SHRP-H-355

Innovative Materials Development and Testing

Volume 4: Joint Seal Repair

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Strategic Highway Research Program
National Research Council
Washington, DC 1993

SHRP-H-355
ISBN 0-309-05612-8
Contract No. H-106
Product No.: 3003

Program Manager: *Don M. Harriott*
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Production Editor: *Katharyn L. Bine Brosseau*

October 1993

key words:
concrete joint sealing
portland cement concrete
rubberized sealant
silicone sealant

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1.5M/NAP/1093

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.

Acknowledgements

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

Special thanks go to the following agencies:

- Arizona Department of Transportation—Phoenix Maintenance District 1
- Colorado Department of Highways—Loveland Maintenance District
- Iowa Department of Transportation—Grinnell Maintenance District
- Kentucky Transportation Cabinet—Frankfort Maintenance District
- South Carolina Department of Highways and Public Transportation—Chester Maintenance District

The authors also wish to recognize Michael Darter, David Peshkin, Sam Carpenter, Michael Belangie, Henry Bankie, and Charles Smyth.

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Abstract

Under the Strategic Highway Research Program (SHRP), contract H-106, a full-scale investigation of the performance of materials and methods for resealing joints in concrete pavements has been initiated. Over 1,600 joints were installed employing four different installation methods and twelve sealant materials, including rubberized asphalt, silicone, and polysulfide, at five sites across the United States. Laboratory analysis of the sealant material properties and evaluation of field performance have been conducted and the results analyzed. Some significant performance differences have been noted between materials and placement methods, although the average adhesion and spall-related failure is only 2.3 percent of the joint lengths. Initial correlations between laboratory test results and field performance indicate that some ASTM D-3407 tests, as well as ASTM D-412 tests, seem to relate slightly to adhesion loss.

Executive Summary

More than 1,600 joints were resealed using twelve different materials in four climatic regions. Sealants were installed using five different methods of preparation and installation. To date, only 1.7 percent of the length of joints at all test sites has developed adhesive failure, and 0.6 percent of the joint lengths contain full-depth spalls. Based on a 95 percent statistical significance (alpha = 0.05), several preliminary observations can be drawn from laboratory testing results and from early field performance data.

- Although no significant difference in full-depth adhesion failure has developed between silicone and rubberized asphalt sealants installed using the same methods, silicone sealants show significantly less partial-depth adhesion loss than most rubberized asphalt sealants.

- Among the rubberized-asphalt sealants, full-depth adhesion loss results for only one configuration at one site indicate that a statistical ranking of material performance can be obtained.

- Silicone and rubberized asphalt sealants installed using the same methods and conditions exhibit no significant difference in full- or partial-depth spall failure.

- Significantly more partial-depth spalls have occurred in joints that were primed before installing silicone sealant than in unprimed joints containing the same sealant.

- There is no conclusive evidence as to which configuration develops the least full-depth adhesive failure, except at the wet-nonfreeze region site where seals installed after sawing and sandblasting outperformed those installed after plowing and airblasting.

- Most rubberized asphalt sealants installed using an overbanded configuration developed significantly less partial-depth adhesion loss than those installed in the traditional recessed configuration.

- In states where large amounts of new edge spalling occurred, significantly larger amounts of partial- and full-depth spalls developed in the lane wheelpaths.

- Crafco RoadSaver 231 rubberized asphalt tends to resist wearing of the overband more than the other hot-applied sealants installed in the project. However, after 18 months, nearly all seals at all sites were greatly worn.

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

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Introduction

The resealing of joints in concrete pavements is a common maintenance activity performed by many state and highway agencies. The purpose of joint resealing is to reduce the amount of water entering a pavement structure and to prevent the filling of joints with incompressible materials. Water entering a pavement structure through joints can lead to pumping, faulting, base and subbase erosion, and loss of support. Incompressible materials filling pavement joints can result in joint spalling, blowups, buckling, or shattered slabs. Although joint resealing is a common maintenance practice, premature seal failure is frequently experienced, requiring additional repair and expenditure. To address the deficiencies of current joint-resealing materials, designs, and practices, the Strategic Highway Research Program (SHRP) is conducting a field performance evaluation of various materials and installation methods under a range of climatic conditions.

Objectives

The goal of improving the performance of joint-resealing materials and methods has been approached from three directions, each having a specific objective. A primary objective of the study was to evaluate the relative performance of selected sealant materials in joint resealing projects based on carefully designed and controlled field installations.[1] A second objective was to determine the effect of selected sealant configurations, or installation methods, on sealant performance, based on the results from the field installations. A last major objective was to identify sealant material properties and tests that correlate well with field performance.

Direct results expected from the study include the length of time that each sealant material effectively functions under conditions representative of each climatic region in the United States and Canada. Also, the sealant installation method that allows sealant materials to perform adequately for the longest period of time will be established. Finally, identifying material properties and tests that correlate well with field performance will provide a basis for the preparation of performance-based specifications for joint-resealing materials.

Production and cost information collected during installation of the test sites, along with field performance rankings, will allow comparison of each material and installation procedure based on cost-effectiveness. Good field performance of most joint-resealing materials to date, however, has not allowed differentiation between materials regarding life expectancy. As collection of field performance information continues, life expectancy estimates and cost-effectiveness comparisons can be made.

Scope

In the spring of 1991, joint-resealing test sites were installed in five states in four climatic regions to study the comparative performance of different sealant materials and various installation methods. The materials and methods used in this project were those identified under the SHRP H-105 project. Regular evaluations of the performance of the sealants used at these test sites has continued through the early winter of 1992.

This report describes the several phases of the joint-resealing study, beginning with a discussion in chapter 1 of the materials and methods used, as well as descriptions of the selected test sites. Details of the installation of materials at each test site are described in chapter 2, including preinstallation measurements, joint preparation and sealant placement procedures, production rates, and other observations. Included in chapter 3 are descriptions of the laboratory tests performed on the sealant materials and discussions of the results of these tests. Summaries of the field performance data collected in the 18 months after test site installation are shown in chapter 4, noting the types of sealant system distress observed and the amount of overall failure for each material to date. Chapters 5 summarizes the analysis of field and laboratory performance, including a discussion of the methodology used for statistical analysis. Last, the observations and recommendations from the study to date are presented in chapter 6. It is expected that future field evaluations will provide additional information to refine the chapter 6 conclusions.

Project Overview

Between April and June 1991, a total of 1,600 joints were resealed at five test sites using twelve sealant materials and four methods of installation. Test sites are located on moderate to high-volume, four-lane highway or Interstate pavements in four climatic regions. Two sites were constructed in the wet-freeze region to compare the effect of short- and long-jointed pavements on sealant performance. These sites are located on the following roadways as shown in figure 1.

- Interstate 17, Phoenix, Arizona, dry-nonfreeze region
- Interstate 77, Columbia, South Carolina, wet-nonfreeze region
- Interstate 25, Ft. Collins, Colorado, dry-freeze region
- Interstate 80, Grinnell, Iowa, wet-freeze region (short joints)
- Rte 127, Frankfort, Kentucky, wet-freeze region (long joints)

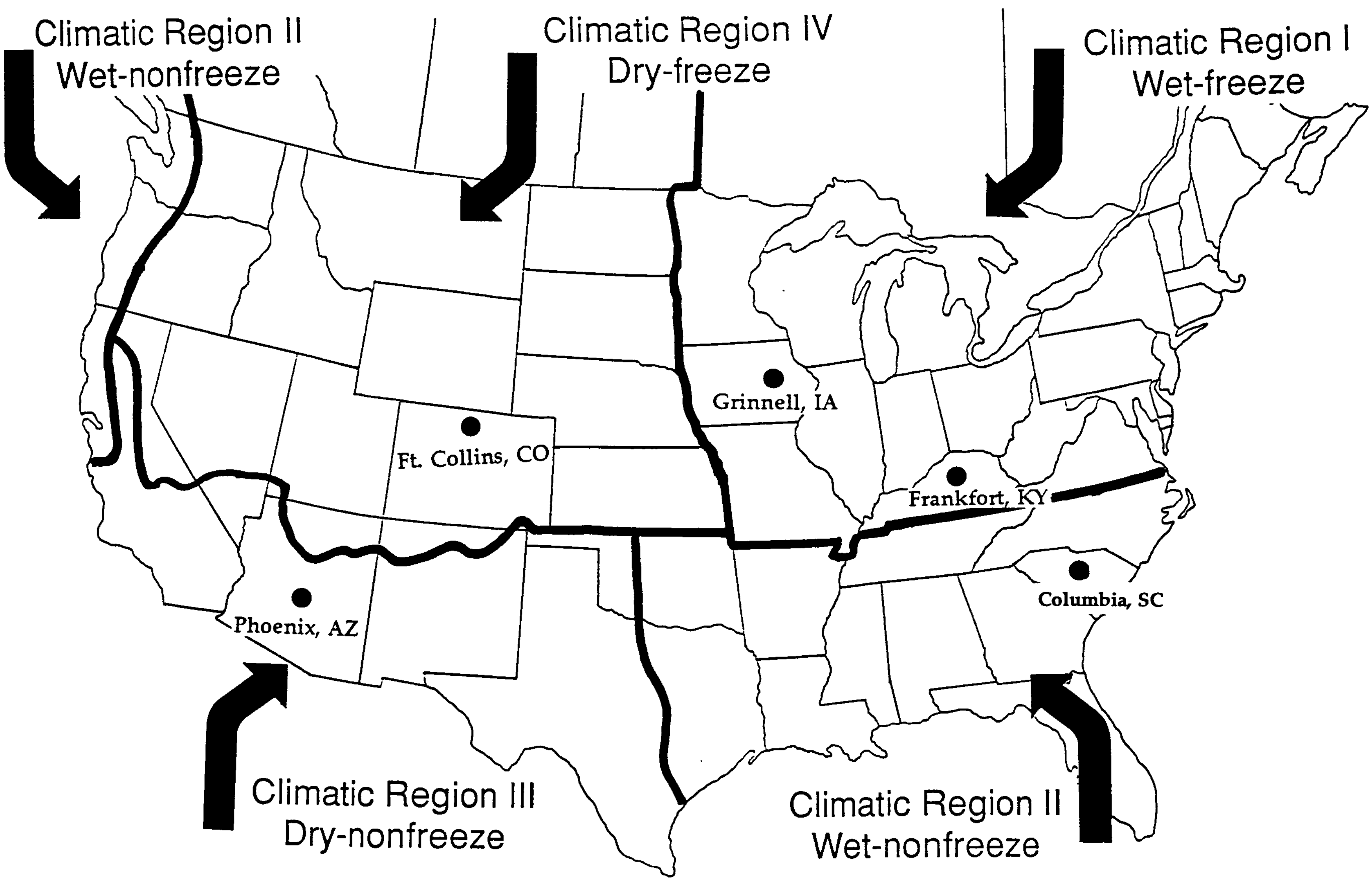


Figure 1. Joint seal repair test site locations and climatic regions

Sealant Materials

Six of the sealant materials recommended in the SHRP H-105 report for use in the full-scale testing were rubberized asphalt containing various blends of polymers, rubbers, and asphalt cements. The remaining three materials were silicone sealants, one non-self-leveling and two self-leveling. The following seven sealants were installed at four of the five test sites:

• Crafco RoadSaver® 231	Low-modulus ASTM D 3405 sealant
• Koch 9005	ASTM D 3405 sealant
• Koch 9030	Low-modulus ASTM D 3405 sealant
• Meadows Sof-Seal®	Low-modulus ASTM D 3405 sealant
• Dow Corning® 888	Non-self-leveling silicone sealant
• Dow Corning® 888-SL	Self-leveling silicone sealant
• Mobay Baysilone 960-SL	Self-leveling silicone sealant

Two rubberized asphalt sealants were installed at the Phoenix site only, replacing Sof-Seal and Koch 9030. These sealants are:

• Crafco RoadSaver 221	ASTM D 3405 sealant
• Meadows Hi-Spec®	ASTM D 3405 sealant

Several participating states requested that additional sealants be installed and evaluated at their test sites. The following three additional sealants were installed at individual test site locations:

• Crafco RoadSaver 903-SL	Self-leveling silicone sealant
• Mobay Baysilone 960	Self-leveling silicone sealant
• Koch 9050	Self-leveling one part polysulfide

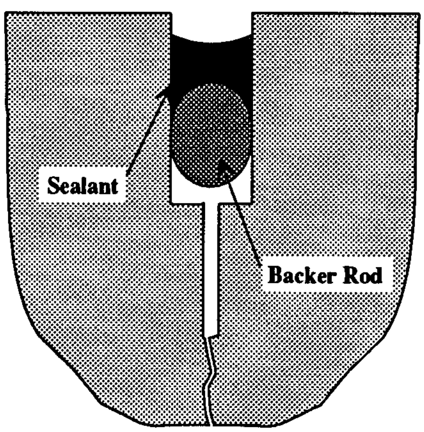
Crafco RS 903-SL was placed at the Phoenix site, Mobay Baysilone 960 was placed at the Grinnell site, and Koch 9050 was placed at the Ft. Collins and Frankfort sites.

At the Iowa site, ten joints of Dow Corning 888 silicone and ten joints of Dow Corning 888-SL silicone were installed using a primer provided by Dow Corning Corporation. This was because Iowa was having trouble with their silicone sealants adhering to the joint faces, and some early adhesion failures were occurring. A primer was also used with Koch 9005 in ten joints at the Kentucky site to evaluate the effect of primer on hot-applied sealant performance.

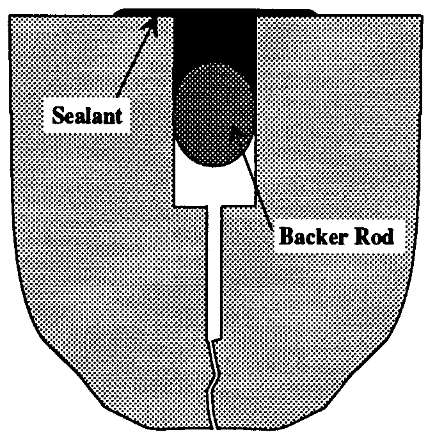
Preparation Methods

Four joint preparation and sealant installation methods were used to place the sealants at the sites. Each of these methods is designated as a configuration and is shown in figure 2. Configuration 1 indicates that the joint faces have been resawed to 0.5 in (12.7 mm) wide, the walls have been sandblasted and airblasted, backer rod has been installed, and sealant is installed in the recommended thickness with the surface about 0.25 in (6.4 mm) below the pavement surface.

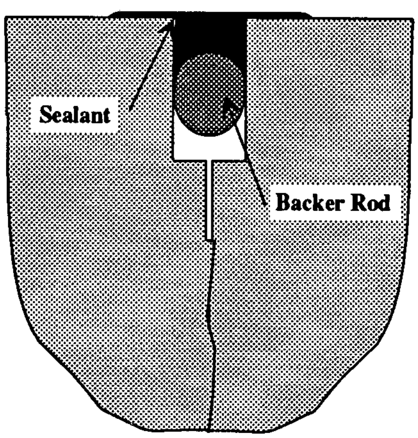
Joints sealed using configuration 2 were also resawed, sandblasted, airblasted, and backer rod was installed. In addition, the pavement surface was sandblasted and airblasted about 1 in (25.4 mm) on either side of the joint and the sealant was installed about 0.5 in (12.7 mm) thick with an overband extending onto the pavement surface about 0.4 in (10.2 mm) on either side of the joint edge.



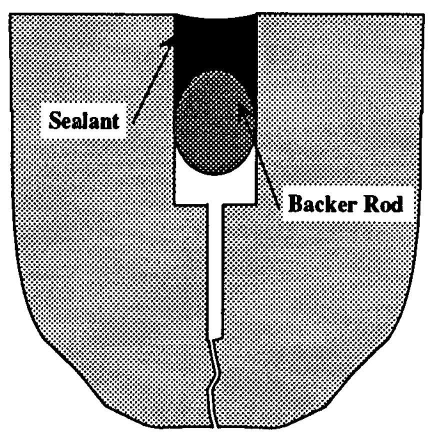
Configuration 1
Saw and Recessed



Configuration 2
Saw and Overband



Configuration 3
Plow and Overband



Configuration 4
Saw and Flush-fill

Figure 2. Joint seal configurations

Resawing was not required for joints prepared using the configuration 3 method. Instead, a joint plow attached to a tractor was scraped against both sides of the joint to remove most of the original sealant. The plowed joints were then airblasted to remove loose debris, backer rod was installed, and the sealant was installed using an overband, as with configuration 2.

Configuration 4, used at two sites, required resawing, sandblasting, airblasting, and installing backer rod. Then the sealant was installed about 0.5 in (12.7 mm) thick, with the sealant surface flush with the pavement surface. All four configurations were used for the hot-applied sealants; only configuration 1 was used for the silicones and polysulfide.

Two sets of ten joints were installed at random locations along the test site for each material-configuration combinations used at the five sites. A summary of the materials and procedures used at the test sites is shown in table 1. The layout of the material-configuration combinations for each test site is shown in tables A-1 and A-2 in Appendix A.

Table 1. Summary of materials and procedures used for joint seal installation

Sealant Material	Config. Number	Procedures	AZ	SC	CO	IA	KY
Crafco RoadSaver 221 (1)[a]	1	Saw, sandblast, recessed sealant	✓				
	2	Saw, sandblast, overband sealant	✓				
	3	Plow, airblast, overband sealant					
	4	Saw, sandblast, flush sealant	✓				
Crafco RoadSaver 231 (2)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
	2	Saw, sandblast, overband sealant	✓	✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant	✓		✓		
Koch 9005 (3)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
	2	Saw, sandblast, overband sealant	✓	✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant	✓		✓		
Koch 9030 (4)	1	Saw, sandblast, recessed sealant		✓	✓	✓	✓
	2	Saw, sandblast, overband sealant		✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant			✓		

[a] SHRP material code

Table 1. Summary of materials and procedures used for joint seal installation (cont.)

Sealant Material	Config. Number	Procedures	AZ	SC	CO	IA	KY
Meadows Hi-Spec (5)[a]	1	Saw, sandblast, recessed sealant	✓				
	2	Saw, sandblast, overband sealant	✓				
	3	Plow, airblast, overband sealant					
	4	Saw, sandblast, flush sealant	✓				
Meadows Sof-Seal (6)	1	Saw, sandblast, recessed sealant		✓	✓	✓	✓
	2	Saw, sandblast, overband sealant		✓	✓	✓	✓
	3	Plow, airblast, overband sealant		✓		✓	✓
	4	Saw, sandblast, flush sealant			✓		
Dow 888 (7)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Dow 888-SL (8)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Mobay 960-SL (9)	1	Saw, sandblast, recessed sealant	✓	✓	✓	✓	✓
Mobay 960 (A)	1	Saw, sandblast, recessed sealant	✓			✓	
Crafco 903-SL (B)	1	Saw, sandblast, recessed sealant	✓				
Koch 9050 (C)	1	Saw, sandblast, recessed sealant			✓		✓
Dow 888 w/ Primer (D)	1	Saw, sandblast, primer, recessed sealant				✓	
Dow 888-SL w/ Primer (E)	1	Saw, sandblast, primer, recessed sealant				✓	
Koch 9005 w/ Primer (F)	1	Saw, sandblast, primer, recessed sealant					✓

[a] SHRP material code

Table 2. Test site characteristics for the joint seal repair project

Test Site	Route	Number of Lanes, 2 dir	2-direction ADT, vpd	Annual Precip., in [b]	Annual Days < 32°F [a,b]
Phoenix, AZ	I-17	6	100,000	7	17
Ft. Collins, CO	I-25	4	27,000	15	158
Grinnell, IA	I-80	4	19,000	31	135
Frankfort, KY	Rte 127	4	14,000	44	94
Columbia, SC	I-77	4	19,400	49	31

[a] Historical averages from the 1983 Climatic Atlas of the United States
[b] 1 in = 2.54 cm; 32°F = 0°C

Test Site Characteristics

Several criteria, as described in volume 1 of this document, were used in selecting test sites for use in the joint seal repair experiment. Five sites were chosen from the twenty eight sites that were inspected. Additional information about the characteristics and locations of these test sites is listed in table 2 and in the following sections.

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 between the Buckeye Road and the VanBuren Road exits (MP 198.8 to MP 199.8). Its location is shown in figure 3. The pavement carries more than 100,000 vpd in both directions; however, the amount of truck traffic in the passing lanes is believed to be very small. It was constructed in 1963 using a 9-in (229-mm) PCC over a granular base and subbase. Most contraction joints are perpendicular to the roadway and spaced about 15 ft (4.6 m) apart. The sealant previously used in the joints of the northbound pavement was asphalt based, and sealant in the joints of the southbound lane was coal-tar based. Immediately prior to seal installation in the spring of 1991, the pavement was ground longitudinally to restore a level profile. Many joints in the northbound lane contained steel crack inducers that were sawed out before installation of the test materials.

I-25, Ft. Collins, Colorado

The test site constructed in a dry-freeze climate is located in the outside northbound lane of I-25 near Ft. Collins, Colorado (MP 260.4 to MP 261.3). Its location is shown in figure 4. This pavement was reconstructed in 1988 by overlaying 8 in (203 mm) of JPCC with an 8-in (203-mm) concrete overlay. Skewed contraction joints were sawed in the overlay with spacings between 12 and 15 ft (3.7 and 4.6 m), and the joints were sealed with a coal-tar-

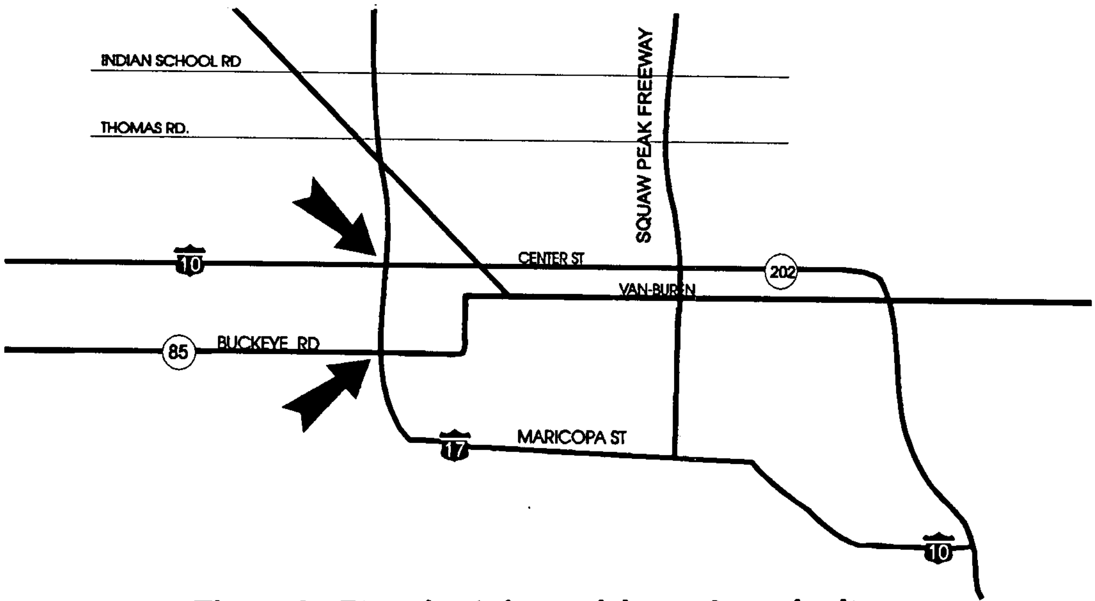


Figure 3. Phoenix, Arizona, joint seal repair site

based sealant that had severely deteriorated by 1991. The pavement surface was tined about 0.125 in (3.18 mm) deep on 0.5-in (13-mm) centers, and the tining continued through all joints. Two-way traffic on the roadway is more than 27,000 vpd. Both the traffic lane and the tied PCC shoulder are in excellent condition. Since sealant installation, the pavement has experienced many freeze-thaw cycles and a minimum temperature of -8°F (-22°C) on January 15, 1992.

I-80, Grinnell, Iowa

The joint seal test site constructed in a wet-freeze region on short-jointed pavement is located in the outside eastbound lane of I-80 near Grinnell, Iowa (MP 188.0 to MP 189.3). Figure 5 shows its location. It was reconstructed in 1985 using a 10-in (254-mm), doweled PCC surface over a granular subbase of variable thickness. The surface was tined with grooves 0.13 in (3.2 mm) to 0.19 in (4.8 mm) deep on 0.5-in (13-mm) centers, and skewed joints were sawed with 20-ft (6.1-m) spacings. The outside slab width is 13 ft (4 m) with the shoulder line painted 1 ft (0.305 m) from the outside slab edge. The pavement is in excellent condition, and carries more than 19,000 vpd in both directions, with a high percentage of trucks. The original seal was a non-self-leveling silicone that had failed in adhesion at some locations. The minimum air temperature experienced by this pavement after test site construction was -8°F (-22°C) on January 16, 1992.

Rte 127, Frankfort, Kentucky

The second test section located in the wet-freeze region was installed in a long-jointed section of Rte 127 in Frankfort, Kentucky (MP 9.9 to MP 10.6). Figure 6 shows the location of the Kentucky test site. The pavement was originally constructed in 1974 using a reinforced 9-in

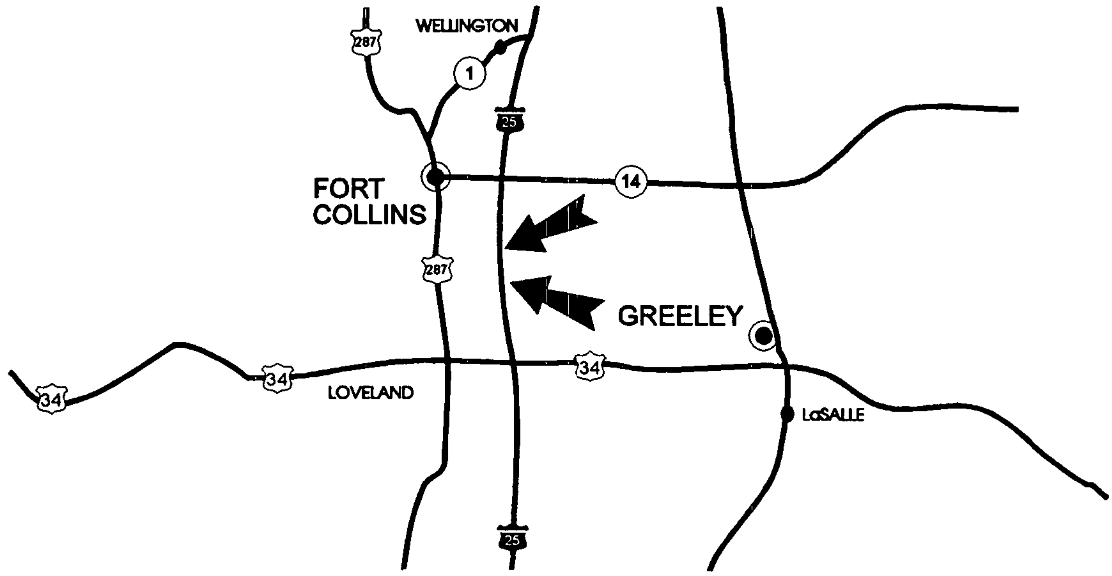


Figure 4. Ft. Collins, Colorado, joint seal repair test site

(228-mm) PCC surface over a 5-in (127-mm) granular base. Joints perpendicular to the roadway were sawed on 50-ft (15.2-m) centers, typically. The pavement is in generally good condition, with some large spalls evident and a few spall patches in place. Joint seal has been missing from the joints for a long time, as evidenced by many joints being filled with dirt and sand. Traffic on the roadway is about 14,000 vpd, with only a small amount of truck traffic.

This roadway is the best of the long-jointed pavements available, but it is the least ideal of the test sites due to slight variations in traffic level, deteriorated pavement conditions, and changes in pavement grade and superelevation. About 50 percent of the slabs included in the test section contain mid-slab cracks that are nonworking. The remaining slabs are uncracked. The site contains a slight grade, one curve that is less than 3 degrees, and five side roads that contribute only small amounts of traffic to the roadway. The experimental sections are constructed in the outside northbound lane and the outside and inside southbound lanes, resulting in the majority of morning traffic using the southbound lanes and the evening traffic using the northbound lanes. The net traffic on each lane is believed to be about the same. A gravel pit is located at the south end of the test site, providing truck traffic in both directions.

I-77, Columbia, South Carolina

The test site in the wet-nonfreeze climatic region is located in the outside northbound lane of I-77, north of Columbia, South Carolina (MP 38.0 to MP 39.9). The location of this test site is marked on figure 7. Originally built in 1981, the pavement was constructed using 10-in (254-mm) JPCC over a 6-in (152-mm) lean concrete base and a 6-in (152-mm) cement-treated stone subbase. Joints were sawed perpendicular to the roadway on staggered spacing of 19 to 25 ft (5.8 to 7.6 m). The original sealant, a nonsag silicone sealant, was still in the joint and performing very well. The pavement remains in excellent condition and carries more than

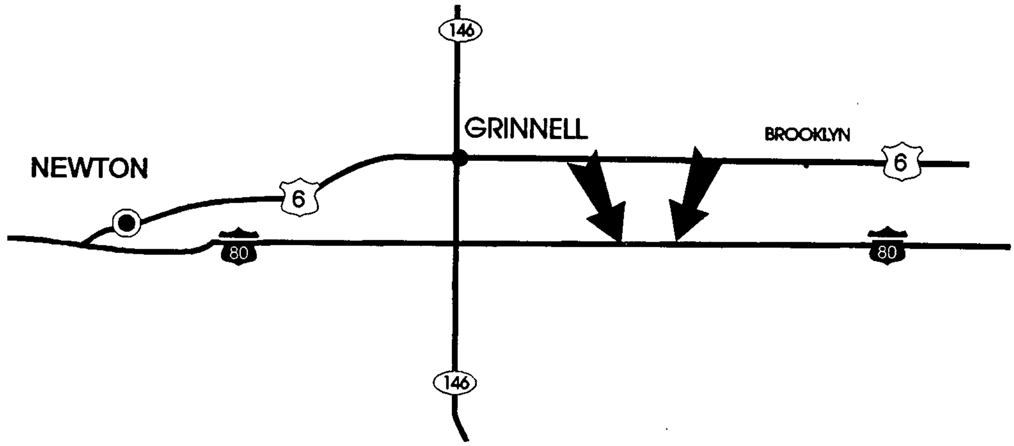


Figure 5. Grinnell, Iowa, joint seal test site

19,400 vpd in both directions, with a high percentage of trucks. Spalls of 1- to 3-in (25- to 76-mm) width are present on more than one-third of the joints about 2 ft (0.6 m) from the outside lane edge. These spalls appear to have resulted from a wheel rim or other sharp, heavy object dragging along the pavement. The minimum air temperature experienced by the pavement since test site installation was 19°F (-7°C) on December 20, 1991.

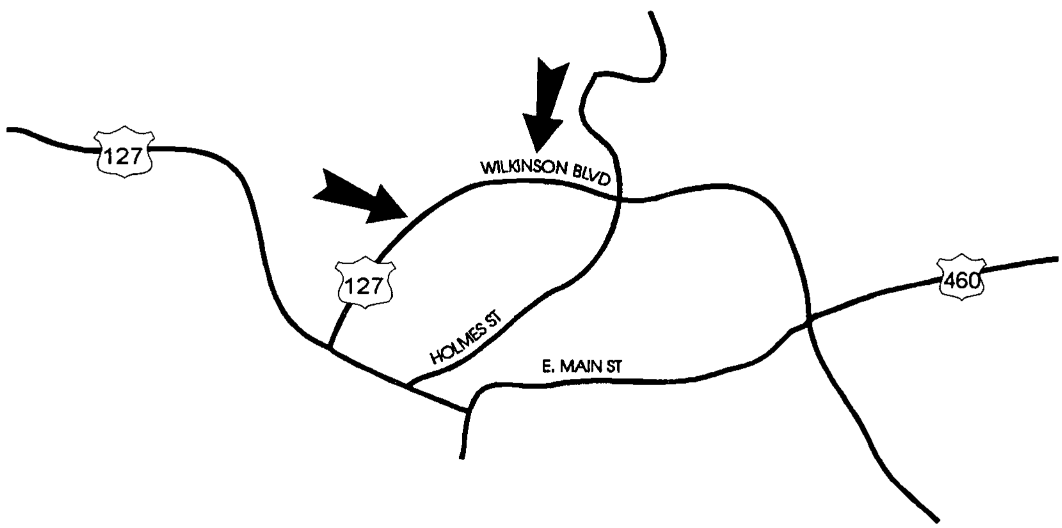


Figure 6. Frankfort, Kentucky joint seal repair test site

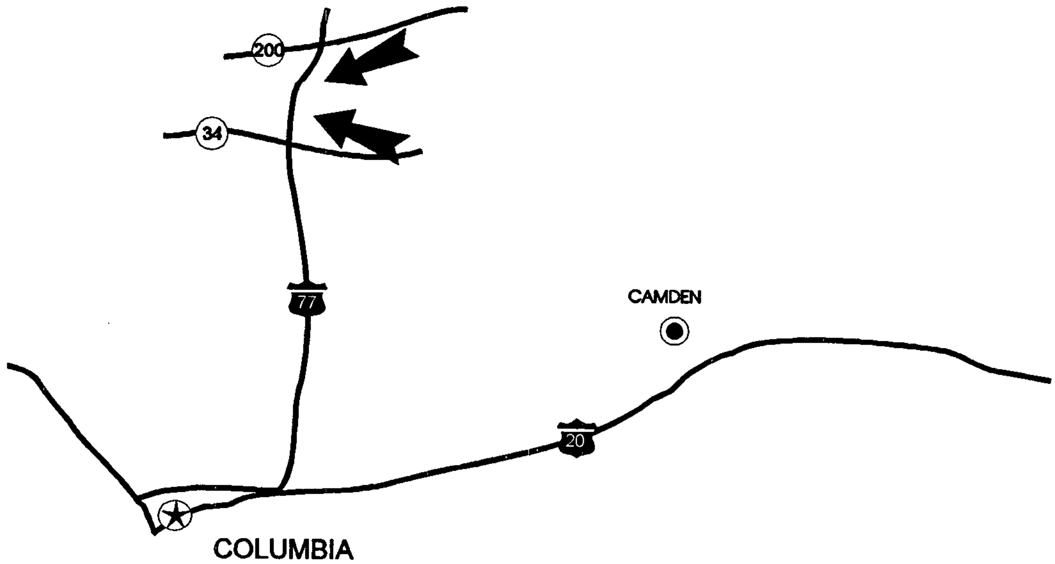


Figure 7. Columbia, South Carolina, joint seal test site

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Test Site Installations

Site selection began in November 1990, and installation of the five test sites began in April 1991, continuing through June 1991. Installation of the test sites was regulated and monitored by the project team, together with representatives from the sealant manufacturers and a consultant with expertise in joint sealing. This chapter presents an overview of the installation-planning process, along with material costs, productivity rates, equipment requirements, problems that were encountered during installation, and comments on the materials and procedures used.

Test Site Arrangements

To install the test sites four preparatory steps were taken. Appropriate locations were identified based on interest shown by state agencies, material requirements were determined for each site, materials were purchased and shipped, and the labor and equipment resources of each participating state agency were ascertained. These are explained further below.

