78	1	W	2.25	12.50	27.50	2.38
45S3601	5/14/91	99	37	1	W	2.00	11.00	92.00	7.02
45S3602	5/13/91	93	51	1	W	4.00	10.00	29.00	2.01
45S360A	5/29/91	90	90	1	W	3.00	10.50	96.00	7.00
45S360B	5/30/91	86	90	1	W	2.25	6.00	26.50	1.10
45S3701	5/15/91	86	71	1	W	2.50	12.00	31.00	2.58
45S3702	5/15/91	86	71	1	W	2.50	9.50	33.50	2.21
45S370A	5/17/91	88	80	1	W	2.50	12.00	32.00	2.66
45S370B	5/17/91	88	57	1	W	3.25	12.00	51.00	4.25
45S3902	5/20/91	71	79	1	W	2.75	10.50	36.00	2.62
45S390B	5/20/91	89	70	1	W	2.00	11.00	32.00	2.44
45S3A02	5/24/91	74	70	1	W	2.50	9.50	27.00	1.78
45S3A0B	5/24/91	74	70	1	W	1.50	10.00	38.00	2.63

Table B-4. Selected summary installation data for Utah (dry-freeze)

SECTION ID	DATE	TEMP (F)	HUMIDITY	LANE	DIRECT	AVG PATCH DEPTH (in)	AVG PATCH WIDTH (in)	AVG PATCH LENGTH (in)	AVG PATCH AREA (sf)
49S2101	4/24/91	63	38	1	N	2.00	8.00	44.00	2.44
49S2102	4/26/91	55	34	2	N	2.50	7.00	7.00	0.34
49S2105	5/1/91	66	32	2	N	2.50	12.00	73.00	6.08
49S2106	4/24/91	64	37	2	N	1.50	8.00	33.00	1.83
49S210A	5/1/91	68	34	2	N	2.25	7.00	11.00	0.53
49S210B	4/30/91	63	37	2	N	2.50	7.00	10.50	0.51
49S210E	5/1/91	67	30	2	N	3.25	8.00	63.25	3.51
49S210Y	5/1/91	42	61	2	N	3.50	10.00	9.00	0.62
49S2201	4/24/91	65	34	2	N	2.50	9.00	16.00	1.00
49S2202	4/23/91	68	34	2	N	2.00	6.00	17.50	0.72
49S220A	4/30/91	56	42	2	N	2.50	7.50	11.50	0.59
49S220B	4/30/91	46	59	2	N	2.50	6.00	18.00	0.75
49S2301	4/22/91	60	30	2	N	3.25	7.50	22.00	1.14
49S2302	4/22/91	70	30	2	N	2.75	9.00	42.00	2.62
49S230A	4/26/91	54	34	2	N	2.00	8.00	10.00	0.55
49S230B	4/30/91	62	38	2	N	2.50	9.00	42.50	2.65
49S2401	4/24/91	63	33	1	N	2.25	8.00	24.00	1.33
49S2402	4/22/91	60	30	2	N	2.75	6.00	30.00	1.25
49S240A	5/1/91	51	40	2	N	2.50	6.00	11.00	0.45
49S240B	4/30/91	62	38	2	N	3.00	7.00	20.00	0.97
49S240Y	5/1/91	51	40	2	N	2.50	7.00	40.00	1.94
49S2501	4/24/91	60	48	2	N	2.00	8.00	84.00	4.66
49S2502	4/23/91	69	34	2	N	2.50	6.00	11.00	0.45
49S250A	5/1/91	56	39	2	N	2.00	7.00	42.00	2.04
49S250B	4/26/91	58	34	2	N	1.75	8.00	11.50	0.63
49S250Y	5/1/91	57	34	2	N	2.25	8.00	13.00	0.72
49S2601	4/26/91	58	34	2	N	2.00	8.00	8.00	0.44
49S2602	4/24/91	67	38	2	N	2.50	8.00	42.00	2.33
49S260A	5/1/91	46	63	2	N		9.00	9.00	0.56
49S260B	5/1/91	68	34	2	N	2.75	7.00	20.00	0.97
49S2701	4/30/91	62	38	2	N	1.75	20.50	17.50	2.49
49S2702	4/30/91	62	36	2	N	3.50	8.00	24.00	1.33
49S270A	4/30/91	55	48	2	N	2.00	8.00	19.00	1.05
49S270B	4/30/91	55	48	2	N	2.50	7.00	10.00	0.48
49S2902	4/23/91	70	34	2	N	2.00	7.75	20.50	1.10
49S290B	5/1/91	64	34	2	N	2.00	9.00	12.00	0.75

Table B-5. Material and procedure codes

Material Code	Material Name	Procedure Code	Procedure Name
1	Type III PCC	1, A, X	saw and patch
2	Duracal	2, B, Y	chip and patch
3	Set-45	3, 7, C, G	mill and patch
4	Five Star HP	4, D	adverse-condition clean and patch
5	MC-64	5, 6, E, F	waterblast and patch
6	SikaPronto 11	8, H	good-condition clean and patch
7	Percol FL		
8	Pyrament 505		
9	UPM High Performance Cold Mix		
A	Spray-Injection Mix		
B	Penatron R/M-3003		

Appendix C

Material Testing Data

The cementitious and polymer materials were tested by an independent laboratory, LAW Engineering, in Atlanta, Georgia. The samples were prepared and cured according to the material manufacturer's instructions to the extent possible. The following testing standards were used:

- "Initial Set," ERES Test Method as given in the SHRP H-106 EDRP.

- "Test Method for Compressive Strength of Hydraulic Cement Mortars," ASTM C 109, using 2-in x 2-in (51-mm x 51-mm) cube specimens for the 2-, 3-, and 4- hour tests.

- "Test Method for Compressive Strength of Cylindrical Concrete Specimens," ASTM C 39, using 3-in x 6-in (76-mm x 152-mm) cylindrical specimens for the 24-hour tests and 4-in x 8-in (102-mm x 203-mm) for the 28-day tests.

- Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete in Compression," ASTM C 469, using 4-in x 8-in (102-mm x 203-mm) cylindrical specimens for the 28-day compressive strength test. A combined compressometer-extensionmeter was used in this test.

- "Test Method for Flexural Strength of Concrete," ASTM C 78, using 3-in x 4-in x 16-in (76-mm x 102-mm x 406-mm) specimens.

- "Test Method for Bond Strength of Epoxy-Resin Systems Used with Concrete," ASTM C 882.

- "Method of Test of Bonding Strength of Concrete Overlay and Patching Materials to PCC," CALTRANS, using 3-in x 4-in x 16-in (76-mm x 102-mm x 406-mm) specimens. For the above two bond tests, BurkEpoxy MV and SikaPronto 19 were used as the bonding agent for the Type III PCC and SikaPronto 11 concrete respectively, in the dry substrate condition.

- "Test Method for Resistance of Concrete to Rapid Freezing and Thawing," ASTM C 666A, Procedure A, using 3-in x 4-in x 16-in (76-mm x 102-mm x 406-mm) specimens, 4 hours per cycle.

- "Test Method for Scaling Resistance of Concrete Surfaces exposed to Deicing Chemicals," ASTM C 672, using 12-in x 12-in x 3-in (229-mm x 229-mm x 76-mm) specimens.

- "Test Method for Determining the Surface Abrasion Resistance of Concrete Specimens," CALTRANS California Test 550.

- "Test Method for Length Change of Hardened Cement Mortar and Concrete," ASTM C 157, using 3-in x 3-in x 11.25-in (76-mm x 76-mm x 286-mm) specimens. All specimens were stored in air at a temperature of 73.4 ± 3.0°F (23 ± 1.7°C) and a relative humidity of 50 ± 4 percent.

- "Test Method for Thermal Compatibility between Concrete and an Epoxy-Resin Overlay," ASTM C 884, using 12-in x 12-in x 3-in (306-mm x 306-mm x 76-mm) concrete blocks and a 0.5-in (13-mm) overlay. All specimens were at 7-day age when the test cycle commenced.

All the test specimens were air cured until the age of test at a temperature of 73.4 ± 3.9°F (23 ± 1.7°C) and a relative humidity of 50 ± 4 percent except for Type III PCC, Five Star HP, and Pyrament 505 which were moist cured at a temperature of 73.4 ± 3.0°F (23 ± 1.7°C.

The bituminous materials were tested by Southwestern Laboratories, in Houston, Texas, using the following testing standards:

- "Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures," ASTM D 4123. Samples were "aged" by heating them overnight in an oven at 275°F (135°C), compacting them hot using 75 blows per side, and allowing the compacted samples to cool in the molds prior to extrusion. Testing was performed at 77°F (25°C) at three different frequencies: 0.33, 0.50, and 1.00 Hz.

- "Test Method for Resistance to Plastic Flow of Bituminous Mixtures," ASTM D 1559. Samples were aged and compacted in the manner described for the resilient modulus test method.

- "Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens," ASTM D 2726. The compactive effort used to prepare the samples was the same as for the resilient modulus and Marshall sample preparation.

- Test Method for Theoretical Maximum Specific Gravity of Bituminous Paving Mixtures," ASTM D 2041. The samples were prepared in the same manner as the bulk specific-gravity samples.

- "Test Method for Coating and Stripping of Bitumen-Aggregate Mixtures," ASTM D 1664.

- "PTI Workability Test," developed by the Pennsylvania Transportation Institute (PTI)[3]. The laboratory procedure used the 0.375-in (9.5-mm) diameter probe developed by PTI. When this attachment was compared directly to the blade attachment, the reading of the blade attachment was approximately 5 times larger. The circular probe seems to work for stiffer mixes, where the smaller cross-section presents less resistance. The blade attachment seems to work for softer mixes, where the length of the blade in contact with the mix provides more resistance.

- "Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixtures," ASTM D 2172.

- "Test Method for Viscosity of Asphalts by Vacuum Capillary Viscometer," ASTM D 2171. The viscosity tests were performed on the binder recovered from the extraction process. Samples of binder were aged in a manner similar to the mixtures, in that the recovered binder was heated at 140°F (60°C) until the reduction in weight stopped. This was used as an indication that the lighter volatiles had been driven off and the material remaining was primarily the residual binder.

- "Test Method for Penetration of Bituminous Materials," ASTM D 5. Preparation of the recovered binder samples was the same for this test as for the viscosity test.

- "Test Method for Ductility of Bituminous Materials," ASTM D 113. Preparation of the recovered binder samples was the same as for the viscosity test.

- "Test Method for Softening Point of Bitumen (Ring-and-Ball Apparatus)," ASTM D 36. Preparation of the recovered binder samples was the same as for the viscosity test.

- "Method for Sieve Analysis of Fine and Coarse Aggregates," ASTM C 136.

- "Test Method for Recovery of Asphalt from Solution by Abson Method," ASTM D 1856.

Tables C-1 through C-18 show the detailed results of the laboratory tests conducted on cementitious and polymer materials. Tables C-19 through C-21 and figure C-1 show the results of the laboratory tests conducted on bituminous materials.

Table C-1. Mix proportions

Mix	Component[1]	Quantity[1]
Duracal	Duracal Lone Star Coarse Aggregate Lone Star Sand Water	25 lb 25 lb 25 lb 6.75 lb
Type III PCC	Dundee Type III Portland Cement 3/8 in Pea Gravel Sand Water Daravair DCI Melment	94 lb 220 lb 118 lb 24 lb 22 mL 64 oz 12 oz
Set-45	Set-45 3/8 in Pea Gravel Water	50 lb 30 lb 4 pints (1.9 L)
Five Star HP	Highway Patch 3/8 in Pea Gravel Water	50 lb 30 lb 73 lb
Pyrament 505	Pyrament 505 3/8 in Pea Gravel Water	50 lb 30 lb 4.75 lb
SikaPronto 11 (plant-proportioned)	Sikapronto 11 Part A Part B 3/8 in Pea Gravel	0.96 gal 68 lb 37.5 lb
MC-64 (plant-proportioned)	Part A Part B Part B 3/8 in Pea Gravel	1 gal 1 gal 68 lb 37.5 lb
MC-64 (plant-proportioned	Part A Part B	1 gal 1 gal
Percol FL (plant-proportioned)	Component A (by volume) Component B (by volume)	1 1

[1] 1 in = 25.4 mm, 1 lb = .455 kg, 1 oz = .237 L, 1 gal = 3.785 L.

Table C-2. Initial Set

	Product							
	Duracal	Type III PCC	Set-45	Five Star HP	Pyrament 505	SikaPronto 11	MC-64	Percol FL
Initial Temperature (°F)[1]								
Ambient	70	41	73	73	73	76	73	73
Materials	72	73	72	72	72	74	73	73
Mixture	73	80	73	72	79	74	80	77
Mixing Time (min)								
1	73	79	76	72	79	74	*	*
2	73	79	79	72	79	74	*	*
3	73	79	80	72	80	73	*	*
4	73	79	81	72	80	73	*	*
5	73	78	82	72	79	74	*	*
7	73	78	84	72	78	74	*	*
10	73	77	90	72	76	74	*	*
15	73	76		72	75	75	*	*
20	73	75		72	74	76	*	*
25	73	74		72	74	76	*	*
30	73	74		72	74	78	*	*
35	73	73		72	74	80	*	
40	73	73		73		83	*	
45	73	73		75				
50		73						
55		73						
60		74						

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[1] °C = (°F - 32) × 5/9.

* MC-64 and Percol FL were not finishable.