Test Site Selection

Using the criteria described in the Experimental Design and Research Plan (EDRP)[1], five pavement sections were chosen to serve as test sites from the twenty eight potential pavements that were inspected. The selected sites are described in the previous chapter.

Computation of Material Quantities

Estimates of individual rubberized asphalt sealant material quantities required for each test site were made assuming sixty joints per site with dimensions of 0.5 in by 0.5 in (12.7 by 12.7 mm). For each silicone sealant, the material quantity for twenty joints per site with

Table 3. Sealant material and coverage costs

Sealant Material	Material Cost ($/lb)	Coverage (lb/100 lin ft) [b]	Coverage Cost ($/100 lin ft)
Crafco RoadSaver 221	0.41	13.0	5.33
Crafco RoadSaver 231	0.56	12.0	6.72
Crafco RoadSaver-SL	2.79	7.1	19.81
Koch 9005	0.23	12.3	2.83
Koch 9030	0.35	11.3	3.96
Koch 9050	1.20	11.5	13.80
Meadows Hi-Spec	0.29	12.6	3.65
Meadows Sof-Seal	0.48	11.4	5.47
Dow 888	2.48 [a]	11.8	29.26
Dow 888-SL	2.79 [a]	7.7	21.48
Mobay 960	3.05 [a]	9.6	29.28
Mobay 960-SL	3.36 [a]	7.8	26.21
5/8" Backer Rod	.0333 $/lin ft		3.33

[a] Cost based on 55-gal (208-L) drums
[b] 1 lb = 0.454 kg; 1 lin ft = 0.305 m

dimensions of 0.5 by 0.25 in (12.7 by 6.2 mm) was approximated. Initially, a wastage factor of 25 percent was used in planning for material purchase. At the suggestion of the manufacturers of rubberized asphalt sealants, the wastage factor was increased to provide enough sealant for flushing the melter-applicator (150 lb [68.1 kg]) and so that the melter-applicator could function properly (300 lb [136.2 kg]). This additional sealant was also expected to reduce the possibility of overheating the sealant.

Manufacturers' literature provides an estimate of the coverage rate for each material in the recessed configuration. These rates are included in table 3. For a typical rubberized asphalt sealant, these figures indicate that about 100 lbs (45.4 kg) of each rubberized asphalt sealant would be required to seal sixty recessed joints at each test site. However, the overband configuration, which was used on 67 percent of the joints, required additional sealant. Although the coverage rates in table 3 are much less than those experienced in the installation of these test sites, they are likely to be closer to those encountered in large-scale joint resealing. The backer rod used at the test sites was approved by each sealant manufacturer, and the quantities ordered were slightly greater than those required.

Material Purchase and Shipping

Sealant materials were purchased from the manufacturers in amounts corresponding to the estimated requirements. Each material used at all five sites was from the same production batch. Costs of materials were set by the manufacturers at the January 1991 typical cost and are listed in table 3. Shipping costs for rubberized asphalt sealants ranged from $0.05 to $0.26 per pound. In the first week of March 1991 all sealant materials were ordered, and by the third week of March all sealants had been shipped to the test site locations.

Assessment and Coordination of Resources

In late January and early February 1991, an individualized copy of the Experimental Design and Research Plan (EDRP)[1] was sent to each state coordinator and to the foreman of the crew scheduled to install the test site. The purpose of the summary was to determine the availability of resources at each test site and to inform the participating state agency of the scope and requirements of the installation procedures. These summaries included lists of materials, detailed descriptions of the preparation and installation procedures to be followed, and maps showing the location of each section of the test site. They also contained a specific list of the equipment and manpower to be provided by the state and of the equipment and supervision provided by the SHRP H-106 contractor. A tentative construction schedule along with construction guidelines were also included.

Labor

Based on discussions with consultants and state workers, the manpower requirements were estimated at nine persons. Four of the participating state agencies indicated the ability to acquire manpower from neighboring maintenance crews on days when additional workers were needed. During construction, the average number of laborers actually used for sawing and airblasting was five; for joint preparation and sealant installation the average was eight.

Equipment

As specified in the EDRP, the minimum equipment requirements for construction of each test site included the following:

- Traffic control equipment (attenuator, signs, cones, placement truck)
- A 65-hp (165-kBtu/hr) water-cooled concrete saw with tandem diamond-tipped blades 10 to 14 in (254 to 356 mm) in diameter or greater. A water truck with a positive pump carrying at least 600 gal (2,271 L) of water.
- A joint plow equipped with a rectangular, not tapered, blade attached to a tractor or other powered vehicle that provides positive control of up-and-down and side-to-side motion.

- Sandblasting equipment, including an air compressor that provides clean, dry air at more than 90 psi (621 kPa).
- An air compressor, hose, and wand with a shutoff valve that can supply clean, dry air at more than 90 psi (621 kPa).
- Conventional double-boiler, oil-jacketed melter-applicator, with a capacity of at least 100 gal (379 L), equipped with a mechanical agitator, separate temperature controls and thermometers for both the oil and melting vat.
- Air-powered, cartridge dispensing caulking guns with a continuous compressed air supply of at least 45 psi (310 kPa).

The quality and availability of equipment at each test site varied significantly, yet the required equipment was procured in time for its required use.

Productivity estimation

Prior to test site construction, it was estimated that about 20 hours would be required to saw 240 joints, and during that time the joint plowing (80 joints) could be completed. One week was allowed at most sites for layout, sawing, plowing, gage plug installation, and joint dimension and fault measurement. This schedule allowed the wet-sawed joints to dry over the weekend.

Based on a projected average of less than 3 minutes per joint, it was estimated that hot-applied sealant could be placed in at least 160 joints per 8-hr day. Plans were made to daily seal 120 joints using two hot-applied sealants. If this schedule were adhered to, installation of the rubberized asphalt sealant at each test site could be completed in 2 working days.

The sandblasting operation was assumed to be the slowest cleaning procedure, and the request was made that states provide two sandblasting units and crews. Only one state was able to comply. It was estimated that 140 joints could be cleaned per 8-hr day using one sandblasting crew of two persons. This would allow for the installation of two rubberized asphalt sealants. As will be shown later, these estimates were not too far from the installation productivity rates actually experienced.

Outside consultants and manufacturers' representatives

Because it was considered critical that sealants be placed correctly and in accordance with manufacturers' recommendations, representatives of each participating sealant manufacturer were requested to observe and participate in the installation of their materials. On the whole, interest among the manufacturers was high and all sent representatives to at least one site. Manufacturers' representatives who attended installation at each test site are listed in table 4. An expert in joint seal installation also attended the first installation in South Carolina. He offered advice on quality control, coordination of manpower and equipment, and evaluation of sealant performance.

Table 4. Manufacturers' representatives present at test site installation

Test Site	Crafco, Inc.	Dow Corning	Koch Materials	Mobay	W. R. Meadows
Arizona	YES		YES		YES
South Carolina	YES	YES	YES		
Colorado	YES		YES	YES	YES
Iowa	YES	YES	YES		
Kentucky	YES		YES		

Installation Process

The installation process required first that the joints be chosen and marked. Preparations were then made for pavement evaluation, and sealants were installed according to manufacturers' recommendations.

Layout

The design of the experiment called for construction of twenty joints of each appropriate combination of the selected materials and configurations. The location for each test section at every test site was randomly selected prior to installation. Maps of the test site were prepared to assist the installation crew in determining the appropriate preparation methods and materials to be installed. At the onset of installation, joints at the test site were inspected for possible use, and selected and marked for inclusion. The dates and number of working days required for layout and construction at each site are shown in table 5.

Joint selection

Several joints at each test site contained spalls greater than 1 in (25.4 mm) long that might affect localized sealant performance. These joints were not used in the experiment and, as time allowed, they were prepared and sealed together with adjacent joints. Many joints at the Arizona test site were spalled and also were wider than the design width of 0.5 in (12.7 mm). These joints were not included in the experiment. Within the test site in Iowa, 97 percent of the available joints were used, in Colorado 94 percent, in Kentucky 77 percent, in South Carolina 67 percent, and in Arizona 45 percent.

Marking of test sections

On the shoulder adjacent to the test site, a 6-in (152-mm) piece of highway-marking tape was placed before the first joint of each test section. The numbers of the adjacent test sections

Table 5. Schedule of test site construction

Test Site Location	Layout/Construction Dates	Total Working Days Layout/Construction
I-17 Phoenix, AZ	April 1-12, 1991	8
I-77 Columbia, SC	April 22-28, 1991	6
I-25 Ft. Collins, CO	April 29 to May 10, 1991	10
I-80 Grinnell, IA	May 20 to June 6, 1991	8
Rte 127 Frankfort, KY	June 10 to July 1, 1991	10

were painted on the shoulder on both sides of the marking tape, as well as the material and configuration to be used. This reduced the confusion during installation when crews were required to prepare only certain test sections.

Preparation

After layout of the test site was completed, preparation began for installation of the joint sealants. Gage plugs were installed on both sides of the joints, and measurements were taken of the joint width and gage plug separation. Measurements of the level of faulting at each joint were also recorded. Joints were refaced with a concrete saw, or sealant was removed with a joint plow. Sandblasting, airblasting, and backer rod installation began immediately prior to sealant installation.

Gage plug installation

Studying the relative opening movement of each joint required the installation of stationary markers on opposite sides of the joints. Gage plugs were installed on the last eight joints of each test section prior to sealant installation while the sawing operation was in progress. The initial gage plugs were 0.375-in (9.5-mm) rod couplers with screws in each end. Holes were drilled in the concrete 2 in (51 mm) from each joint edge and 18 in (457 mm) from the shoulder-pavement interface. The gage plugs were then set in the holes with epoxy cement.

This process proved to be time consuming, and the original gage plugs were replaced with 1.387-in (35-mm) Parker-Kalon® (P-K) nails that were epoxied into predrilled, countersunk holes at the above specified locations. To provide positive positioning for the center points of the caliper, small indentations were formed in the center of each nail head using a center punch. Installed P-K nails are shown in figure 8.

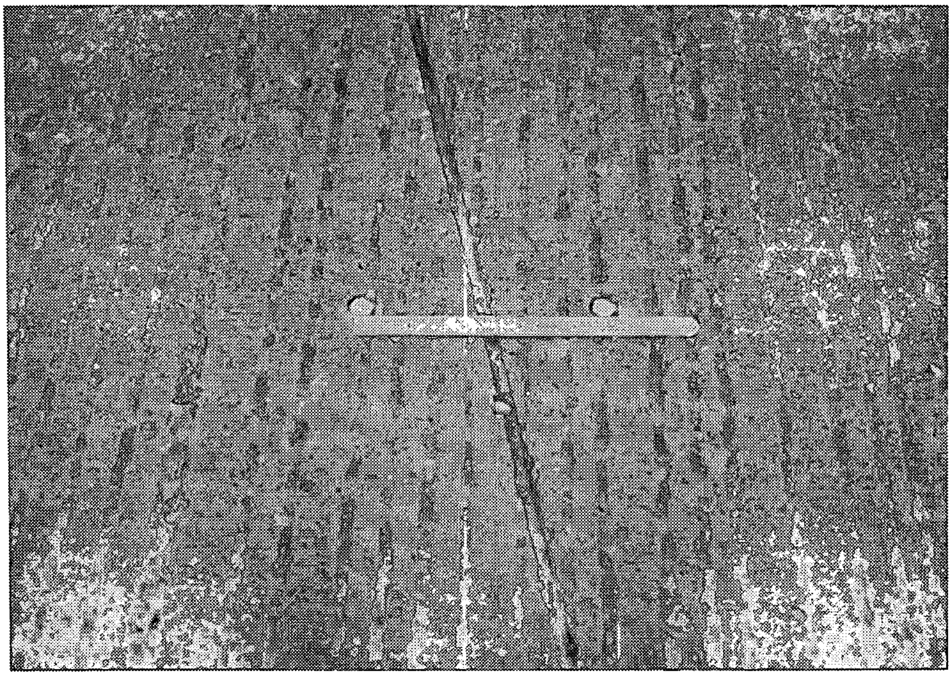

Figure 8. Installed gage plugs

Measurement of faulting and joint dimensions

The initial faulting condition at each pavement joint of each test site was determined using a digital readout fault-measuring device developed at the Georgia Department of Transportation. Two readings were taken at each joint at 12 to 20 in (305 to 508 mm) from the inside shoulder edge and were recorded. Figure 9 shows the fault measurement device in use. deeply tined or milled pavement caused minor problems with the repetitiveness of the fault measurements; however, the readings indicated that no faulting was present.

After the epoxy holding the gage plugs had a chance to dry, measurements were taken using a digital caliper between the plug centers at each joint, as well as of the width of the joint between the gage plugs. While these gage plug readings were taken, climatic conditions and pavement temperatures were obtained on an hourly basis to allow study of correlations between joint movement and air and pavement temperature. Judging from repetitive testing of joint measurement, the accuracy of the measurements is to 0.01 in (0.254 mm).

Joint preparation

The original experimental design called for three configurations, or preparation and installation techniques, to be used for the installation of each rubberized asphalt sealant. These three techniques are described as the standard recessed, the saw-and-overband, and the plow-and-overband configurations, and the basic steps for their completion are listed below. The properties of the silicone sealants required that they be installed in the standard recessed configuration 1 only.

- Standard recessed (configuration 1)
  - Saw the joint reservoir to achieve clean sawed faces on both walls.
  - Sandblast the dry vertical joint walls.
  - Airblast the sealant reservoir.
  - Place backer rod in the joint reservoir.
  - Install sealant in the standard recessed configuration.

- Saw and overband (configuration 2)
  - Saw the joint reservoir to achieve clean, sawed faces on both walls.
  - Sandblast the dry vertical joint walls and adjacent pavement surface.
  - Airblast the sealant reservoir and adjacent pavement surface.
  - Place backer rod in the joint reservoir.
  - Install sealant in overband configuration.

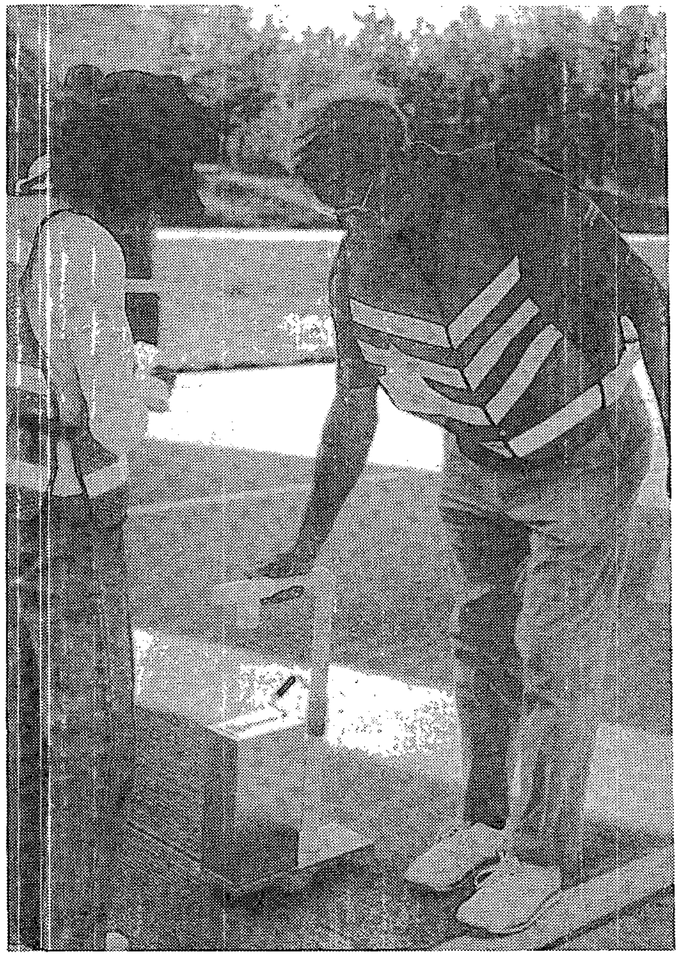

Figure 9. Fault measurement

- Plow and overband (configuration 3)
  - Plow the sealant from the existing joint.
  - Airblast the reservoir and adjacent pavement surface.
  - Place backer rod in the joint reservoir.
  - Install sealant in the overband configuration.

Due to unforeseen circumstances, a fourth configuration replaced the third configuration at the Arizona and Colorado sites. These circumstances will be discussed in the joint-plowing sections. The fourth configuration, designated as the saw-and-flush fill, employs all of the steps of the standard recessed configuration, but the sealant reservoir is filled to the surface instead of recessed 0.25 in (6.4 mm).

Joints for configurations 1, 2, and 4 at each test site were sawed using 65-hp (165-kBtu/hr) water-cooled, diamond-bladed concrete saws. The design width of joint sawing was 0.5 in (12.7 mm) and the design depth was 1.75 in (44.5 mm). Shown in figure 10 is the saw used at the Iowa test site. Several joints at the Arizona site were dry-sawed using 18-hp (46-kBtu/hr) crack saws.

The joint-plowing operation was considered to be the quickest and easiest method of joint preparation. It was noted, however, that joint plowing on a 12-ft (3.7-m) lane of a road that

Figure 10. Joint-sawing operation

carries traffic in the adjacent lane is difficult. The difficulty is increased when sharp side slopes, guard rails, or curbs are present on the adjacent shoulder. Joints that were too shallow to allow sealant and backer rod placement were also encountered, as well as joints containing PVC coal-tar sealant that is known to react negatively with asphalt-based sealants.

Joints for configuration 3 were plowed in South Carolina, Iowa, and Kentucky. An 8-year-old silicone in excellent condition was removed in South Carolina, a 6-year-old failed silicone sealant was removed in Iowa, and a failed asphalt-based sealant of unknown age was removed in Kentucky. The plowing operation in Iowa is shown in figure 11.

At the Arizona site, at least half the joints required for plowing were sawed between the time of layout (February) and the installation (April). This was required because steel inserts had to be removed from the joints. It was discovered during the plowing operation that about half the remaining joints to be plowed were less than 0.5 in (12.7 mm) deep, making it impossible to install backer rod beneath the sealant. The third configuration was, therefore, replaced by a fourth configuration that involved sawing and flush-filling the joints.

Plowing at the Colorado site was attempted and also discontinued in favor of the fourth configuration. There were two reasons for this decision. First, the joint plow available at the site could not be stabilized so that the plow blade would effectively scrape the sides of the joint. Second, the sealant present in the joints was a PVC coal-tar material that was less than 5 years old and was expected to react with the sealants used in the experiment, forming a softened region at their interface.

When the sawed joints had been initially blown out with compressed air and had dried, the inside edges of the joints for configurations 1 and 4 were thoroughly sandblasted. At the South Carolina, Colorado, and Kentucky sites, the sandblast nozzle was held by the operator at a distance of 2 to 6 in (51 to 152 mm) from the joint face and at an angle of 60 to 80 degrees from the plane of the pavement surface. Attached to the sandblast hose and nozzle at the Arizona site was a 5-ft (1.5-m) length of angle iron, as shown in figure 12. The tip of the angle iron had been ground to a point so it could fit into the joint, allowing the nozzle to be dragged at the desired angle and distance from the joint face.

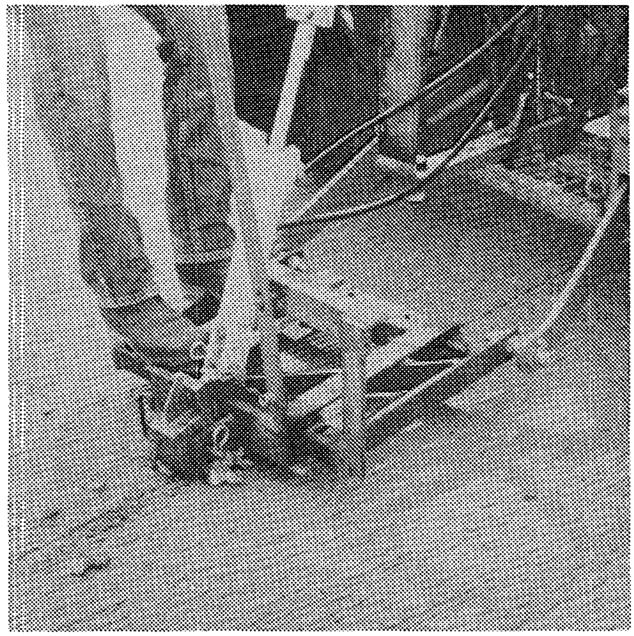

Figure 11. Joint-plowing operation

A more elaborate method of sandblasting was used at the Iowa site. A stainless steel plate was attached to a handle. The hose and nozzle were fixed to the plate and handle at the desired angle and position, and the guide was pulled through each joint held in position by a centering pin in the steel plate. Two sandblast units were used for this operation, one for each joint face. This sandblast apparatus is shown in figure 13.

Sawed joints that were to be overbanded were not only sandblasted along each joint wall, but the adjacent surface to 1 in (25.4 mm) from the joint edge was also sandblasted. This work was in most cases conducted freehand by the operator, but a guide was used at the Iowa test site for about half of the overbanded joints.

Airblasting, shown in figure 14, was accomplished using an air compressor with the cleanest, driest airstream available. After the sandblasting operation had progressed at least ten joints ahead, the sand and dust in the joints was removed by airblasting the reservoir. Sand and dust from the sawing and the sandblasting operations were also blown from the pavement surface to the adjacent shoulder or gutter.

When the airblasting operation had progressed at least five joints ahead, a crew of two or three persons installed backer rod in the joints to be sealed. An adjustable backer rod placement roller was used to recess the rod to the required depths. Typically, backer rod was cut slightly longer than the length of the joint, and one end of the rod was placed in the jointed at the lane edge nearest the shoulder. Then the person unrolling the backer rod would move to the opposite end of the joint and slightly stretch the backer rod as it was recessed, thus easing the rolling procedure. This is shown in figure 15. When the rolling was nearly complete, the backer rod was cut to the exact length required for providing a tight seal, and the entire length was rolled a second time.

Several widths of backer rod were required because of widened areas and narrow unsawed joint widths. To improve this installation process, the necessary rolls of backer rod were mounted in the back of an available truck and unrolled as needed for each joint. If sealant installation was delayed more than about 50 minutes, the joint was cleaned with an additional low-pressure air stream.

The Arizona site, in particular, presented logistics problems for preparation and installation. Due to the high traffic volume, the subcontractor's workmen were only allowed on the pavement between 9:00 p.m. and 3:30 a.m. As a result, preparation and installation were hurried in an effort to install two rubberized asphalt sealants per night. The road was equipped with street lights, but it was learned on the first night that the main contractor was putting in additional lights and he required that the lights remain off during most of the preparation and installation process. Additional portable lights were brought in the next night, but it was difficult to find the test section locations and to monitor the sawing and cleaning operations.

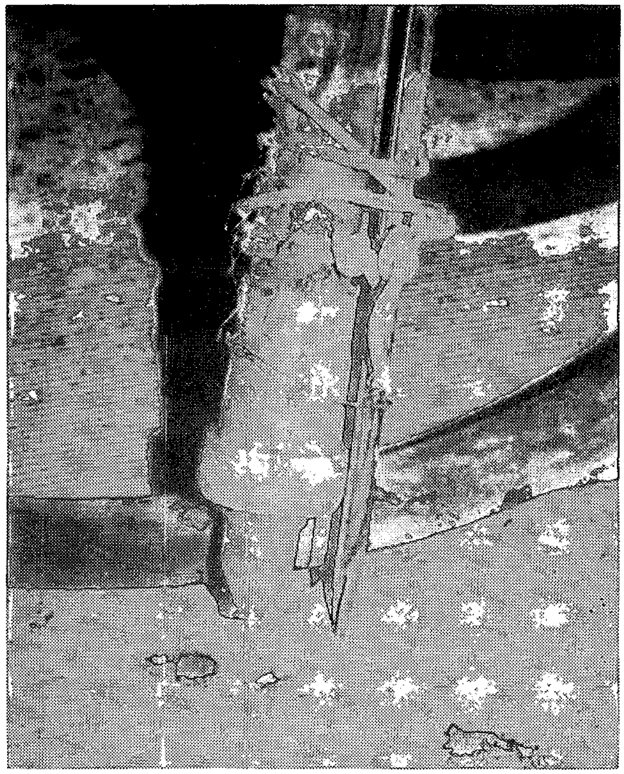

Figure 12. Arizona sandblasting nozzle

Figure 13. Sandblasting operation

Figure 14. Airblasting operation

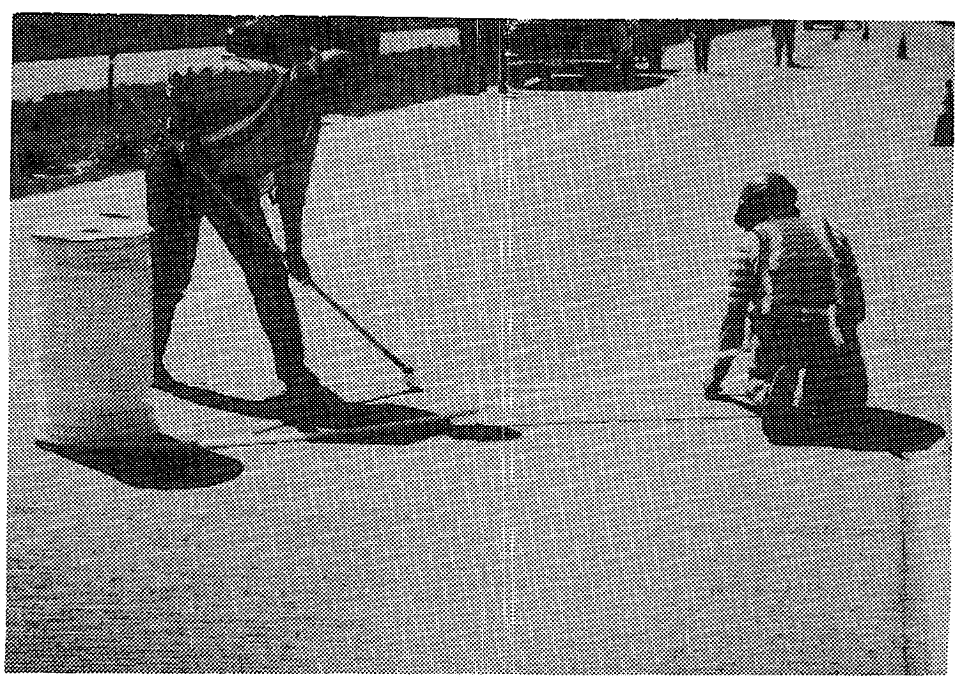

Figure 15. Backer rod installation

Installation

The order of placement for the various sealant materials and configurations described in the EDRP was generally adhered to in the field installation. A summary of the number of joints sealed at each site using the selected materials and procedures is shown in table 6.

Table 6. Summary of materials and procedures used for joint seal installation

Sealant Material	Config. - Prep. [a]	Phoenix, AZ	Columbia, SC	Ft. Collins, CO	Grinnell, IA	Frankfort, KY
Crafco RoadSaver 221	1	20 [b]				
	2	20				
	4	20				
Crafco RoadSaver 231	1	20	20	20	20	20
	2	20	20	20	20	20
	3		20		20	20
	4	20		20		
Koch 9005	1	20	20	20	20	20
	2	20	20	20	20	20
	3		20		20	20
	4	20		20		
Koch 9030	1		20	20	20	20
	2		20	20	20	20
	3		20		20	20
	4			20		

[a] Configuration 1: Saw and recessed
Configuration 2: Saw and overband
Configuration 3: Plow and overband
Configuration 4: Saw and flush-fill

[b] Number of joints installed at the site

Table 6. Summary of materials and procedures used for joint seal installation (cont.)

Sealant Material	Config. - Prep. [a]	Phoenix, AZ	Columbia, SC	Ft. Collins, CO	Grinnell, IA	Frankfort, KY
Meadows Hi-Spec	1	20 [b]				
	2	20				
	4	20				
Meadows Sof-Seal	1		20	20	20	20
	2		20	20	20	20
	3		20		20	20
	4			20		
Dow 888	1	20	20	20	20	20
Dow 888-SL	1	20	20	20	20	20
Mobay 960-SL	1	20	20	20	20	20
Mobay 960	1				20	
Crafco 903-SL	1	20				
Koch 9050	1			20		10
Dow 888 w/ Prime	1				10	
Dow 888-SL w/ Prime	1				10	
Koch 9005 w/ Prime	1					10

[a] Configuration 1: Saw and recessed
Configuration 2: Saw and overband
Configuration 3: Plow and overband
Configuration 4: Saw and flush-fill

[b] Number of joints installed at the site

One significant change from the initial experimental design is the replacement of the configuration 3 overbanded joints in Phoenix and Ft. Collins with a fourth configuration, the flush-fill method. Also, since the primer for Koch 9005 could not be supplied in time for installation at the site in Iowa, those test sections were replaced with Dow Corning 888 and Dow Corning 888-SL silicone with primer. A test section for Koch 9005 with primer was installed at the Kentucky site.

Materials

The joint sealing materials installed at the test sites were those recommended in the SHRP H-105 report. These included several rubberized asphalt sealants as well as silicone sealants. At the request of the participating state agencies, additional silicone and polysulfide sealants were installed for further evaluation.

Rubberized asphalt

Rubberized asphalt sealants having ASTM D 3407 penetrations between 75 and 85 dmm were installed using the preparation methods and configurations described in the preceding section. Koch 9005 was placed in 60 joints at each site to serve as the control material. In addition, Meadows Hi-Spec and Crafco RoadSaver 221 were installed on I-17 in Phoenix, replacing Koch 9030 and Meadows Sof-Seal. The configurations and number of joints sealed with each material are shown in table 6.

Each rubberized asphalt sealant material is packaged in 50-lb (22.7-kg) blocks for easy placement in a melter-applicator. The recommended pouring temperature for the rubberized asphalt sealants varies from 370 to 390°F (188 to 199°C), and the maximum safe heating temperature ranges from 390 to 410°F (199 to 210°C). Sealant and heating oil temperatures were monitored carefully during installation to ensure that overheating the sealants did not occur. In many cases representatives from the sealant manufacturers were present to monitor and assist in installation.

As might be expected when inexperienced workmen attempt to install sealant for the first time, some difficulties were encountered during installation. On occasion, depending on the coordination of the person installing the recessed sealant and the type of sealant wand, the sealant was installed too thinly or too thickly in the reservoir. If the sealant was less than about 0.25 in (6.4 mm), a second layer of sealant was added immediately after initial installation to obtain the desired sealant thickness. Occasionally, due to inadequate backer rod installation, sealant would flow through gaps in the backer rod and leave a sunken area of sealant. This problem was addressed by tighter monitoring of backer rod installation.

Bubbles were noted in the sealant material at several of the sites. It was initially assumed that these were the result of moisture in or below the pavement, even though the pavement appeared dry and it had not rained for the previous 24 hours. Some bubbles were also determined to be the result of air entrained in the sealant by the agitator in the melter-applicator. When this was noted, additional sealant was added to the heating chamber and the motion of the agitator was reduced or reversed. At the Colorado site, it was noted that severe bubbling was occurring in the first joint using Koch 9005. Assuming that moisture was the problem, installation was halted. Returning to the site the next day, the same problem was encountered. Further investigation revealed that the backer rod used in that joint was defective and was melting and producing bubbles when heated sealant was placed over it. The backer rod was 0.875-in (22.2-mm) HBR-XL, closed-cell, expanded polyethylene. Since 0.625-in (16-mm) backer rod was required for 75 percent of the joints at the site and the

0.625-in (16-mm) rod from the same manufacturer was not melting, the remainder of the joints were sealed. Where large-diameter backer rod was required, a thin first layer was applied over the 0.875-in (22.2-mm) rod, followed by another layer to reach the required depth. This significantly reduced the bubbling problem. Suitable large-diameter backer rod was provided by the manufacturer for use at the remaining sites.

Traffic was not allowed on the joints sealed using rubberized asphalt for at least 60 minutes at any of the sites. That time could have been reduced to about 15 minutes if the conditions had so required.

Low-modulus rubberized asphalt

Low-modulus rubberized asphalt sealant materials have a greater working range with respect to low-temperature extensibility and resistance to high-temperature softening. Penetrations of the materials installed at the sites vary from 110 to 140 dmm. Recommended pouring temperatures range from 370 to 390°F (188 to 199°C), and the maximum safe heating temperatures vary from 390 to 410°F (199 to 210°C).

The same preparations and installation procedures used for the rubberized asphalt sealants were used with the low-modulus sealants: Crafco RoadSaver 231, Meadows Sof-Seal, and Koch 9030. The locations, configurations, and number of joints sealed with each material are listed in table 6. Some bubbling was noted at each test site, and the above-mentioned procedures were used to reduce this bubbling. Some sealant was also lost through gaps at the backer rod ends. At most sites, the thick consistency of the Crafco RoadSaver 231 eliminated this problem for that material.

Again no traffic was allowed on the low-modulus sealant joints until they had cured at least an hour. This time could have been reduced to less than 15 minutes if necessary.

Silicone

Two self-leveling and one non-self-leveling silicone sealants were installed at the five test sites. In addition, two more silicone sealants were added to the Arizona and Iowa sites. The configuration, location, and number of sealed joints are shown for each silicone sealant in table 7. The preparation for each sealant included resawing the joint, sandblasting, airblasting, and installing backer rod. A reticulated, closed-cell backer rod of extruded polyolefin foam was used to support the sealant and to create the lower bound of the sealant reservoir. Air-powered cartridge applicators were used to place the sealant in the joints. Each silicone was recessed 0.125 to 0.25 in (3.2 to 6.4 mm) and installed with thicknesses varying from 0.25 to 0.375 in (6.4 to 9.5 mm).

During installation it was noted that several bubbles were forming in the Mobay 960-SL silicone sealant. Some air was typically forced into the sealant by the cartridge applicator as it ran out of sealant. Since about three 11-oz (325-mL) cartridges were used for each joint, this may have caused some of the bubbling. The other silicone sealants did not show problems with bubbling in any significant amount.

The self-leveling silicone sealant flows in the joint reservoir in a manner similar to the hot-applied sealants. As a result, in a few places where gaps existed between the backer rod and the sidewall or at the ends of joints, the sealant tended to flow around the rod, leaving areas of thin sealant. This was addressed by more tightly controlling the backer rod installation.

Due to time limitations, traffic was allowed on one silicone sealant within 30 minutes of installation at the Phoenix site. This resulted in fine sand particles adhering to the sealant surface. However, no performance problems are expected. In most cases, about 1 hour was needed before allowing traffic on the non-self-leveling sealants and about 90 minutes was required for the self-leveling sealants to form a protective skin.

Polysulfide

A one-part, moisture-cured, self-leveling polysulfide was installed at the Colorado and Kentucky sites. Preparation included sawing, sandblasting, airblasting, and inserting backer rod. Sealant was installed about 0.5 in (12.7 mm) thick and recessed about 0.125 in (0.318 mm).

No problems were noted during installation, and the skin-over time in Colorado was about 15 to 25 minutes. In Kentucky the sealant had not skinned over after more than an hour. Traffic allowed on the pavement after about 60 minutes did track some of the high sealant onto the pavement surface, but a new skin was formed, and adhesion loss did not occur.

Equipment

Equipment for construction of the test sites was, in most cases, readily available to the state crews or contractors, although some modifications were made for the equipment to perform satisfactorily. Some state agencies, however, could not obtain the required equipment, and the project was required to provide the necessary items:

- Crafco 100 gal (378.5 L) melter-applicator for use in Ft. Collins, Colorado
- Cleasby 100 gal (378.5 L) melter-applicator for use in Ft. Collins, Colorado
- Joint plow for use in Colorado, Iowa, and Kentucky

In most states, 65-hp (165-kBtu/hr), water-cooled concrete saws made by Cimline or Target were used to reface the joints. It was noted at the Iowa site that the type and thickness of blade can affect production significantly. Several blades were warped at that site because blades of insufficient thickness were used. Using these blades significantly slowed the operation.

A joint plow fabricated in Granite City, Illinois was used to remove sealant from the joints in Colorado, Iowa, and Kentucky. This plow was attached to the three-point hitch of highway department tractors. A rectangular bit with a carbide tip was attached to the plow and pulled through the joint, making two passes and removing the bulk of the old sealant material.

Problems were encountered in Colorado with keeping the plow frame rigidly mounted to the tractor. Rigid mounting was required so that the blade could be firmly pushed against the joint edge while cleaning. Keeping the tractor in line with the skewed joints was also difficult. Spalling resulted when the tractor was misaligned. Also, since the plow was mounted on the rear of the tractor, the operator found it difficult to drive the tractor and watch the plow. Guard rails near the shoulder, elevated curbs, and shoulder dropoffs also caused difficulty for the plowing operators.

Clemco 600-lb (272-kg) blast machines were used at all sites except Colorado, where a shop-made blasting apparatus was employed. Typically, one pass was made to clean each joint face. It was discovered that the sandblasting operation does a poor job of removing old sealant from the joint face. This was especially true of silicone sealants and other sealants that still retained some resiliency. The sand rebounded off the sealant, and continued blasting typically left gouges in the concrete around the periphery of the old sealant. As a result, workers with hand-held knives removed the majority of any sealant material that remained from the sawing operation before final sandblasting. Visual inspection of the joints after sandblasting were completed on an intermittent basis to assure the effectiveness of the operation.

Air compressors of varying vintages were used for test site installation. Prior to use at the site, air from each compressor was blown onto the pavement and onto a nearby tire. If any signs of oil or moisture were left on the pavement or the tire after this test, the compressor was rejected. Several compressors were rejected during this testing and were upgraded by adding oil and water traps. In some cases, older compressors were used since they did not have systems that add lubricating oil to the airstream.

Melter-applicators manufactured by BearCat, Crafco, Steppes, Cleasby, and Cimline were used for hot-poured sealant application. These varied in capacity from 100 to 300 gal (379 to 1,136 L). The time required for initial heating of sealant for use in the project was 1 to 1.5 hours for the smaller melters and about 2.5 hours for the 300-gal (1,136-L) applicators. Melters with auger-type agitators seemed to require slightly more time in heating than those equipped with full-sweep agitators.

The squeegees used for overbanding the hot-applied sealants were made from 14-in (356-mm) industrial floor squeegees formed into a U shape. The back dimension of the squeegees was 3.5 in (89 mm), and a 0.0625-by-1.325-in (1.6-by-33.7-mm) notch was cut from the rubber insert in the back of the squeegees to promote the formation of the overband on the pavement surface. The squeegee was either pushed or pulled as required by the adjacent traffic patterns and worker preferences.

Procedures

Hot-applied, rubberized asphalt sealants were installed using configuration 1 according to manufacturers' recommendations, filling from the bottom up and keeping the sealant surface 0.125 to 0.25 in (3.2 to 6.4 mm) below the pavement surface. Application in South Carolina is shown in figure 16. Using the configuration 4 method, the sealant was placed from the bottom up to just even with the pavement surface. Flush-filled, hot-applied sealant is shown in figure 17. The average sealant thickness was 0.5 in (12.7 mm).

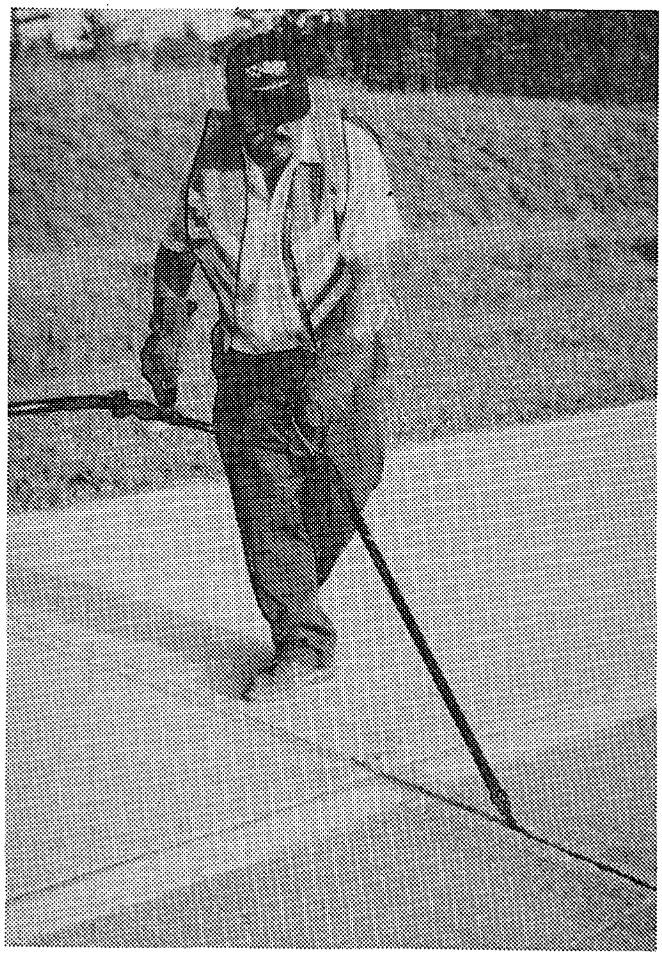

Figure 16. Recessed sealant installation

Approved oil-jacketed melter-applicators of various types were used to install sealant at the test sites. Sealants were applied at temperatures within the manufacturers' recommended ranges, and careful attention was paid to keeping the sealant temperature below the safe heating temperature at all times. To reduce the possibility of contamination, before using any melter-applicator all sealant was drained from the kettle and 100 to 150 lb (45 to 68 kg) of fresh sealant was heated, circulated through the pump and hose, and completely drained. After flushing, 300 to 400 lb (136 to 182 kg) of sealant were placed in the heating chamber and heated.

During heating and application, correlations were made between the sealant temperature measured using calibrated, hand-held thermometers and temperatures indicated by the thermometers on the melter-applicators. Samples of each hot-applied sealant were retained after installation for possible laboratory testing.

Hot-applied sealants were installed using the overbanded configurations according to manufacturers' recommendations, filling from the bottom up and slightly overfilling the joints. The average sealant thickness was 0.5 in (12.7 mm) for configuration 2 and 0.375 in (9.5 mm) for configuration 3. A squeegee followed the applicator wand at a distance of 6 to 24 in (152 to 610 mm), striking off the surface and leaving an overband about 0.0625 in (1.6 mm) thick and 1.325 in (33.7 mm) wide, with a total wipe zone width of about 3.5 in (89 mm). The overband installation process is shown in figure 18, and a recently installed overband is shown in figure 19. Traffic was kept off of the sealant until it had sufficiently cooled.

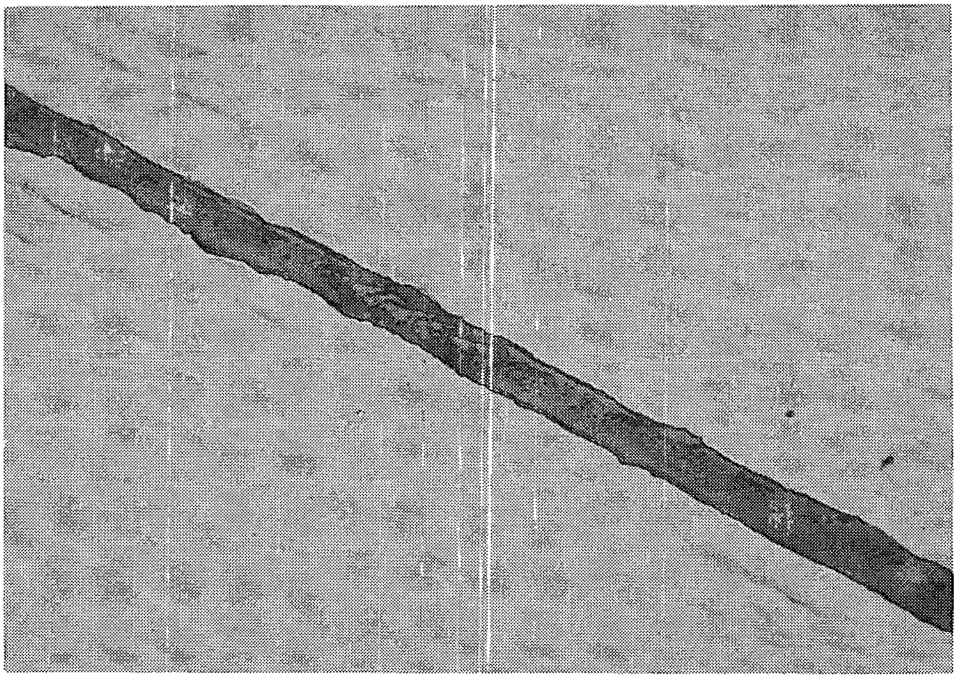

Figure 17. Installed flush-filled sealant

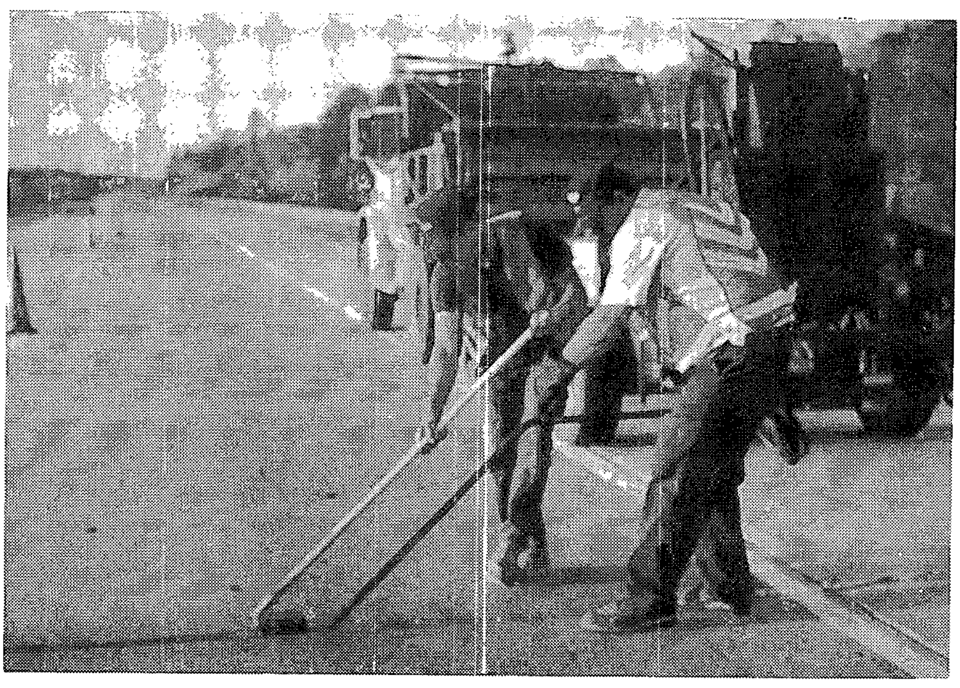

Figure 18. Overbanded sealant installation

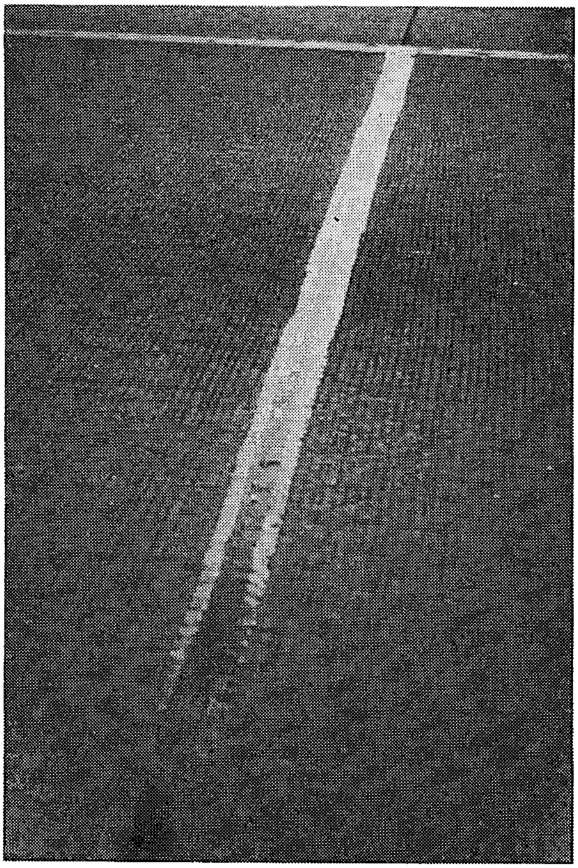

Figure 19. Installed overbanded sealant

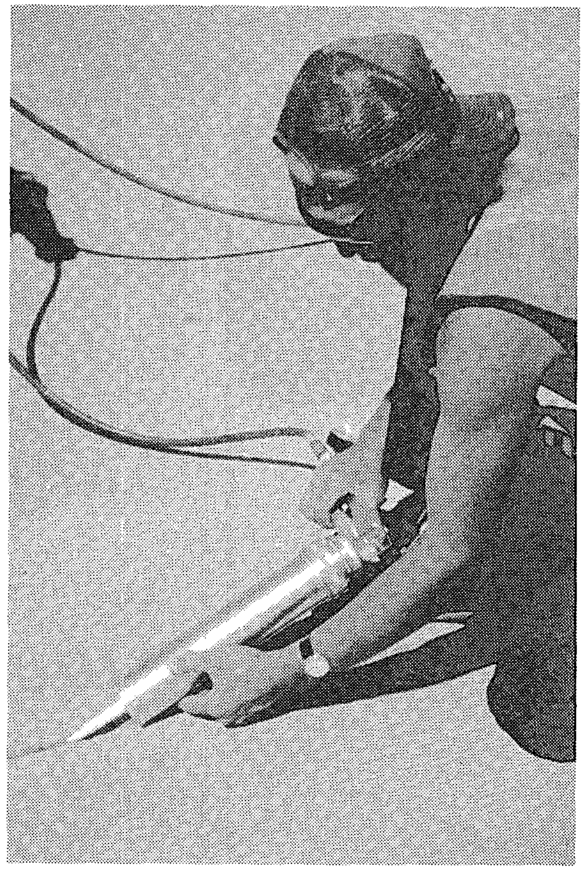

Figure 20. Silicone sealant installation

Silicone and polysulfide sealants were installed using air-powered cartridge applicators, according to manufacturers' recommendations, as shown in figure 20. The non-self-leveling silicone sealants were tooled to a maximum recess of about 0.25 in (6.4 mm) using folded pieces of oversized backer rod. This left a thickness of about 0.375 in (9.5 mm). Tooling was completed within 1 minute of sealant installation. The self-leveling silicone sealants were installed 0.375 in (9.5 mm) thick to about 0.25 in (6.4 mm) below the pavement surface.

Some bubbles were noticed in the Mobay Baysilone 960-SL sealant as it was placed. Spot-checks of sealant thickness were made during installation by inserting a metal ruler through the fresh sealant to the top of the backer rod. Traffic was not generally allowed onto the sealant until it had cured at least an hour. Production rates for silicone and hot-applied sealants are shown in table 6.

Productivity and Cost Data

Project staff were present at each site during preparation and installation to direct and monitor the operations. Journals of installation were kept for each site and production rate

Table 7. Productivity rates, labor, and equipment requirements

Procedure	Persons Required	Equipment Required	Time per 10 Joints (min)
Wet saw	2	65-hp saw, water truck	20 to 60
Airblast or waterwash	2	Air compressor or water sprayer, truck	15 to 20
Plow	2	Powered joint plow	20 to 40
Sandblast (recessed)	2	Sandblaster, air compressor, truck	15 to 30
Sandblast (overband)	2	Sandblaster, air compressor, truck	20 to 45
Airblast	2	Air compressor, truck	10 to 15
Backer rod installation	2	Installation tool, optional truck	10 to 15
Recessed hot-pour installation	2	Approved melter-applicator	10 to 15
Overbanded hot-pour installation	3	Approved melter-applicator, squeegee	10 to 15
Tooled silicone installation	2	Silicone pump or air compressor and cartridge applicator, tooling apparatus	40 to 50
Self-leveling silicone installation	3	Silicone pump or air compressor and cartridge applicator	30 to 40

information for preparation operations was recorded on sheets similar to figures B-1 through B-5 in appendix B. Average production rates for each procedure are listed in table 7.

Production rates for each operation, material, and configuration are listed for each site in table B-1 of appendix B. For this project, the average amount of labor required for one joint to be sawed, initially airblasted, sandblasted, airblasted, and have backer rod and sealant installed in a recessed configuration is about 25 person-minutes. This does not include startup time and sealant-heating time.

Costs of sealant materials and shipping used in this project are listed in table 3. Shipping costs for the silicone sealants were paid by the manufacturer. The cost of shipping the rubberized asphalt sealant materials ranged from 19 to 83 percent of the per-pound sealant cost.

This productivity and cost information can be used, together with field performance results, to determine the cost-effectiveness of each material. A method for determining cost-effectiveness is shown in appendix E. Sample calculations are also included in that appendix.

Documentation

In order to effectively document and evaluate joint movement, pavement condition, installation techniques, and rates, seven information sheets were completed during installation. These installation forms are contained in the SHRP H-106 Evaluation and Analysis Plan [2] and in appendix B. Among the data collected are the following:

- Climatic conditions
- Pavement condition
- Pavement temperatures
- Initial joint dimensions
- Gage plug separations
- Joint faulting
- Temperatures of hot-applied sealants
- Production rates
- Labor requirements

Photo documentation was made of each installation procedure and representative photos of each material and configuration were taken at the test sites.

Comments

Several items should be mentioned in a reflective analysis of the installation of the joint-resealing test sites. Among these are items pertaining to the sealant removal and cleaning operations and to the control of material placement.

Various problems were encountered in the joint-plowing operation. Some were related to the original reservoir depth, some related to the old sealant material, and some related to the difficulties inherent in a rear-mounted plowing system. The speed of the plowing operation was somewhat comparable to that of the sawing operation; however, the quality of cleaning was far less. If a maneuverable plow with positive horizontal and vertical control were available, this might increase the advantages of the joint plow. Also, if the plowed joint were in such condition that the remaining sealant could be removed by sandblasting, the plowing operation could compete with sawing and sealing since it leaves a dry joint and does not significantly widen the joint. Good engineering judgement should be applied when choosing to use a joint plow, taking into account such variables as existing joint dimensions, condition of the existing sealant, and effectiveness of sandblasting.

Due to the inability to effectively plow joints at the Phoenix and Ft. Collins sites, the third configuration could not be used with the hot-applied sealants at those sites. This reduced the comprehensiveness of the factorial design, not allowing comparison of sealant performance in the third configuration in those regions. It also reduces the effectiveness of performance analysis across climatic regions.

In most cases, the resealing of joints in concrete pavements requires working with traffic in the adjacent lane. This sets up a situation in which sand and dirt in the adjacent lane can be blown into the joint reservoir in the period between cleaning and sealant placement. In the installation of the test sites, this problem was reduced by blowing sand and dirt from the joint reservoir and the pavement surface onto the nearest shoulder, using compressed air. In situations where curbs are present or the prevailing winds are contrary, joints can be quickly contaminated by blowing debris. Possibly it should be specified that a waterless street sweeper/vacuum be used to remove dirt from the pavement in conjunction with the sandblasting and the airblasting operations.

Night construction makes good-quality joint resealing even more difficult to obtain. Adequate lighting needs to be available for all operations, including the inspection process. Time constraints make it tempting to cut corners in preparation thoroughness and installation quality. If the sealant is not preheated, there is motivation to heat the sealant quickly, possibly resulting in overheating. Additional inspection personnel may be necessary to maintain installation quality.

Finally, the rubberized asphalt, hot-applied sealants are very sensitive to overheating and to extended heating. Although overheating of materials was not recorded during installation, it is very tempting to speed the heating operation by raising the oil temperature to more than 500°F (260°C), and thereby induce localized overheating of the sealant material. Sufficient monitoring of the sealant temperatures should be conducted to ensure that the sealant does not exceed the safe heating temperature at any time.

3

Material Testing

In addition to the data collected during installation of the joint-resealing materials, laboratory testing was performed on the primary sealant materials. Initial tests were run to confirm the compliance of each sealant to the stated manufacturers' specifications as well as to the ASTM D-3405 specifications for the hot-applied materials. The materials also underwent supplemental testing, following test site installation. The purpose for this additional testing was to compare the laboratory-defined material properties of each material with the sealant's performance at the controlled test sites. Supplemental test procedures were conducted using tests that may correlate well with such performance properties as adhesion loss, overband wear, stone intrusion, cohesive failure, and spalling of the joint walls. Laboratory tests and material properties showing significant correlation with field performance will be considered for inclusion in performance-based material specifications.

To ensure that the materials tested were representative of the material at each site, the silicone and hot-applied sealant materials installed at all five sites were each selected from a single production batch. Suitably sized samples of each silicone sealant and rubberized asphalt material were obtained from the South Carolina and Colorado sites, respectively, and shipped to two approved laboratories for testing.

Laboratory Tests Performed

Several of the initial tests were performance-based tests. These included ASTM D 3407 penetration, flow, bond, and resilience tests for rubberized asphalt materials, as well as ASTM D 412 tensile stress and elongation tests for silicone sealants. Additional initial tests were used to measure general sealant material properties, such as the specific gravity, extrusion rate, and tack-free time.

Supplemental performance tests were selected to investigate specific sealant performance properties, such as adhesive strength, cohesion strength, flexibility, durability, resilience, and resistance to weathering. The effects of extreme temperature on some of these properties was also investigated. These tests and any modifications made to them are described in the EAP.

Two tests performed on all nine sealants, which may be useful in relating laboratory properties to sealant performance in the field, are the ASTM D-412 tensile test, shown in figure 21, and the ASTM D-3583 immersed bond strength test, shown in figure 22. The tensile test was performed on all sealant materials under temperature conditions ranging from 0°F to 140°F (-18°C to 60°C). Tensile test results were also obtained for the silicone sealants after the specimens had undergone 504 hours of ASTM G-23 weathering.

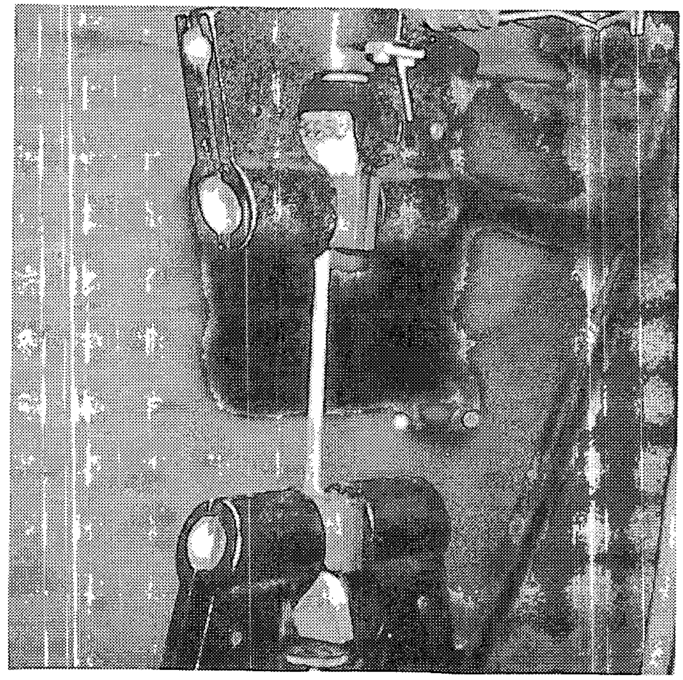

Figure 21. ASTM D-412 testing

Most of the tests originally described in the analysis plan were completed successfully; however, due to procedural or equipment problems, two tests required additional modification or could not be run. Table 8 lists the supplemental laboratory tests used in the experimental design, the properties sought in the testing, and

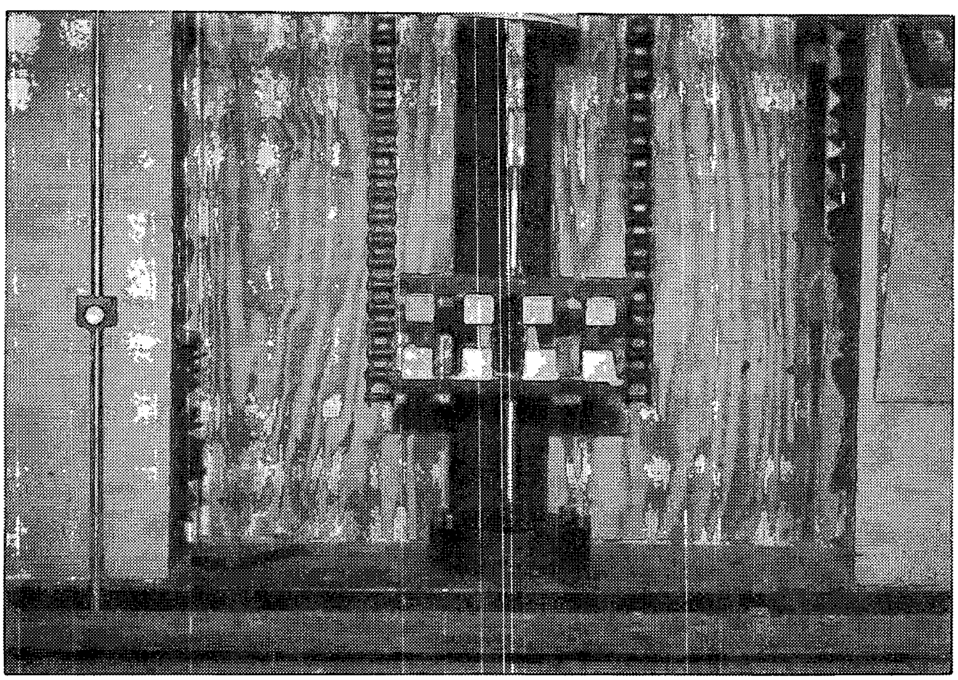

Figure 22. ASTM D-3583 testing

Table 8. Target properties and modifications of supplemental performance tests

Test	Procedure	Pertinent Properties	Material	General Comments
Softening point	ASTM D-36	High-temperature tracking potential	Rbrzd. Asphalt	No modifications
Cone penetration, 0°F	ASTM D-3407	Low-temperature flexibility	Rbrzd. Asphalt	Conducted at 0°F
Cold bend	Utah Spec.	Cohesion	Rb. Asp.	Conducted at 0°F
Force ductility	ASTM D-113 & Utah Spec.	Flexibility	R. Asp. Silicone	Ductility test run at 39.2°F
Tensile adhesion	ASTM D-3583	Adhesion/cohesion	R. Asp. Silicone	Standard test run at 75°F, Soaked and unsoaked PCC blocks
Modulus: 0°F 39°F 75°F 140°F	ASTM D-412	Flexibility	Silicone	Conducted at a separation rate of 2 in/min instead of 20 in/min. Originally designed for 0, 75, and 140°F. High temp. replaced with 39°F due to material softening.
Modulus after artificial weathering, 504 hrs	ASTM G-23 ASTM D-412	Durability/flexibility	Rbrzd. Asphalt	Completed on silicone only at 75°F. Asphalt-based sealants deformed during weathering phase.
Track abrasion	ASTM D-3910	Durability	Silicone	Test discontinued due to migration and pullup problems.
Cyclic adhesion/cohesion	ASTM C-719	Adhesion/cohesion		Performed at 765°F. Cycling 50% compression to 100% extension.

Note: 1 in = 25.4 cm; °C = (°F-32)*5/9.

comments about the testing procedures. Results of these tests have been collected and are listed in the following section and in appendix C.

Laboratory Test Results

The rubberized sealant materials used in this study contain different amounts of asphalt and other additives, such as polymers, rubbers, and filler materials, blended and linked in a manner that results in some variation in the outcome of laboratory testing. Results of the initial laboratory tests on the hot-applied and the low-modulus, hot-applied sealants are shown in tables 9 and 10. Typically, two or three replicates of each test were performed, and the results of each replicate as well as the average for each test are shown in these tables. Table 9 also contains the limits set by the ASTM D-3405 specification for comparison. For the low-modulus, hot-applied sealants, several states have developed specifications for assistance in screening and quality control. The specifications used in Minnesota, Michigan, and Iowa are shown in table 10 for comparison.

Table 9. Results of initial laboratory tests on hot-applied sealants

Test Description	ASTM Test Method	ASTM D 3405-78 Specification Limits	Crafco RS 221	Meadows Hi-Spec	Koch 9005
Penetration at 77°F (25°C), 150 gm, 5 sec	D 3407-78	≤ 90	75.5	63.5	82.0
Flow at 140°F (60°C), mm	D 3407-78	≤ 3.0 mm	0	0	1
Bond at -20°F (-29°C), 3 cycles, 50% extension	D 3407-78	3 cycles	Pass	Pass	Pass
Resilience at 77°F (25°C), %	D 3407-78	≥ 60%	65.3	63.7	70.3
Specific gravity at 60°F (15.6°C)	D 3407-78		1.180	1.112	1.068

Table 10. Results of initial laboratory tests on low-modulus, hot-applied sealants

Test Description	ASTM Test Method	Typical Specifications			Crafco RS 231	Meadows Sof-Seal	Koch 9030
		MN	MI	IA			
Penetration at 77°F (25°C), 150 gm, 5 sec	D 3407-78	110 to 150	110 to 150	90 to 150	75.3	137	114.5
Flow at 140°F (60°C), mm	D 3407-78	≤ 3	≤ 3	≤ 3	0	0	0
Bond at -20°F (-29°C), 3 cycles, 100% extension	D 3407-78	3 cycles	3 cycles	3 ccl. 200%	Pass	Pass	Pass
Resilience at 77°F (25°C), %	D 3407-78	≥ 60	≥ 60	≥ 60	70.7	69.7	83.7
Specific gravity at 60°F (16°C)	D 3407-78				1.128	1.078	1.101

Table 11. Results of initial laboratory tests on non-self-leveling silicone sealants

Test Description [a]	ASTM Test Method	Typical Specification GA 83306-A [b]	Dow 888
Tack-free time at 77°F (25°C), 50% Rel. Humidity, minutes	C 679-87	Skin-over ≤ 90	65
Durometer hardness, shore 00, 77°F (25°C)	D 2240-86	Shore A 10 to 25	70
Flow at 122°F (50°C), in	D 2202-88		0.25
Extrusion rate, gm/min	C 603-83	≥ 75	81.8
Ultimate elongation, 77°F (25°C), %	D 412-87 die C		1950
Tensile stress at 150% Elongation, 77°F (25°C), psi	D 412-87 die C	≤ 45	34.0

[a] Cured 21 days at 77°F (25°C), 50% relative humidity
[b] Cured 28 days at 77°F (25°C), 50% relative humidity

Table 12. Results of initial laboratory tests on self-leveling silicone sealants

Test Description [a]	ASTM Test Method	Typical Specifications GA 83306-B [b]	Dow 888-SL	Mobay 960-SL
Tack-free time at 77°F (25°C), 50% Rel. Humidity, minutes	C 679-87	Skin-over ≤ 90	150	240
Durometer hardness, Shore 00, 77°F (25°C)	D 2240-86	40-80	59	50
Extrusion rate, 77°F (25°C), gm/min	C 603-83	> 90	180	300
Ultimate elongation, 77°F (25°C), %	D 412-87 die C		2150	647
Tensile stress at 150% elongation, 77°F (25°C), psi	D 412-87 die C	< 40	16.5	24.9

[a] Cured 21 days at 77°F (25°C), 50% relative humidity
[b] Cured 28 days at 77°F (25°C), 50% relative humidity

One non-self-leveling silicone sealant, Dow Corning 888, was tested, and the results of the initial tests along with the current Georgia Department of Transportation specification are shown in table 11. The Georgia specifications for shore A hardness and skin-over time are included, although these are not the same tests used in the H-106 laboratory testing program. Two self-leveling silicone sealants, Dow Corning 888-SL and Mobay Baysilone 960-SL, were also tested and the results of the initial tests are compared with Georgia specification 83306-B in table 12. Summaries of the results of supplemental tests performed on silicone and hot-applied sealants are shown in tables C-1 through C-7 in appendix C.

4

Field Performance

Five evaluations of the performance of the joint seals have been completed at 1, 5, 9, 12, and 18 months after installation. The lanes in which each test site was installed were closed down, and a detailed 1-to-2-day inspection was carried out, evaluating the condition of the sealant and the surrounding concrete. The following section discusses the types of performance data collected and presents a summary of the field performance to date.

Performance Data Collection

Toward the goal of collecting the required performance data efficiently, consistently, and completely, joint seal evaluation sheets were prepared and are shown in appendix D. One page was completed for each joint at each test site with locations for recording the following information on a foot-by-foot basis:

- Partial-depth adhesion loss (approach and leave side)
- Full-depth adhesion failure (approach and leave side)
- Partial-depth spall failure (approach and leave side)
- Full-depth spall failure (approach and leave side)
- Overband wear (approach and leave side)
- Stone intrusion
- Partial-depth cohesive failure
- Full-depth cohesive failure

The predominant distresses after 18 months are adhesion loss and spall failure. Figure 23, taken on I-25 in Colorado, shows a typical partial-depth adhesion loss. Partial-depth adhesion loss, where present, ranges in depth from 0.125 in (3.2 mm) to 60 percent of the sealant thickness, with an average depth of about half the sealant thickness. Spall-related failure, shown in figure 24, occurred predominantly in the colder states of Iowa and Colorado. Typically, in these states, partial-depth spalls occurred three to seven times more frequently than full-depth spalls. Reduction in the thickness of the overbanded sealant material, as shown in figure 25, is also a common occurrence.

Field Performance Results

All the performance data from the joint sealant study has been entered into a database; due to the large amount of data, only summary tables of the sealant distresses are included in this report. An example summary table for partial-depth spall failure at the test site on I-25 in Colorado is shown in table 13. Each row in this table represents a summation for ten joints prepared with the same materials and preparation procedures. The remaining performance summary tables for each site and distress are included in appendix D. Summaries of the full-depth adhesion and spall failures after 18 months for each site, material, and installation method are shown in figures 26 through 30.