Table C-3. Compressive strength results, ASTM C 109, ASTM C 39

Product	Specimen	Compressive Strength (psi)[1]									
		2 hours		3 hours		4 hours		24 hours		28 days	
			Average		Average		Average		Average		Average
Duracal	1	3,020	3,040	3,150	3,100	3,280	3,160	4,010	4,030	7,340	7,110
	2	3,030		2,960		3,230		4,010		6,940	
	3	3,070		3,200		2,960		4,080		7,040	
Type III PCC	1	280	300	890	950	1,760	1,890	7,100	6,880	9,270	9,370
	2	310		830		1,840		6,700		9,950	
	3	320		980		2,080		6,850		8,900	
Set-45	1	5,130	7,390	10,080	10,010	9,680	9,570	6,050	5,930	7,490	7,550
	2	8,400		10,040		9,910		5,490		6,910	
	3	8,630		9,920		9,110		6,240		8,260	
Five Star HP	1	3,800	4,010	4,400	4,340	4,600	4,660	4,970	5,340	6,700	6,590
	2	3,960		4,390		4,780		5,370		6,610	
	3	4,270		4,220		4,600		5,680		6,460	
Pyrament 505	1	2,710	2,660	3,190	3,300	3,820	3,840	5,400	5,350	8,410	8,220
	2	2,700		3,280		3,930		5,290		7,860	
	3	2,560		3,420		3,760		5,360		8,380	
Sika Pronto 11	1	4,580	5,100	5,330	6,100	5,580	6,160	6,710	6,680	7,500	1,490
	2	5,220		6,330		6,440		6,690		7,530	
	3	5,500		6,630		6,450		6,680		7,470	
MC-64	1	*	*	*	*	*	*	*	*	1,400	1,430
	2	*		*		*		*		1,400	
	3	*		*		*		*		1,480	
Percol FL	1	710	650	670	670	660	700	830	790	710	790
	2	710		650		750		770		750	
	3	520		700		680		780		910	

[1] 1 psi = 6.89 kPa.

* Specimens continued to deform under load without well-defined fracture occurring.

Table C-4. Static modulus of elasticity and Poisson's ratio, ASTM C 469

Product	Test Age (days)	Specimen	Static Modulus of Elasticity (10^6 psi)[1]		Poisson's Ratio	
				Average		Average
Duracal	28	1	5.60	5.60	0.27	0.25
		2	5.60		0.25	
		3	5.55		0.22	
Type III PCC	28	1	6.65	6.95	0.16	0.17
		2	7.15		0.17	
		3	7.05		0.17	
Set-45	28	1	6.85	6.70	0.20	0.20
		2	6.60		0.20	
		3	6.70		0.20	
Five Star HP	28	1	5.75	5.60	0.16	0.17
		2	5.40		0.17	
		3	5.65		0.18	
Pyrament 505	28	1	7.25	7.20	0.15	0.16
		2	7.25		0.15	
		3	7.20		0.17	
SikaPronto 11	28	1	3.45	3.45	0.31	0.30
		2	3.35		0.28	
		3	3.50		0.32	
MC-64	28	1	*	*	*	*
		2	*		*	
		3	*		*	
Percol FL	28	1	*	*	*	*
		2	*		*	
		3	*		*	

[1] 1 psi = 6.89 kPa.

* Strain range exceed 20% beyond capacity of compressometer or strain gauge.

Table C-5. Flexural strength test results, ASTM C 78 (24 hours)

Product	Age	Specimen	Average Width (in)[1]	Average Depth (in)[1]	Span Length (in)[1]	Maximum Load (lbf)[1]	Modulus of Rupture (psi)[1]	Average M.O.R.
Duracal	24	1	3.00	4.05	12.0	2,568	630	645
		2	3.00	4.00	12.0	2,545	650	
		3	3.00	4.00	12.0	2,603	660	
Type III PCC	24	1	3.00	4.00	12.0	2,750	690	610
		2	3.00	4.10	12.0	2,500	595	
		3	3.00	4.10	12.0	2,320	550	
Set-45	24	1	3.10	4.00	12.0	2,117	510	460
		2	3.10	4.00	12.0	1,704	410	
		3	3.00	4.00	12.0	1,845	460	
Five Star HP	24	1	3.00	4.00	12.0	2,053	520	555
		2	3.00	4.00	12.0	2,410	600	
		3	3.00	4.00	12.0	2,170	540	
Pyrament 505	24	1	3.00	4.00	12.0	1,980	495	495
		2	3.10	4.00	12.0	2,012	490	
		3	3.00	4.00	12.0	2,022	505	
SikaPronto 11	24	1	3.10	4.20	12.0	8,315	1,830	1,935
		2	3.10	4.10	12.0	9,002	2,070	
		3	3.10	4.10	12.0	8,255	1,900	
MC-64	24	1	3.00	4.00	12.0	2,069	*	*
		2	3.00	4.00	12.0	1,928	*	
		3	3.00	4.00	12.0	2,059	*	
Percol FL	24	1	2.90	4.00	12.0	2,202	*	*
		2	2.90	4.00	12.0	1,695	*	
		3	2.90	4.00	12.0	1,925	*	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

* No fracture occurred. Maximum load obtained at 1.4 in maximum deflection allowed by testing jig.

Table C-6. Flexural strength test results, ASTM C 78 (28 days)

Product	Age (days)	Specimen	Avg. Width (in)[1]	Avg. Depth (in)[1]	Span Length (in)[1]	Maximum Load (lbf)[1]	Modulus of Rupture (psi)[1]	Avg. M.O.R.
Duracal	28	1	3.00	4.00	12.0	2,669	665	655
		2	3.00	4.00	12.0	2,420	605	
		3	3.00	4.00	12.0	2,803	700	
Type III PCC	28	1	3.00	4.00	12.0	4,947	1,235	1,160
		2	3.05	4.05	12.0	4,116	985	
		3	3.05	4.00	12.0	5,120	1,260	
Set-45	28	1	3.00	4.00	12.0	2,107	525	495
		2	3.05	4.00	12.0	1,824	450	
		3	3.05	4.00	12.0	2,074	510	
Five Star HP	28	1	3.00	4.00	12.0	2,650	665	675
		2	3.00	4.00	12.0	2,957	740	
		3	3.00	4.00	12.0	2,495	625	
Pyrament 505	28	1	3.00	4.00	12.0	5,080	1,270	1,230
		2	3.00	4.00	12.0	4,962	1,240	
		3	3.00	4.00	12.0	4,734	1,185	
SikaPronto 11	28	1	3.00	4.00	12.0	8,988	2,250	2,200
		2	3.10	4.00	12.0	9,125	2,210	
		3	3.05	4.00	12.0	8,852	2,140	
MC-64	28	1	3.10	4.10	12.0	4,137	*	*
		2	3.00	4.10	12.0	4,008	955	
		3	3.10	4.10	12.0	4,137	*	
Percol FL	28	1	2.90	4.10	12.0	2,056	*	*
		2	2.90	4.10	12.0	2,510	*	
		3	2.90	4.10	12.0	2,617	*	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

* No fracture occurred. Maximum load obtained at 1.4" maximum deflection allowed by testing jig.

Table C-7. Slant-shear bond test results, ASTM C 882 (dry condition, 24 hours)

Product	Age (hrs)	Specimen	Bond Area (in^2)[1]	Type of Fracture[+]	Position of Fracture[++]	Bond Strength (psi)[1]	
							Avg.
Duracal	24	1	14.13	A	I	1,760	1,450
		2	14.13	A	I	1,060	
		3	14.13	A	I	1,520	
Type III PCC	24	1	14.13	A	I	400	450
		2	14.13	A	I	470	
		3	14.13	A	I	470	
Set-45	24	1	14.13	A	I	590	650
		2	14.13	A	I/P	600	
		3	14.13	A	I	1,450*	
Five Star HP	24	1	14.13	A	I	2,620	2,570
		2	14.13	A	I	2,510	
		3	14.13	A	I	2,570	
Pyrament 505	24	1	14.13	A	I	2,780	2,730
		2	14.13	A	I	2,930	
		3	14.13	A	I	2,480	
Sikapronto 11	24	1	14.13	A	I	2,340	2,420
		2	14.13	A	I	2,530	
		3	14.13	A	I	2,400	
MC-64	24	1	14.13	A/C	I/B	320	360
		2	14.13	A/C	I/B	360	
		3	14.13	A/C	I/B	390	
Percol FL	24	1	14.13	A	I/B	270	260
		2	14.13	A	I	260	
		3	14.13	A	I/B	260	

[1] 1 in = 25.4 mm, 1 psi = 6.89 kPa.

* Discard, bad specimen.

[+] A = adhesive failure, C = cohesive failure.

[++] I = interface, B = base concrete, P = patching material.

Table C-8. Slant-shear bond test results, ASTM C 882 (dry condition, 28 days)

Product	Age (days)	Specimen	Bond Area (in^2)[1]	Type of Fracture[+]	Position of Fracture[++]	Bond Strength (psi)[1]	
							Avg.
Duracal	28	1	14.13	A	I	2,430	2,110
		2	14.13	A	I	1,570	
		3	14.13	A	I	2,340	
Type III PCC	28	1	14.13	A	I	990	900
		2	14.13	A	I	970	
		3	14.13	A	I	730	
Set-45	28	1	14.13	A	I	1,260	1,190
		2	14.13	A	I	1,180	
		3	14.13	A	I	1,140	
Five Star HP	28	1	14.13	A/C	B/P/I	3,260	3,260
		2	14.13	C	B/P	3,080	
		3	14.13	A/C	B/P/I	3,440	
Pyrament 505	28	1	14.13	C	B/P	3,580	3,630
		2	14.13	C	B/P	3,720	
		3	14.13	A/C	B/P/I	3,590	
SikaPronto 11	28	1	14.13	A	I	2,920	2,870
		2	14.13	A	I	2,890	
		3	14.13	A	I	2,800	
MC-64	28	1	14.13	A/C	I/B	440	460
		2	14.13	A/C	I/B	440	
		3	14.13	A/C	I/B	490	
Percol FL	28	1	14.13	A	I	260	260
		2	14.13	A	I	190	
		3	14.13	A	I	330	

[1] 1 in = 25.4 mm, 1 psi = 6.89 kPa.

[+] A = adhesive failure, C = cohesive failure.

[++] I = interface, B = base concrete, P = patching material.

Table C-9. Slant-shear bond test results, ASTM C 882 (wet condition, 24 hours)

Product	Age (hrs)	Specimen	Bond Area (in^2)[1]	Type of Fracture[+]	Position of Fracture[++]	Bond Strength (psi)[1]	
							Average
Duracal	24	1 2 3	14.13 14.13 14.13	A A A	I I I	1,550 2,100 1,350	1,630
Type III PCC	24	1 2 3	14.13 14.13 14.13	A A A	I I I	1,110 1,400 1,450	1,320
Set-45	24	1 2 3	14.13 14.13 14.13	A A/C A	I I/P I	610 880 540	675
Five Star HP	24	1 2 3	14.13 14.13 14.13	A A A	I I I	2,130 2,015 2,475	2,205
Pyrament 505	24	1 2 3	14.13 14.13 14.13	A A/C A	I I/P I	1,740 1,040 1,220	1,330
SikaPronto 11	24	1 2 3	14.13 14.13 14.13	A A A	I I I	0 0 0	0[*]
MC-64	24	1 2 3	13.97 13.97 13.97	A A A	I I I	150 95 75	110
Percol FL	24	1 2 3	14.13 14.13 14.13	A A A	I I I	60 40 70	55

[1] 1 in = 25.4 mm, 1 psi = 6.89 kPa.

[*] Specimens debonded after demolding.

[+] A = adhesive failure, C = cohesive failure.

[++] I = interface, B = base concrete, P = patching material.

Table C-10. Slant-shear bond test results, ASTM C 882 (wet condition, 28 days)

Product	Age (days)	Specimen	Bond Area (in^2)[1]	Type of Fracture[+]	Position of Fracture[++]	Bond Strength (psi)[1]	
							Average
Duracal	28	1	14.13	A	I	2,790	2,585
		2	14.13	A	I	2,440	
		3	14.13	A	I	2,520	
Type III PCC	28	1	14.13	A	I/P	1,910	2,020
		2	14.13	A	I	2,190	
		3	14.13	A	I	1,955	
Set-45	28	1	14.13	A	I	1,660	1,445
	30	2	14.13	A	I	695[**]	
	30	3	14.13	A	I	1,230	
Five Star HP	28	1	14.13	A	I	2,875	2,630
		2	14.13	A	I	2,600	
		3	14.13	A	I	2,410	
Pyrament 505	28	1	14.13	A	I	2,910	2,830
		2	14.13	A	I	2,560	
		3	14.13	A	I	3,020	
SikaPronto 11	28	1	14.13	A	I	0	0[*]
		2	14.13	A	I	0	
		3	14.13	A	I	0	
MC-64	28	1	14.13	A	I	215	245
		2	14.13	A	I/P	290	
		3	14.13	A	I	235	
Percol FL	28	1	14.13	A	I	40	60
		2	14.13	A	I	95	
		3	14.13	A	I	50	

[1] 1 in = 25.4 mm, 1 psi = 6.89 kPa.

[*] Specimens debonded after demolding.

[**] Discard, bad specimen.

[+] A = adhesive failure, C = cohesive failure.

[++] I = interface, B = base concrete, P = patching material.

Table C-11. Center-point bond strength test results, CALTRANS (dry condition, 24 hours)

Production	Age (hrs)	Specimen	Width (in)[1]	Depth (in)[1]	Span (in)[1]	Position of Fracture+	Area of Break (%)	Maximum Load (lbf)[1]	Modulus of Rupture (psi)[1]	
										Average
Duracal	24	1	3.1	4.1	12.0	I	---	670	230	235
		2	3.0	4.0	12.0	I	---	709	265	
		3	3.0	4.0	12.0	I	---	563	210	
Type III PCC	24	1	3.0	4.0	12.0	I	---	1,200	450	415
		2	3.0	4.0	12.0	I	---	1,300	490	
		3	3.0	4.0	12.0	I	---	800	300	
Set-45	24	1	3.1	4.0	12.0	I	---	1,153	425	345
		2	3.1	4.0	12.0	I	---	692	255	
		3	3.1	4.0	12.0	I	---	944	350	
Five Star HP	24	1	3.0	4.0	12.0	I	---	1,384	520	525
		2	3.0	4.1	12.0	I	---	1,605	575	
		3	3.0	4.0	12.0	I	---	1,287	485	
Pyrament 505	24	1	3.10	4.00	12.0	I	---	850	310	330
		2	3.05	4.05	12.0	I	---	963	345	
		3	3.00	4.05	12.0	I	---	899	330	
Sikapronto 11	24	1	3.0	4.0	12.0	I	---	2,346	880	880
		2	3.1	4.1	12.0	I	---	2,229	770	
		3	3.0	4.0	12.0	I	---	2,633	985	
MC-64	24	1	3.1	4.1	12.0	I	---	1,113	400	365
		2	3.1	4.1	12.0	I	---	980	350	
		3	3.1	4.1	12.0	I	---	943	340	
Percol FL	24	1	3.1	4.0	12.0	I	---	1,343	485	495
		2	2.9	4.0	12.0	I	---	1,248	485	
		3	2.9	4.0	12.0	I	---	1,313	510	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

+ I = interface, B = base concrete, P = patching material.