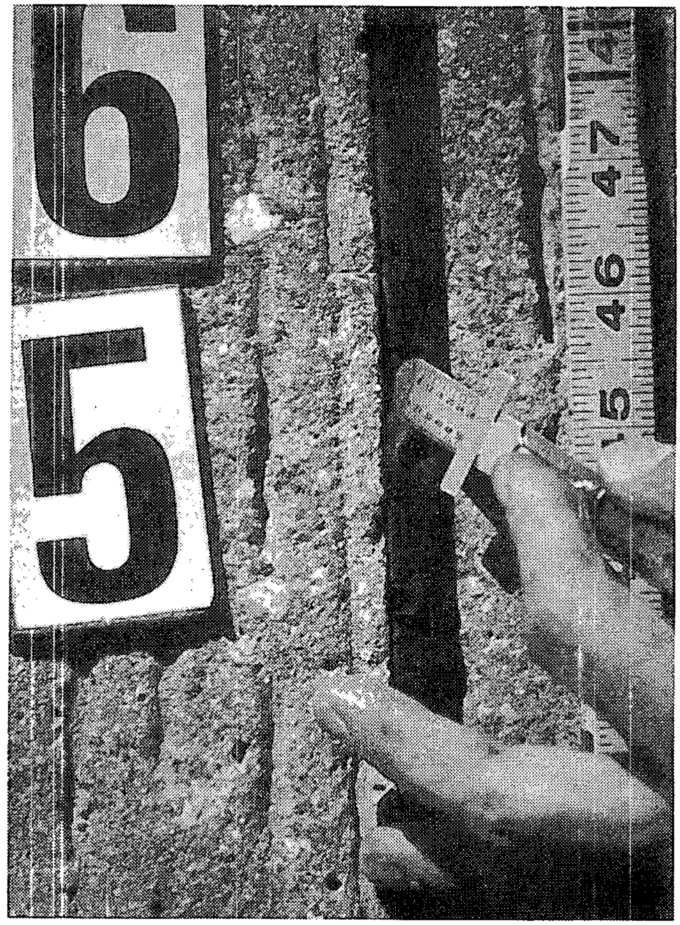

Figure 23. Partial-depth adhesion loss

For all five evaluations the table shows values for left, right, and percent. The left and right values correspond with the inches of spalling or adhesion loss on the approach side and leave side of the joint. The percent value is the average percent of joint length that contains partial-depth spalling on either side of the joint.

Full-depth failure has been rare for most joint seals in the test site. Joints containing full-depth failure have separated from the sidewall or have spalled sufficiently to allow moisture or debris to pass the seal and enter the joint. A summary of the inches of full-depth failure observed at each test site 18 months after installation is shown in table 14. It should be noted that the values in table 14 include both spall and adhesion failure and that no statistical difference may exist between seals having different percent failures. Statistical analysis of these results is described in chapter 5.

The chosen definition of a failed joint is one that allows moisture or debris past the sealant for at least 50 percent of the joint length. No joints in the project come close to this amount of failure, and an estimated 95 percent of the joints are in good to excellent condition. The major exceptions are the hot-applied sealants installed at the South Carolina site using configuration 3. These joints average between 11.6 and 41.9 percent full-depth failure.

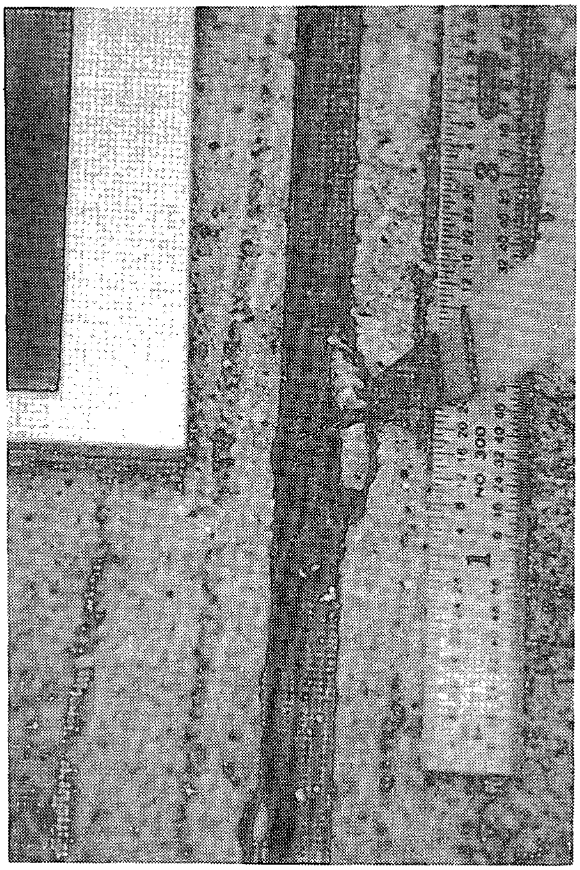

Figure 24. Full-depth spall failure

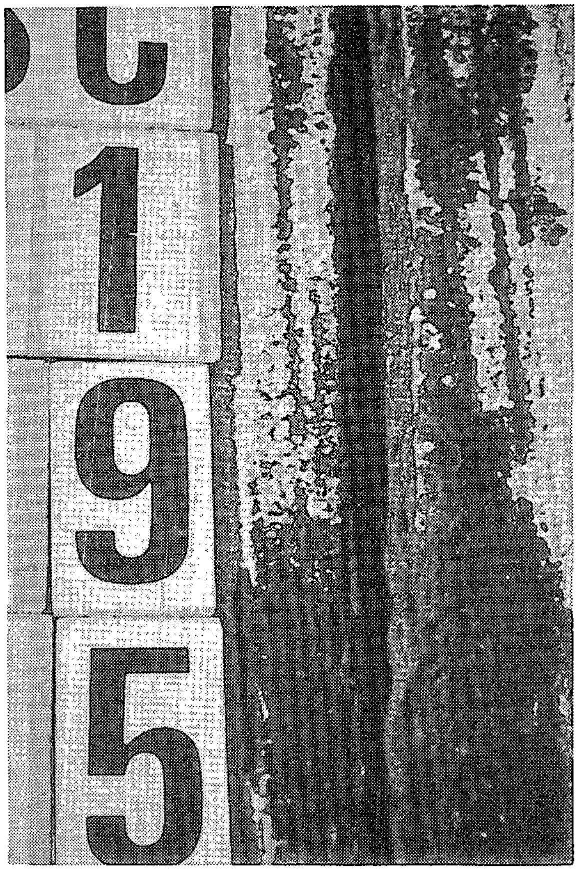

Figure 25. Overband wear

In addition to full-depth failure, some sealant system distresses have been noted during inspection, such as partial-depth adhesion loss, overband wear, stone intrusion, and partial-depth spalling. Low-intensity stone intrusion has been noted in the Koch 9005 at the Iowa and Arizona test sites. At this time, there is not sufficient stone intrusion to affect sealant performance or to contribute to spalling.

Table 13. Overall distress at Colorado I-25 site after 18 months

				Adhesion Distress									Spall Distress							
Material	Rep	Cnfg	Test Sectn	Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	A-Loss Rating (in)	Total Partl (in)	Total Partl (%)	Total Full (in)	Total Full (%)	Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	Total Prtl (in)	Total Prtl (%)	Total Full (in)	Total Full (%)
C-231	1	1	8	12	1	2	4	12.5	13	0.5	6	0.4	38	18	12	1	56	3.9	13	0.9
C-231	2	1	8	34	117	0	14	89.5	151	5.2	14	1.0	39	23	16	0	62	4.3	16	1.1
C-231	1	2	4	90	4	1	0	48	94	3.3	1	0.1	11	1	36	0	12	0.8	36	2.5
C-231	2	2	4	14	4	0	1	10	18	0.6	1	0.1	16	3	14	3	19	1.3	17	1.2
C-231	1	4	3	201	5	3	0	106	206	7.2	3	0.2	56	17	15	5	73	5.1	20	1.4
C-231	2	4	3	2	0	0	0	1	2	0.1	0	0.0	9	1	7	0	10	0.7	7	0.5
K-9005	1	1	1	833	874	20	45	918.5	1707	59.3	65	4.5	49	8	9	4	57	4.0	13	0.9
K-9005	2	1	1	297	1237	0	0	767	1534	53.3	0	0.0	23	2	1	2	25	1.7	3	0.2
K-9005	1	2	11	0	98	0	0	49	98	3.4	0	0.0	27	12	3	0	39	2.7	3	0.2
K-9005	2	2	11	0	47	0	0	23.5	47	1.6	0	0.0	17	2	1	4	19	1.3	5	0.3
K-9005	1	4	7	108	272	0	4	194	380	13.2	4	0.3	17	13	4	0	30	2.1	4	0.3
K-9005	2	4	7	36	136	0	0	86	172	6.0	0	0.0	31	22	3	0	53	3.7	3	0.2
K-9030	1	1	5	307	1113	27	110	847	1420	49.3	137	9.5	27	11	30	11	38	2.6	41	2.8
K-9030	2	1	5	658	694	47	53	776	1352	46.9	100	6.9	19	23	10	4	42	2.9	14	1.0
K-9030	1	2	9	562	75	37	9	364.5	637	22.1	46	3.2	31	11	21	12	42	2.9	33	2.3
K-9030	2	2	9	388	400	73	36	503	788	27.4	109	7.6	15	16	16	6	31	2.2	22	1.5
K-9030	1	4	13	485	176	35	32	397.5	661	23.0	67	4.7	42	21	17	8	63	4.4	25	1.7
K-9030	2	4	13	137	103	17	22	159	240	8.3	39	2.7	27	21	33	14	48	3.3	47	3.3
M-SS	1	1	6	203	1057	0	28	658	1260	43.8	28	1.9	45	22	19	6	67	4.7	25	1.7
M-SS	2	1	6	441	933	9	41	737	1374	47.7	50	3.5	22	13	6	2	35	2.4	8	0.6
M-SS	1	2	2	498	209	15	17	385.5	707	24.5	32	2.2	57	46	25	16	103	7.2	41	2.8
M-SS	2	2	2	94	54	2	4	80	148	5.1	6	0.4	9	4	26	2	13	0.9	28	1.9
M-SS	1	4	14	13	15	8	9	31	28	1.0	17	1.2	59	37	14	8	96	6.7	22	1.5
M-SS	2	4	14	2	24	2	5	20	26	0.9	7	0.5	51	36	31	12	87	6.0	43	3.0
D-888	1	1	10	4	4	0	0	4	8	0.3	0	0.0	97	63	11	2	160	11.1	13	0.9
D-888	2	1	10	0	0	0	0	0	0	0.0	0	0.0	33	40	18	7	73	5.1	25	1.7
D-888-SL	1	1	15	0	0	0	0	0	0	0.0	0	0.0	55	31	12	2	86	6.0	14	1.0
D-888-SL	2	1	15	1	0	0	0	0.5	1	0.0	0	0.0	35	39	8	7	74	5.1	15	1.0
M-960-SL	1	1	12	8	9	0	2	10.5	17	0.6	2	0.1	52	42	5	0	94	6.5	5	0.3
M-960-SL	2	1	12	0	0	0	0	0	0	0.0	0	0.0	39	33	46	12	73	5.1	58	4.0
K-9050	1	1	16	1	45	88	455	566	46	1.6	543	37.7	43	15	5	0	58	4.0	5	0.3
K-9050	2	1	16	1	19	22	290	322	20	0.7	312	21.7	33	25	11	7	58	4.0	18	1.3

Table 13. Overall distress at Colorado I-25 site after 18 months (cont.)

				Overband Wear								Stone Intrusion			Sunken Sealant					
Material	Rep	Cnfg	Test Sectn	Thick <50% (in)	Thick <50% (%)	Thick <10% (in)	Thick <10% (%)	Edge Left (in)	Edge Left (%)	Edge Right (in)	Edge Right (%)	Single Stones (#)	Filled w/ stns (in)	Filled w/ stns (%)	Low (in)	Low (%)	Med (in)	Med (%)	High (in)	High (%)
C-231	1	1	8	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	1	0.1	2	0.1
C-231	2	1	8	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
C-231	1	2	4	528	36.7	468	32.5	284	19.7	18	1.3	4	0	0.0	6	0.4	2	0.1	0	0.0
C-231	2	2	4	552	38.3	540	37.5	447	31.0	270	18.8	3	0	0.0	6	0.4	0	0.0	1	0.1
C-231	1	4	3	0	0.0	0	0.0	0	0.0	0	0.0	20	0	0.0	0	0.0	0	0.0	6	0.4
C-231	2	4	3	552	38.3	420	29.2	290	20.1	216	15.0	26	0	0.0	0	0.0	0	0.0	0	0.0
K-9005	1	1	1	0	0.0	0	0.0	0	0.0	0	0.0	3	575	39.9	0	0.0	0	0.0	5	0.3
K-9005	2	1	1	0	0.0	0	0.0	0	0.0	0	0.0	25	1029	71.5	0	0.0	0	0.0	9	0.6
K-9005	1	2	11	108	7.5	1332	92.5	1326	92.1	1242	86.3	666	4	0.3	1252	86.9	8	0.6	0	0.0
K-9005	2	2	11	36	2.5	1404	97.5	1316	91.4	1304	90.6	846	7	0.5	1299	90.2	32	2.2	8	0.6
K-9005	1	4	7	0	0.0	0	0.0	0	0.0	0	0.0	528	84	5.8	0	0.0	0	0.0	0	0.0
K-9005	2	4	7	0	0.0	8	0.6	0	0.0	0	0.0	1044	3	0.2	30	2.1	19	1.3	23	1.6
K-9030	1	1	5	0	0.0	0	0.0	0	0.0	0	0.0	0	169	11.7	0	0.0	0	0.0	0	0.0
K-9030	2	1	5	0	0.0	0	0.0	0	0.0	0	0.0	0	178	12.4	0	0.0	0	0.0	0	0.0
K-9030	1	2	9	120	8.3	1272	88.3	830	57.6	341	23.7	1	0	0.0	6	0.4	0	0.0	0	0.0
K-9030	2	2	9	132	9.2	1308	90.8	1132	78.6	1034	71.8	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9030	1	4	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	6	0.4	5	0.3	2	0.1
K-9030	2	4	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	2	0.1	3	0.2
M-SS	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	490	34.0	0	0.0	0	0.0	0	0.0
M-SS	2	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	170	11.8	0	0.0	2	0.1	3	0.2
M-SS	1	2	2	0	0.0	1404	97.5	1132	78.6	962	66.8	0	0	0.0	1426	99.0	12	0.8	2	0.1
M-SS	2	2	2	84	5.8	1344	93.3	847	58.8	739	51.3	4	3	0.2	79	5.5	220	15.3	1006	69.9
M-SS	1	4	14	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	114	7.9	198	13.8	81	5.6
M-SS	2	4	14	0	0.0	0	0.0	0	0.0	0	0.0	0	10	0.7	708	49.2	225	15.6	97	6.7
D-888	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	0	0.0	0	0.0	0	0.0
D-888	2	1	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	2	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
M-960-SL	1	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	24	1.7	1	0.1	0	0.0
M-960-SL	2	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9050	1	1	16	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9050	2	1	16	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	0	0.0	2	0.1	0	0.0

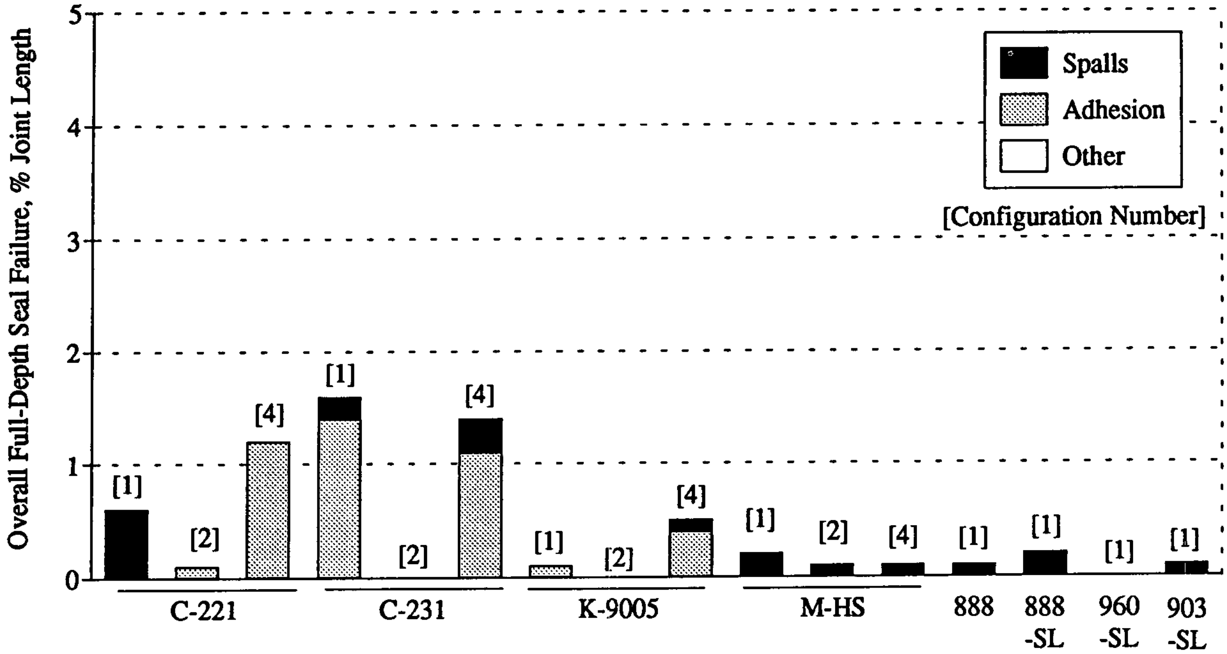

Figure 26. Overall failure at Arizona I-17 site after 18 months

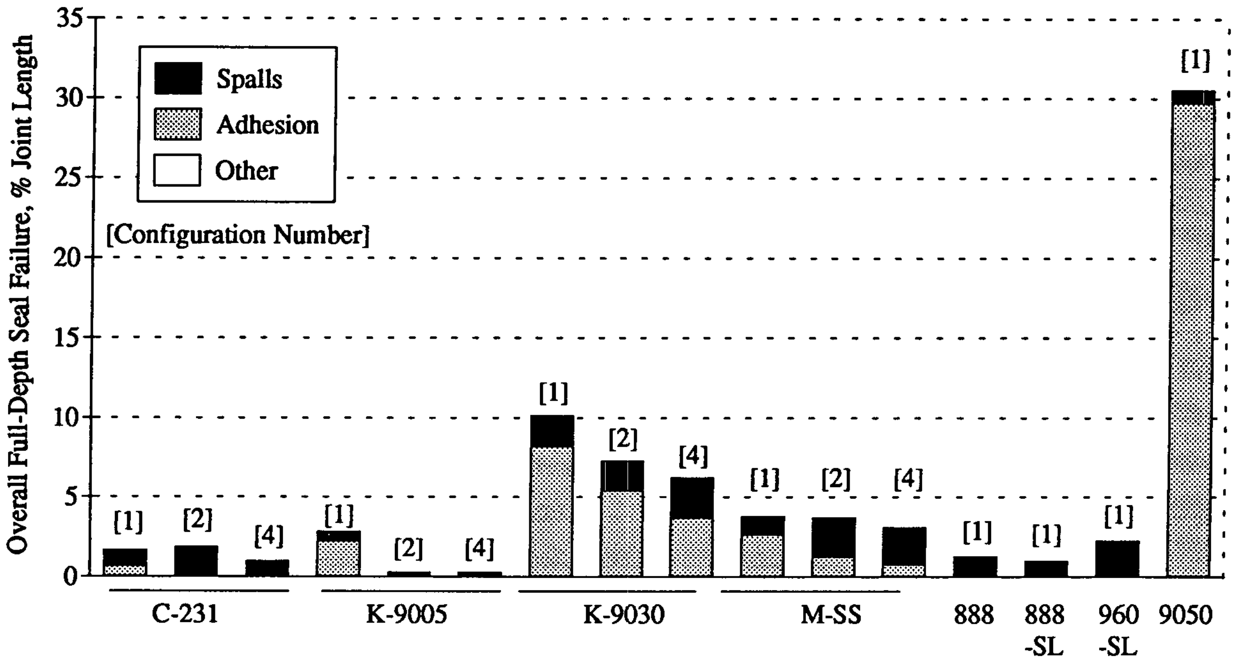

Figure 27. Overall failure at Colorado I-25 site after 18 months

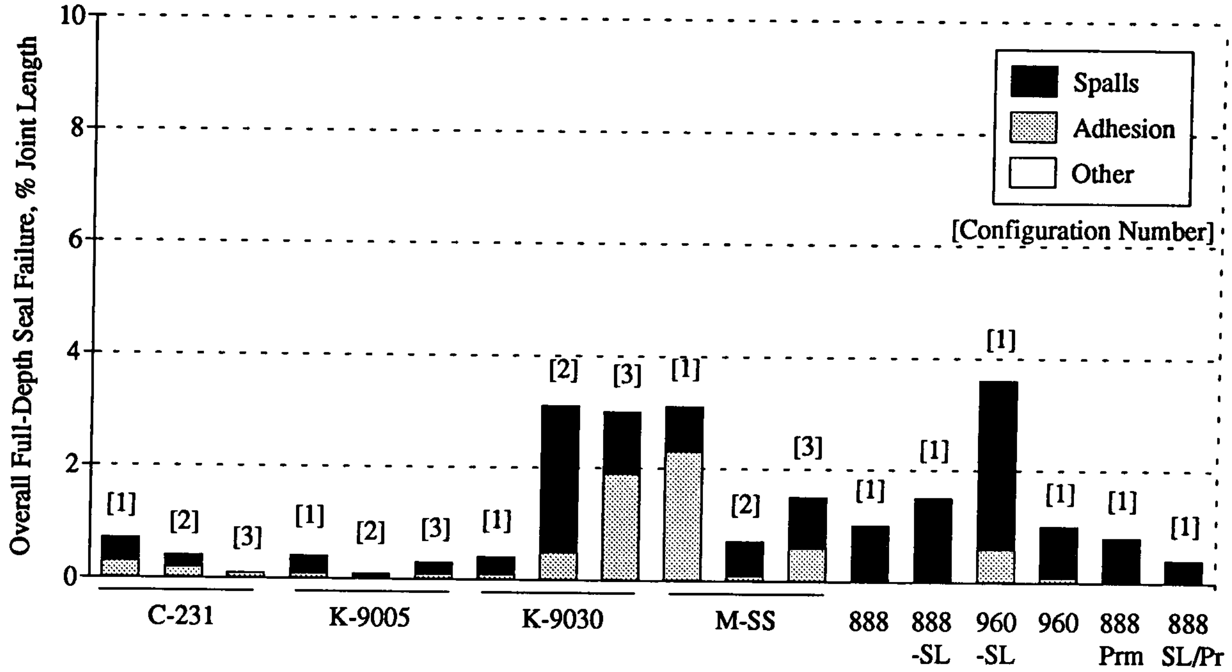

Figure 28. Overall failure at Iowa I-80 site after 18 months

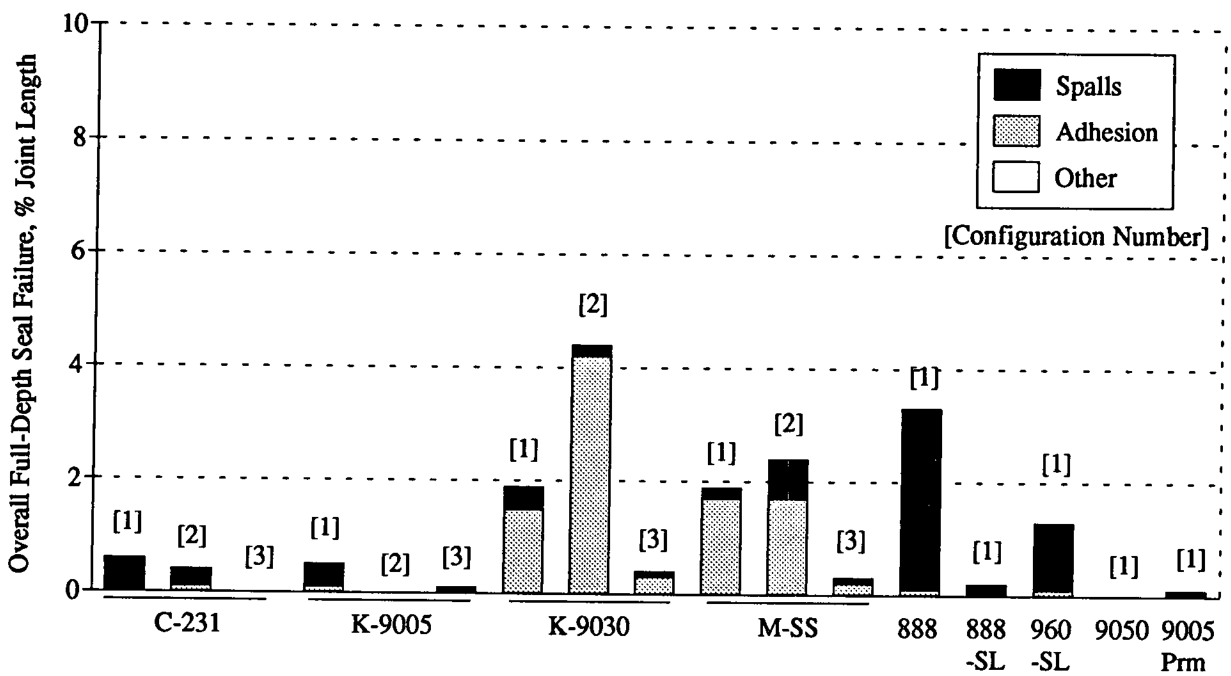

Figure 29. Overall failure at Kentucky US 127 site after 18 months

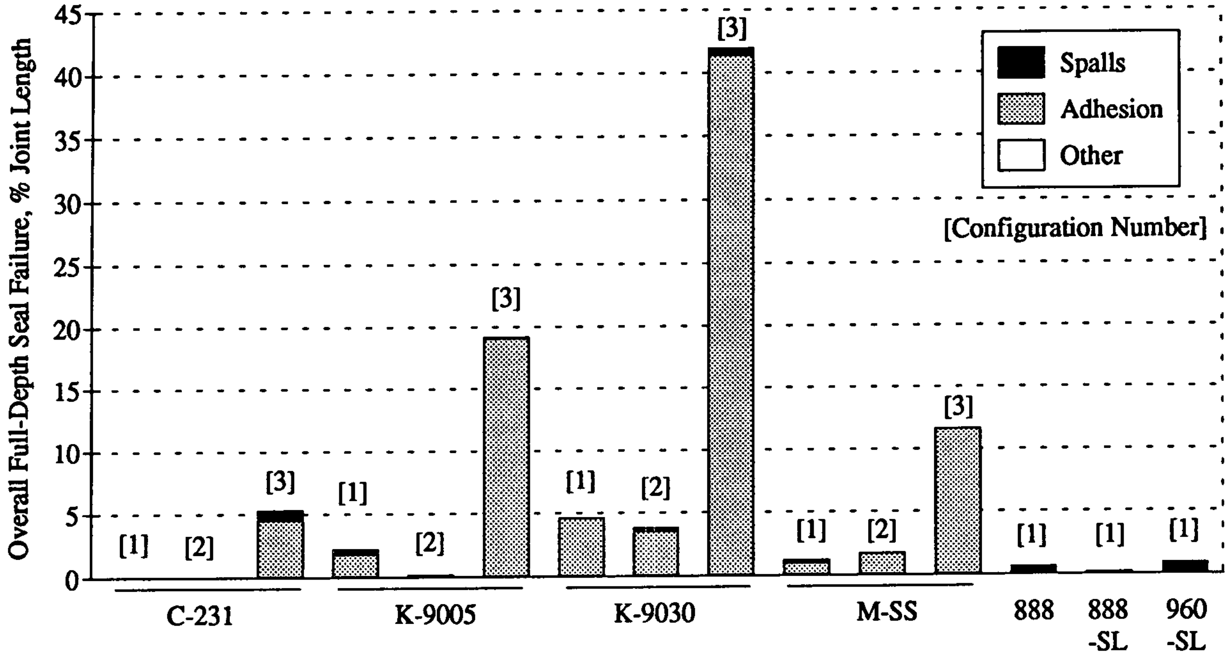

Figure 30. Overall failure at South Carolina I-77 site after 18 months

Table 14. Summary of full-depth failure for all sites

Sealant Material	Config.	Total Joints Installed	Percent of full-depth failure after 18 months				
			Arizona	South Carolina	Colorado	Iowa	Kentucky
Koch 9005	1	100	0.1	2.2	2.9	0.5	0.5
	2	100	0.0	0.2	0.3	0.1	0.0
	3	60		19.2		0.3	0.1
	4	40	0.5		0.3		
Crafco RoadSaver 231	1	100	1.6	0.0	1.7	0.7	0.6
	2	100	0.0	0.0	1.9	0.4	0.4
	3	60		5.3		0.1	0.0
	4	40	1.4		1.0		
Meadows Sof-Seal	1	80		1.2	3.8	3.1	1.9
	2	80		1.7	7.3	0.7	2.4
	3	60		11.6		1.5	0.3
	4	20			6.2		
Koch 9030	1	80		4.6	10.1	0.4	1.9
	2	80		3.8	7.3	3.2	4.4
	3	60		41.9		3.0	0.4
	4	20			6.2		
Meadows Hi-Spec	1	20	0.2				
	2	20	0.1				
	4	20	0.1				
Crafco RoadSaver 221	1	20	0.6				
	2	20	0				
	4	20	1.2				
Dow 888	1	100	0.1	0.6	1.3	1.0	3.3
Dow 888-SL	1	100	0.2	0.2	1.0	1.5	0.2
Mobay 960-SL	1	100	0.0	0.9	2.2	3.6	1.3
Mobay 960	1	20				1.0	
Crafco 903-SL	1	20	0.1				
Koch 9050	1	30			0.8		0.0
Dow 888 w/ Primer	1	10				0.8	
Dow 888-SL w/ Primer	1	10				0.4	
Koch 9005 w/ Primer	1	10					0.1

5

Analysis

A primary objective of this project is to determine which materials and procedures result in the longest-lasting joint seal performance. As rankings of material-configuration performance are determined, the cost-effectiveness of each material and procedure can be computed. A second aim of the project is determining which laboratory tests and properties relate well with field performance. Such knowledge would assist maintenance planners in specifying and using high-quality materials. Although very little full-depth failure has developed in the test sites after 18 months, some significant differences in performance are evident. The following sections present the methodology used in determining statistical differences in joint seal performance and outline the results of statistical analysis with regard to field performance and laboratory testing.

Statistical Methodology

Analysis of field and laboratory performance data was performed using SAS® statistical software. In preparation for analysis, the performance data was compiled in computer spreadsheets and converted to ASCII format for rapid and accurate reading by the SAS program. SAS "command" files were created to instruct the program in how to read the data, what types of statistical analysis to perform, and what form of output was desired.

The joint-resealing experiment was designed for a randomized block design analysis with two factors (i.e., treatments and position along the joint). The two blocks in the design were the two replicates. Individual treatments were the unique combinations of materials and configuration. To test whether there was a significant difference in the mean amounts of distress observed for each material/configuration combination, a multivariate analysis of variance (MANOVA) was performed using the SAS general linear model procedure. This procedure used the mean distress values and the variability associated with each distress (i.e., adhesion loss, spall distress) to determine whether there is a significant difference between the means of the each treatment. When it was determined that a significant difference existed between treatment means, a Tukey's Studentized Range (HSD) analysis of ordered means was completed at a confidence level of 95 percent ($\alpha=0.05$).

The Tukey analysis ordered the mean distress values for each treatment in descending order and indicated by a grouping letter which means were not statistically different. The following is an example of the means and groupings for each treatment at the Arizona test site as ranked by the amount of partial-depth adhesion loss:

Treatment	Material	Configuration	Mean	Groupings		
1	Crafco 221	1	40.5	A		
2	Hi-Spec	1	38.8	A		
3	Koch 9005	1	36.0	A		
4	Crafco 231	1	21.7		B	
5	Koch 9005	4	5.4			C
6	Hi-Spec	4	1.3			C
7	Crafco 221	4	1.1			C
8	Crafco 231	4	1.1			C
9	Crafco 231	2	0.1			C
10	Hi-Spec	2	0.02			C
11	Mobay 960-SL	1	0.03			C
12	Dow Corning 888-SL	1	0.02			C
13	Koch 9005	2	0.02			C
14	Crafco 221	2	0			C
15	Dow Corning 888	1	0			C
16	Crafco 903-SL	1	0			C

This example, shown graphically in figure 31, indicates that the amount of partial-depth adhesion loss is not significantly different for treatments 1, 2, and 3. There is also no significant difference in the adhesion loss of treatments 5 through 16. Statistically, the treatments in the A grouping are exhibiting more adhesion loss than the ones in the B and C groupings, and the treatment in the B grouping has developed more distress than those in the C grouping.

Analysis of the relation between laboratory test results and field performance was completed using the SAS CORR procedure. Comparisons were made, in this procedure, between the mean values of laboratory testing results and the mean amounts of field distress. For example, the relation between sealant stress at 150 percent elongation and the amount of full-depth adhesive failure was analyzed. The closeness of each relationship was measured by the Pearson correlation coefficient (r). Coefficients near zero indicate that no relationship exists between the test result and the field distress. Values of r near 1 or -1 indicate that a strong relation may exist. Positive values of r indicate a direct relationship between the variables, and negative r values indicate an indirect relationship.

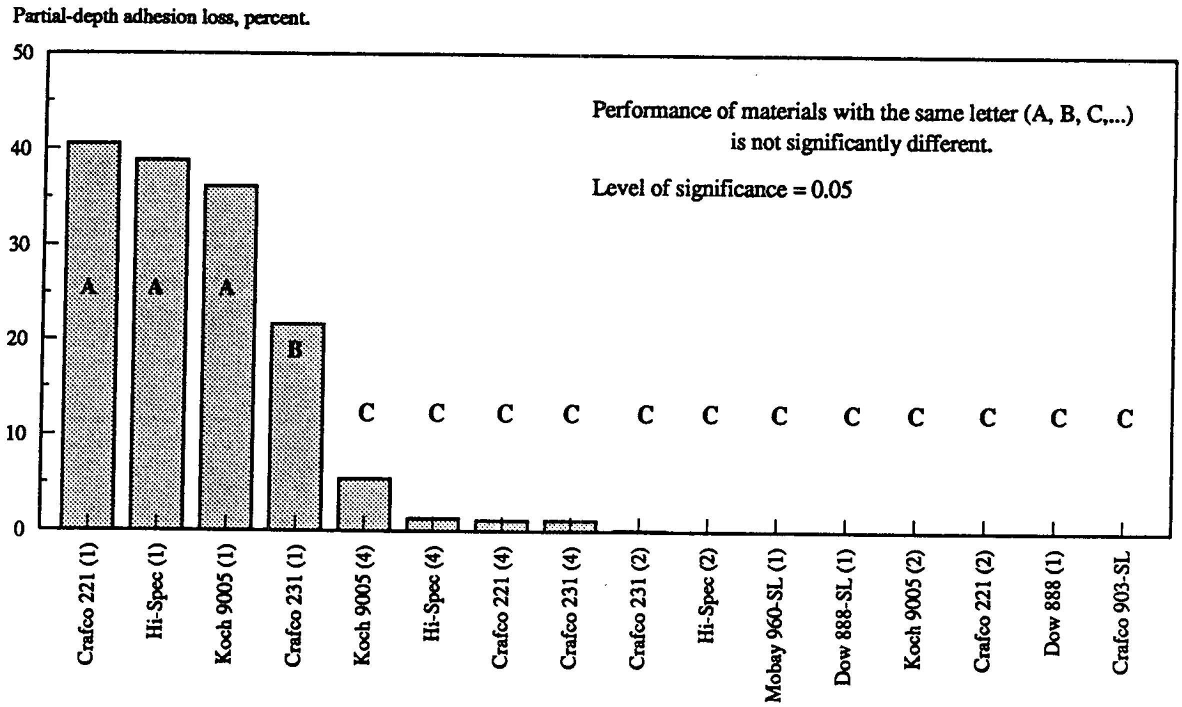

Figure 31. HSD rankings for partial-depth adhesion loss at the Arizona site

Field Performance

Analysis of field performance was made between materials, between preparation and installation method, between states, over time, and along the length of the joint. The materials will be referred to by their names or by a number or a letter as listed in table 15, and configuration or installation methods will be designated by the numbers or letters listed in table 16. Figure 2 illustrates the profile of each configuration.

Comparison of Materials and Preparation Methods

Comparison of material performance can be based on full-depth seal system failure or nonfailure distresses. The definition of full-depth seal system failure used in this report is a seal system that allows unrestricted infiltration of moisture and/or incompressible material below the joint seal. To date, the only distresses observed that meet this system failure criteria are full-depth adhesion and full-depth spall failures. Nonfailure distresses that have been observed at the test sites include overband wear, tracking, partial-depth adhesion loss, and partial-depth spall distress.

Table 15. Sealant names and material codes

Material Code	Manufacturer	Sealant Name	Sealant Type	Abbreviation
1	Crafco	RoadSaver 221	Rubberized asphalt	C-221
2	Crafco	RoadSaver 231	Low mod. rubr. asp.	C-231
3	Koch	9005	Rubberized asphalt	K-9005
4	Koch	9030	Low-mod. rubr. asp.	K-9030
5	Meadows	Hi-Spec	Rubberized asphalt	M-HS
6	Meadows	Sof-Seal	Low-mod. rubr. asp.	M-SS
7	Dow	888	Silicone	888
8	Dow	888-SL	Self-leveling silicone	888-SL
9	Mobay	960-SL	Self-leveling silicone	960-SL
A	Mobay	960	Silicone	960
B	Crafco	Road Saver 903-SL	Self-leveling silicone	RS-SL
C	Koch	9050	1-part polysulfide	K-9050
D [a]	Dow	888	Silicone	888-Prm
E [a]	Dow	888-SL	Self-leveling silicone	888-SL/Pr
F [a]	Koch	9005	Rubberized asphalt	K-9005 Prime

[a] Joint walls for these material codes were primed.

Table 16. Configurations (preparation methods) and their abbreviations

Configuration Number	Preparation Method	Abbreviation
1	Saw, sandblast, airblast, install recessed	S&R
2	Saw, sandblast, airblast, install overbanded	S&O
3	Plow, airblast, install overbanded	P&O
4	Saw, sandblast, install flush with surface	S&F

In the MANOVA analyses of full-depth spalls and adhesion failure, the results indicated that a significant difference in performance was evident between at least one material-configuration combination and the remaining combinations. This allowed HSD comparison of the univariate means to determine the ranking of performance between materials and configurations. Results of the HSD comparisons between materials for full-depth adhesion loss at each test site are shown in figures 32 through 36. HSD results of comparison between materials regarding full-depth spall failure are illustrated in figures 37 through 41. Summaries of the HSD analysis of partial-depth adhesion loss and spall distress are included in appendix D.

In comparing the performance of materials in each configuration, one item that stands out is that although some differences in the amount of failure is evident between materials, very little statistical difference can be found in both spall failure and adhesion failure. Exceptions to this, in spall development, are that Mobay 960-SL and Koch 9005 have developed fewer full-depth spalls than Crafco 221 in configuration 1 in Arizona; Koch 9005 is showing better spall performance than Sof-Seal in configurations 2 and 4 in Colorado; Mobay 960-SL is experiencing more full-depth spalling than the other materials in configuration 1 in Iowa; Koch 9030 is showing more spalling than the other materials in configuration 2 in Iowa; and all materials are exhibiting less spalling than Dow Corning 888 in configuration 1 in Kentucky.

Similar comparisons can be made for full-depth adhesion loss at the five sites. At the Arizona test site, Crafco 231 is experiencing more adhesion loss in configuration 1 than the other materials. Also in Arizona, Crafco 221 and Crafco 231 are performing better than Koch 9005 and Meadows Hi-Spec in configuration 4. Koch 9050 polysulfide and Koch 9030 are developing more adhesion loss in configuration 1 in Colorado than other sealants, and Crafco 231 and Koch 9005 are outperforming Koch 9030 in configuration 2. At the Iowa site, Meadows Sof-Seal is not performing as well in adhesion as the other sealants in configuration 1, and Koch 9030 is not performing as well as the others in configuration 3. The full-depth adhesion performance in configuration 3 at the South Carolina site is significantly different between materials, with performance decreasing from Crafco 231 to Meadows Sof-Seal to Koch 9005 to Koch 9030.

It should be noted that full-depth spall failure remains at less than 3.2 percent of the overall joint length for any material, and it remains at less than 2 percent of the joint length for 93 percent of all test sections. Full-depth adhesion failure is less than 1 percent for 71 percent of the material-configuration combinations. It is less than 2 percent for 83 percent of combinations, and less than 5 percent for 93 percent of combinations. The large amount of adhesion failure for Mobay 960-SL in Iowa resulted from partial-depth spalls that loosened the sealant and, over time, pulled the sealant away from the remaining joint wall. The large amount of full-depth spalling in Mobay 960-SL and Dow Corning 888 at the Kentucky site resulted mainly from deteriorated concrete in one joint of each material.

Figures 42 to 51 illustrate the same statistical comparison shown in figures 32 through 41; however, these the performance of each material in the different configurations are positioned together to simplify evaluation. These comparisons are also based on HSD testing at a significance level of 0.05. Very little significant difference in full-depth spalling has developed between configurations for the same material. In Arizona, Crafco 221 developed more spalling in configuration 1 than the other configurations, and at the Iowa site Koch 9030 developed more full-depth spalls when placed in configuration 2.

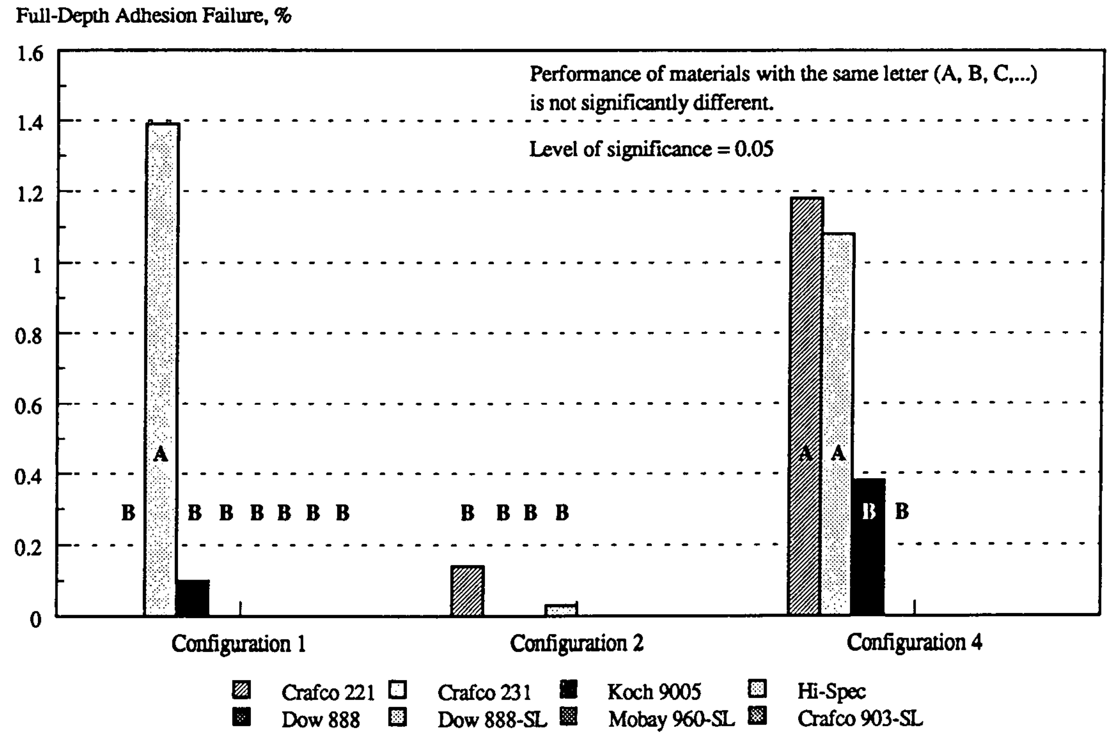

Figure 32. HSD ranking of full-depth adhesion failure at AZ site, by configuration

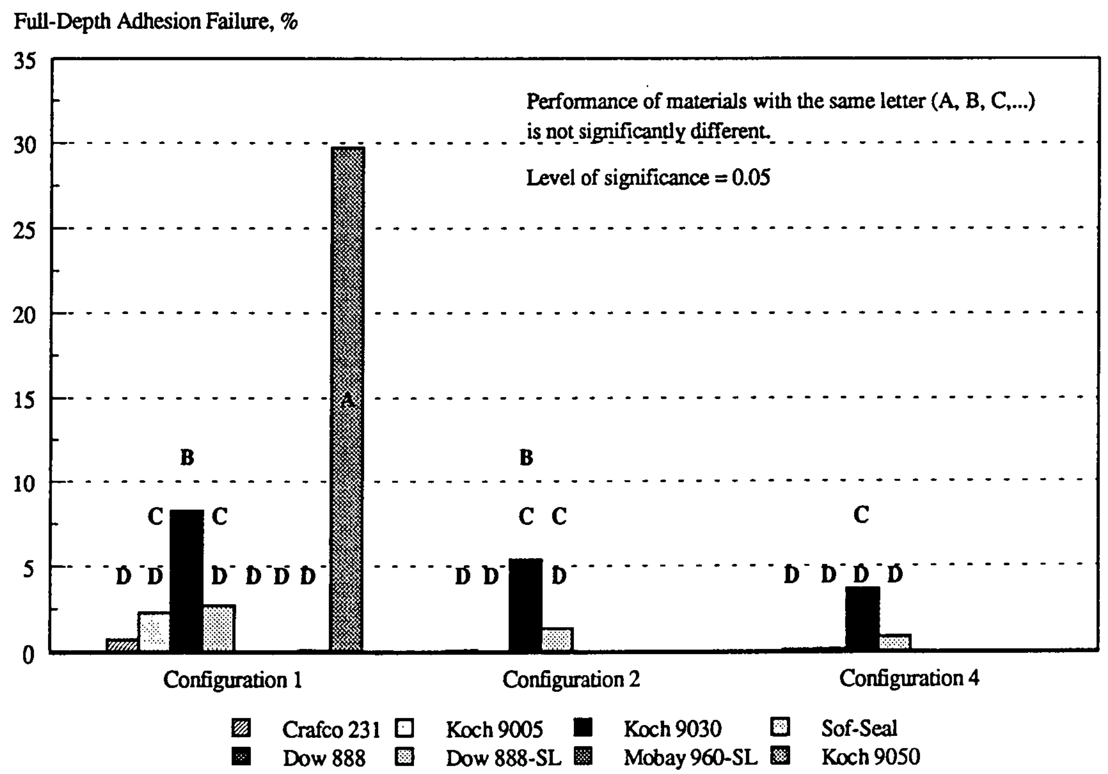

Figure 33. HSD ranking of full-depth adhesion failure at CO site, by configuration

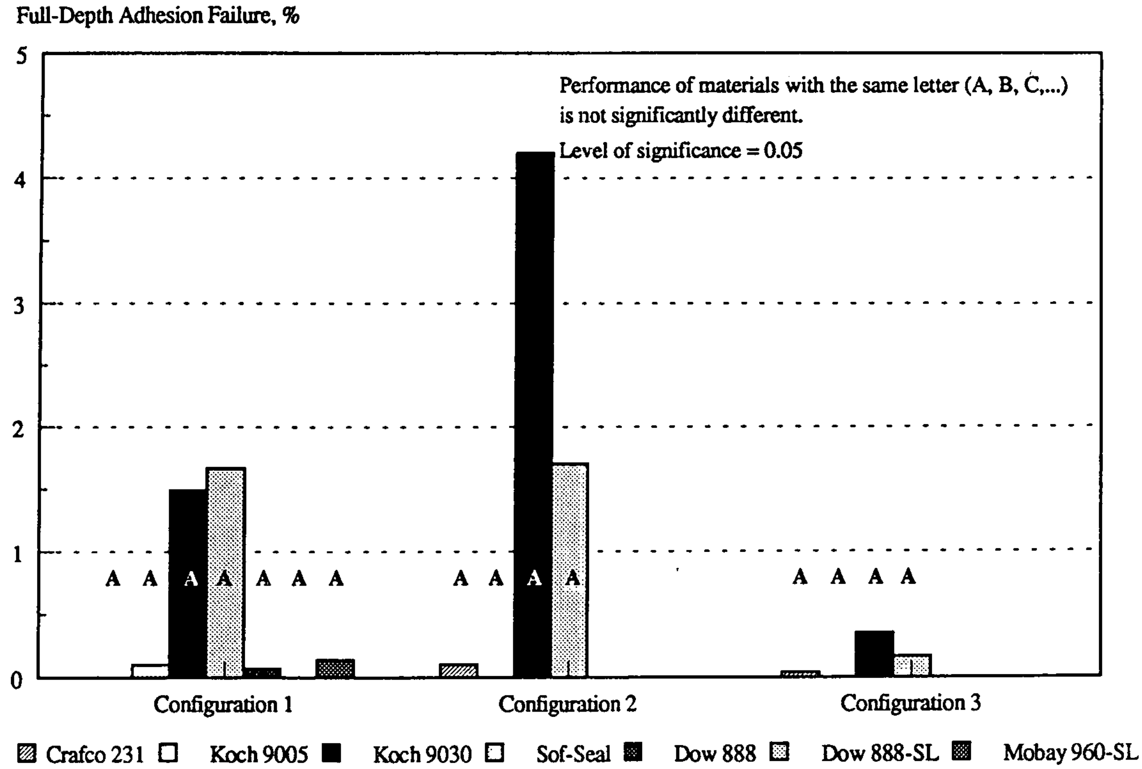

Figure 34. HSD ranking of full-depth adhesion failure at IA site, by configuration

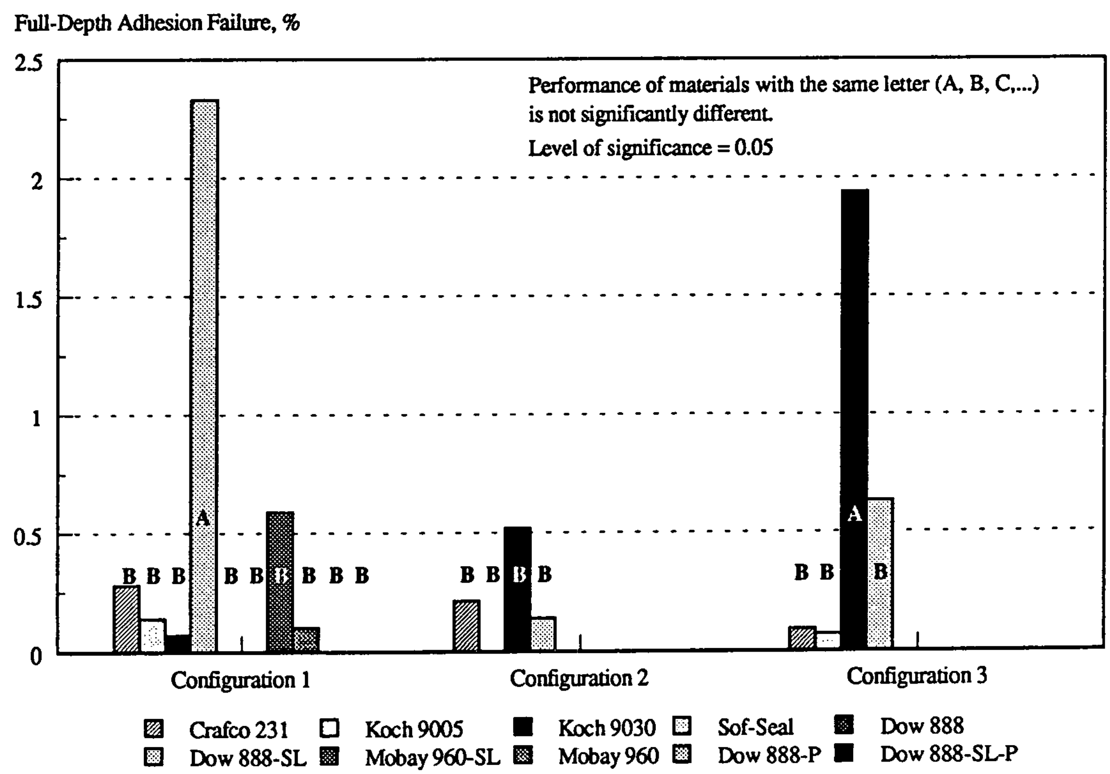

Figure 35. HSD ranking of full-depth adhesion failure at KY site, by configuration

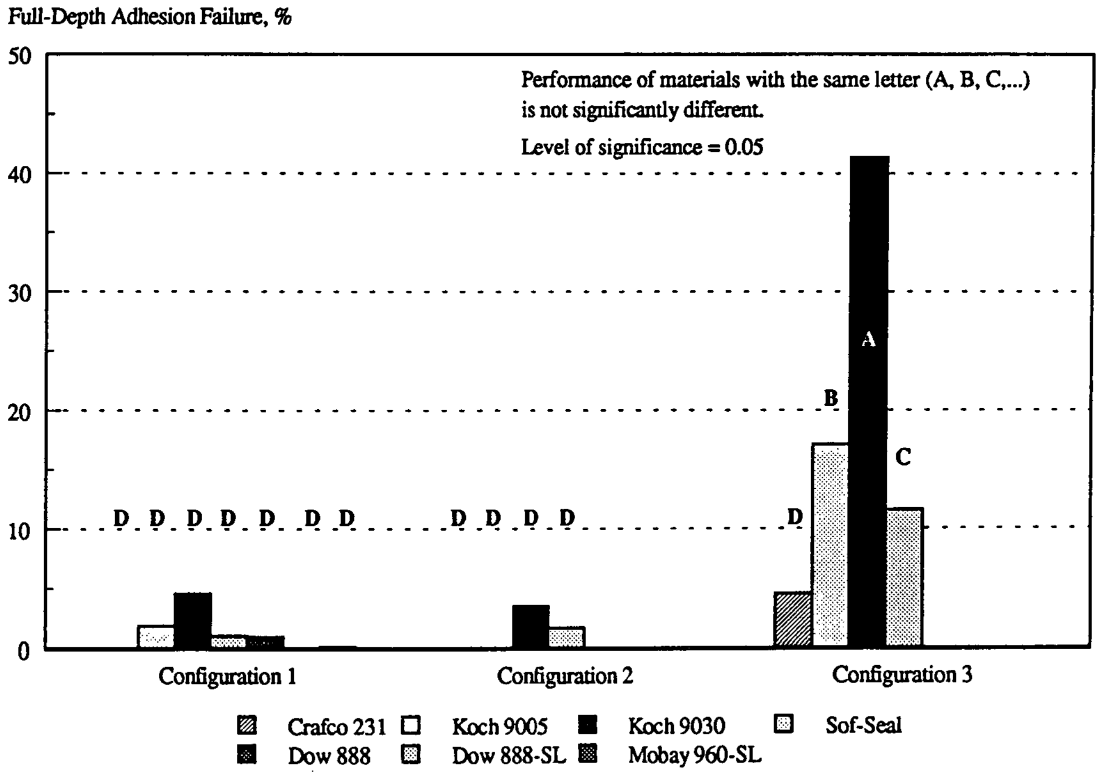

Figure 36. HSD ranking of full-depth adhesion failure at SC site, by configuration