Table C-12. Center-point bond strength test results, CALTRANS (dry condition, 28 days)

Product	Age (days)	Specimen	Width (in)[1]	Depth (in)[1]	Span (in)[1]	Position of Fracture[+]	Area of Break (%)[1]	Maximum Load (lbf)[1]	Modulus of Rupture (psi)[1]	
										Average
Duracal	28	1	3.0	4.0	12.0	I/B	5	726	220	255
		2	3.0	4.1	12.0	I/P	5	5,677	240	
		3	3.0	4.1	12.0	I	---	255	*	
Type III PCC	28	1	3.1	4.1	12.0	I	---	1,220	420	480
		2	3.1	4.1	12.0	I	---	1,400	525	
		3	3.1	4.1	12.0	I	---	1,320	495	
Set-45	28	1	3.1	4.0	12.0	I	---	1,606	585	585
		2	3.1	4.0	12.0	I/B	10	1,551	565	
		3	3.1	4.0	12.0	I/B	10	1,666	605	
Five Star HP	28	1	3.0	4.1	12.0	I/P	80	1,673	595	535
		2	3.0	4.1	12.0	I/P	60	1,504	535	
		3	3.0	4.1	12.0	I/P	70	1,338	480	
Pyrament 505	28	1	3.1	4.1	12.0	I/B	5	2,150	745	690
		2	3.0	4.1	12.0	B	100	1,890	675	
		3	3.0	4.1	12.0	I/B	10	1,805	645	
SikaPronto 11	28	1	3.0	4.0	12.0	I/B	95	2,650	995	965
		2	3.0	4.0	12.0	I/B	95	2,600	975	
		3	3.1	4.0	12.0	I/B	70	2,560	930	
MC-64	28	1	3.0	4.1	12.0	I/P	5	1,374	490	475
		2	2.9	4.1	12.0	I	---	1,244	460	
		3	2.9	4.1	12.0	I	---	1,274	470	
Percol FL	28	1	3.0	4.0	12.0	I/B	40	1,550	580	580
		2	3.0	4.0	12.0	I/B	5	1,594	600	
		3	2.9	4.0	12.0	I	---	1,444	560	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

[+] I = interface, B = base concrete, P = patching material.

Table C-13. Center-point bond strength test results, CALTRANS (wet condition, 24 hours)

Product	Age (hrs)	Specimen	Width (in)[1]	Depth (in)[1]	Span (in)[1]	Position of Fracture	Area of Break (%)	Maximum Load (lbf)[1]	Modulus of Rupture (psi)[1]	
										Average
Duracal	24	1	3.0	4.1	12.0	I	---	922	330	240
		2	3.1	4.1	12.0	I	---	562	195	
		3	3.0	4.1	12.0	I	---	538	195	
Type III PCC	24	1	3.0	4.1	12.0	I	---	285	105	90
		2	3.0	4.0	12.0	I	---	221	85	
		3	3.0	4.0	12.0	I	---	206	75	
Set-45	24	1	3.1	4.1	12.0	I	---	626	215	220
		2	3.1	4.1	12.0	I	---	615	210	
		3	3.0	4.2	12.0	I	---	685	235	
Five Star HP	24	1	3.1	4.0	12.0	I/P	30	615	225	235
		2	3.1	4.0	12.0	I	---	586	215	
		3	3.0	4.0	12.0	I/P	30	723	270	
Pyrament 505	24	1	3.1	4.2	12.0	I	---	722	240	295
		2	3.1	4.1	12.0	I	---	999	345	
		3	3.1	4.2	12.0	I	---	916	300	
SikaPronto 11	24	1	3.1	4.1	12.0	I	---	0	0	0*
		2	3.1	4.1	12.0	I	---	0	0	
		3	3.1	4.1	12.0	I	---	0	0	
MC-64	24	1	3.0	4.0	12.0	I	---	749	280	290
		2	3.0	4.1	12.0	I	---	840	300	
		3	3.1	4.1	12.0	I	---	850	295	
Percol FL	24	1	2.9	4.0	12.0	I	---	0	0	0*
		2	2.9	4.0	12.0	I	---	0	0	
		3	2.9	4.0	12.0	I	---	0	0	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

* Specimens debonded after demolding.

+ I = interface, B = base concrete, P = patching material.

Table C-14. Center-point bond strength test results, CALTRANS, (wet condition, 28 days)

Product	Age (days)	Specimen	Width (in)	Depth (in)	Span (in)	Position of Fracture	Area of Break (%)	Maximum Load (lbf)	Modulus of Rupture (psi)i	
										Average
Duracal	28	1	3.1	4.0	12.0	I	---	1,310	475	435
		2	3.1	4.0	12.0	I	---	1,099	400	
		3	3.1	4.0	12.0	I	---	1,200	435	
Type III PCC	28	1	3.1	4.0	12.0	I	---	1,016	370	365
		2	3.1	4.0	12.0	I	---	956	345	
		3	3.1	4.0	12.0	I/B	5	1,036	375	
Set-45	28	1	3.1	4.0	12.0	I/P	5	605	220	225
		2	3.1	4.1	12.0	I	---	615	210	
		3	3.1	4.0	12.0	I/P	40	676	245	
Five Star HP	28	1	3.1	4.1	12.0	I	---	880	305	330
		2	3.1	4.1	12.0	I/P	70	1,029	355	
		3	3.1	4.1	12.0	I	---	950	330	
Pyrament 505	28	1	3.0	4.0	12.0	I	---	1,090	410	385
		2	3.0	4.1	12.0	I	---	1,075	385	
		3	2.9	4.0	12.0	I	---	920	355	
SikaPronto 11	28	1	3.1	4.1	12.0	I	---	0	0	0*
		2	3.1	4.1	12.0	I	---	0	0	
		3	3.1	4.1	12.0	I	---	0	0	
MC-64	28	1	2.9	4.0	12.0	I	---	950	370	330
		2	2.8	4.0	12.0	I	---	779	315	
		3	2.9	4.0	12.0	I	---	767	300	
Percol FL	28	1	2.9	4.0	12.0	I	---	0	0	0*
		2	2.9	4.0	12.0	I	---	0	0	
		3	2.9	4.0	12.0	I	---	0	0	

[1] 1 in = 25.4 mm, 1 lbf = 4.448 N, 1 psi = 6.89 kPa.

[*] Specimens debonded after demolding.

[+] I = interface, B = base concrete, P = patching material.

Table C-15. Freeze-thaw test results, ASTM C 666

Product	Sample	No. of Cycles	Initial Weight (g)	Final Weight (g)	Weight Change (g)		Initial Resonant Frequency (KHz)	Final Resonant Frequency (KHz)	Relative Dynamic Modulus	Durability Factor	
						Avg.					Avg.
Duracal	1	152	7,690.4	7,678.7	-11.7	-39.4	2,223	1,699	58.4	29.6	43.0
	2	190*	7,569.9	7,555.5	-14.4		2,227	2,163	94.3	59.7	
	3	260	7,662.3	7,570.2	-92.1		2,223	1,504	45.8	39.7	
Type III PCC	1	308	7,780.8	7,778.0	-2.8	-12.3	2,470	2,424	96.3	98.9	— 101.3
	2	308	7,845.6	7,845.0	-0.6		2,510	2,468	96.7	99.3	
	3	308	7,801.5	7,768.1	-33.4		2,417	2,454	103.1	105.8	
Set-45	1	72	7,469.5	7,452.2	-17.3	-36.0	1,605	1,299	58.6	14.1	24.9
	2	72*	7,473.6	7,462.3	-11.3		1,615	1,499	86.2	20.7	
	3	227	7,463.9	7,384.4	-79.5		2,470	1,792	52.6	39.8	
Five Star HP	1	72	7,515.8	---	---	---	2,241	1.392	38.6	9.3	10.1
	2	72	7,370.1	---	---		2,215	---	---	---	
	3	72	7,501.2	---	---		2,227	1,493	44.9	10.8	
Pyrament 505	1	308	7,688.9	7,687.7	-1.9	-5.6	2,400	2,481	106.9	109.7	124.9
	2	308	7,671.7	7,667.0	-1.7		2,410	2,473	105.3	108.1	
	3	308	7,682.1	7,671.8	-10.3		1,998	2,470	152.8	156.9	
SikaPronto 11	1	306	7,296.3	7,295.2	-1.1	3.5	1,983	1,747	77.6	79.2	76.3
	2	306	7,403.1	7,408.0	4.9		1,970	1,783	81.9	83.6	
	3	306	7,313.4	7,320.1	6.7		1,992	1,602	64.7	66.0	
MC-64	1	306	2,691.1	2,807.4	116.3	61.7	1,805	1,690	87.7	89.4	96.2
	2	306	2,638.7	2,693.7	55.0		1,834	1,813	97.7	99.7	
	3	306	2,690.8	2,704.6	13.8		1,857	1,835	97.6	99.6	
Percol FL	1	306	6,149.3	6,172.0	22.7	56.9	3.081	2,156	49.0	49.9	57.1
	2	306	6,163.0	6,206.3	43.3		2.854	2,218	60.4	61.6	
	3	306	5,894.3	5,998.9	104.6		1.542	1,181	58.7	59.8	

-- Samples were too badly deteriorated to make a reading or weight measurement.

* Specimens fractured near midsection; test terminated.

Table C-16. Wear-resistance test results, CALTRANS T 550

Product	Specimen	Abrasion Loss (g)		Percent loss		Test Age (days)
			Average		Average	
Duracal	1	21.5	19.8	2.27	2.04	7
	2	18.6		1.83		7
	3	19.3		2.01		7
Type III PCC	1	19.6	18.7	1.86	1.77	7
	2	17.5		1.67		7
	3	18.9		1.77		7
Set-45	1	23.9	23.7	2.46	2.45	7
	2	23.5		2.45		7
	3	23.7		2.44		7
Five Star HP	1	20.0	19.5	2.19	2.11	7
	2	19.6		2.14		7
	3	18.8		1.99		7
Pyrament 505	1	25.9	25.5	2.70	2.65	7
	2	23.7		2.35		7
	3	26.8		2.91		7
SikaPronto 11	1	12.3	12.7	1.27	1.31	7
	2	13.0		1.35		7
	3	10.8*		1.06*		7
MC-64	1	-0.8	-0.8	-0.22	-0.21	8
	2	-0.6		-0.16		8
	3	-0.9		-0.25		8
Percol FL	1	0.0	0.0	0.0	0.01	8
	2	0.0		0.0		8
	3	0.2		0.03		8

* Discard; sample size too high.

Table C-17. Length-change test results, ASTM C 157

Product	Specimen	Length Change (%)					
		4 hours	8 hours	24 hours	3 days	28 days	60 days
Duracal	1	-0.017	0.002	-0.003	-0.004	-0.017	-0.025
	2	-0.016	-0.012	-0.014	-0.014	-0.023	-0.032
	3	-0.020	-0.015	-0.009	-0.014	-0.027	-0.037
	Average	-0.018	-0.008	-0.009	-0.011	-0.022	-0.031
Type III PCC	1	-0.002	-0.005	-0.013	-0.021	-0.039	-0.059
	2	-0.006	-0.019	-0.025	-0.031	-0.043	-0.062
	3	-0.007	-0.007	-0.014	-0.028	-0.039	-0.059
	Average	-0.005	-0.010	-0.017	-0.027	-0.040	-0.060
Set-45	1	-0.005	-0.005	-0.007	-0.009	-0.009	-0.013
	2	-0.014	-0.016	-0.018	-0.020	-0.024	-0.027
	3	-0.011	-0.017	-0.019	-0.021	-0.022	-0.025
	Average	-0.010	-0.013	-0.015	-0.017	-0.018	-0.022
Five Star HP	1	-0.005	-0.008	-0.012	-0.018	-0.032	-0.039
	2	-0.009	-0.013	-0.020	-0.025	-0.039	-0.047
	3	-0.006	-0.008	-0.017	-0.021	-0.035	-0.040
	Average	-0.007	-0.010	-0.016	-0.021	-0.035	-0.042
Pyrament 505	1	0.000	-0.020	-0.042	-0.042	-0.052	-0.055
	2	-0.002	-0.016	-0.038	-0.037	-0.048	-0.053
	3	-0.007	-0.022	-0.039	-0.041	-0.054	-0.056
	Average	-0.003	-0.019	-0.040	-0.040	-0.051	-0.055
SikaPronto 11	1	-0.017	-0.022	-0.027	-0.032	-0.042	-0.047
	2	-0.010	-0.013	-0.025	-0.025	-0.035	-0.036
	3	-0.019	-0.027	-0.033	-0.035	-0.043	-0.051
	Average	-0.015	0.0210	-0.028	-0.031	-0.040	-0.045
MC-64	1	*	*	*	*	*	*
	2	*	*	*	*	*	*
	3	*	*	*	*	*	*
	Average	*	*	*	*	*	*
Percol FL	1	*	*	*	*	*	*
	2	*	*	*	*	*	*
	3	*	*	*	*	*	*
	Average	*	*	*	*	*	*

* Unable to obtain well-defined readings. Specimens exhibited elastic behavior at all ages. Bottom gauge stud was pushed inside specimen by specimen's own weight.

Table C-18. Thermal compatibility test results, ASTM C 884

Product	Specimen	Number of Cycles	Observation		Result
			Delamination	Horizontal Crack	
Duracal	1	5	Yes	None	Fail
	2	5	No	None	Pass
	3	5	No	None	Pass
Type III PCC	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass
Set-45	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass
Five Star HP	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass
Pyrament 505	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass
SikaPronto 11	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass
MC-64	1	5	Yes	None	Fail
	2	5	No	None	Pass
	3	5	Yes	None	Fail
Percol FL	1	5	No	None	Pass
	2	5	No	None	Pass
	3	5	No	None	Pass

Table C-19. Summary of laboratory testing for UPM (South Carolina and Arizona)

Test Name, ASTM Designation[1]	Replicate Number			Average Values
	1	2	3	
Resilient Modulus, D 4123 77°F, 0.33 Hz (ksi) 77°F, 0.50 Hz (ksi) 77°F, 1.00 Hz (ksi)	 319.52 307.66 318.47	 346.38 336.38 351.68	 203.65 199.74 205.91	 289.85 281.26 292.02
Marshall Stability, D 1559 (lbs) Marshall Flow (0.01 in)	4,972 9.0	5,304 10.0	4,976 10.0	5,084 9.7
Bulk Specific Gravity, D 2726	2.260	2.254	2.264	2.259
Maximum Specific Gravity, D 2041	2.535	2.536	2.539	2.537
Air Voids (percent)	10.8	11.1	10.8	10.9
Anti-Stripping, Modified D 1664	+ 95 %	+ 95 %	-	-
Workability, PTI Method	0.5	0.5	0.5	0.5
AC Content, D 2172 (percent)	3.5	3.3	3.6	3.5
Viscosity, D 2171, 140°F (Poise)	621	657	-	639
Penetration, D 5, 77°F, 100 g, 5 sec (dmm)	200	192	-	196
Ductility, D 113, 77°F, 5 cm/min, (cm)	150 +	150 +	-	150 +
Softening Point, D 36 (°F)	108	110	-	109

[1] 1 in = 25.4 mm, °C = (°F - 32) × 5 / 9, 1 lb = 0.455 kg.

Table C-20. Summary of laboratory testing for UPM (Utah)

Test Name, ASTM Designation[1]	Replicate Number			Average Values
	1	2	3	
Resilient Modulus, D 4123 77°F, 0.33 Hz (ksi) 77°F, 0.50 Hz (ksi) 77°F, 1.00 Hz (ksi)				
Marshall Stability, D 1559 (lb) Marshall Flow (0.01 in)	4100 12.0	4178 11.3	3742 12.0	4007 11.8
Bulk Specific Gravity, D 2726	2.162	2.173	2.154	2.163
Maximum Specific Gravity, D 2041	2.298	2.315	2.301	2.305
Air Voids (percent)	5.9	6.1	6.4	6.1
Anti-Stripping, Modified D 1664				
Workability, PTI Method				
AC Content, D 2172 (percent)	4.0	4.0	4.1	4.0
Viscosity, D 2171, 140°F (Poise)	351	229	-	193
Penetration, D 5, 77°F, 100 g, 5 sec. (dmm)	336	363	-	350
Ductility, D 113, 77°F, 5 cm/min., (cm)				
Softening Point, D 36 (°F)	100	93	-	96

[1] 1 in = 25.4 mm, °C = (°F - 32) × 5 / 9, 1 lb = 0.455 kg.

Table C-21. Summary of laboratory testing for spray-injection mix (South Carolina)

Test Name, ASTM Designation[1]		Replicate Number 1	2	3	Average Values
Marshall Stability, D 1559 (lbs) Marshall Flow (0.01 in)		4595 18.7	4858 14.7	5000 18.0	4818 17.1
Bulk Specific Gravity, D 2726		2.139	2.154	2.157	2.150
Maximum Specific Gravity, D 2041		2.451	2.447	2.445	2.448
Air Voids (percent)		12.7	12.0	11.8	12.2
Extraction-Gradation, % Passing, D 2172, C 136 Sieve Size	1/2 in	99.3	99.3	99.2	99.3
	3/8 in	85.0	83.1	84.7	84.3
	No.4	31.6	33.7	45.6	37.0
	No. 8	7.4	8.6	21.1	12.4
	No. 16	3.2	3.5	11.7	6.1
	No. 30	2.0	2.0	7.3	3.8
	No. 50	1.4	1.3	4.7	2.5
	No. 100	1.0	0.9	2.9	1.6
	No. 200	0.7	0.6	1.8	1.0
	% A.C.	3.9	3.9	4.2	4.0
Viscosity, D 2171, 140°F (Poise)		4831	4976	-	4904
Penetration, D 5, 77°F, 100 g, 5 sec (dmm)		68	67	-	68
Softening Point, D 36 (°F)		127.5	128.5	-	128.0

[1] 1 in = 25.4 mm, °C = (°F - 32) × 5 / 9, 1 lb = 0.455 kg.

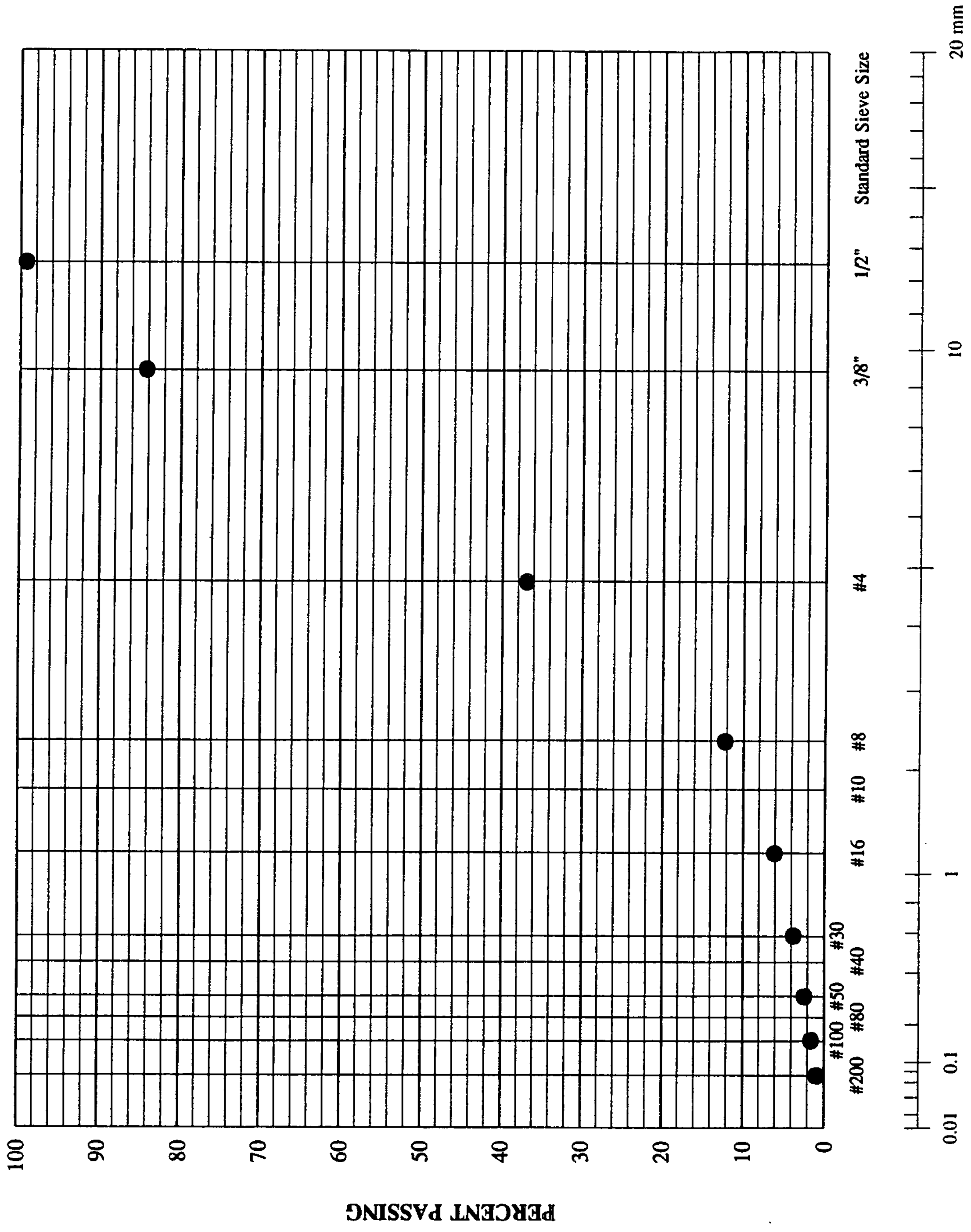

Figure C-1. Gradation for spray-injection mix (South Carolina)

Appendix D

Field Performance Data

Field evaluation of the patches entailed mainly visual observations of the distresses. At the time of the evaluations, only the length, width, depth (if appropriate), and severity of the distresses were recorded. Later, these dimensions were converted into percentages and ratings. Non-numeric observations, such as adjacent patch type and joint sealant condition also were recorded. In addition, photographs were taken during the evaluations to visually document the condition of the patches.

Patch performance was evaluated periodically through field surveys. The following distresses were measured for evaluating the field performance of cementitious and polymeric patches:

- Spalling
- Cracking
- Wearing
- Oxidizing
- Edge fraying
- Adjacent pavement deterioration
- Adjacent pavement corner break
- Joint sealant condition
- Faulting
- Debonding

The distresses measured for evaluating the field performance of bituminous patches include:

- Dishing
- Ravelling
- Shoving
- Cracking
- Bleeding
- Edge disintegration
- Missing patch

Forms

The forms used to record field performance data are included in this appendix. Figure D-1 shows the form used for bituminous patches; figure D-2 shows the form used for cementitious and polymer patches.

Distress Identification Guide and Rating Procedures

This section presents the guidelines used during field surveys to record the performance of the partial-depth patches.

Concrete and Polymer Patches

The distresses and conditions observed for cementitious and polymer patches include transverse cracking, longitudinal cracking, perimeter cracking/debonding, spalling, wearing, oxidizing, edge fraying, debonding, adjacent pavement deterioration, adjacent pavement corner break, and joint sealant condition. These are described in more detail in the following sections.

Transverse Cracking

Transverse cracking is defined as cracking in the interior of the patch that is transverse to the longest dimension of the patch. It excludes cracking at the perimeter of the patch. Length was measured in inches to the nearest inch and width in inches to the nearest 0.01 in (0.254 mm) up to a maximum of 0.06 in (1.524 mm), then to the nearest 0.125 in (3.18 mm). If the crack was frayed, it was indicated.

Longitudinal Cracking

Longitudinal cracking is defined as cracking that is parallel to the longest dimension of the patch. It excludes cracking at the perimeter of the patch. Length was measured in inches to the nearest inch and width in inches to the nearest 0.01 in (0.254 mm) up to a maximum of 0.06 in (1.524 mm), then to the nearest 0.125 inch (3.18 mm).

Perimeter Cracking/Debonding

This distress is defined as cracking or debonding of the patch/pavement interface as a result of shrinkage of the patch away from the sides of the original pavement. The sides of the patch where the perimeter cracking was observed were recorded. Length was measured in inches to the nearest inch and width in inches to the nearest 0.01 in (0.254 mm) up to maximum of 0.06 in (1.524 mm), then to the nearest 0.125 in (3.18 mm).

PCC SPALL REPAIR EVALUATION FORM (BITUMINOUS MATERIALS)

ID NUMBER 49 /S/ 2 / 9 /0/ B / 10A / 6 Position 1 2 3 [✓ 4] 5 6
State Regn Mat Prod Pch # Eval #

DISHING		RAVELLING		SHOVING		CRACKING	
depth (in)	area %	severity	area %	height (in)	area %	width (in)	length (in)
<0.25	50	loss of small rocks	40	<0.25		<0.0625	27
0.26 to 0.5	20	loss of large rocks	5	0.26 to 0.50		<0.25	
0.51 to 1.0	5	top 0.5 in gone		0.51 to 1.0		>0.25	
>1.0		top 1.0 in gone		>1.0		alligatored	

DISTRESS	PERCENT OF AREA									
BLEEDING	[✓ 0]	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-85	85-100
EDGE DINSINTEGRATION	0	1-10	11-20	[✓ 21-30]	31-40	41-50	51-60	61-70	71-85	85-100
MISSING PATCH	[✓ 0]	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-85	85-100

COMMENTS ....

Figure D-1. Patch-performance data form for bituminous materials

PCC SPALL REPAIR EVALUATION FORM (CEMENTITIOUS AND POLYMERIC MATERIALS)

ID NUMBER 49 (State) /S/ 2 (Regn) / 4 (Mat) /0/ 1 (Prod) / 11B (Pch #) / 6 (Eval #) Position 1 [✓ 2] 3 4 5 6

TRANSVERSE CRACKING

1 l 8.5 in 2 l___ in 3 l___ in 4 l___ in 5 l___ in 6 l___ in 7 l___ in 8 l___ in 9 l___ in 10 l___ in

w .01 in w___ in w___ in w___ in w___ in w___ in w___ in w___ in w___ in w___ in

PERIMETER CRACKING/SHRINKAGE

SIDE 1 l 16 in SIDE 2 l 8.5 in SIDE 3 l 16 in SIDE 4 l 8.5 in

w .01 in w .01 in w .01 in w .01 in

d___ in d___ in d___ in d___ in

LONGITUDINAL CRACKING

1 l___ in 2 l___ in 3 l___ in 4 l___ in

w___ in w___ in w___ in w___ in

	SPALLING		WEAR\RAVELLING		OXIDIZING		EDGE FRAYING	
SEVERITY	area (lxw)	%	area (lxw)	%	area (lxw)	%	length	%
NONE								
LOW	2 × 0.25							
MEDIUM								
HIGH								

BOND (% of patch bonded)										
[✓ 100]	90	80	70	60	50	40	30	20	10	0

ADJ DETERIORATION							JOINT SEALANT	FAULTING (in)
CORNER CRACK					SPALLING		GOOD	- 0.10
CRK WIDTH	<1/16"	1/16-1/8"	1/8-1/4"	>1/4"	SEVERITY	LENGTH (in)	POOR	
LS SPALLING					LOW		[✓ NONE]	PATCH
MS SPALLING					MEDIUM			PCC
HS SPALLING					HIGH			AC

COMMENTS ....

Figure D-2. Patch-performance data form for cementitious and polymer materials

Spalling

Spalling is defined as full- or partial-depth cracking **and** debonding of the repair material, either within the patch itself or from the pavement. Material may still be retained in the repair location. The severity, as defined below, and dimension of the spalled area were recorded:

- Low Severity: The spall does not extend more than 3 in (76 mm) from the edge of the patch, is not full depth and, if fragmented, the loose pieces are retained within the patch.