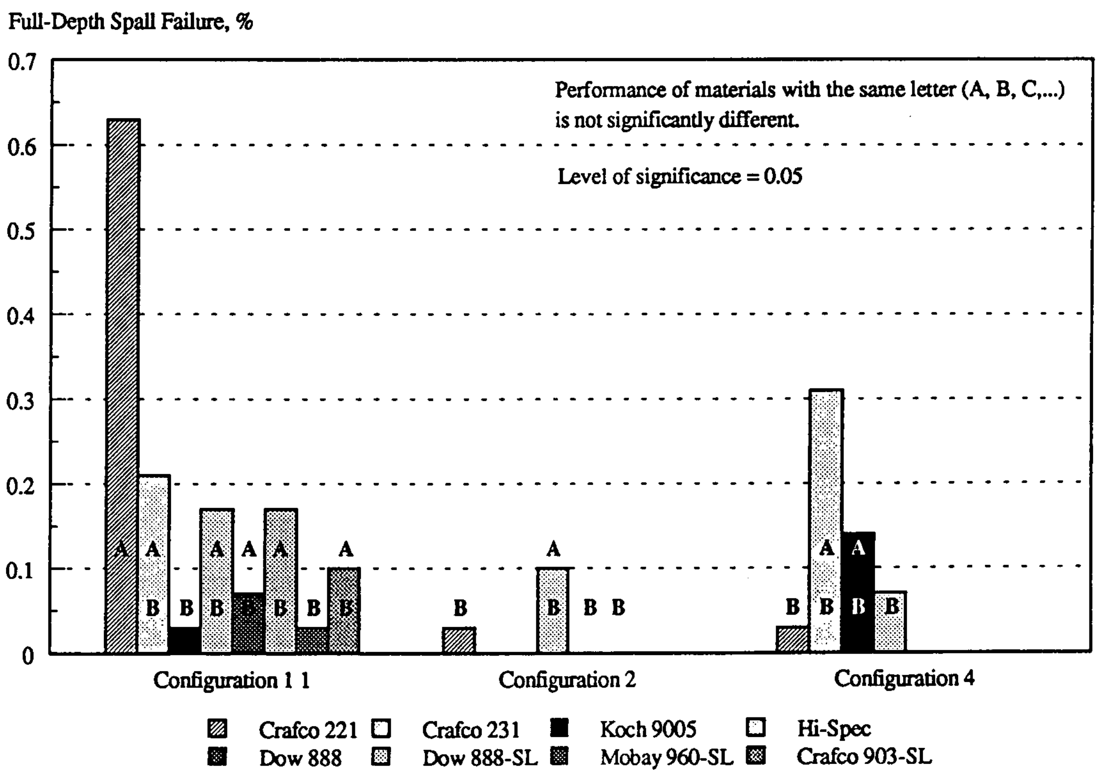

Figure 37. HSD ranking of full-depth spall failure at AZ site, by configuration

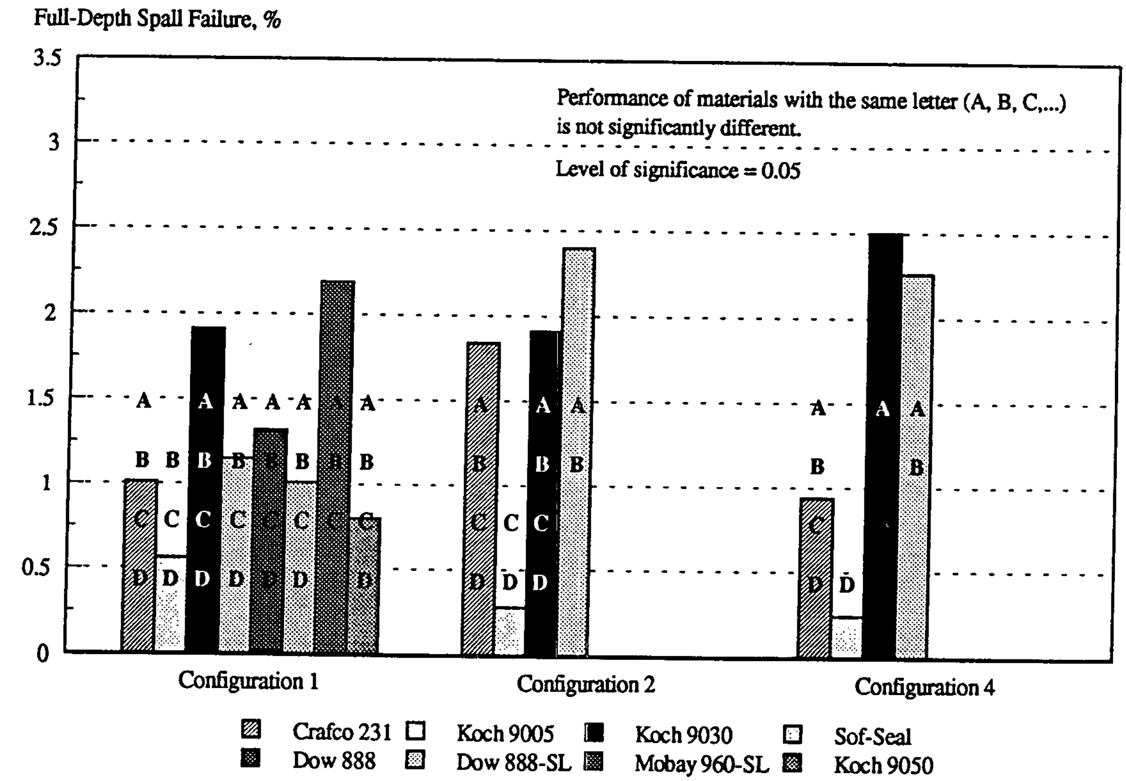

Figure 38. HSD ranking of full-depth spall failure at CO site, by configuration

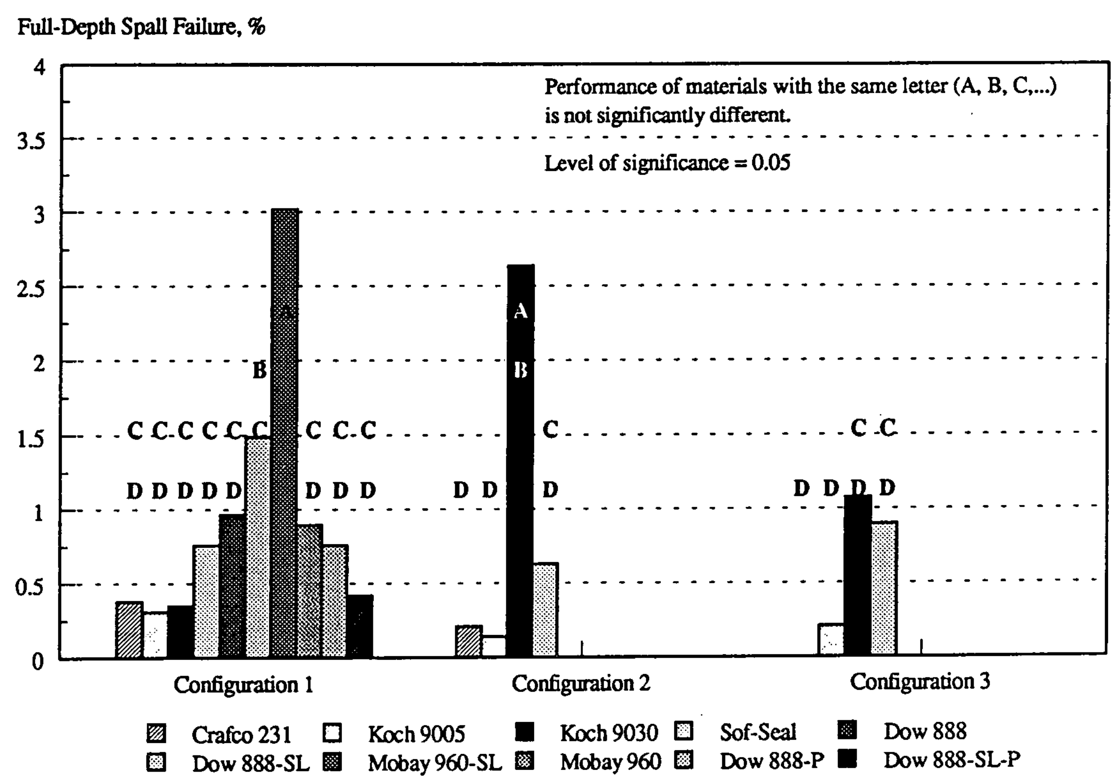

Figure 39. HSD ranking of full-depth spall failure at IA site, by configuration

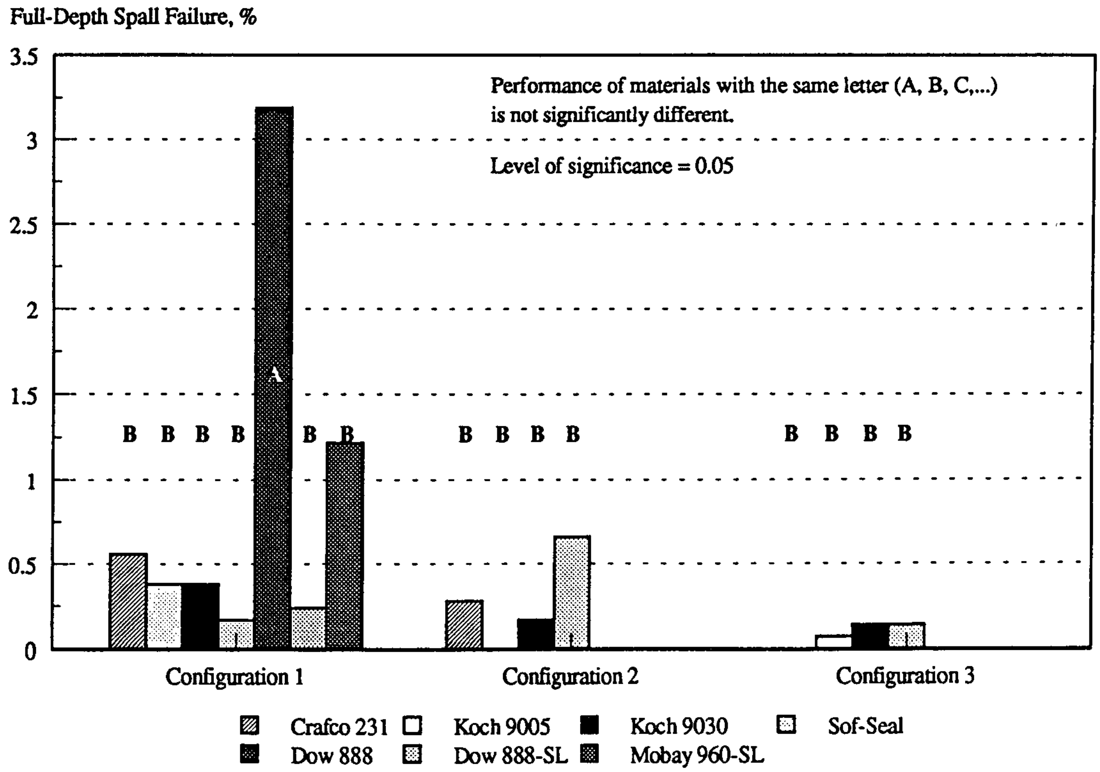

Figure 40. HSD ranking of full-depth spall failure at KY site, by configuration

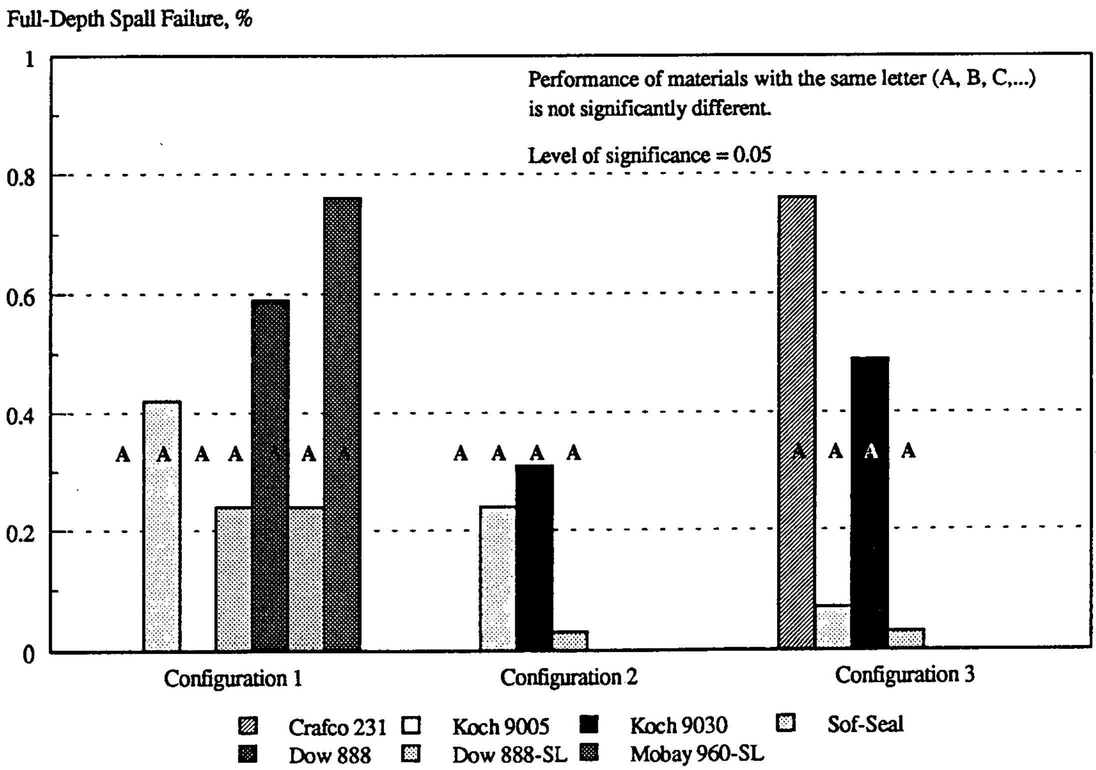

Figure 41. HSD ranking of full-depth spall failure at SC site, by configuration

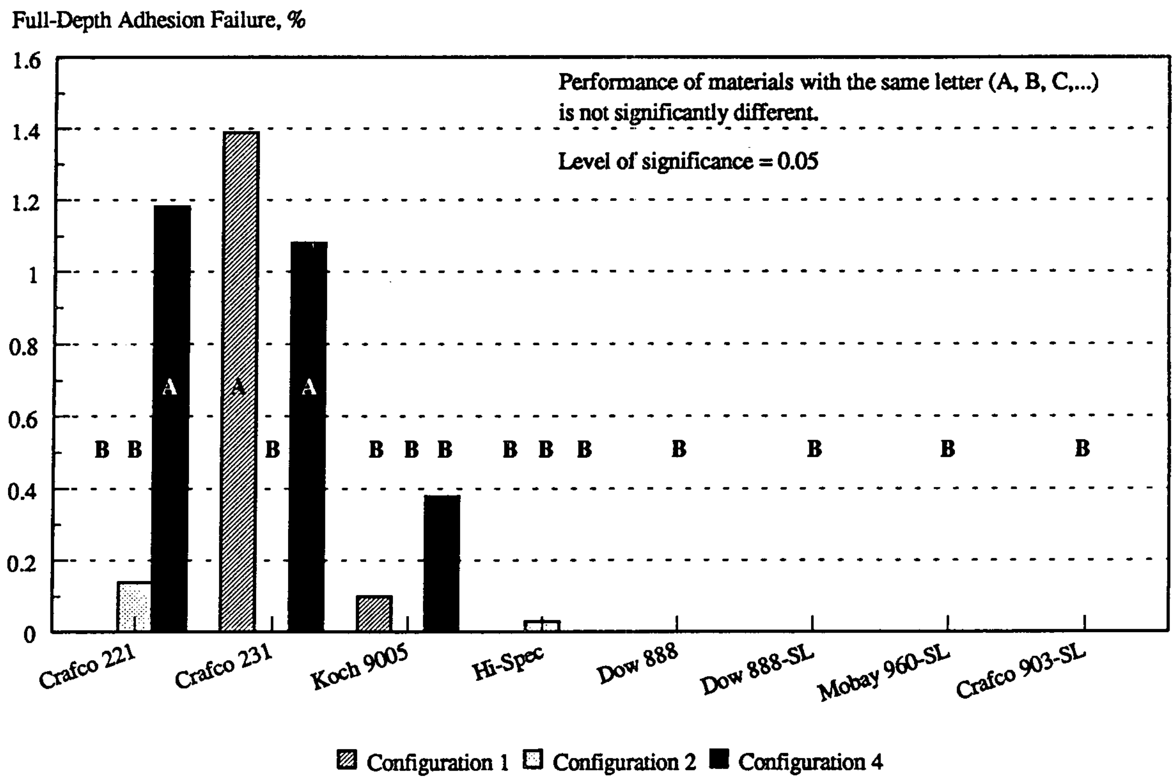

Figure 42. HSD ranking of full-depth adhesion failure at AZ site, by material

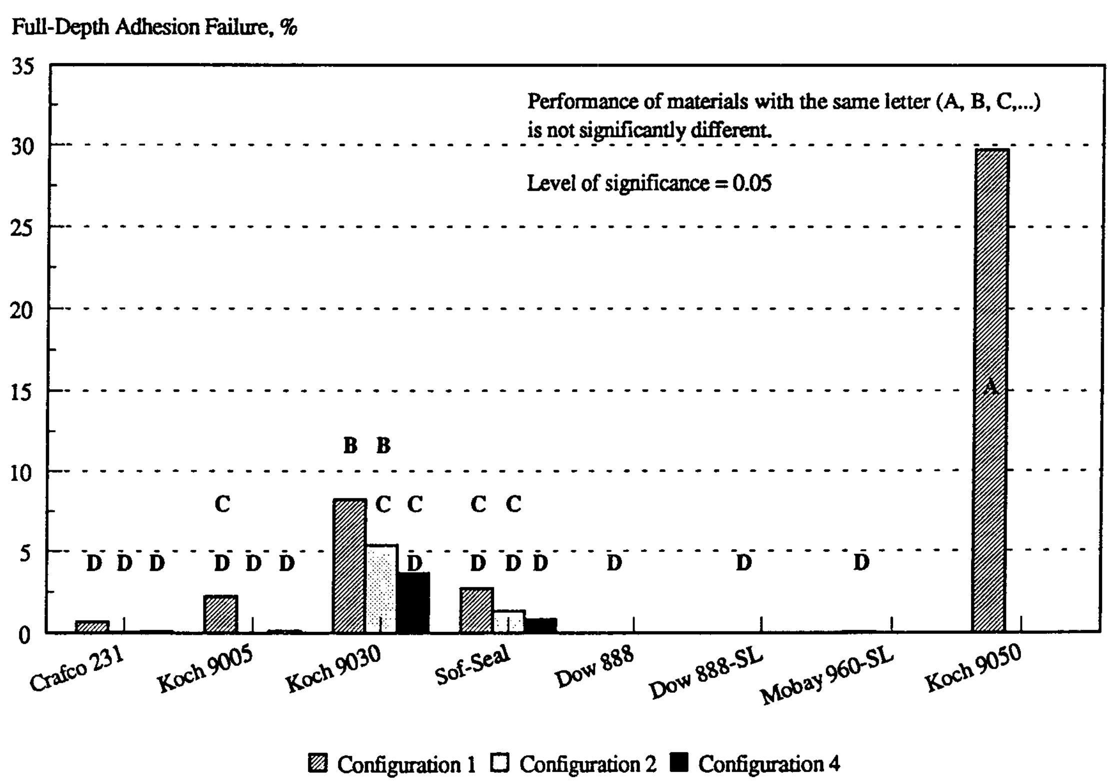

Figure 43. HSD ranking of full-depth adhesion failure at CO site, by material

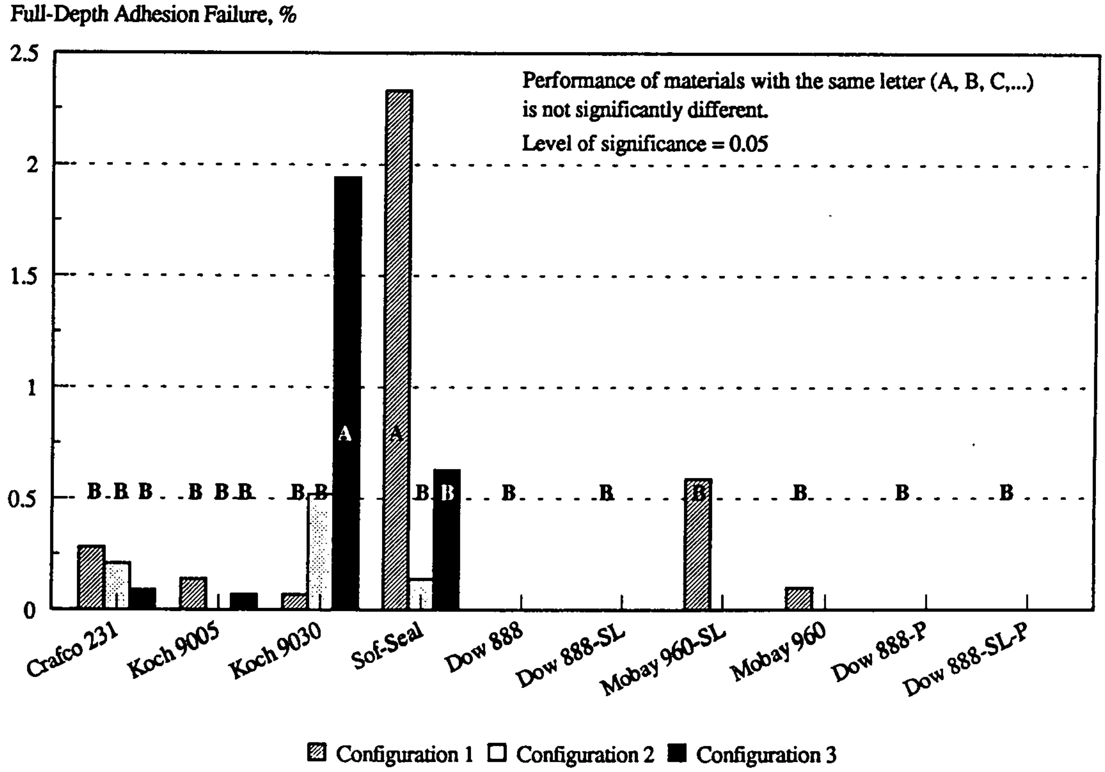

Figure 44. HSD ranking of full-depth adhesion failure at IA site, by material

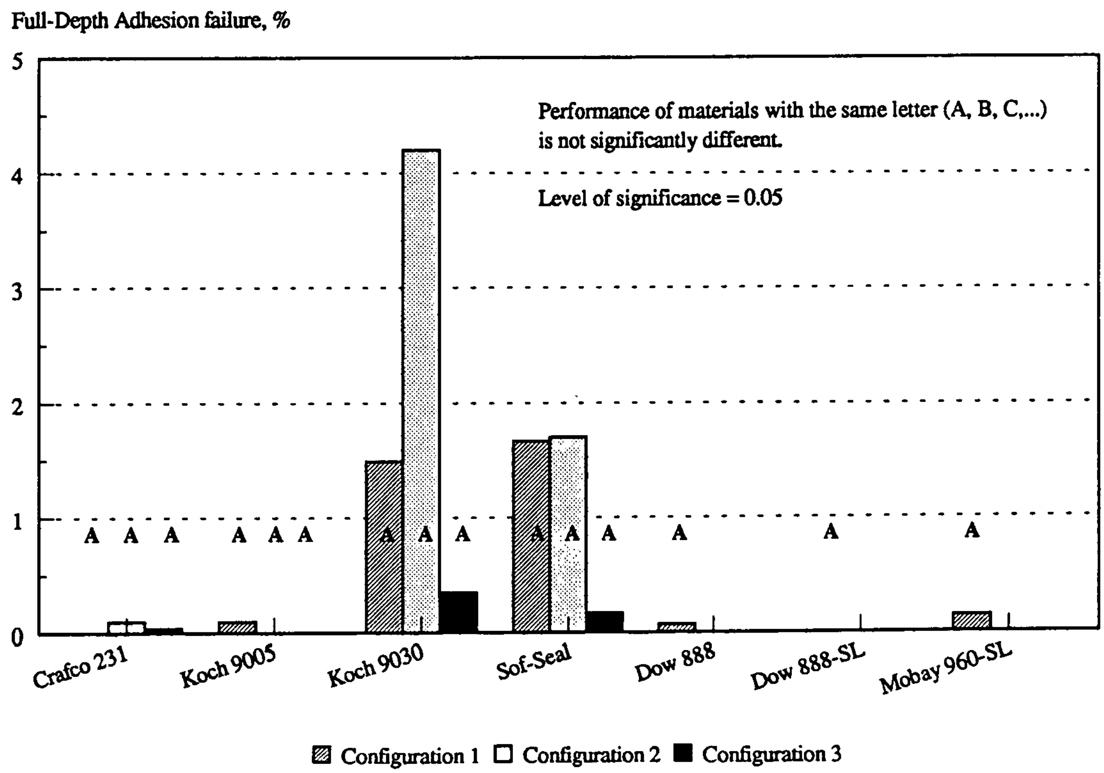

Figure 45. HSD ranking of full-depth adhesion failure at KY site, by material

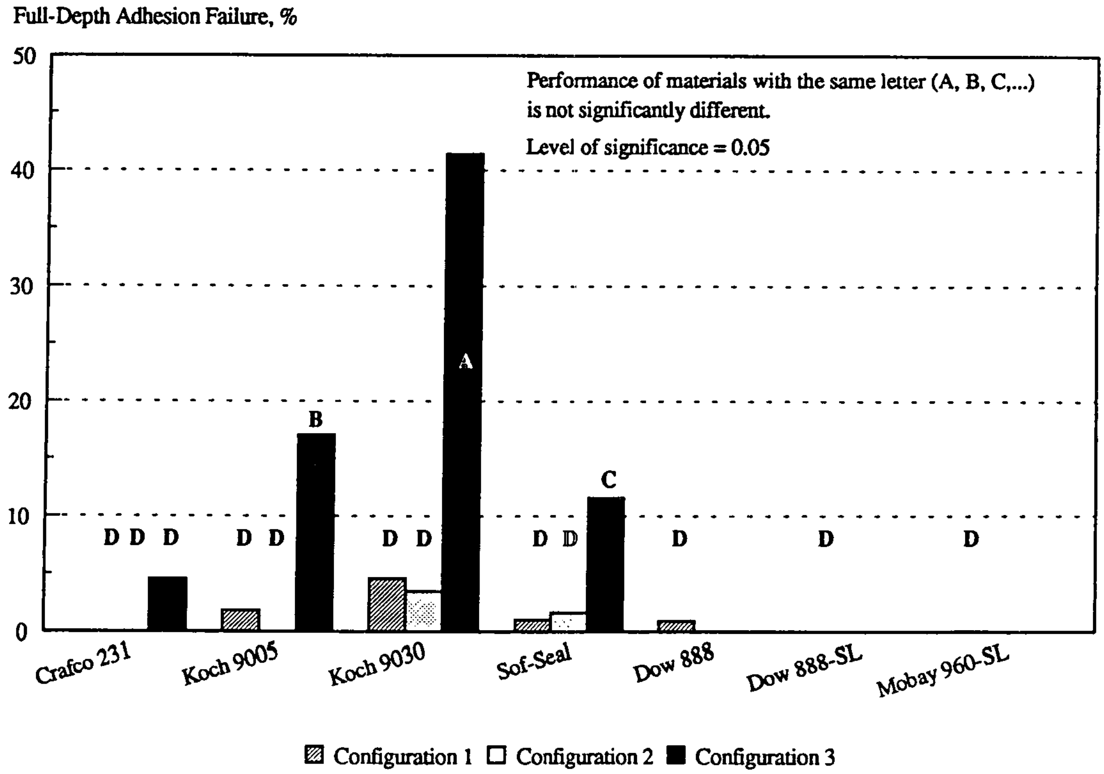

Figure 46. HSD ranking of full-depth adhesion failure at SC site, by material

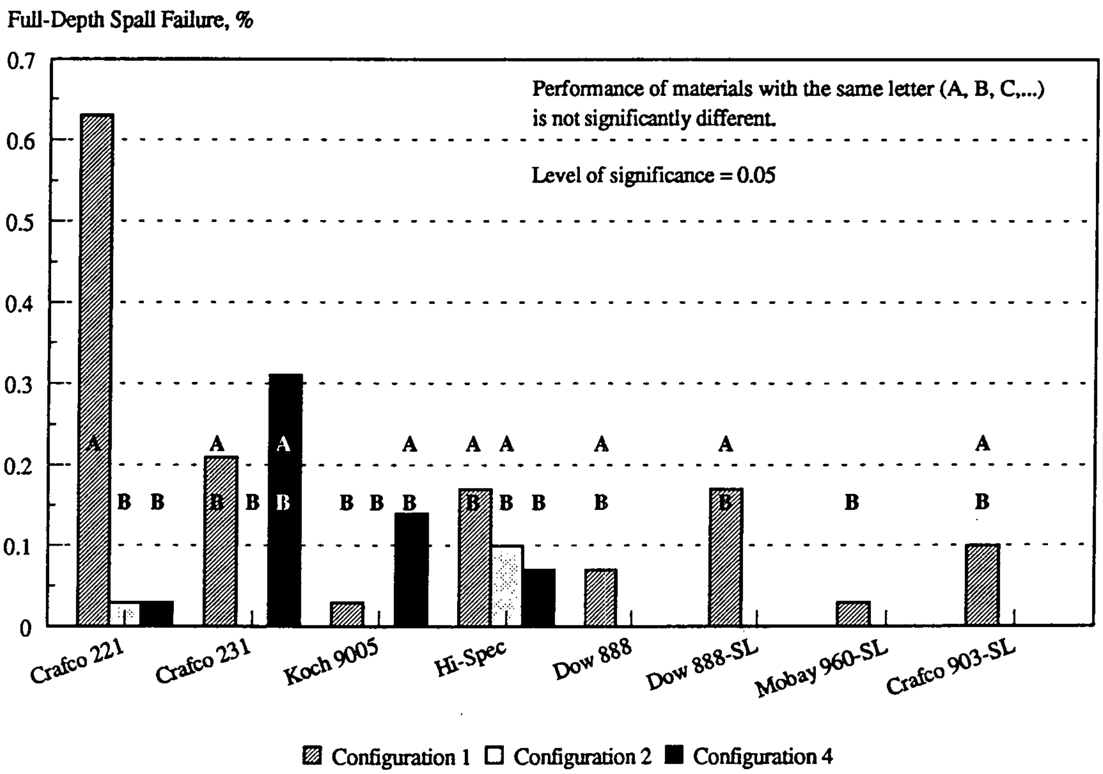

Figure 47. HSD ranking of full-depth spall failure at AZ site, by material

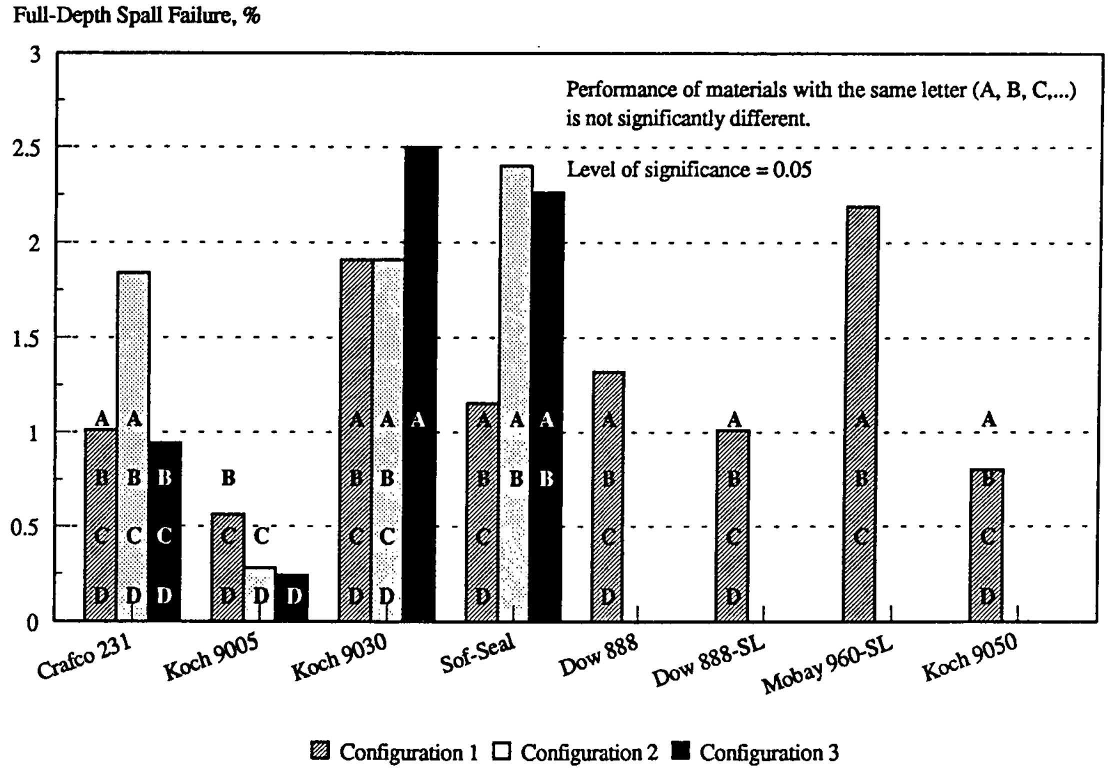

Figure 48. HSD ranking of full-depth spall failure at CO site, by material

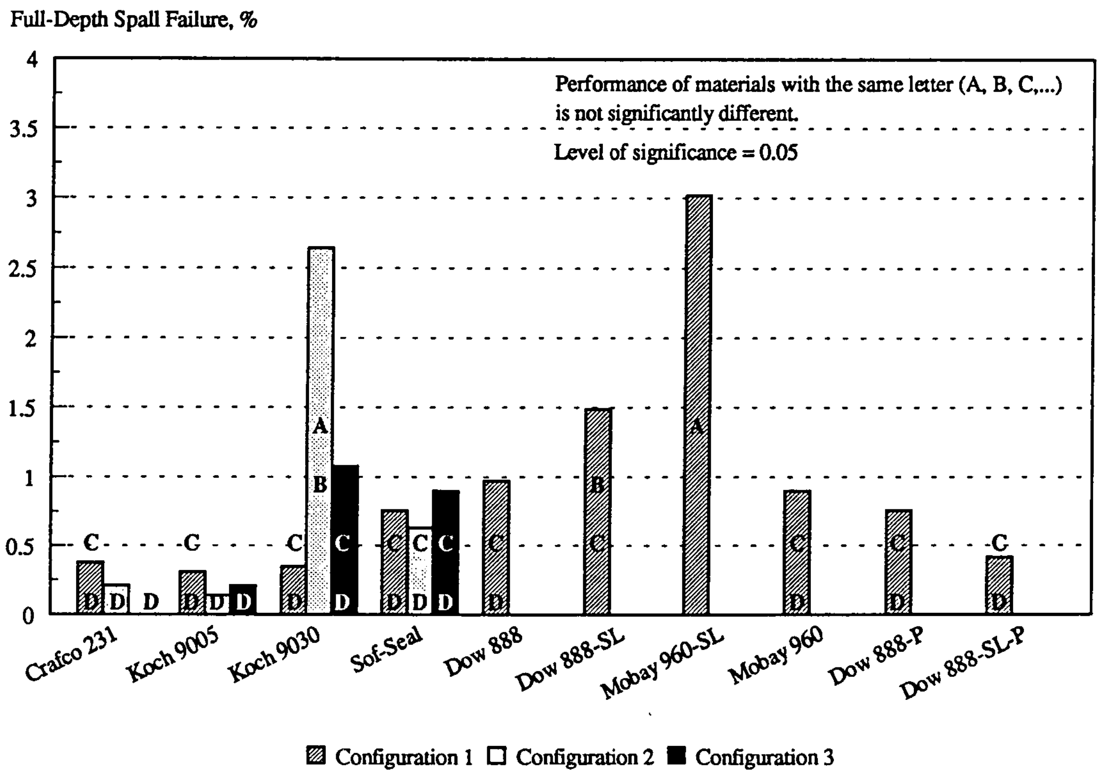

Figure 49. HSD ranking of full-depth spall failure at IA site, by material

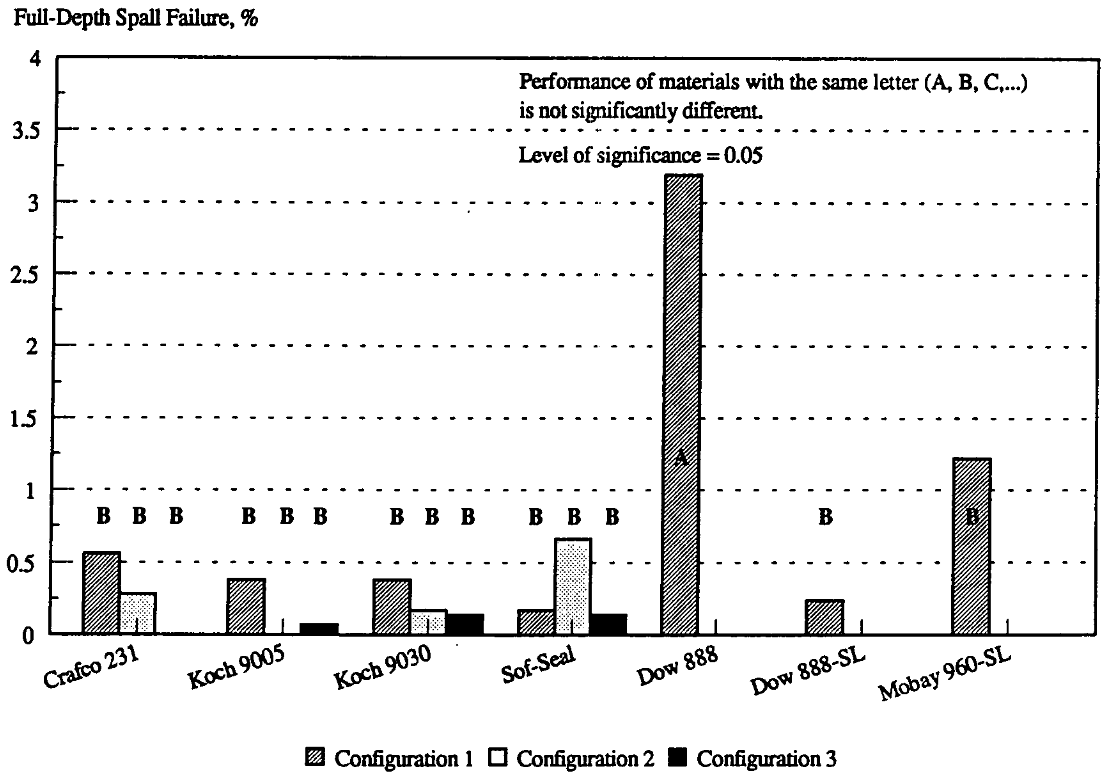

Figure 50. HSD ranking of full-depth spall failure at KY site, by material

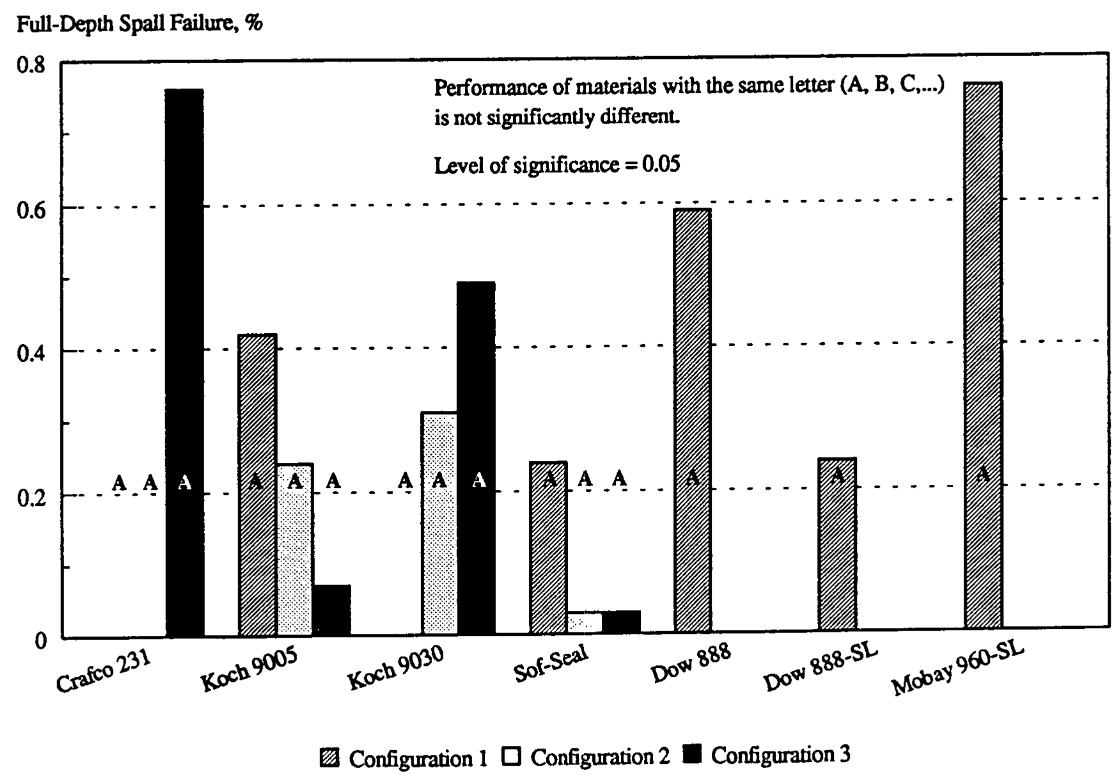

Figure 51. HSD ranking of full-depth spall failure at SC site, by material

Comparing performance in full-depth adhesion loss between configurations indicates that only a few significant differences have developed at most sites, with the exception of the South Carolina site. Crafco 221 in Arizona is performing better in configurations 1 and 2 than in configuration 4. Crafco 231 has developed less adhesion loss in configuration 2 at the Arizona site than in configuration 1 or 4. Koch 9030 is showing less adhesion failure at the Iowa site in configuration 3 than in configuration 1. Three of the four rubberized asphalt sealant materials installed at the South Carolina site developed significantly more full-depth adhesion failure when installed in configuration 3, the plow-and-seal configuration, than in configurations 1 or 2.

Why have the plowed (configuration 3) joints remained sealed in Iowa and Kentucky and failed in up to 41 percent of the joint length at the South Carolina site? One reason for the apparent difference is that silicone sealant was plowed from the South Carolina joints whereas failed hot-applied sealant was plowed from the Kentucky joints. The rubberized asphalt sealants that were used in the configuration 3 joints are not designed to adhere to silicone sealant, and since silicone sealant remained on the joint faces in South Carolina, as soon as the overband was worn down or the sealant was expanded sufficiently, the new sealant lost all adhesion and slipped down into the joint. The sealant plowed from the Iowa site was also silicone. Although newer than the in-place South Carolina sealant, it had failed in adhesion in more than 15 percent of the joint length. Consequently, the plowing operation at the Iowa site removed 70 to 85 percent of the remaining sealant from the joint faces, leaving a relatively fresh bonding surface. As a result of these types of differences, comparison of performance of plowed joints between sites may be difficult.

Comparing nonfailure distresses statistically indicates that there is more significant differentiation in performance between materials and configurations for partial-depth spalling and adhesion loss than for full-depth spalling and adhesion failure. Figures D-18 through D-27 in appendix D contain the results of HSD comparisons for partial-depth distresses as they relate to materials and configurations.

As shown in figure D-18 of appendix D, Crafco 231 developed less partial-depth adhesion loss at the Arizona site than Crafco 221, Koch 9005, or Meadows Hi-Spec in configuration 1, and the silicone sealants experienced significantly less partial-depth adhesion loss than the rubberized asphalt sealants. The silicone sealants and Crafco 231 exhibited significantly less partial-depth adhesion loss than the remaining rubberized asphalt sealants in configuration 1 at the Colorado, Iowa, and South Carolina sites. In configuration 2 at the Colorado site, Crafco 231 and Koch 9005 showed less partial-depth adhesion loss than Koch 9030 or Meadows Sof-Seal. Crafco 231 and Meadows Sof-Seal developed less adhesion loss in configuration 4 at the Colorado site than Koch 9005 or Koch 9030.

Only the wet-freeze and dry-freeze sites in Iowa and Colorado exhibited a significant difference in partial-depth spalling between materials in each configuration. The silicone materials in Colorado developed more partial-depth spalls in configuration 1 than most of the hot-applied sealants. At the Iowa site, a difference in spall development between silicone and hot-applied sealants is not as distinct.

One most striking conclusion that can be drawn from these figures is that for most hot-applied sealants installed in the five test sites, less partial-depth adhesion loss has developed when the sealants were installed in configurations 2, 3, and 4 than when installed using configuration 1. The possible exception to this is Crafco 231, which developed no significant difference in partial-depth adhesion loss in four of the five sites.

The larger amount of spalling developed in the silicone sealants may, in part, be traced to the stress developed when the sealant is elongated. As shown in tables C-4 and C-6, the stress in silicone sealants is much higher than that in rubberized asphalt sealants when stretched to 150 percent of their original length. The bond strength between the sealant and the concrete was better than the tensile strength of the concrete, and, in conjunction with cold-weather elongation and traffic loads, more new spalls developed along the joints containing silicone sealants.

Joints primed and sealed with a non-self-leveling Dow Corning 888 silicone developed significantly more partial-depth spalls than unprimed joints sealed with Dow Corning 888. However, joints primed and sealed with a self-leveling Dow Corning 888-SL silicone sealant did not show a significant difference in partial-depth spall development from unprimed joints sealed with the same material. No explanation is currently available for this phenomenon.

Relation of Performance with Position Along Joint

The effect of tire contact and traffic loads on adhesion loss and spall distress was studied, and preliminary results indicate that spalling occurs more frequently in the wheelpaths. Only minor differences in adhesion performance as a function of the distance from the shoulder edge have been noted, and these differences do not correlate well with the wheelpath positions. The relations between distance from the shoulder edge and adhesion loss or spall failure are shown in figures 52 and 53. The adhesion loss rating is the average, in inches, of the sum of full depth adhesion failure on both sides of the joint and the length along the joint of partial depth adhesion loss. Adhesion loss rating values for Colorado at the first (position 1) designated distance from the shoulder edge are the average rating along the entire Colorado site for the position between the shoulder edge and 1 ft (0.3 m) from the edge.

Statistical analysis of variance of the full- and partial-depth spalling and adhesion loss indicates that, at all but the Arizona site, a difference does exist in seal performance depending on its position in the lane. The rankings of position for each distress are shown in tables 17 and 18. For example, at the Iowa site, more full-depth spalls developed at positions 2, 3, 4, and 10 (the wheelpaths) and more partial-depth spalls developed at positions 3, 4, 10, and 11. At the Colorado site, more partial-depth spalls occurred at positions 2, 3, and 10.