- Medium Severity: The spall extends more than 3 in (76 mm) from the perimeter of the patch and is not fragmented, or the spall is less than 3 in (76 mm) and the fragmented pieces are missing from the patch.

- High Severity: The patch is severely spalled with missing pieces greater than 6 in (76 mm) in length or width. Temporary patching may have been placed because of the spalling.

Wearing

This distress is defined as the wearing away of the surface of the patch. The severity level, defined below, and the dimensions of the affected area in each severity category were recorded:

- Low Severity: Cement has started to wear away such that the aggregate is exposed no more than 0.125 in (3.18 mm).

- Medium Severity: Cement has started to wear away such that the aggregate is exposed 0.125 in (3.18 mm) to 0.25 in (6.35 mm) or the whole patch surface has worn down 0.125 in (3.18 mm) to 0.25 in (6.35 mm).

- High Severity: Cement has started to wear away such that the aggregate is exposed more than 0.25 in (6.35 mm) or the whole patch surface has worn down 0.25 in (6.35 mm) or more.

Oxidizing

Oxidizing applies only to epoxy and polymer concretes. It is defined as hardening and/or surface cracking of the patching material. The severity levels for oxidizing are defined as follows:

- Low Severity: The patch has started to darken and harden, but with little or no appreciable cracking.

- Medium Severity: The patch has darkened and hardened and is starting to crack.
- High Severity: The patch has darkened and hardened and cracking is present in significant quantities.

Edge Fraying

Edge fraying is defined as minor raveling or wear of the repair material around the patch perimeter due to overfinishing, high placement, or wear over the joint bond-breaker. The severity, as defined below, and length in inches in each severity category were recorded.

- Low Severity: The fraying is less than 0.5-in (12.7-mm) wide and 0.5-in (12.7-mm)
- Medium Severity: The fraying is 0.5 in to 1 in (12.7 mm to 25.4 mm) wide and less than 0.5 in (12.7 mm) deep.
- High Severity: The fraying is 1 in to 2 in (25.4 mm to 50.8 mm) wide and less than 0.5 in (12.7 mm) deep. If the fraying is wider than 2 in (50.8 mm), classify as wear or spalling, whichever is more appropriate.

Debonding

Debonding is defined as loss of bond between the original pavement substrate and the repair material, particularly at the bottom interface. The location and dimension of the debonded area were recorded.

Adjacent Pavement Deterioration

Adjacent pavement deterioration is defined as spalling or cracking of the pavement immediately adjacent to the patch. The severity and dimension of the deterioration were recorded.

Adjacent Pavement Corner Break

An adjacent pavement corner break is defined as full-depth cracking of the adjacent pavement running from the patch to the corner of the slab or shoulder. The width of the crack and the severity of any crack spalling were recorded.

Joint Sealant Condition

The condition of the poured joint sealant at the location of the original transverse joint, as defined below, was recorded:

- Good: Sealant is bonded to the edges and is preventing the intrusion of incompressibles into the joint.
- Poor: Sealant is worn, not bonded, or low, and does not prevent the intrusion of incompressibles into the joint.
- None: The joint was either not sealed or the sealant has completely worn away.

Bituminous Patches

The distresses recorded for bituminous patches include dishing, raveling, shoving, cracking, bleeding, missing material, and edge disintegration. These distresses are described in detail in the following sections.

Dishing

Dishing is defined as depression or subsidence of the patching material below the surface of the adjacent pavement material. The difference in elevation between the highest and lowest point of the patch to the nearest 0.25 in (6.35 mm) was recorded.

Raveling

Raveling is defined as wearing away of the patch surface caused by the dislodging of aggregate particles and loss of asphalt binder. Wearing was classified into the categories defined below, and the area affected in each category was recorded:

- Low Severity: loss of small rocks
- Medium Severity: loss of large rocks
- High Severity: top 0.5 in (12.7 mm) gone
- Very High Severity: top 1 in (25.4 mm) gone

Shoving

Shoving is defined as the upheaval of the patching material above the surface of the adjacent pavement surface. The difference in elevation between the highest and lowest point of the patch to the nearest 0.25 in (6.35 mm) was measured and recorded.

Cracking

This distress is defined as cracking in the interior portions of the patch. Cracking near the edge of the patch is excluded. The length and average width of the individual cracks were measured and recorded. Alligator cracking was recorded as high severity and the area of cracking was recorded.

Bleeding

Bleeding is defined as the presence of free asphalt binder on the patch surface. The approximate area of the patch affected was recorded.

Missing Material

This distress is defined as the occurrence of patching material missing from the patch. The approximate area of the patch affected was recorded.

Edge Disintegration

Edge disintegration is defined as cracking and/or spalling along the edge of the patch, adjacent to the original pavement. The approximate area of the patch that was affected was recorded.

Distress Ratings for Cementitious and Polymer Patches

The method used to calculate the distress ratings for cementitious and polymer patches from the raw field data is described in the following sections.

Rating for Patch Spalling

The rating for patch spalling was calculated using Equation 1, as shown below.

Equation 1. $R_{sp} = 10 - (A_l \times 0.04) - (A_m \times 0.06) - (A_h \times 0.08)$

where:

R_{sp} = rating for patch spalling
A_l = percent area affected by low-severity spalling
A_m = percent area affected by medium-severity spalling
A_h = percent area affected by high-severity spalling

Rating for Patch Cracking

Three categories of cracking were measured: transverse, longitudinal, perimeter, and shrinkage cracking. Table D-1 was used to determine the rating for each of these types of patch cracking.

Rating for Wearing or Raveling of the Patch Surface

The rating for wearing or raveling of the patch surface was calculated using Equation 2, as shown below.

Equation 2. $R_{wr} = 10 - (A_l \times 0.01) - (A_m \times 0.02) - (A_h \times 0.04)$

where:

R_{wr} = rating for patch wearing or raveling
A_l = percent area affected by low-severity wear
A_m = percent area affected by medium-severity wear
A_h = percent area affected by high-severity wear

Rating for Oxidizing of the Patch Surface

A polymer partial-depth patch may harden and age when exposed to weathering. When the polymer patching material hardens, it may crack, deteriorate, or cause surface raveling. Oxidizing was rated according to the same scheme and equation as that used for wearing and raveling.

Rating for Edge Fraying

The rating for edge fraying was calculated using Equation 3, as shown below.

Equation 3. $R_{fr} = 10 - (A_l \times 0.01) - (A_m \times 0.02) - (A_h \times 0.04)$

where:

R_{fr} = rating for patch edge fraying
A_l = percent area affected by low-severity edge fraying
A_m = percent area affected by medium-severity edge fraying
A_h = percent area affected by high-severity edge fraying

Table D-1. Rating for patch cracking

Density[1] %	Crack Width (in)[2]				
	<0.03 (<1/32)	0.03 to 0.0625 (-1/16)	0.0625 to 0.125 (-1/8)	0.125 to 0.25 (-1/4)	>0.25 (>1/4)
0	10	10	10	10	10
1-20	9	8	7	6	5
21-40	9	8	6	6	4
41-60	8	7	6	5	3
61-80	8	7	5	4	2
81-100	7	6	5	3	1
>100	7	6	4	2	0

[1] Density for transverse and longitudinal cracking is determined by dividing the length of cracking by the area of the patch times 100. Density for perimeter or shrinkage cracking is determined by dividing the length of cracking by the perimeter of the patch times 100.

[2] 1 in = 25.4 mm.

Rating for Bond

The bond rating is a function of the percent of area bonded, as shown in table D-2. Thus, the patch receives a rating of 10 if it is fully bonded and a rating of 0 if it is completely debonded.

Rating for Adjacent Pavement Deterioration

Occasionally, the substrate adjacent to the patch will deteriorate, even if the patch is functioning well. This distress may be in the form of spalling at the slab/patch joint, a corner break in the adjacent or same slab, or a second patch placed adjacent to the original patch. If no patch-adjacent distress is found, a rating of 10 is given.

Rating for Spalling in the Adjacent Slab at the Slab/Patch joint

Spalling of the pavement at the patch boundaries may be the result of incomplete removal of the deteriorated area or continued deterioration of the pavement. In some cases, the repair material may expand and be responsible for the pavement spalling or bonding tenaciously so that shrinkage of the repair material will cause spalling in the adjacent pavement. Spalling of the pavement at the patch boundaries may indirectly affect the performance of the patch. The following scheme is used to rate the spalling in the adjacent pavement:

Table D-2. Rating for patch bonding

	Percentage of Patch Area Bonded										
	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Rating	0	1	2	3	4	5	6	7	8	9	10

Equation 4. $R_{pasp} = 10 - (A_l \times 0.04) - (A_m \times 0.06) - (A_h \times 0.08)$

where:

R_{pasp} = rating for patch-adjacent spalling
A_l = percent perimeter affected by low-severity spalling
A_m = percent perimeter affected by medium-severity spalling
A_h = percent perimeter affected by high-severity spalling

Rating for Corner Break

A corner break is a crack that intersects the joints at a distance less than 6 ft (1.83 m) on either side measured from the corner of the slab. In the case of a patch-adjacent distress, the corner crack must originate at the partial-depth patch. Table D-3 shows the rating scale used to rate a corner break. If the area inside the corner crack is spalled, the rating scheme described for patch-adjacent spalling is used.

Rating for Patching

If a permanent patch, constructed with a cementitious or polymer patching material, is present next to the patch being evaluated, a rating of 5 is given. If the patch is a temporary bituminous patch, a rating of 4 is given.

Rating for Faulting

Faulting is measured at the center of the patch. Faulting measurements are taken after construction and during the final evaluation trip. Faulting of the pavement generally results from poor load transfer and/or weak subgrade support. As this condition would not be corrected by partial-depth patching, the faulting measurements are not used in calculating a patch rating.

Table D-3. Rating for patch-adjacent corner break

Spalling	Corner Crack Width			
	<1/16"	1/16"-1/8"	1/8"-1/4"	>1/4"
None	9	8	7	6

Rating for Joint Sealant Condition

The presence of a joint sealant in the joint adjacent to the patch may be critical to preventing spalling and intrusion of water. The condition of the joint sealant should be noted. However, the condition of the sealant generally will depend on the joint sealant material and installation procedure rather than the spall repair patching material. Therefore, the joint sealant condition is not used in calculating a patch rating.

Distress Ratings for Bituminous Patches

The method used to calculate the distress ratings for bituminous patches from the raw field data is described in the following sections.

Rating for Dishing, Shoving, and Raveling

The rating for dishing, shoving, and raveling is calculated using Equation 5, as shown below.

Equation 5. $R_D = 10\text{-}(A_1 \times 0.03) - (A_2 \times 0.06) - (A_3 \times 0.08) - (A_4 \times 0.1)$

where: R_D = rating for patch distress D
A_1 = percent area affected by severity 1 distress D
A_2 = percent area affected by severity 2 distress D
A_3 = percent area affected by severity 3 distress D
A_4 = percent area affected by severity 4 distress D
D = dishing, shoving, or raveling

Rating for Cracking

The rating for cracking is calculated using Equation 6, as shown below.

Equation 6. $R_c = 10\text{-}0.03^{\frac{L_P}{l_1}} - 0.06^{\frac{L_P}{l_2}} - 0.08^{\frac{L_P}{l_3}} - 0.1^{\frac{L_P}{l_4}}$

where:

R_c = rating for patch cracking
l_1 = length of cracking less than 0.0625 in (0.159 cm) wide
l_2 = length of cracking less than 0.25 in (0.635 cm) wide
l_3 = length of cracking greater than 0.25 in (0.635 cm) wide
l_4 = length of area exhibiting alligator cracking

Rating for Bleeding, Edge Disintegration, or Missing Patch

The rating for bleeding, edge disintegration, or missing patch is determined as shown in table D-4.

Overall Patch Rating

The overall patch rating combines the effects of the individual distresses into one total performance indicator. Recognizing that distresses are interactive, an attempt was made to adjust the ratings when a combination of distresses is evident on a patch. As such, deduct values based on the initial distress ratings are calculated, summed, and then the sum of the deduct points are adjusted for interaction to determine an overall patch rating. The steps for calculating the overall patch rating are shown below.

First, calculate the deduct points for each distress, as shown in Equation 7.

Equation 7. $d_d = 10 - R_d$

where:

R_d = individual distress rating
d_d = deduct points

Second, sum the deduct points for all distresses (D). Third, count the number of distresses for which d_d is greater than 0.0 (q). Fourth, calculate the adjusted deduct value (D_{adj}) using Equation 8, as shown below.

Equation 8.

If $q = 0$ $D_{adj} = 0$
If $q = 1$ $D_{adj} = D$
If $q = 2$ $D_{adj} = 0.1 + .688D$
If $q = 3$ $D_{adj} = -0.1 + .638D$
If $q = 4$ $D_{adj} = -0.17 + .586D$
If $q = 5$ $D_{adj} = -0.268 + .567D$
If $q = 6$ $D_{adj} = -0.4 + .55D$
If $q \geq 7$ $D_{adj} = -0.4 + .50D$

where:

q = number of distresses for which the deduct points are greater than D,
D = sum of deduct points for all distresses

Table D-4. Rating for patch bleeding, edge disintegration, or missing patch

	Percentage of Area Affected by Bleeding, Edge Disintegration or Missing Patch										
	0	1-10	11-20	21-30	31-40	41-50	51-60	61-70	71-80	81-90	91-100
Rating	10	9	8	7	6	5	4	3	2	1	0

Fifth, calculate the overall patch rating using Equation 9, as shown below.

Equation 9. $R_{adj} = 10 - D_{adj}$

Summary Data

A huge amount of raw performance data was collected during the project. Since it is not feasible to present those data in their entirety, summary data showing average overall and distress ratings are presented in this section. The data shown in tables D-5 through D-9 represent average ratings for patches prepared with a given material-procedure treatment (TRT). The first character of the treatment code represents the patching material and the second character represents the patching procedure, as shown in table D-10.

Table D-5 shows the following average patch ratings for bituminous material-procedure combinations in all sites: overall (OVER), dishing (DISH), raveling (RAVL), shoving (SHOV), cracking (CRCK), bleeding (BLED), edge fraying (EDGE), missing (MISS). In table D-5, "AZ" indicates the dry-nonfreeze region (Arizona), "PA" represents the wet-freeze region (Pennsylvania), "SC" represents the wet-nonfreeze region (South Carolina), and "UT" represents the dry-freeze region (Utah).

Tables D-6 through D-9 show the following average patch ratings for cementitious and polymer materials in each of the four climatic regions: overall (OVER), spalling (SPLL), wearing (WEAR), fraying (FRAY), bonding (BOND), longitudinal cracking (LCRK), transverse cracking (TCRK), and oxidizing (OXID). Materials that do not oxidize have no oxidization rating, indicated by a period.

Table D-5. Average ratings for bituminous material-procedure treatments at all sites

SITE	TRT	OVER	DISH	RAVL	SHOV	CRCK	BLED	EDGE	MISS
AZ	92	8.56850	8.24400	10.0000	10.0000	9.97550	10.0000	9.70000	9.9250
PA	A8	7.82619	9.06429	8.4352	9.9286	9.99762	9.6905	9.50000	10.0000
PA	92	6.60750	7.83900	9.6845	9.8380	8.65050	10.0000	8.22500	10.0000
SC	92	8.83550	8.64450	9.9550	10.0000	9.97500	10.0000	9.77500	9.9750
SC	A8	7.54950	7.44200	8.7940	10.0000	9.96950	9.9000	9.80000	10.0000
UT	92	7.35484	7.18323	9.6071	10.0000	9.97774	10.0000	8.90323	9.9355

Table D-6. Average ratings for cementitious and polymer materials in Arizona

TRT	OVER	SPLL	WEAR	FRAY	BOND	LCRK	TCRK	OXID
51	9.46250	10.0000	10.0000	10.0000	9.70000	10.0000	10.0000	9.7450
61	9.42200	9.9980	9.9855	9.9840	9.35000	10.0000	10.0000	.
53	9.37700	10.0000	9.9750	9.9875	9.95000	10.0000	10.0000	9.4480
52	9.35150	10.0000	9.9735	10.0000	9.50000	10.0000	10.0000	9.7405
62	9.18500	9.9780	9.9870	9.9720	9.10000	10.0000	10.0000	.
41	9.05000	9.9600	9.4311	9.9761	9.72222	10.0000	9.3889	.
12	9.02200	9.9680	9.8465	9.8640	9.45000	9.8000	9.3000	.
42	8.54450	9.9740	9.4910	9.8510	9.00000	9.9500	9.3000	.
11	8.52900	9.9700	9.7870	9.8470	8.70000	9.9500	9.3500	.
32	8.25150	9.9720	9.0175	9.8900	8.45000	9.6000	9.4000	.
83	8.22550	9.9740	10.0000	9.7930	8.60000	9.4000	9.0000	.
22	7.59450	9.9600	9.9575	9.9030	6.65000	9.7500	9.2500	.
72	7.47250	10.0000	9.9370	10.0000	7.05000	9.9000	9.9000	10.0000
31	7.39700	9.9800	8.9883	9.9700	9.16667	9.5556	9.3889	.
21	6.96900	9.8100	9.8490	9.9905	6.45000	9.9500	9.5000	.
73	4.76000	9.9763	9.9584	9.9853	4.05263	9.8947	10.0000	10.0000
71	2.44550	10.0000	9.9420	9.9980	2.20000	9.5333	10.0000	10.0000
B1	2.30150	10.0000	9.9620	10.0000	0.60000	10.0000	10.0000	9.9950

Table D-7. Average ratings for cementitious and polymer materials in Pennsylvania

TRT	OVER	SPLL	WEAR	FRAY	BOND	LCRK	TCRK	OXID
72	9.12050	9.9940	9.7820	10.0000	9.05000	10.0000	10.0000	10.0000
71	8.61100	9.9960	9.8675	10.0000	8.60000	9.9000	9.9500	10.0000
61	8.45381	9.9381	9.9424	9.9090	8.57143	10.0000	9.2381	.
33	8.26300	9.7235	9.9895	9.9600	8.35000	9.5500	9.7000	.
31	8.14250	9.9670	9.5250	9.9610	8.05000	9.7500	9.5000	.
12	7.94667	9.5483	9.9929	9.9458	8.41667	9.8333	9.0833	.
51	7.84200	10.0000	9.9705	10.0000	7.80000	9.8000	10.0000	9.9000
73	7.82250	9.9740	9.6660	9.9945	7.30000	9.7500	10.0000	10.0000
43	7.60850	9.9489	9.8950	9.9217	8.88889	9.3333	8.8889	.
13	7.60850	9.9756	10.0000	9.9422	9.16667	9.2222	9.0556	.
62	7.27250	9.8600	9.9890	9.9260	6.55000	9.9000	9.1000	.
52	7.12600	9.9090	9.9775	9.9585	6.85000	9.2500	9.7500	9.8500
32	6.98100	9.6513	9.7031	9.8544	9.18750	9.7500	9.8125	.
82	6.90350	9.8358	9.9953	9.9637	6.89474	9.7895	9.0526	.
41	6.74550	9.7268	9.6584	9.9532	6.89474	9.6842	9.1053	.
11	6.31095	9.1650	10.0000	9.9660	6.25000	9.8500	8.9000	.
81	6.29400	9.0022	9.9900	9.9544	7.22222	9.7778	9.1111	.
42	6.22450	9.8339	9.5867	9.8278	6.72222	9.6111	9.1111	.

Table D-8. Average ratings for cementitious and polymer materials in South Carolina

TRT	OVER	SPLL	WEAR	FRAY	BOND	LCRK	TCRK	OXID
21	9.58300	9.9920	9.8110	9.9680	9.80000	10.0000	9.9500	.
11	9.37900	9.9790	9.9895	9.9675	9.85000	9.9500	9.4000	.
12	9.27800	9.9780	10.0000	9.9705	9.80000	9.8000	9.4000	.
32	9.26900	9.9660	9.9995	9.9625	9.45000	9.9000	9.6500	.
71	9.06550	10.0000	9.1425	10.0000	9.95000	10.0000	9.9500	10.0000
61	8.89600	9.8375	9.9765	9.9300	9.10000	10.0000	9.5000	.
22	8.79450	9.9900	9.7040	9.9995	9.05000	9.9000	9.7000	.
41	8.77100	9.9860	9.9370	9.9195	9.20000	9.9000	9.2000	.
42	8.45850	9.9920	9.9270	9.8705	8.55000	9.9500	9.2000	.
62	8.35600	9.9240	9.9960	9.7865	8.15000	9.9000	9.5500	.
31	8.25700	9.9911	9.8500	9.9489	9.33333	10.0000	9.7778	.
52	8.09800	9.9940	9.8650	10.0000	7.95000	9.7500	10.0000	10.0000
51	7.93789	9.9574	10.0000	10.0000	8.00000	9.8947	9.9474	10.0000
72	6.14700	9.9973	9.3000	10.0000	8.40000	10.0000	10.0000	10.0000

Table D-9. Average ratings for cementitious and polymer materials in Utah

TRT	OVER	SPLL	WEAR	FRAY	BOND	LCRK	TCRK	OXID
51	9.86160	10.0000	9.9816	10.0000	9.88000	10.0000	10.0000	10.0000
61	9.55231	9.9554	9.8465	9.9577	9.88462	10.0000	9.8077	.
42	9.47324	9.9718	9.7615	9.9335	9.82353	10.0000	9.7647	.
62	9.41929	9.9257	9.9814	9.9807	9.42857	9.9643	9.9643	.
52	9.35464	9.9986	9.8268	10.0000	9.35714	10.0000	10.0000	10.0000
22	9.34240	9.9232	9.6012	9.9932	9.84000	9.8000	9.8000	.
11	9.30760	9.9608	9.97520	9.9592	9.92000	9.9600	9.2000	.
41	9.28421	9.9684	9.91000	9.9595	9.31579	10.0000	9.7895	.
32	9.26609	9.9287	9.64217	9.9283	9.52174	9.9130	9.9130	.
15	9.25676	9.9481	9.97378	9.9497	9.86486	9.7838	9.2703	.
12	9.22343	9.9177	9.98200	9.9754	9.48571	9.8857	9.6286	.
31	9.16000	9.9233	9.60292	9.9825	9.45833	9.9167	9.9583	.
21	9.03818	9.9600	9.22545	9.9491	9.50000	10.0000	9.9545	.
72	7.94276	10.0000	9.61552	9.9990	7.93103	10.0000	10.0000	10.0000
71	7.36429	9.9100	9.48429	10.0000	7.21429	9.9643	10.0000	10.0000

Table D-10. Material and procedure codes for tables D-5 through D-9

Material Code	Material Name	Procedure Code	Procedure Name
1	Type III PCC	1	saw and patch
2	Duracal	2	chip and patch
3	Set-45	3	mill and patch
4	Five Star HP	4	adverse-condition clean and patch
5	MC-64	5	waterblast and patch
6	SikaPronto 11	8	good-condition clean and patch
7	Percol FL		
8	Pyrament 505		
9	UPM High Performance Cold Mix		
A	Spray-Injection Mix		
B	Penatron R/M-3003		

Appendix E

Cost-Effectiveness

The calculation of overall cost-effectiveness of a partial-depth patching operation requires an estimate of the cost of materials, labor, and equipment; the expected life of the partial-depth patch when constructed with a particular material and method; and user inconvenience. The initial cost of materials, labor, and equipment can be estimated fairly easily. However, the adjustment of all costs to reflect the expected life of the given repair requires that the expected life be known. The calculation of user costs is even more difficult.

Cost-Effectiveness Worksheet

This section presents a worksheet that helps calculate the cost of a partial-depth spall repair operation. The worksheet asks the user to input values and perform calculations in a step-by-step fashion. When worksheets have been completed for different combinations of materials and procedures, they can be compared to determine which is the most cost-effective.

The cost-effectiveness worksheet is shown in figure E-1. Explanations for the variables included in the worksheet follow.

Project Size or Seasonal Partial-Depth Patching Needs Variables

(A) Expected Number of Patches–The number of partial-depth patches (not the number of spalls, as several small spalls may be repaired with one patch) expected in the project or in a given season. This number could be based on the number of spalls repaired in the previous season or on a field survey.

(B_1) Average Finished Patch Length–The expected average length of the finished patches in inches. This value could be based on data from the previous season or on a field survey in which several patches throughout the project are sounded to determine the

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount	units	
Expected Number of Patches	______		(A)
Average Finished Patch Length	______	in	(B_1)
Average Finished Patch Width	______	in	(B_2)
Average Finished Patch Depth	______	in	(B_3)
Expected Total Volume of Finished Patches ($B_1 \times B_2 \times B_3 \times A$) ÷ 46656	______	yd^3	(C)

MATERIAL COSTS (e.g., cold mix, cement, aggregate, sand, bonding agent, joint bond-breaker, curing agent, etc.)

Material 1 = ______________

Material 1 Purchase Cost	______	\$/__	(D_1)
Expected Material 1 Needs	______	____	(E_1)
Material 1 Shipping Cost	______	\$	(F_1)
Total Material 1 Cost [($D_1 \times E_1$) + F_1]	______	\$	(G_1)

Material 2 = ______________

Material 2 Purchase Cost	______	\$/__	(D_2)
Expected Material 2 Needs	______	____	(E_2)
Material 2 Shipping Cost	______	\$	(F_2)
Total Material 2 Cost [($D_2 \times E_2$) + F_2]	______	\$	(G_2)

Material 3 = ______________

Material 3 Purchase Cost	______	\$/__	(D_3)
Expected Material 3 Needs	______	____	(E_3)
Material 3 Shipping Cost	______	\$	(F_3)
Total Material 3 Cost [($D_3 \times E_3$) + F_3]	______	\$	(G_3)

Material 4 = ______________

Material 4 Purchase Cost	______	\$/__	(D_4)
Expected Material 4 Needs	______	____	(E_4)
Material 4 Shipping Cost	______	\$	(F_4)
Total Material 4 Cost [(D_4 x E_4) + F_4]	______	\$	(G_4)

Figure E-1. Cost-effectiveness worksheet

LABOR COSTS

	amount	units	
Number in Repair Crew	______		(H)
Average Daily Wage per Person	______	$/day	(I)
Number in Traffic Control Crew	______		(J)
Average Daily Wage per Person	______	$/day	(K)
Supervisor Daily Wage	______	$/day	(L)

EQUIPMENT COSTS

Material Truck	______	$/day	(M)
Traffic Control Truck and Signs	______	$/day	(N)
Patch Preparation Equipment (e.g., concrete saw, jackhammer, milling machine, waterblaster)	______	$/day	(O_1)
	______	$/day	(O_2)
Cleaning Equipment (e.g., sandblaster, airblaster)	______	$/day	(P_1)
	______	$/day	(P_2)
Mixing Equipment (e.g., mortar mixer, Jiffy mixer)	______	$/day	(Q_1)
	______	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	______	$/day	(R)
Extra Equipment Truck	______	$/day	(S)
Miscellaneous Equipment (e.g., spray-injection machine, joint sealing equipment, etc.)	______	$/day	(T_1)
	______	$/day	(T_2)

Figure E-1. Cost-effectiveness worksheet (cont.)

SUMMARY COSTS

	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	______	\$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	______	\$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) +$ $(P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) +$ $R + S + (T_1 + T_2 + ...)]$	______	\$/day	(W)
User Costs	______	\$/day	(X)
Average Daily Productivity	______	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	______	days	(Z)
Total Labor and Equipment Cost $[(V + W) \times Z]$	______	\$	(AA)
Total Patching Operation Cost $[U + AA + (X \times Z)]$	______	\$	(BB)
Partial-depth Patch Survival Rate[1] (Duration may vary)	______	%	(CC)
Effective Patching Cost $[BB \times (2 - \{CC \div 100\})]$	______	\$	(DD)

[1] Until patch survival rates have been determined, agency experience should be applied.

Figure E-1. Cost-effectiveness worksheet (cont.)

dimensions of a deteriorated area. This value is helpful in estimating the amount of repair materials needed in the project (e.g., bonding agent and/or curing compound surface area, joint bond-breaker length, etc.)