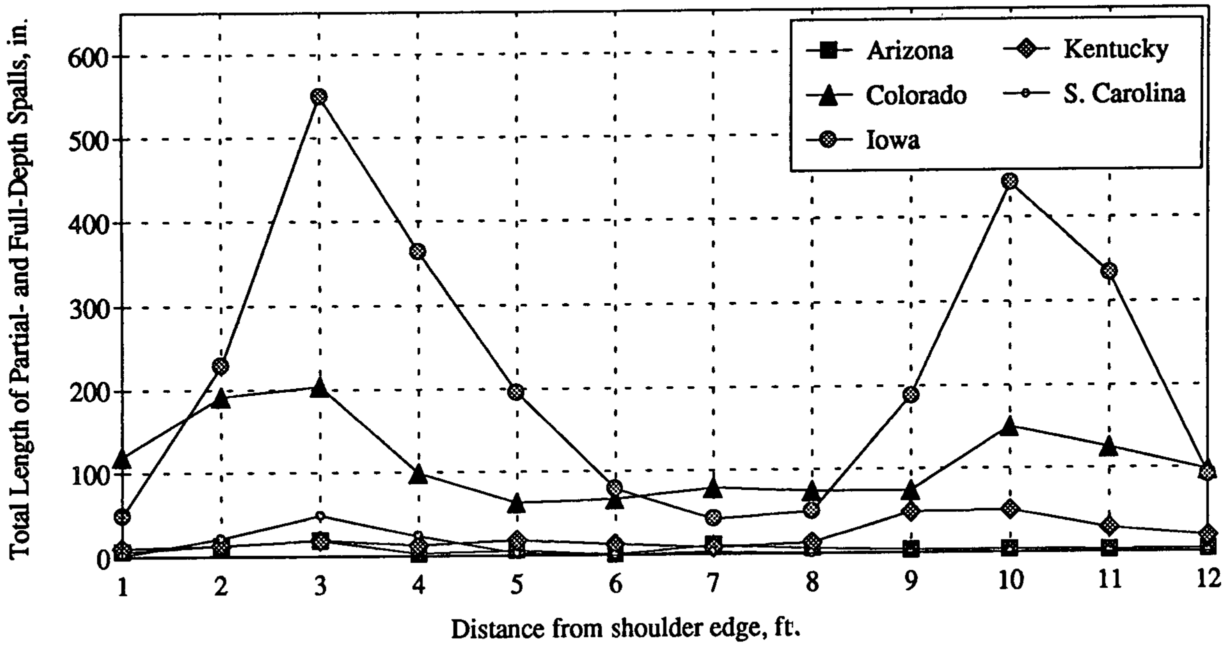

Figure 52. New partial- and full-depth spalls vs. distance from shoulder

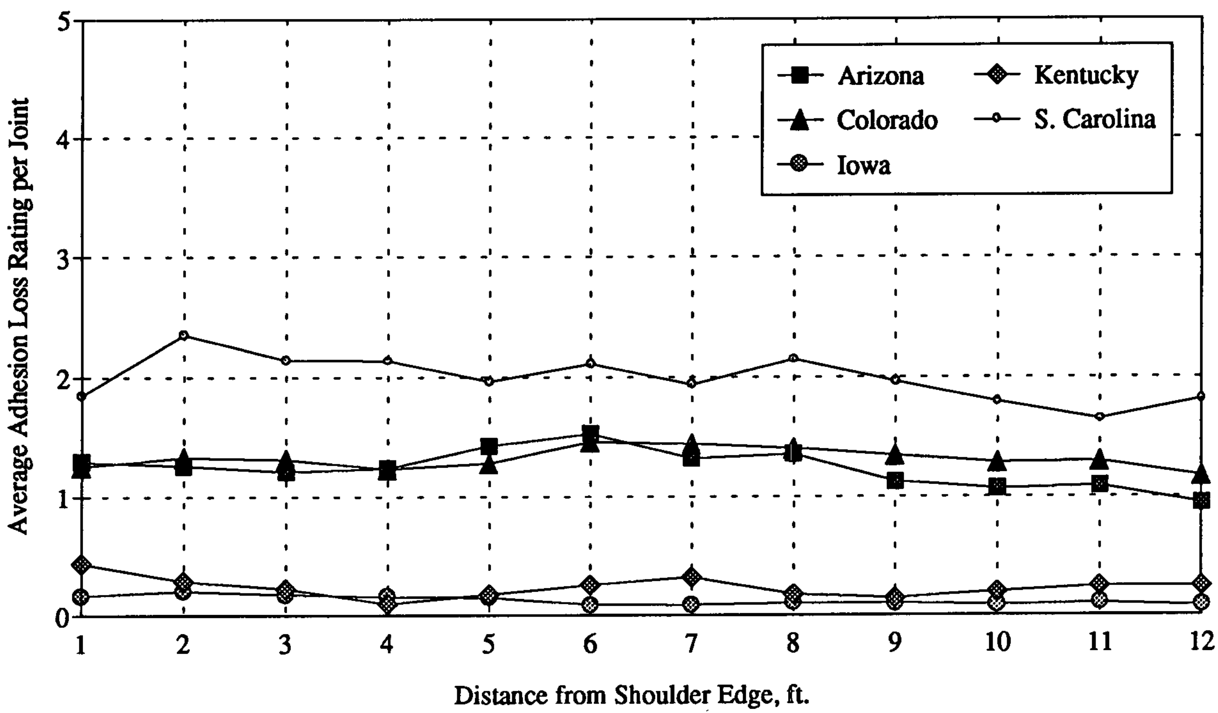

Figure 53. Adhesion loss rating (ALR) vs. distance from shoulder (18 months)

Table 17. Relation of full-depth failure to lane position

Site	Full-Depth Spall Failure				Full-Depth Adhesion Loss		
	More Distress [a] ⇒ ⇒ ⇒ ⇒				More Distress [a] ⇒ ⇒ ⇒ ⇒		
AZ	4,11,6,9,10,7, 5,12,8,1,2,3 [b]				12,1,6,9,2,11, 7,4,8,10,5,3		
CO	9,5,7,8,12,6, 1,11,10,4	12,6,1,11,10, 4,2,3			1,2,3,12,4,5, 11,7,6,10	2,3,12,4,5, 11,7,6,10,8,9	
IA	6,12,7,8,1,5, 11,9	5,11,9,2	11,9,2,10, 4	2,10,4,3	12,8,7,1,10, 11,6,5,2,9	10,11,6,5,2,9, 4,3	
KY	6,7,8,1,4,3,2, 5,12,11,9,10				12,6,11,8,1, 5,10,2,4,7,3,9		
SC	12,11,6,9,8,7, 5,10,1,2,4	4,3			6,7,5,12,11, 10,1,8,9,4,3	7,5,12,11,10, 1,8,9,4,3,2	

[a] Level of significance = 0.05
[b] Position number (distance from shoulder edge, ft)

Table 18. Relation of partial-depth distress to lane position

Site	Partial-Depth Spall Distress						Partial-Depth Adhesion Loss			
	More Distress [a] ⇒ ⇒ ⇒ ⇒						More Distress [a] ⇒ ⇒ ⇒ ⇒			
AZ	6,11,12,8,10,1, 4,5,2,9,7,3 [b]						12,10,9,11,3, 4,1,7,2,8,5,6			
CO	1,5,6,12,8,9,7, 4,11	7,4,11, 10	4,11, 10,2	10, 2,3			12,11,10,1,2, 3,6,4,9,7,5	11,10,1,2 ,3,6,4,9,7 ,5,8		
IA	7,1,8,6,12	12,9	9,2,5	11, 4	4, 10	3	11,9,10,4,8, 12,3,7,2,6,5,1			
KY	12,11,1,3,8,4, 2,5,10,7,6,9						4,5,9,8,10,3,1 1,6,7	9,8,10,3, 11,6,7,12	8,10,3, 11,6,7, 12,2	11,6, 7,12, 2,1
SC	12,10,8,6,11,9, 1,7,5,2	11,9,1, 7,5,2,3	55,2, 3,4				1,12,10,3,11, 9,4,5,7,2,8,6			

[a] Level of significance = 0.05
[b] Position number (distance from shoulder edge, ft)

Full-depth adhesion loss was more prevalent in positions 8 and 9 of the Colorado site than in position 1. At the Iowa site, more full-depth adhesive failure occurred in positions 4 and 3 than in positions 12, 8, 7, and 1, and at the South Carolina site, full-depth adhesive failure developed more frequently in position 2 than in position 6. Partial-depth adhesion loss occurred more frequently in positions 1, 2, and 12 of the Kentucky site than in positions 3, 4, 5, 8, 9, and 10.

A relationship does exist between spalling and distance from the shoulder edge on a 12-ft (3.7-m) joint, as evidenced in figure 52. At the Iowa site, the partial-depth spalling is significantly higher at the wheelpath positions 2, 3, 4, 5, 9, 10, and 11. The other site that showed a large amount of spalling is Colorado, where significantly more partial-depth spalls are located in the wheelpath positions 2, 3, and 10. The Arizona, Kentucky, and South Carolina sites contain too few spalls to indicate any significant difference in spalling intensity in the wheelpath.

Comparison of Performance Between States

When making sealant performance comparisons between test sites, several variables, in addition to climatic conditions, enter into the analysis. Many of these variables are difficult to quantify and tend to confound the analysis.

Among these new variables are the design and properties of the pavement surface, base, and subgrade, including the type and strength of aggregate and mortar. Preparation variables, such as the type and quality of sandblasting and airblasting, the presence of traffic adjacent to the work zone, whether the installation was during the day or the night, the condition and type of old sealant to be plowed from the joints, and the amount of wind and airborne dust particles present during installation, also enter the analysis. Each of these preparation variables was controlled to the best of the contractor's ability by using only oil- and moisture-free air compressors, training workers as necessary, inspecting sandblasted and airblasted joints for cleanliness and ordering additional cleaning as necessary, bringing in additional lighting where needed, removing sandblasting particles from the adjacent pavement surface as well as from the joint reservoir, and requiring additional low-pressure air cleaning of joints containing backer rod if dust had accumulated in them prior to sealant installation. Nevertheless, some additional variation is present and must be noted when making performance comparisons.

The partial- and full-depth adhesion loss for recessed-joint sealants is compared between states in figures 54 and 55. One thing that stands out is the excellent adhesion performance of the silicone sealants in every state. Only slight adhesion loss in silicone sealants has been noted in any state, with the majority of that distress related to partial-depth spalling. Small amounts of full-depth adhesion failure have been observed in hot-applied seals, with most sealants exhibiting less than 0.5 percent of the joint length failed.

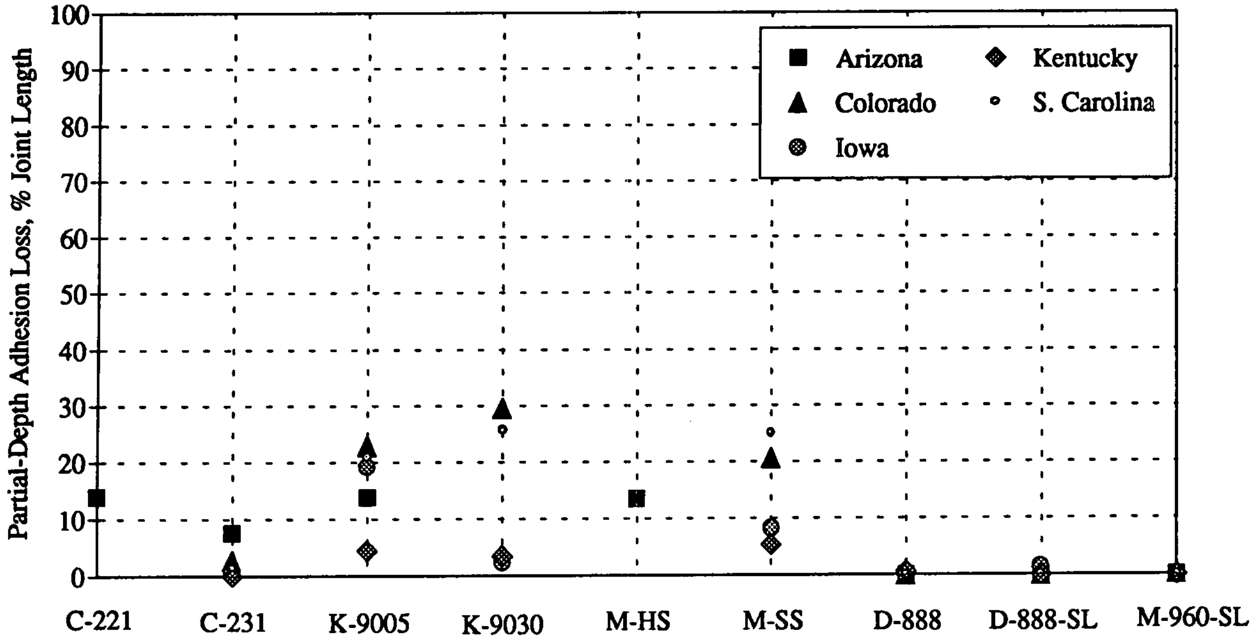

Figure 54. Partial-depth adhesion loss for recessed joint seals (18 months)

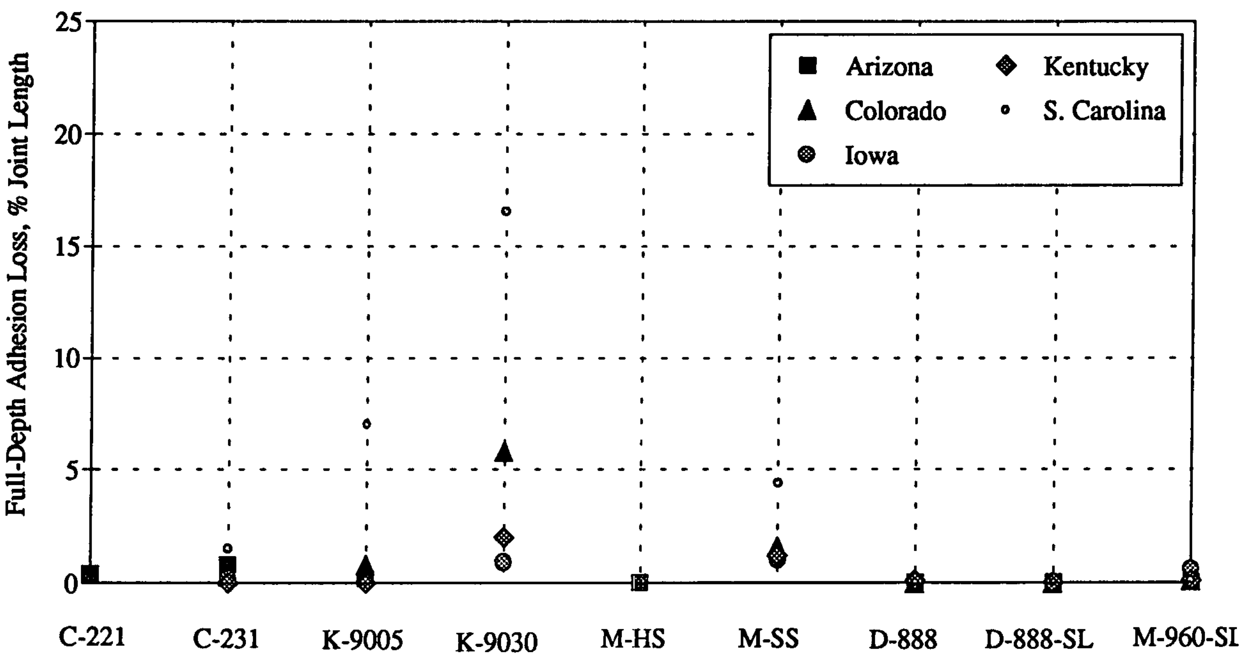

Figure 55. Full-depth adhesion loss for recessed joint seals (18 months)

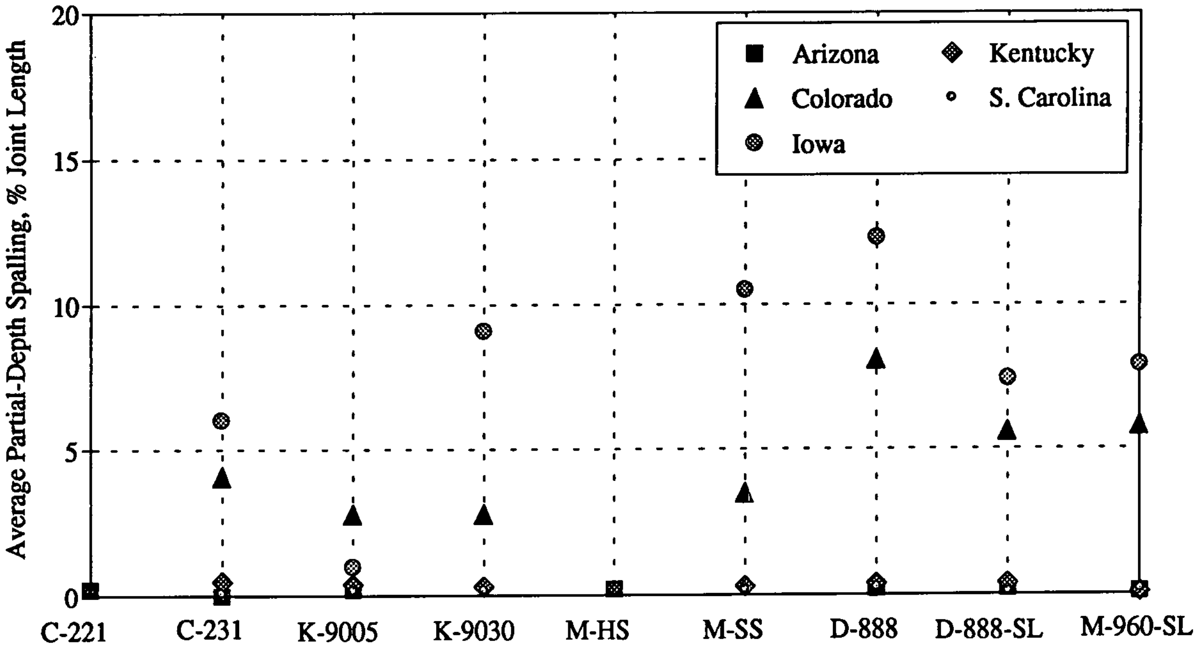

Figure 56. New partial-depth spalls for recessed joints (18 months)

Partial-depth adhesion loss is larger for three of the four hot-applied sealants at the Colorado and Kentucky sites. Full-depth adhesion failure is much more prevalent at the South Carolina site for rubberized asphalt sealants. This is in most part due to the seal performance in configuration 3 where silicone sealant on the plowed joint face did not allow the sealant to adhere well.

As shown in figures 56 and 57, partial- and full-depth spall failure is much more prevalent at the Colorado and Iowa sites. These sites are in cold climatic regions where joints experience large opening widths at the same time that sealant materials are colder and stiffer. Spalling at the Iowa site was generally greater than at the Colorado site, this possibly being a function of differences in aggregate and mortar strength or a difference in the amount of moisture present.

Comparison of Field Performance over Time

As the time that a joint sealant remains in place increases, the effects of microthermal and macrothermal cycling come into play, causing widening and closing of the joint reservoir as well as thermal softening and hardening of the sealant. Weathering and the effects of oxidization and ultraviolet light cause hardening of some sealants. Traffic loads accumulate shear stress cycles for the sealant and the surrounding concrete as well as reduce overbanded layer thickness. The resistance of materials installed using various preparation techniques to the accumulated effects of time is a key property that researchers and manufacturers study to

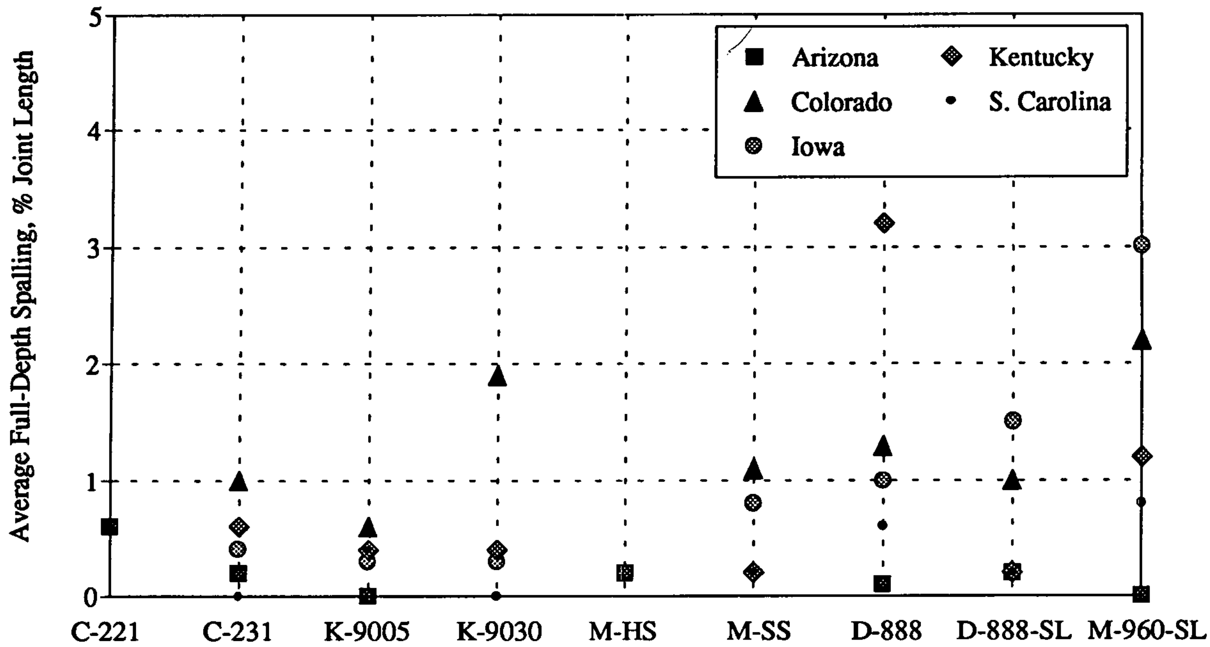

Figure 57. New full-depth spalls for recessed joint seals (18 months)

help rank sealant performance. This preliminary performance comparison divides the sealants into silicone and hot-applied types and studies the effect of time on adhesion loss and spall failure.

The relationship of time after installation with the average full-depth adhesion loss for each test site is shown in figure 58 for the hot-applied sealants. The general trend is toward increased adhesion loss with time. Moreover, at the South Carolina site, there is an increase in adhesion loss in the 8th and 9th months after installation, immediately following the first winter season. Very little adhesion loss had occurred in the silicone sealants over 18 months, and, as a result, the adhesion rating for all silicone sealants remained near zero.

The relationship between time and spall failure at the test sites is shown for silicone sealants in figure 59 and for hot-applied sealants in figure 60. Both these figures indicate a large increase in spalling in the fall and early winter period between the 5th and 9th months at the dry-freeze site in Colorado and the wet-freeze site in Iowa. The Kentucky site also exhibited a slight increase in spalling through the early winter period. Spalling in the 1st year after resealing joints in the two cold-region states was significantly increased through the early winter months.

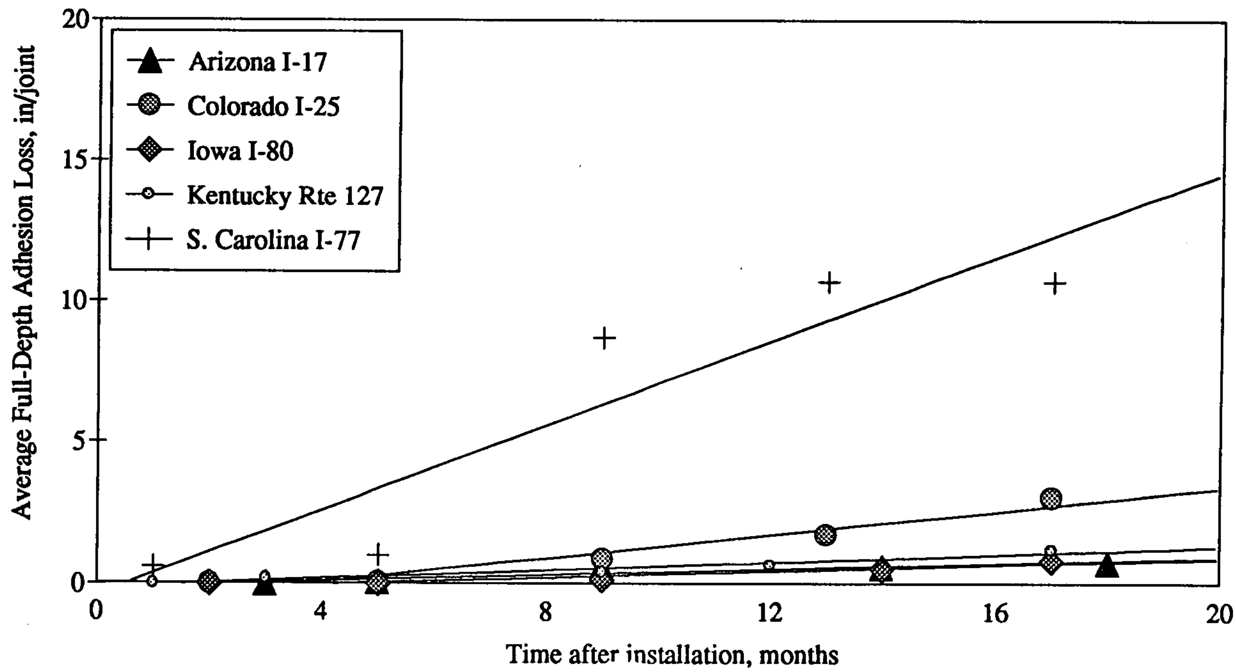

Figure 58. Relation of time to adhesion loss for hot-applied sealants

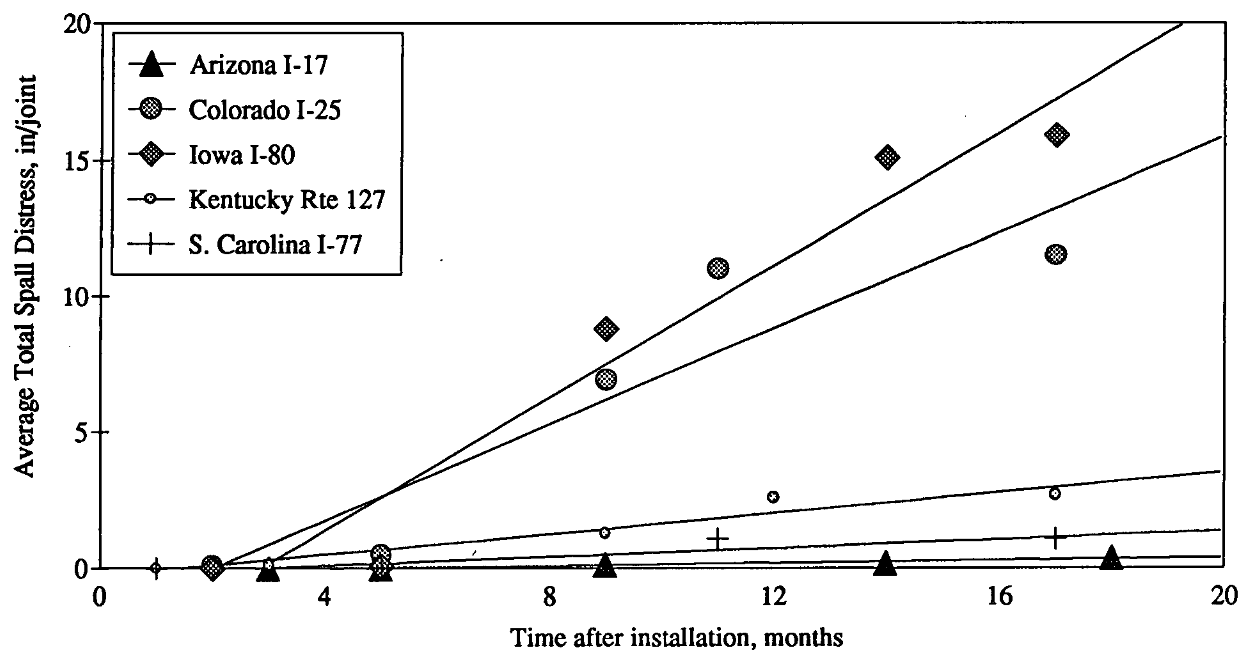

Figure 59. Relation of time to spall failure for silicone seals (18 months)

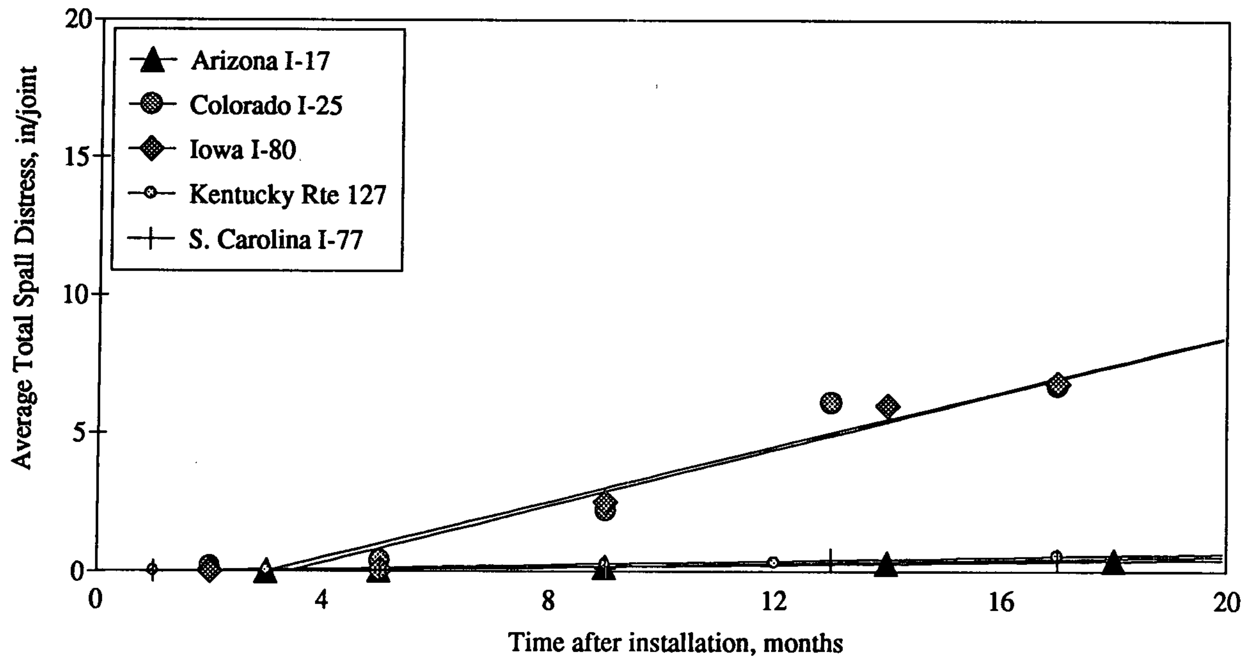

Figure 60. Relation of time to spall failure for rubberized asphalt seals

Laboratory Result Comparison and Correlation

Laboratory tests indicate that the various sealant materials exhibit significant differences in several test results. Correlation of laboratory test results with field performance indicators suggest that some field-laboratory relations may exist.

Comparison of Laboratory Results

Inspection of the initial test results indicate that the cone penetration values for the low-modulus sealants are more than 1.4 times larger than the standard rubberized asphalt sealants. This is to be expected of a low-modulus sealant, and the results of the ASTM D-412 tensile test indicate that the stress in the low-modulus sealants at 150 percent elongation at 77°F (25°C) is on average 42 percent less than that of the standard rubberized asphalt sealants.

An across-temperature tensile test comparison of the hot-applied sealants indicates some unique differences in materials, as shown in figure 61. Between the temperatures of 77°F (25°C) and 0°F (-18°C), the stress in ASTM D-412 samples elongated to 150 percent of their original length increased between 1.3 and 1.9 times for the Koch and W. R. Meadows sealants. However, the stress in both of the Crafco sealants increased significantly, with the RoadSaver 221 increasing 7.1 times and the RoadSaver 231 failing in cohesion before reaching 150 percent elongation at 0°F (-18°C). These differences have not yet translated into differences in adhesion performance at the test sites. In fact, the RoadSaver 231 is not

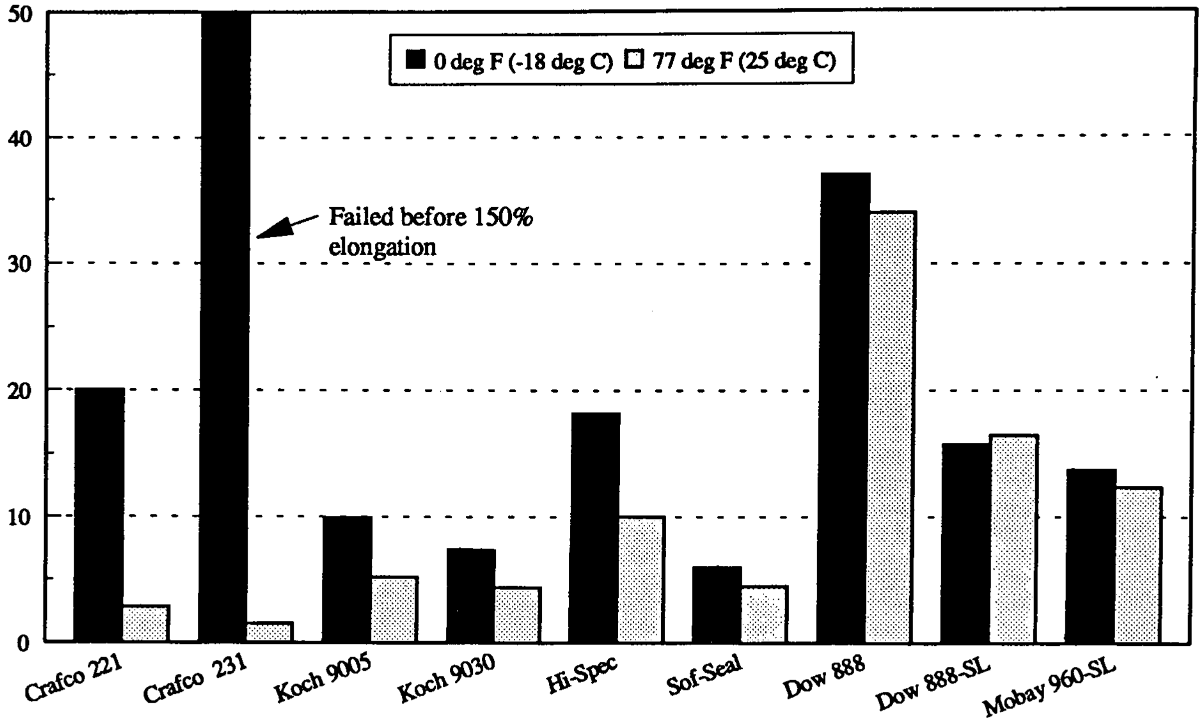

Figure 61. ASTM D-412 stress at 150 percent elongation

performing significantly differently from the other hot-applied sealants in adhesion, and no significant difference in spall development with these sealants has been noted.

The laboratory results for the three silicone sealants are significantly different in most cases. For instance, the ASTM D-412 ultimate elongation at 77°F (25°C) is 647 percent for the Mobay Baysilone 960-SL. It is about 300 and 330 percent higher, respectively, for the Dow Corning 888 and the self-leveling Dow Corning 888. This is a great difference in material laboratory performance, but considering that typical joint widths are designed to allow no more than 50 to 100 percent elongation, this test result may not be directly comparable with field performance.

Additional test results indicate that the increase in stress at 150 percent elongation between 140°F (60°C) and 0°F (-18°C) ranges from 1.1 to 1.8 times, with the Mobay Baysilone 960-SL being the most affected. The effect of weathering on the stress at 150 percent elongation for silicone sealants is negligible, resulting in an increase in stress ranging from 1.1 to 1.2 times the original after 504 hours of weathering.

A comparison of the stress at 150 percent at 77°F (25°C) between the different types of sealants indicates that the low-modulus sealants generally exhibited the lowest stress. When compared with the stress developed in low-modulus, rubberized asphalt sealants, the standard D-3405 rubberized asphalt sealants maintained stresses about 1.7 times greater; the self-leveling sealant stresses were about 4.2 times greater; and the Dow Corning 888 non-self-leveling sealant was about 9.8 times greater.

Correlation with Field Performance

Statistical comparisons between the mean adhesion and spall performance of each material and the mean result of each laboratory test indicate that weak relationships may exist between field performance and some laboratory test results. At the 95 percent confidence level, the correlation coefficient (r) values for significant relationships at all test sites are listed in table 19. Positive r values indicate a direct relation and negative values indicate an inverse relation.

Table 19. Field and laboratory performance statistical comparison summary

Field Distress	Laboratory Test [a]		Correlation Coefficient (r)	Probability > R	Number of Observations
Full-depth adhesion failure	D-3407	Penetration (77°F)	0.46008	0.0412	20
	D-3407	Resilience (77°F)	0.55281	0.0115	20
	D-3407	Specific gravity (60°F)	-0.33670	0.0480	35
	D-412	Ult. elongation (77°F) silicone	-0.52956	0.0423	15
	D-412	Stress at 150% elongation (77°F)	-0.36735	0.0299	35
	D-412	Stress at 150% elongation (0°F)	-0.41605	0.0222	30
	D-412	Stress at 150% elongation (39°F)	-0.51251	0.0249	19
	D-412	Ult. elongation (140°F) silicone	-0.51917	0.0473	15
Partial-depth adhesion loss	D-3407	Specific gravity (60°F)	-0.53418	0.0009	35
	D-3583	Immersed elongation (75°F)	0.57471	0.0003	35
	D-412	Stress at 150% elongation (0°F)	-0.47714	0.0077	30
	D-412	Stress at 150% elongation (77°F)	-0.53251	0.0010	35

[a] °C = (°F-32) 5/9

As additional failures develop in the sealants more reliable, and possibly more significant, correlations should become evident. However, these preliminary correlations indicate that, with regard to adhesion loss, the ASTM D 3407-78 tests for penetration and resilience are fair indicators of adhesion performance. In addition, the ASTM D 412-87 tensile stress at 150 percent elongation appears to be related to adhesion performance for both hot-applied and silicone sealants. Possibly, the ASTM D 412-87 ultimate elongation test is related to full-depth failure in silicone sealants, but considering the small amount of such failure at any of the test sites, very little weight can be placed on that relation at this time.

6

Preliminary Findings

The SHRP H-106 project is the most extensive full-scale maintenance experiment conducted to date. The intent of the joint seal maintenance quarter of the project is to improve the state of the art in sealing joints in concrete pavements through head-to-head performance comparisons of materials and preparation methods under a variety of pavement and climatic conditions. Potential benefits of this study — more cost-effective maintenance operations, less exposure of highway workers to adjacent traffic, and fewer maintenance delays for the traveling public — make the results of this study very timely in these days of increased demand for effective maintenance procedures.