(B_2) Average Finished Patch Width–The expected average width of the finished patches in inches. This value could be based on data from the previous season or on a field survey in which several patches throughout the project are sounded to determine the dimensions of the deteriorated area. This value is helpful in estimating the amount of repair materials needed in the project (e.g., bonding agent and/or curing compound surface area, joint bond-breaker length, etc.)

(B_3) Average Finished Patch Depth–The expected average depth of the finished patches in inches. This value could be based on data from the previous season or on a field survey in which several patches in the project are sounded and cored to determine the depth of the deteriorated area. This value is helpful in estimating the necessary depth of the joint bond-breaker or fiberboard.

(C) Expected Total Volume of Finished Patches–The estimated total in-place volume of material needed to fill the patches based on the estimated average length (B_1), width (B_2), and depth (B_3). This value could be based on the previous season's data or the results of a field survey. This value is helpful in estimating the amount of material components needed for the project (e.g., cold mix, cement, aggregate, sand, etc.)

Material Cost Variables

(D_n) Material Purchase Cost–The cost of purchasing each material used to repair the partial-depth spalls. Materials will include the patching material and possibly materials such as a bonding agent, joint bond-breaker, and/or curing compound. This cost does not include shipping. The amount should be entered in dollars per ton, yd^3, gal, yd, etc., as appropriate for each material. If there are more than four materials, the worksheet can be duplicated.

(E_n) Expected Material Needs–The amount of each material needed for the project, such as the amount of the patching material, bonding agent, joint bond-breaker, and/or curing compound, taking into consideration a wastage factor of 10 to 20 percent. The amount should be entered in units of ton, yd^3, gal, yd, etc., as appropriate for each material.

(F_n) Material Shipping Cost–The cost of shipping each material from the site of production to the site of storage during the project.

(G_n) Total Material Cost–The total cost in dollars of each material, including shipping.

Labor and Equipment Costs Worksheet Variables

(H) Number in Repair Crew–The number of workers who will be performing the partial-depth patching operation. This number does not include traffic control personnel.

(I) Average Daily Wage per Person–The average wage paid to the members of the repair crew. By multiplying this figure by (H), the total labor costs for the workers doing the patching can be obtained. The amount entered should be in dollars per day.

(J) Number in Traffic Control Crew–The number of workers required to set up and conduct the traffic control operation. When the repair crew sets up signs and cones before beginning the repair operation, the number of traffic control workers is zero, so that the workers are not counted twice.

(K) Average Daily Wage per Person–The average wage paid to the members of the traffic control crew. By multiplying this number by (J), the total labor costs for the workers doing the traffic control can be obtained. The amount entered should be in dollars per day.

(L) Supervisor Daily Wage–The wage paid to the supervisor who oversees the repair operation. The amount entered should be in dollars per day.

(M) Material Truck–The operating charge associated with the truck carrying the repair material (excluding the driver's wages). Only trucks carrying the repair material should be included. The amount entered should be in dollars per day.

(N) Traffic Control Truck and Signs–The cost associated with all traffic control, including the cost of arrow boards, attenuator trucks, etc. If vehicles are used to set up traffic control and then are used for other activities during the day, a fraction of the daily cost should be used to approximate the time spent setting up traffic control for the repair operation. The amount entered should be in dollars per day and should not include the cost of labor.

(O_n) Patch Preparation Equipment–The cost associated with each piece of equipment that is used to saw the patch boundaries and/or to remove the deteriorated concrete (e.g., concrete saw, jackhammers, milling machine, waterblasting machine, etc.). The amount entered should be in dollars per day.

(P_n) Cleaning Equipment–The cost associated with each piece of equipment used to clean the repair hole after the deteriorated concrete has been removed. If a spray-injection machine's air hose has been used to clean the repair hole, this value should be zero. The amount entered should be in dollars per day.

(Q_n) Mixing Equipment–The cost associated with each piece of equipment used to mix the repair material(s). The amount should be entered in dollars per day.

(R) Consolidation/Compaction Equipment–The cost associated with the equipment used to consolidate or compact the partial-depth patches. The amount should be entered in dollars per day.

(S) Extra Equipment Truck–The cost associated with any equipment used to transport preparation, cleaning, mixing, consolidation and/or compaction equipment to the site. The amount should be entered in dollars per day.

(T_n) Miscellaneous Equipment–The cost associated with each piece of any other equipment used in the partial-depth spall repair process that was not included in (M) through (S) (e.g., spray-injection machine, joint-sealing equipment, etc.) The amount entered should be in dollars per day.

Summary Costs Variables

(U) Total Material Cost–The cost of all materials used in the partial-depth spall repair process.

(V) Total Daily Labor Cost–The cost per day of all labor used in the partial-depth spall repair process.

(W) Total Equipment Cost–The cost per day of all equipment used in the partial-depth spall repair process.

(X) User Costs–The costs to the highway user per day due to the delay associated with the repair operation. This value is fairly difficult to calculate. Agency experience may be applied.

(Y) Average Daily Productivity–The rate at which the partial-depth spall repair patching can be done by the patching crew. This amount should reflect the size and experience of the crew specified above. The amount should be in patches per day.

(Z) Estimated Number of Days for Patching Operation–An estimate of the number of days required to perform the partial-depth spall repairs.

(AA) Total Labor and Equipment Cost–The cost of labor and equipment for the duration of the partial-depth spall repair process.

(BB) Total Patching Operation Cost–The total initial cost of the entire partial-depth repair process. It does not take into account the expected life of the partial-depth patches. To compare the cost-effectiveness of different material and procedure combinations without knowing the partial-depth patch survival rate, the costs per project or season of using each one can be compared.

(CC) Partial-Depth Patch Survival Rate–An estimate of the number of patches that will survive for a specific duration. The amount entered should be in percent. To compare the cost-effectiveness of different material and procedure combinations, the user must enter percent survival for each using the same time period (i.e., 1 year, 5 years, 10 years) for each material and procedure combination.

(DD) Effective Patching Cost–The cost of partial-depth patching, adjusted to reflect the expected life of the partial-depth patches.

Calculation of Survival Rate

When partial-depth patch performance is monitored, the patch survival rate can be determined and used in the cost-effectiveness worksheets for comparisons between material-procedure patch treatments. One method for calculating a performance factor is described in this section.

Data Required

To determine the effectiveness of a given patch type (material-procedure combination), a field survey must be conducted periodically to count the number of patches from the patching operation that are still present and not failed. The time of the field survey must also be recorded. Table E-1 shows a typical collection of patch performance data.

Figure E-2 shows several plots of patch survival over time. In all three cases, the percent of patches remaining after 10 years is 80 percent. However, patch type B would have the highest patch survival rate when compared with patch types A and C because type B performed better longer than the other two patch types and consequently has a larger area under its survival curve.

Calculations

The patch survival rate is the area under the patch survival curve. The worksheet presented in table E-2 can be used to calculate the area for any available patch survival data. The worksheet allows for the systematic calculation of the area under the patch survival curve between each time of observation, as well as the final calculation of a performance rating by which patch types can be compared. As an example, the data from table E-1 have been used to calculate a patch survival rate using the worksheet in table E-2.

Each average percent surviving, P_{avg}, is calculated by averaging the two percent values that straddle the line being calculated, as shown in the shaded region of worksheet in table E-2.

Table E-1. Sample patch performance data

Time of survey (years) (T_t)	Patches in place (R_{ip})	Cumulative patches failed (R_f)[1]	Cumulative patches lost to rehabilitation (R_l)[2]	Percent patches surviving (P_s)[3]
0	200	0	0	100
1	194	6	0	97
2	186	12	2	94
3	180	16	4	92
4	175	20	4	90
6	153	38	9	80

[1] R_f = the number of patches that have failed since the time of installation.

[2] R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.

[3] $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$.

Each time interval, T_i, is calculated by subtracting the earlier time, T_t, from the later time, T_{t+1}, again for the two lines straddling the line being calculated, as shown in the shaded region of the worksheet.

Each partial area under the percent patch survival curve, A_{part}, is calculated by multiplying the P_{avg} and T_i values for that line. Each total area, A_{tot}, is calculated by multiplying the time interval, T_i, by 100. The total area under the patch survival curve, A_{tot}, represents the best possible performance that could occur for a patch type, i.e., 100 percent of all patches survived during the observed time period.

The patch survival rate is calculated by dividing the sum of the partial areas, A_{part}, by the sum of the total possible areas, A_{tot}, under the curve and multiplying by 100.

Example Calculation of Cost-Effectiveness

Sample worksheets for calculating cost-effectiveness are presented in this section. Different material and procedure combinations illustrate the differences that can occur when different patching operations are considered.

When using the examples in the following sections, it is important to remember that crew size and productivity differ greatly among agencies. These examples are fictitious and their

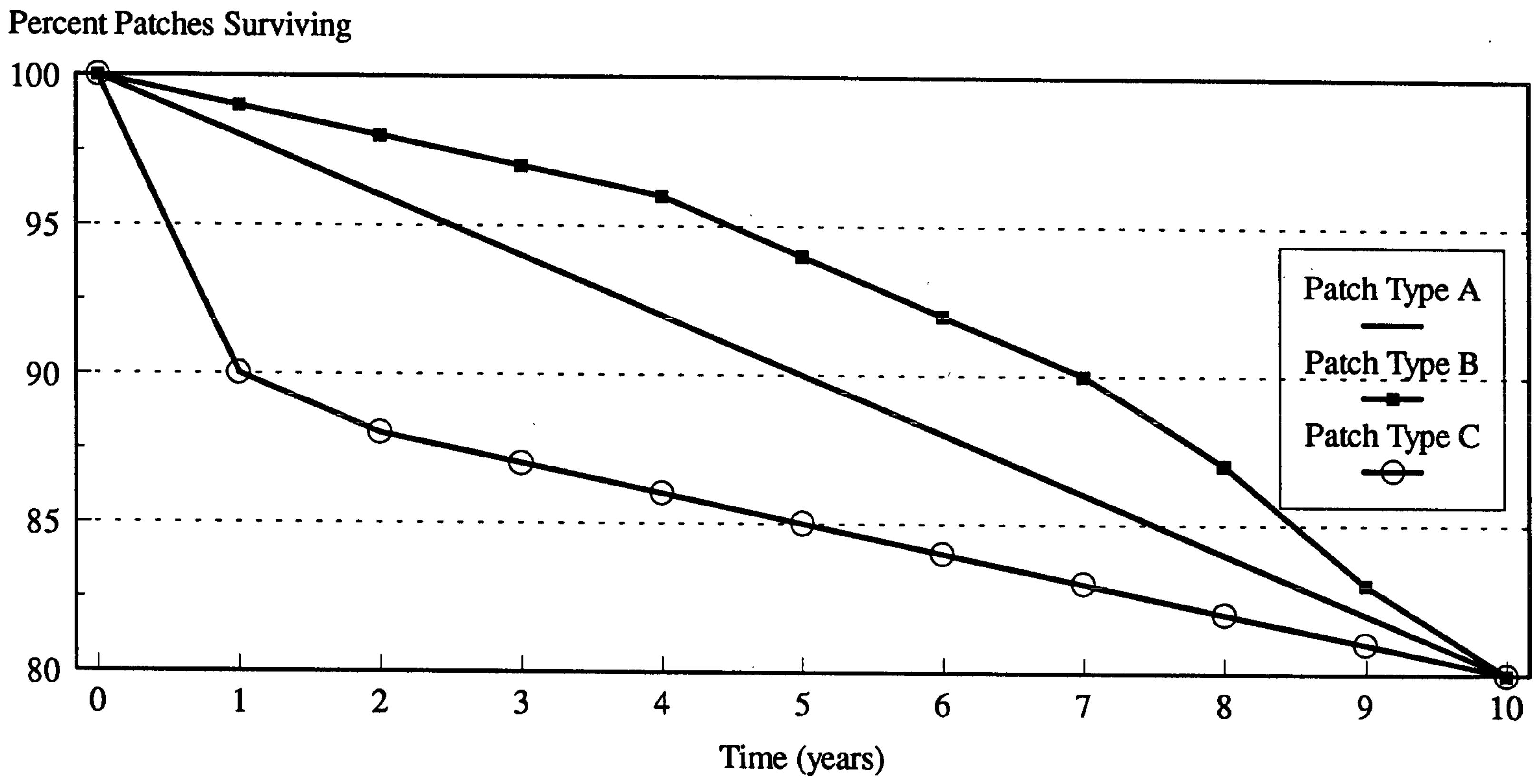

Figure E-2. Patch survival curves.

Table E-2. Worksheet for calculating patch survival rate

No. of Observ. (t)	Time (years) (T_t)	Percent Survived (P_s)
1	0	100
2	1	97
3	2	94
4	3	92
5	4	90
6	6	80
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		

Avg. % Survived ($P_{avg(t)}$)[1]	No. of Time Interval (t)	Time Interval (years) (I_t)[2]	Partial Area ($A_{part(t)}$)[3]	Total Possible Area ($A_{tot(t)}$)[4]
98.5	1	1	98.5	100
95.5	2	1	95.5	100
93	3	1	93	100
91	4	1	91	100
85	5	2	170	200
	6			
	7			
	8			
	9			
	10			
	11			
	12			
	13			
	14			
	15			
	16			
Sum Total			**548**	**600**

[1] $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$

[2] $I_t = T_{t+1} - T_t$

[3] $A_{part(t)} = P_{avg(t)} \times I_t$

[4] $A_{tot(t)} = I_t \times 100$

Patch Survival Rate $= (\Sigma A_{part(t)} / \Sigma A_{tot(t)}) \times 100$

$= (548 / 600) \times 100 = 91\%$

purpose is only to show how the worksheets are used when completing them with the information relevant to a particular agency.

Table E-3 is a blank worksheet that may be used to summarize the patch-performance data on a particular patch type. Table E-4 is a blank worksheet that may be used to calculate the patch survival rate, which is used in the cost-effectiveness worksheet.

Each example consists of the placement of 200 partial-depth patches with an average finished patch length of 18 in, width of 9 in, and depth of 2 in. Therefore, for all examples the expected total volume of the finished patches is 1.39 yd^3. The average daily wage for the maintenance worker is assumed to be $120 per day in each example. Other input variables vary from example to example.

Table E-3. Blank patch-performance data worksheet

Time of survey (years) (T_t)	Patches in place (R_{ip})	Cumulative patches failed $(R_f)^1$	Cumulative patches lost to rehabilitation $(R_l)^2$	Percent patches surviving $(P_s)^3$
0^4		0	0	100

[1] R_f = the number of patches that have failed since the time of installation.

[2] R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.

[3] $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$

[4] Installation.

Calculation of the amount of materials needed–such as a patching material, bonding agent, joint bond-breaker, or curing compound–is not demonstrated. It is assumed that agencies already are familiar with their calculation from the number, length, width, and depth of the patches, and a typical waste factor for each material.

Example 1

Example 1 consists of 200 material "A" patches placed using the saw-and-patch procedure. Material, labor, and equipment costs can be directly input into the cost-effectiveness worksheet. However, the average daily productivity, the estimated number of days for the

Table E-4. Blank worksheet for calculating patch survival rate

No. of Observ. (t)	Time (years) (T_t)	Percent Survived (P_s)	Avg. % Survived $(P_{avg(t)})$[1]	No. of Time Interval (t)	Time Interval (years) (I_t)[2]	Partial Area $(A_{part(t)})$[3]	Total Possible Area $(A_{tot(t)})$[4]
1	0	100		1			
2				2			
3				3			
4				4			
5				5			
6				6			
7				7			
8				8			
9				9			
10				10			
11				11			
12				12			
13				13			
14				14			
15				15			
16				16			
17			**Sum Total**				

[1] $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$

[2] $I_t = T_{t+1} - T_t$

[3] $A_{part(t)} = P_{avg(t)} \times I_t$

[4] $A_{tot(t)} = I_t \times 100$

Patch Survival Rate = $(\Sigma A_{part(t)} / \Sigma A_{tot(t)}) \times 100$

patching operation, and the partial-depth patch survival rate require a few advance calculations.

In calculating the average daily productivity and estimated number of days for patching, it is assumed that the last patch will be placed at the latest possible time and that preparation will stop when there is enough time to place the last patch. Therefore the patch preparation rate will control the number of patches that can be placed per day. It is also assumed that a crew of seven places the patches, having a placement rate of 7 patches per hour, and that the average patch volume is 0.187 ft^3.

Patches prepared per hour =	7
Work hours per day =	8
Material cure time =	4 hr

Number of hours available for preparation and placement =
work hrs - cure hrs and placement = 4 hr
Average preparation rate =
(7 patches/hr) × (0.187 ft^3/patch) = 1.31 ft^3/hr
Average daily productivity =
4 hr × 1.3 ft^3/hr × (1 patch/0.187 ft^3) = 28 patches
Estimated number of days for patching (rounded up) =
200 / 28 = 8 days

The patch survival rate is calculated using tables E-5 and E-6. Assume that in a previous project, 200 partial-depth patches made with material "A" had been placed using the saw-and-patch procedure. If these 200 patches experienced a 30 percent failure rate over the 10 years following their installation, the patch survival rate would be 85 percent, as shown in table E-6. Figure E-3 shows the completed cost-effectiveness worksheet for this example.

Example 2

Example 2 consists of 200 material "B" patches placed using the chip-and-patch procedure. As in example 1, material, labor, and equipment costs can be directly input into the cost-effectiveness worksheet. However, the average daily productivity, the estimated number of days for the patching operation, and the partial-depth patch survival rate require a few advance calculations.

The same assumptions are made here as are made in example 1 regarding the calculation of the average daily productivity and estimated number of days for patching. It is assumed that sawing equipment will be needed to reestablish the joints and that the chip-and-patch preparation process will have the same productivity as the saw-and-patch preparation process, because the time needed for jackhammering will take up the time not needed for sawing.

The patch survival rate is calculated using tables E-7 and E-8. In this example, it is assumed that the agency is familiar with a previous project in which 200 partial-depth patches made with material "B" were placed using the chip-and-patch procedure. In this fictitious project, 25 patches failed during the 5 years following installation, and 55 more patches failed during the next 5 years. Table E-8 shows that this pattern of failure would result in a patch survival rate of 84 percent. Figure E-4 shows the completed cost-effectiveness worksheet for this example.

Table E-5. Example 1 patch-performance data

Time of survey (years) (T_t)	Patches in place (R_{ip})	Cumm. patches failed (R_f)[1]	Cumm. patches lost to rehab. (R_l)[2]	Percent patches surviving (P_s)[3]
0	200	0	0	100
10	140	60	0	70

[1] R_f = the number of patches that have failed since the time of installation.

[2] R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.

[3] $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$

Table E-6. Example 1 patch survival rate calculation

No. of Observ. (t)	Time (years) (T_t)	Percent Survived (Ps)	Avg. % Survived ($P_{avg(t)}$)[1]	No. of Time Interval (t)	Time Interval (years) (I_t)[2]	Partial Area ($A_{part(t)}$)[3]	Total Possible Area ($A_{tot(t)}$)[4]
1	0	100	85	1	10	850	1,000
2	10	70	Sum Total			850	1,000

[1] $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$

[2] $I_t = T_{t+1} - T_t$

[3] $A_{part(t)} = P_{avg(t)} \times I_t$

[4] $A_{tot(t)} = I_t \times 100$

Patch Survival Rate $= (\Sigma A_{part(t)} / \Sigma A_{tot(t)}) \times 100$

$= (850 / 1000) \times 1000 = 85\%$

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount		units	
Expected Number of Patches	200			(A)
Average Finished Patch Length	18	in		(B_1)
Average Finished Patch Width	9	in		(B_2)
Average Finished Patch Depth	2	in		(B_3)
Expected Total Volume of Finished Patches ($B_1 \times B_2 \times B_3 \times A$) ÷ 46656	1.39		yd^3	(C)

MATERIAL COSTS (e.g., cold mix, cement, aggregate, sand, bonding agent, joint bond-breaker, curing agent, etc.)

Material 1 = Patching Material "A"			
Material 1 Purchase Cost	132	$\$/yd^3$	(D_1)
Expected Material 1 Needs	1.60	yd^3	(E_1)
Material 1 Shipping Cost	0	$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	211	$	(G_1)
Material 2 = Bonding Agent			
Material 2 Purchase Cost	45	$/gal	(D_2)
Expected Material 2 Needs	15	gal	(E_2)
Material 2 Shipping Cost	0	$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	675	$	(G_2)
Material 3 = Joint Bond-breaker			
Material 3 Purchase Cost	32.80	$/ft	(D_3)
Expected Material 3 Needs	500	ft	(E_3)
Material 3 Shipping Cost	0	$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	164	$	(G_3)
Material 4 = Curing Compound			
Material 4 Purchase Cost	10	$/gal	(D_4)
Expected Material 4 Needs	2	gal	(E_4)
Material 4 Shipping Cost	0	$	(F_4)
Total Material 4 Cost $[(D_4 \text{ x } E_4) + F_4]$	20	$	(G_4)

Figure E-3. Example 1 cost-effectiveness worksheet

LABOR COSTS

	amount	units	
Number in Repair Crew	9		(H)
Average Daily Wage per Person	120	$/day	(I)
Number in Traffic Control Crew	2		(J)
Average Daily Wage per Person	120	$/day	(K)
Supervisor Daily Wage	200	$/day	(L)

EQUIPMENT COSTS

Material Truck	20	$/day	(M)
Traffic Control Trucks and Signs	150	$/day	(N)
Patch Preparation Equipment			
(e.g., concrete saw, jackhammer,	225	$/day	(O_1)
milling machine, waterblaster)	60	$/day	(O_2)
Cleaning Equipment	350	$/day	(P_1)
(e.g., sandblaster, airblaster)	0	$/day	(P_2)
Mixing Equipment	35	$/day	(Q_1)
(e.g., mortar mixer, Jiffy mixer)	0	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	20	$/day	(R)
Extra Equipment Truck	0	$/day	(S)
Miscellaneous Equipment	0	$/day	(T_1)
(e.g., spray-injection machine, joint sealing equipment, etc.)	0	$/day	(T_2)

Figure E-3. Example 1 cost-effectiveness worksheet (cont.)

SUMMARY COSTS

	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	1,070	$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1,520	$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) + (P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) + R + S + (T_1 + T_2 + ...)]$	860	$/day	(W)
User Costs	1,000	$/day	(X)
Average Daily Productivity	28	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	8	days	(Z)
Total Labor and Equipment Cost $[(V + W) \times Z]$	19,040	$	(AA)
Total Patching Operation Cost $[U + AA + (X \times Z)]$	28,110	$	(BB)
Partial-depth Patch Survival Rate[1] (Duration may vary)	85	%	(CC)
Effective Patching Cost $[BB \times (2 - \{CC \div 100\})]$	32,327	$	(DD)

[1] Until patch survival rates have been determined, agency experience should be applied.

Figure E-3. Example 1 cost-effectiveness worksheet (cont.)

Table E-7. Example 2 patch performance data

Time of survey (years) (T_t)	Patches in place (R_{ip})	Cumm. patches failed (R_f)[1]	Cumm. patches lost to rehab. (R_l)[2]	Percent patches surviving (P_s)[3]
0	200	0	0	100
5	175	25	0	87.5
10	120	80	0	60

[1] R_f = the number of patches that have failed since the time of installation.

[2] R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.

[3] $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$

Table E-8. Example 2 patch survival rate calculation

No. of Observ. (t)	Time (years) (T_t)	Percent Survived (P_s)	Avg. % Survived ($P_{avg(t)}$)[1]	No. of Time Interval (t)	Time Interval (years) (I_t)[2]	Partial Area ($A_{part(t)}$)[3]	Total Possible Area ($A_{tot(t)}$)[4]
1	0	100					
			94	1	5	470	500
2	5	87.5					
			74	2	5	370	500
3	10	60					
			Sum Total			840	1000

[1] $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$

[2] $I_t = T_{t+1} - T_t$

[3] $A_{part(t)} = P_{avg(t)} \times I_t$

[4] $A_{tot(t)} = I_t \times 100$

Patch Survival Rate $= (\Sigma A_{part(t)} / \Sigma A_{tot(t)}) \times 100$
$= (840 / 1000) \times 100 = 84\%$

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount		units	
Expected Number of Patches	200			(A)
Average Finished Patch Length	18	in		(B_1)
Average Finished Patch Width	9	in		(B_2)
Average Finished Patch Depth	2	in		(B_3)
Expected Total Volume of Finished Patches ($B_1 \times B_2 \times B_3 \times A$) ÷ 46656	1.39		yd^3	(C)

MATERIAL COSTS (e.g., cold mix, cement, aggregate, sand, bonding agent, joint bond-breaker, curing agent, etc.)

Material 1 = Material B			
Material 1 Purchase Cost	214	\$/yd^3	(D_1)
Expected Material 1 Needs	1.60	yd^3	(E_1)
Material 1 Shipping Cost	0	\$	(F_1)
Total Material 1 Cost [($D_1 \times E_1$) + F_1]	342	\$	(G_1)
Material 2 = Joint Bond-breaker			
Material 2 Purchase Cost	34.80	\$/f	(D_2)
Expected Material 2 Needs	500	ft	(E_2)
Material 2 Shipping Cost	0	\$	(F_2)
Total Material 2 Cost [($D_2 \times E_2$) + F_2]	675	\$	(G_2)
Material 3 = ________________			
Material 3 Purchase Cost	0	\$/___	(D_3)
Expected Material 3 Needs	0	_____	(E_3)
Material 3 Shipping Cost	0	\$	(F_3)
Total Material 3 Cost [($D_3 \times E_3$) + F_3]	0	\$	(G_3)
Material 4 = ________________			
Material 4 Purchase Cost	0	\$/___	(D_4)
Expected Material 4 Needs	0	_____	(E_4)
Material 4 Shipping Cost	0	\$	(F_4)
Total Material 4 Cost [(D_4 x E_4) + F_4]	0	\$	(G_4)

Figure E-4. Example 2 cost-effectiveness worksheet

LABOR COSTS

	amount	units	
Number in Repair Crew	7		(H)
Average Daily Wage per Person	120	$/day	(I)
Number in Traffic Control Crew	2		(J)
Average Daily Wage per Person	120	$/day	(K)
Supervisor Daily Wage	200	$/day	(L)

EQUIPMENT COSTS

Material Truck	20	$/day	(M)
Traffic Control Trucks and Signs	150	$/day	(N)
Patch Preparation Equipment			
(e.g., concrete saw, jackhammer,	225	$/day	(O_1)
milling machine, waterblaster)	60	$/day	(O_2)
Cleaning Equipment	350	$/day	(P_1)
(e.g., sandblaster, airblaster)	0	$/day	(P_2)
Mixing Equipment	35	$/day	(Q_1)
(e.g., mortar mixer, Jiffy mixer)	0	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	20	$/day	(R)
Extra Equipment Truck	0	$/day	(S)
Miscellaneous Equipment	0	$/day	(T_1)
(e.g., spray-injection machine, joint sealing equipment, etc.)	0	$/day	(T_2)

Figure E-4. Example 2 cost-effectiveness worksheet (cont.)

SUMMARY COSTS

	amount	units	
Total Material Cost ($G_1 + G_2 + G_3 + G_4 + ...$)	1,017	$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1,280	$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) + (P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) + R + S + (T_1 + T_2 + ...)]$	860	$/day	(W)
User Costs	1,000	$/day	(X)
Average Daily Productivity	7	patches/day	(Y)
Estimated Number of Days for Patching Operation ($A \div Y$)	8	days	(Z)
Total Labor and Equipment Cost $[(V + W) \times Z]$	17,120	$	(AA)
Total Patching Operation Cost $[U + AA + (X \times Z)]$	26, 137	$	(BB)
Partial-depth Patch Survival Rate[1] (Duration may vary)	84	%	(CC)
Effective Patching Cost $[BB \times (2 - \{CC \div 100\})]$	30,319	$	(DD)

[1] Until patch survival rates have been determined, agency experience should be applied.

Figure E-4. Example 2 cost-effectiveness worksheet (cont.)

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