This chapter presents the preliminary findings available at this time from the SHRP H-106 PCC joint seal study. Findings presented here are based on evaluations of each joint seal test site over an 18-month period. However, joint seals in concrete pavements often remain in good to excellent condition for 2 to 7 years or longer, and in order to draw statistically accurate conclusions, some joint seals may require more than 5 years of additional monitoring.

Observations

Adhesion failure has only occurred on 1.7 percent of the length of resealed joints, and more than half of that failure can be attributed to 80 joints in South Carolina in which the old silicone sealant was not completely removed by the plowing operation. Generally, the experimental joint seals are performing well. However, some significant performance differences have developed. Based on a statistical analysis at a 95 percent statistical significance, and on the information available to date, the following observations are given:

- Considering full-depth adhesion, there is no conclusive evidence as to which configuration performs best, except at the South Carolina site, where seals installed after sawing and sandblasting outperformed those installed after plowing and airblasting.

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

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

- No significant difference has developed in full-depth adhesion failure between silicone and rubberized asphalt sealants installed using the same methods. Silicone and rubberized asphalt sealants have developed 0.1 and 1.7 percent adhesion failure, respectively.

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

- Sixty joints at the Iowa site, have indicated that significantly more partial-depth spalls occur in joints primed before installing silicone sealant than in unprimed joints containing the same sealant. No explanation for this development is currently available.

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

- The rubberized asphalt overbanded material remained effective in the pavement wheelpaths for 9 to 18 months. In nonwheelpath areas, many overbanded sealants remain effective after 18 months. Crafco RoadSaver 231 rubberized asphalt tends to resist wearing of the overband more than the other hot-applied sealants.

- The penetration, resilience, stress at 150 percent elongation, immersed elongation, and ultimate elongation tests may be slightly correlated with adhesion loss in the field after 18 months. These correlations may increase as time progresses.

Recommendations

The SHRP H-106 project has taken the first steps toward improving the state of the practice of resealing joints in concrete pavements. Although definite progress has been made, room for additional improvement exists. Recommendations for actions that may lead to further progress in joint resealing are listed below:

- Continue monitoring repair sites. The investment made in the installation of these sites will provide a major payoff if monitoring is continued and additional results are gathered and analyzed.

- Set up regional testing centers for continued testing. While the SHRP H-105 project attempted to identify those materials and procedures that had the most performance potential, many materials were not tested under SHRP H-106, and new materials are continually being produced. In addition to evaluating new materials, this would allow the controlled study of new equipment such as heat lances, modern joint plows, automated backer rod insertion tools, sandblasting nozzles and guides, and installation wands and tooling devices. Also, methods for installation, joint cleanliness quantification, and moisture detection could be developed and analyzed.

- Transfer the technology. The information gathered under the SHRP H-106 program can be put to its best use when it reaches the most people on the decision-making, supervisory, and installation levels of joint resealing. Therefore, incorporating it into a technology transfer program is essential.

Appendix A

Test Site Layout

The joint-resealing test sites were laid out in two replicates, generally end to end. Each replicate contained test sections consisting of ten joints resealed using one of each sealant material-preparation method combination. The order of material placement at each test site was chosen randomly. Tables A-1 and A-2 list the materials and placement methods used at each site in the order that they lie along the roadway.

Table A-1. Layout of test sections at AZ and CO sites

Test Section	Sealant Material (Configuration)	
	I-17 Phoenix, Arizona, Site	I-25 Ft. Collins, Colorado Site
1	Crafco RoadSaver 231 (4)	Koch 9005 (1)
2	Dow 888-SL silicone (1)	Meadows Sof-Seal (2)
3	Koch 9005 (1)	Crafco RoadSaver 231 (4)
4	Dow 888 silicone (1)	Crafco RoadSaver 231 (2)
5	Crafco RoadSaver 221 (2)	Koch 9030 (1)
6	Mobay Baysilone 960-SL (1)	Meadows Sof-Seal (1)
7	Meadows Hi-Spec (1)	Koch 9005 (4)
8	Crafco RoadSaver 231 (1)	Crafco RoadSaver 231 (1)
9	Meadows Hi-Spec (4)	Koch 9030 (2)
10	Crafco RoadSaver 221 (1)	Dow 888 silicone (1)
11	Koch 9005 (2)	Koch 9005 (2)
12	Crafco RoadSaver 221 (4)	Mobay Baysilone 960-SL (1)
13	Koch 9005 (4)	Koch 9030 (4)
14	Crafco RoadSaver 231 (2)	Meadows Sof-Seal (4)
15	Meadows Hi-Spec (2)	Dow 888-SL silicone (1)
16	Crafco 903-SL silicone (1)	Koch 9050 polysulfide (1)

Table A-2. Layout of test sections at SC, IA, and KY test sites

Test Section	Sealant Material (Configuration)		
	I-80 Grinnell, IA	Rte 127 Frankfort, KY	I-77 Fairfield, SC
1	Koch 9005 (1)	Koch 9005 (1)	Koch 9005 (1)
2	Meadows Sof-Seal (2)	Meadows Sof-Seal (2)	Meadows Sof-Seal (2)
3	Crafco RoadSaver 231 (3)	Crafco RoadSaver 231 (2)	Crafco RoadSaver 231 (3)
4	Dow 888-SL/888 w/ primer	Koch 9030 (1)	Crafco RoadSaver 231 (2)
5	Crafco RoadSaver 231 (2)	Crafco RoadSaver 231 (3)	Koch 9030 (1)
6	Koch 9030 (1)	Meadows Sof-Seal (1)	Meadows Sof-Seal (1)
7	Meadows Sof-Seal (1)	Crafco RoadSaver 231 (1)	Koch 9005 (3)
8	Koch 9005 (3)	Koch 9005 (3)	Crafco RoadSaver 231 (1)
9	Crafco RoadSaver 231 (1)	Koch 9030 (2)	Koch 9030 (2)
10	Koch 9030 (2)	Dow 888 silicone (1)	Dow 888 silicone (1)
11	Dow 888 silicone (1)	Koch 9005 (2)	Koch 9005 (2)
12	Koch 9005 (2)	Mobay 960-SL silicone (1)	Mobay 960-SL silicone (1)
13	Mobay 960-SL silicone (1)	Koch 9030 (3)	Koch 9030 (3)
14	Koch 9030 (3)	Meadows Sof-Seal (3)	Meadows Sof-Seal (3)
15	Meadows Sof-Seal (3)	Dow 888-SL silicone (1)	Dow 888-SL silicone (1)
16	Dow 888-SL silicone (1)	Koch 9005 w/ primer (1)	
17	Mobay Baysilone 960 (1)	Koch 9050 polysulfide (1)	

Appendix B

Installation Data

During installation of the test sites, several items were documented, including the production rates of each operation, climatic conditions, width of joints, faulting of joints, sealant temperature, and any other items considered of importance. Appendix B contains examples of the data sheets used for collection of this information. These are included in figures B-1 through B-5. Summaries of the documented installation items are included in tables B-1 through B-4.

SHRP H-106 Installation Monitoring Form.

Site:

AZ (04)
SC (45)
CO (08)
IA (19)
KY (21)

Material:

1 C-221
2 C-231
3 K-9005
4 K-9030
5 M-HS
6 M-SS
7 D-888
8 D-888-SL
9 M-960-SL
A M-960
B C-RS-SL
C K-9050
D D-888-P
E D-888-SL-P
F K-9005-P

Replicate:

1
2

Config:

1
2
3

Test Section:

1 11
2 12
3 13
4 14
5 15
6 16
7 17
8
9
10

Site Id No: 1 9 1 1 7 1 1 ** **
1 2 3 4 5 6 7 8 9

INSTALLATION - PREPARATION:

Preparation Operations	Beginning		Ending	
	Date	Time	Date	Time
Sawing	***5-22-91***	***10:10***		***11:00***
Plowing				
Sandblast #1	***6-6-91***	***8:12***		***8:22***
Sandblast #2				
Airblast #1	***5-22-91***	***12:26***		***12:42***
Airblast #2	***6-6-91***	***8:33***		***8:53***

INSTALLATION - SEALANT PLACEMENT:

Installation Operations	Beginning		Ending	
	Date	Time	Date	Time
Primer				
Backer rod	***6-6-91***	***8:55***		***9:12***
Sealant	***6-6-91***	***9:15***		***10:00***

Figure B-1. Field installation data sheet

Installation and Evaluation Climatic Conditions

This form is to be completed by the H-106 contractor during both installation and evaluation. Readings will be taken at 60 min (± 5 min) time intervals. The method for obtaining the readings is explained in the Evaluation and Analysis Plan. [2]

Date: 5-8-91 **Inspector:** ARR **Site:** AZ SC (CO) IA KY

Time	Air Temperature (°F)	Relative Humidity (%)	Percent Clouds (%)	Pavement Surface Temp (°F)	Pavement Center Temp (°F)	Pavement Base Temp (°F)
6:00 a.m./p.m.						
7:00						
8:00	62.8	50	10	51.2	51.9	53.6
9:00	59.0	64	5	57.5	55.5	55.9
10:00	68.5	42	5	65.3	61.3	58.2
11:00	68.8	46	5	68.7	64.2	60.6
12:00	70.8	35	5	74.6	70.3	65.6
1:00	75.6	29	5	78.2	72.5	68.5
2:00	79.7	27	5	82.0	75.9	71.4
3:00	80.2	27	10	85.1	78.4	74.3
4:00	82.1	27	10	88.1	82.4	78.2
5:00	84.0	26	5	86.7	82.5	78.9
6:00	83.5	27	10	85.4	82.7	80.4
7:00						
8:00						

Figure B-2. Climatic conditions data collection form

Installation Joint Width Form

Site: AZ SC CO IA (KY)

Replicate: (1) 2

Test Section Number: 1 (2) 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17

Inspector: ARR

Site Identification Number 2 1 J 1 6 1 2 * *

JOINT MOVEMENT EVALUATION:

Joint Number	Date (mm/dd/yy)	Time (begin/end)	Joint Depth (in)	Joint Width (in)	Gage Plug Width (in)
1	6/13/91	9:22 am	2.72	0.4390	4.4715
2			2.25	0.4665	4.3860
3			2.31	0.4390	4.6230
4			2.19	0.5480	4.7270
5			2.35	0.5980	4.5150
6			2.68	0.4980	4.5035
7			2.00	0.3790	4.6405
8			2.04	0.4965	4.6310
9			1.88	0.4460	4.5965
10		9:30 am	2.30	0.5465	4.5430

Figure B-3. Installation joint and gage plug width form

Joint Faulting Data Collection Sheet

Site: AZ SC CO (IA) KY

Replicate: (1) 2

Test Section Number: 1 2 3 4 5 6 7 8 9 (10) 11 12 13 14 15 16 17

Inspector: ARR

Site Identification Number 1 9 J 1 4 1 2 * *

JOINT FAULTING EVALUATION:

Joint Number	Station Number	Date (mm/dd/yy)	Time (begin/end)	Fault Measurement (0.05 in)	
				Outside [a]	Inside [b]
1		7/23/91	10:25	0	0
2				0	1
3				0	0
4				0	0
5				0	0
6				0	0
7				0	0
8				0	0
9				0	0
10			10:30	0	0

[a] Positioned 16 in (406 cm) from the outside shoulder edge
[b] Positioned 20 in (508 cm) from the outside shoulder edge

Figure B-4. Joint-faulting data collection form

Installation Sealant Temperatures

This form is to be completed by the person responsible for each melter/applicator. Readings using the thermometer provided by the H-106 contractor will be taken at 60 min (± 5 min) time intervals. One form will be completed for each sealant material and for each day. Temperatures will be reported in degrees Fahrenheit. Nozzle readings are optional if the air temperature is greater than 60°F.

Date: 6-5-91 Kettle Type: Crafco

Kettle Tender: Steve Kettle Size (gal): 200

Sealant Material:
1.) Crafco RoadSaver 221
2.) Crafco RoadSaver 231 (circled)
3.) Koch 9005
4.) Koch 9030
5.) Meadows Hi-Spec
6.) Meadows Sof-Seal

Begin Heating Time: 6:00 am

Time Product at Application Temperature: 7:45 am

Time	Heating Oil Gage Tmp. (°F)	M/A Sealant Gage Tmp. (°F)	Recirculation Gage Tmp. (°F)	Measured M/A Slnt. Tmp. (°F)	Nozzle Temp. (°F)
6:00 a.m./p.m.					
7:00					
8:00					
9:00	360	360	345	355	355
10:00	445	380	375	375	375
11:00	370	380	365	375	370
12:00	450	390	345	380	355
1:00	375	390	385	380	380
2:00					
3:00					
4:00					

Figure B-5. Sealant temperature data collection form

Table B-1. Time required for joint sealant installation operations

Operation	Config.	Arizona I-17	Colorado I-25	Iowa I-80	Kentucky Rte 127	S. Carolina I-77	Average
Sawing	1, 2, 4	2:39	5:26	4:50	4:55	2:37	4:05
Plowing	3			1:45	1:23	2:02	1:43
Sandblasting	1	1:19	2:00	1:12	3:11	1:41	1:53
	2	2:19	3:08	2:23	4:46	2:33	3:02
	4	1:16	2:54				2:05
Airblasting	1	1:25	1:50	1:31	2:19	1:27	1:42
	2	1:42	2:07	1:05	2:06	1:21	1:40
	3			0:58	0:47	1:22	1:02
	4	1:22	1:28				1:25
Backer rod installation	1	2:03	1:58	1:27	1:57	1:25	1:46
	2	1:34	2:17	1:02	1:42	1:36	1:38
	3			1:04	1:56	1:31	1:30
	4	2:09	1:59				2:04
Sealant installation	1 AC	1:07	1:14	1:06	1:52	1:18	1:19
	1 Sil	4:30	3:19	3:39	3:45	5:30	4:09
	2	1:08	1:23	1:16	1:57	1:18	1:24
	3			1:16	1:23	1:17	1:19
	4	1:08	1:25				1:17

Table B-2. Average air temperature during sealant installation

Material	Config.	Average Air Temperature (°F)				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	Rte 127 Kentucky	I-77 S. Carolina
Crafco 221	1	70.5				
	2	66.8				
	4	70.9				
Crafco 231	1	74.7	62.0	85.6	90.5	78.5
	2	65.1	63.6	85.3	87.1	74.8
	3			83.8	88.8	75.1
	4	66.8	61.8			
Koch 9005	1	66.8	53.9	78.3	85.8	71.7
	2	70.8	56.9	80.0	88.3	74.7
	3			82.9	90.5	74.4
	4	70.9	59.8			
Koch 9030	1		55.1	85.0	88.4	74.7
	2		61.6	79.7	91.5	74.0
	3			84.9	87.3	70.1
	4		64.8			
Meadows Hi-Spec	1	66.9				
	2	71.1				
	4	67.3				
Meadows Sof-Seal	1		59.5	85.2	90.0	77.5
	2		54.0	83.3	86.6	75.4
	3			84.9	87.6	77.1
	4		56.6			
Dow 888	1	66.8	57.5	80.6	92.1	77.4
Dow 888-SL	1	66.8	66.4	83.0	89.5	71.4
Mobay 960-SL	1	66.8	64.9	81.2	88.3	75.1
Mobay 960	1			83.5		
Crafco 903-SL	1	69.0				
Koch 9050	1		65.7		84.8	

Table B-3. Average joint width during sealant installation

Material	Config.	Average Joint Width (inches)				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	Rte 127 Kentucky	I-77 S. Carolina
Crafco 221	1	0.5071				
	2	0.5039				
	4	0.5379				
Crafco 231	1	0.4871	0.5427	0.5055	0.4791	0.5248
	2	0.4832	0.5465	0.5219	0.4601	0.5417
	3			0.3128	0.2539	0.3841
	4	0.4332	0.5667			
Koch 9005	1	0.4449	0.5343	0.4561	0.4690	0.5215
	2	0.5031	0.5710	0.4682	0.4563	0.5163
	3			0.2707	0.2543	0.3663
	4	0.5185	0.5412			
Koch 9030	1		0.5349	0.4940	0.4610	0.5652
	2		0.5431	0.4931	0.4617	0.5780
	3			0.2804	0.2659	0.3723
	4		0.5656			
Meadows Hi-Spec	1	0.5158				
	2	0.4935				
	4	0.5760				
Meadows Sof-Seal	1		0.5483	0.4734	0.4755	0.5596
	2		0.5857	0.4594	0.4705	0.5052
	3			0.2795	0.2656	0.3588
	4		0.5508			
Dow 888	1	0.5104	0.5614	0.4669	0.4545	0.5740
Dow 888-SL	1	0.4521	0.5722	0.4671	0.4529	0.5682
Mobay 960-SL	1	0.5134	0.5663	0.4822	0.4743	0.5121
Mobay 960	1			0.4629		
Crafco 903-SL	1	0.4997				
Koch 9050	1		0.5687			

Table B-4. Average joint faulting at the time of sealant installation

Material	Config.	Average Joint Faulting (inches) [Resolution = 0.05 in (1.3 mm)]				
		I-17 Arizona	I-25 Colorado	I-80 Iowa	Rte 127 Kentucky	I-77 S. Carolina
Crafco 221	1	0.00				
	2	-0.01				
	4	-0.01				
Crafco 231	1	-0.01	0.00	0.00	0.00	0.00
	2	-0.01	-0.01	0.00	0.00	0.00
	3			0.00	0.00	0.00
	4	-0.01	0.00			
Koch 9005	1	-0.01	0.00	0.00	-0.01	0.00
	2	-0.01	0.00	0.00	0.00	0.00
	3			0.00	-0.01	0.00
	4	0.00	0.00			
Koch 9030	1		0.00	0.00	0.00	0.00
	2		0.00	0.00	-0.01	0.00
	3			0.00	0.00	0.00
	4		0.00			
Meadows Hi-Spec	1	-0.01				
	2	0.00				
	4	-0.01				
Meadows Sof-Seal	1		-0.01	0.00	-0.01	0.00
	2		0.00	0.00	-0.01	0.00
	3			0.00	-0.02	0.00
	4		0.00			
Dow 888	1	-0.01	0.00	0.00	-0.01	0.00
Dow 888-SL	1	-0.01	0.00	0.00	-0.01	0.00
Mobay 960-SL	1	-0.01	-0.01	0.00	0.00	0.00
Mobay 960	1			0.00		
Crafco 903-SL	1	-0.01				
Koch 9050	1		0.00			

Appendix C

Material Testing Data

Laboratory tests were conducted on six rubberized asphalt, hot-applied sealants and on three silicone sealants to ensure the characteristics of the sealant used in the project, as well as to allow comparison of field performance with laboratory results. Results of the initial quality assurance laboratory tests are listed in tables 8 through 12. Results of the supplemental tests completed on the nine sealants are listed in tables C-1 through C-7.

Table C-1. Results of supplemental lab tests on hot-applied joint sealants

Material Test	ASTM Test Method	Crafco RS 231	Meadow Sof-Seal	Koch 9030	Meadow Hi-Spec	Crafco RS 221	Koch 9005
Softening point	D 36	190	187	198	186	192	182
		191	189	199	186	193	184
Brookfield viscosity	D4402	2350	2500	1300	3550	4800	525
		2300	2550	1250	3925	5200	550
Ductility	D 113	81	52	30	45	71	59
		70	46	31	43	60	74
Cold bend (0°F) [-18°C]	Utah Spec.	Pass	Pass	Pass	Pass	Pass	Pass
		Pass	Pass	Pass	Pass	Pass	Pass
Cone penetration (0°F) [-18°C]	D3407	73	82	60	15	9	57
		75	81	60	15	7	57

Table C-2. Force-ductility test results for hot-applied joint sealants

Material Test	ASTM Spec.	Crafco RS 231	Meadow Sof-Seal	Koch 9030	Meadows Hi-Spec	Crafco RS 221	Koch 9005
Maximum elongation, cm	D 113	81	52	30	45	71	59
		70	46	31	43	60	74
	Average	**75.50**	**49.00**	**30.50**	**44.00**	**65.50**	**66.50**
Maximum load, lbs	D 113	2.7	2.1	4.6	5.2	3.8	2.5
		2.9	1.6	4.3	5.1	4.3	2.3
	Average	**2.80**	**1.85**	**4.45**	**5.15**	**4.05**	**2.40**
Maximum engineering stress, psi	D 113	17.4	13.5	29.5	33.3	24.4	15.9
		18.8	10.3	27.8	33.1	27.7	14.6
	Average	**18.10**	**11.90**	**28.65**	**33.20**	**26.05**	**15.25**
Maximum engineering strain, in/in	D 113	27.0	17.3	19.7	15.0	23.7	10.0
		23.4	15.3	24.7	14.3	20.0	10.3
	Average	**25.20**	**16.30**	**22.20**	**14.65**	**21.85**	**10.15**
Maximum true stress, psi	D 113	467.7	238.4	584.3	510.4	493.3	161.0
		441.8	164.3	680.4	480.5	520.0	160.7
	Average	**454.75**	**201.35**	**632.35**	**495.45**	**506.65**	**160.85**
Maximum true strain, in/in	D 113	3.3	2.9	3.0	2.8	3.2	2.4
		3.2	2.8	3.2	2.7	3.0	2.4
	Average	**3.25**	**2.85**	**3.10**	**2.75**	**3.10**	**2.40**
Area under engr. curve, psi	D 113	32.6	20.2	60.2	52.4	65.1	15.2
		27.9	14.5	64.5	51.2	62.1	14.7
	Average	**30.25**	**17.35**	**62.35**	**51.80**	**63.60**	**14.95**
Area under true curve, psi	D 113	210.4	130.7	388.4	338.2	420.6	98.5
		180.3	93.5	416.5	330.6	401.3	94.7
	Average	**195.35**	**112.10**	**402.45**	**334.40**	**410.95**	**96.60**
Asphalt modulus	D 113	1.7	4.1	30.0	29.6	30.0	8.5
		0.9	4.4	12.1	34.3	33.5	7.0
	Average	**1.30**	**4.25**	**21.05**	**31.95**	**31.75**	**7.75**
Polymer modulus	D 113	853.5	366.4	668.9	582.2	495.5	210.1
		973.6	192.2	786.4	548.1	507.0	183.9
	Average	**913.55**	**279.30**	**727.65**	**565.15**	**501.25**	**197.00**

Table C-3. Results of tensile adhesion tests on hot-applied joint sealants

Test	ASTM Test Method	Crafco RS 221	Meadows Hi-Spec	Koch 9005	Crafco RS 231	Meadows Sof-Seal	Koch 9030
75°F, Nonimmersed							
Maximum elongation, in	D 3583	4.20	3.35	4.38	3.60	3.08	1.85
		4.63	3.68	4.30	2.80	3.08	2.73
		2.93	3.53	4.90	3.18	2.38	2.03
Average		**3.92**	**3.52**	**4.53**	**3.19**	**2.85**	**2.20**
Percent elongation, %	D 3583	840	670	876	720	615	370
		926	736	860	560	615	546
		586	706	980	636	475	406
Average		**784**	**704**	**905**	**639**	**568**	**441**
Type of failure	D 3583	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion
75°F, Immersed							
Maximum elongation, in	D 3583	3.00	N/C [a]	4.13	2.93	1.20	0.88
		2.70	N/C	3.95	2.93	1.80	0.75
		2.38	N/C	3.98	2.25	1.75	1.08
Average		**2.69**	**N/C**	**4.02**	**2.70**	**1.58**	**0.90**
Percent elongation, %	D 3583	600	N/C	826	585	240	176
		540	N/C	790	585	360	150
		476	N/C	796	450	350	216
Average		**539**	**N/C**	**804**	**540**	**317**	**181**
Type of failure	D 3583	Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion
		Adhesion	N/C	Adhesion	Adhesion	Adhesion	Adhesion

[a] Test not completed.

Table C-4. Tensile stress at 150 percent elongation—hot-applied sealants

Material Tests	ASTM Test Method	Crafco RS 231	Meadows Sof-Seal	Koch 9030	Crafco RS 221	Meadows Hi-Spec	Koch 9005
Tensile stress at 150% elongation at 0°F (-18°C), psi	D-412	N/A [a]	5.7	8.2	19.5	19.7	9.2
		N/A [a]	6.3	6.5	20.5	16.7	10.5
	Average	N/A [a]	**6.0**	**7.4**	**20.0**	**18.2**	**9.9**
Tensile stress at 150% elongation at 39°F (4°C), psi	D-412	27.4	6.9	3.5	14.7	N/A [b]	21.1
		25.5	3.7	5.9	14.4	N/A [b]	17.6
	Average	**26.5**	**5.3**	**4.7**	**14.6**	N/A [b]	**19.4**
Tensile stress at 150% elongation at 73.4°F (23°C), psi	D-412	1.8	4.0	4.1	2.8	11.1	5.1
		1.3	5.0	4.7	2.9	8.8	5.2
	Average	**1.5**	**4.5**	**4.4**	**2.8**	**10.0**	**5.2**

[a] Failed in cohesion before reaching 150% elongation
[b] Test not completed

Table C-5. Results of ultimate elongation tests for silicone joint sealants

Material Tests	ASTM Spec.	Dow 888	Dow 888-SL	Mobay 960-SL
Ultimate elongation at 0°F (-18°C), %	D 412	1242	1962	689
		2021	2511	719
		1806	2566	782
	Average	1690	2346	730
Ultimate elongation at 77°F (25°C), %	D 412	1840	2290	630
		1950	2040	660
		2060	2120	650
	Average	1950	2150	647
Ultimate elongation at 140°F (60°C), %	D 412	1156	1457	670
		1297	1661	580
		1304	1554	480
	Average	1252	1557	577
Ultimate elongation at 77°F (25°C), after 504 hrs weathering, %	D 412	791	1103	359
		727	1081	355
		755	1172	422
	Average	758	1119	379

Table C-6. Tensile stress at 150 percent elongation — silicone sealants

Material Tests	ASTM Spec.	Dow 888	Dow 888-SL	Mobay 960-SL
Tensile stress at 150% elongation at 0°F (-18°C), psi	D 412	28.8	16.3	15.3
		40.2	15.7	14.0
		42.2	15.3	12.0
	Average	**37.0**	**15.8**	**13.8**
Tensile stress at 150% elongation at 77°F (25°C), psi	D 412	32.3	17.1	25.5
		34.1	16.5	24.1
		35.6	16.0	25.0
	Average	**34.0**	**16.5**	**12.4**
Tensile stress at 150% elongation at 140°F (60°C), psi	D 412	36.5	13.3	8.5
		34.7	13.1	7.4
		33.3	12.7	6.7
	Average	**34.8**	**13.0**	**7.5**
Tensile stress at 150% elongation at 77°F (25°C) after 504 hrs weathering, psi	D 412	40.8	16.3	14.3
		39.6	17.9	14.9
		38.8	17.4	14.0
	Average	**39.7**	**17.2**	**14.4**

Table C-7. Results of supplemental performance tests for silicone sealants

Material Tests	ASTM Spec	Dow 888	Dow 888-SL	Mobay 960-SL
Cyclic adhesion/cohesion test, 73.4°F (23°C), -50% to +100% cycling	C 719	5% adh. fail., 10 cycles	Slight deform., bbls., 10 cycles	Adh. failure, 1 cycle
		5% coh. fail., 10 cycles	Slight deform., 10 cycles	Adh. failure, 1 cycle
Tensile adhesion at 73.4°F (23°C), nonimmersed	D 3583	333.3	382.7	625.0
		241.8	194.6	371.3
		223.8	251.0	440.6
	Average	266.3	276.1	479.0
Tensile adhesion at 73.4°F (23°C), immersed	D 3583	277.2	255.6	436.8
		227.2	377.4	462.6
		588.2	224.8	601.8
	Average	364.2	285.9	500.4
Density at 77°F (25°C)	D 1475	1.501	1.356	1.128

Appendix D

Field Performance Data

A wealth of performance data has been collected during the five evaluations conducted since test site installation. This data is stored in spreadsheets and in the H-106 database, and summaries of the field performance are contained in appendix D. Joint width and joint faulting data were collected during subsequent evaluations using the forms contained in appendix B. Results of visual inspections of each joint on foot-by-foot basis were recorded on forms similar to figure D-1. Tables D-1 through D-10 list summaries of the adhesion, spall, overband, intrusion, and sunken sealant distress for each replicate (ten joints) at the five test sites. An explanation of the values in this table is contained in chapter 4. To assist in visualizing trends in the data, summary graphs have been prepared, and are presented in figures D-2 through D-32.

Date: 10-15-91

Time:
Begin: 1:51
End: 1:53

Surveyor: LDE

Site Id No: 1 9 J 1 4 1 2 0 4 __ (positions 1 2 3 4 5 6 7 8 9 10)

Site: AZ, SC, CO, IA (circled), KY

Replicate: 1 (circled), 2

Material:
1 C-221
2 C-231
3 K-9005
4 K-9030 (circled)
5 M-HS
6 M-SS
7 Dow 888
8 D-888-SL
9 M-890-SL
Other (A,B,C,D,E,F)

Config: 1, 2 (circled), 3, 4

Joint: 1, 2, 3, 4 (circled), 5, 6, 7, 8, 9, 10

Position from Shoulder (ft)	Adhesive Loss (in)				Cohesive Failure (in)				Overband Wear	
	Partial		Full		Tensile Stress		Bubbling			
	Left	Right	Left	Right	Part'l	Full	Part'l	Full	Low	High
0-1										
1-2	1								12	
2-3										12
3-4	3									12
4-5									12	
5-6									12	
6-7									12	
7-8									12	
8-9									12	
9-10										12
10-11										12
11-12									12	

Joint Segment	Spall Related, in				Stone Intrusion		Overall Sealant System Failure (in)
	Partial Depth		Full-Depth				
	Left	Right	Left	Right	Low	High	
0-1							
1-2							
2-3			1	2			3
3-4	1						
4-5							
5-6							
6-7							
7-8							
8-9							
9-10							
10-11							
11-12							

Figure D-1. Joint seal evaluation form

Table D-1. Summary of distresses at Arizona I-17 site

				Adhesion Loss										Spall Distress							
Material	Cnfg	Rep	Test Sectn	Part Left (in)	Part Right (in)	Full Left (in)	Full Right (in)	A-Loss Rating (in)	A-Loss Rating (%)	Total Partial (in)	Total Partial (%)	Total Full (in)	Total Full (%)	Part Left (in)	Part Right (in)	Full Left (in)	Full Right (in)	Total Partl (in)	Total Partl (%)	Total Full (in)	Total Full (%)
C-221	1	1	10	435	458	0	0	447	31.0	893	31.0	0	0.0	1	0	0	14	1	0.1	14	1.0
C-221	1	2	10	730	710	0	0	720	50.0	1440	50.0	0	0.0	0	5	0	4	5	0.3	4	0.3
C-221	2	1	5	0	0	0	0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0.0	0	0.0
C-221	2	2	5	0	0	2	2	4	0.3	0	0.0	4	0.3	0	0	1	0	0	0.0	1	0.1
C-221	4	1	12	1	1	0	0	1	0.1	2	0.1	0	0.0	0	0	0	0	0	0.0	0	0.0
C-221	4	2	12	46	17	18	16	65.5	4.5	63	2.2	34	2.4	3	8	0	1	11	0.8	1	0.1
C-231	1	1	14	13	35	21	9	54	3.8	48	1.7	30	2.1	0	0	2	2	0	0.0	4	0.3
C-231	1	2	14	527	674	3	7	611	42.4	1201	41.7	10	0.7	0	0	2	0	0	0.0	2	0.1
C-231	2	1	8	0	5	0	0	2.5	0.2	5	0.2	0	0.0	0	0	0	0	0	0.0	0	0.0
C-231	2	2	8	0	2	0	0	1	0.1	2	0.1	0	0.0	0	0	0	0	0	0.0	0	0.0
C-231	4	1	1	11	10	0	1	11.5	0.8	21	0.7	1	0.1	1	2	1	3	3	0.2	4	0.3
C-231	4	2	1	3	41	1	29	52	3.6	44	1.5	30	2.1	2	3	0	5	5	0.3	5	0.3
K-9005	1	1	3	733	615	0	0	674	46.8	1348	46.8	0	0.0	3	2	0	0	5	0.3	0	0.0
K-9005	1	2	3	351	377	0	3	367	25.5	728	25.3	3	0.2	0	2	1	0	2	0.1	1	0.1
K-9005	2	1	11	0	0	0	0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0.0	0	0.0
K-9005	2	2	11	1	0	0	0	0.5	0.0	1	0.0	0	0.0	0	0	0	0	0	0.0	0	0.0
K-9005	4	1	13	4	2	0	0	3	0.2	6	0.2	0	0.0	0	1	2	1	1	0.1	3	0.2
K-9005	4	2	13	225	82	8	3	165	11.4	307	10.7	11	0.8	9	2	0	1	2	0.1	1	0.1
M-HS	1	1	7	85	658	0	0	372	25.8	743	25.8	0	0.0	4	0	1	1	4	0.3	2	0.1
M-HS	1	2	7	339	1152	0	0	746	51.8	1491	51.8	0	0.0	0	1	0	3	1	0.1	3	0.2
M-HS	2	1	15	0	3	0	1	2.5	0.2	3	0.1	1	0.1	0	0	1	0	0	0.0	1	0.1
M-HS	2	2	15	0	0	0	0	0	0.0	0	0.0	0	0.0	0	0	2	0	0	0.0	2	0.1
M-HS	4	1	9	23	35	0	0	29	2.0	58	2.0	0	0.0	1	1	0	1	2	0.1	1	0.1
M-HS	4	2	9	3	12	0	0	7.5	0.5	15	0.5	0	0.0	1	2	0	1	2	0.1	1	0.1
D-888	1	1	4	0	0	0	0	0	0.0	0	0.0	0	0.0	1	1	0	3	2	0.1	3	0.2
D-888	1	2	4	0	0	0	0	0	0.0	0	0.0	0	0.0	2	2	0	0	4	0.3	0	0.0
D-888-SL	1	1	2	1	0	0	0	0.5	0.0	1	0.0	0	0.0	2	0	3	0	2	0.1	3	0.2
D-888-SL	1	2	2	0	0	0	0	0	0.0	0	0.0	0	0.0	0	4	2	0	4	0.3	2	0.1
M-960-SL	1	1	6	1	1	0	0	1	0.1	2	0.1	0	0.0	1	1	0	0	2	0.1	0	0.0
M-960-SL	1	2	6	0	0	0	0	0	0.0	0	0.0	0	0.0	0	0	1	0	0	0.0	1	0.1
C-903-SL	1	1	B	0	0	0	0	0	0.0	0	0.0	0	0.0	2	0	1	3	2	0.1	4	0.3
C-903-SL	1	2	B	0	0	0	0	0	0.0	0	0.0	0	0.0	1	3	0	0	3	0.2	0	0.0

Table D-1. Summary of distresses at Arizona I-17 site (cont.)

Material	Cnfg	Rep	Test Sectn	Overband Wear: Thick < 50% (in)	Thick < 50% (%)	Thick < 10% (in)	Thick < 10% (%)	Edge Left (in)	Edge Left (%)	Edge Right (in)	Edge Right (%)	Stone Intrusion: Single Stones (#)	Filled w/stns (in)	Filled w/stns (%)	Sunken Sealant: Low (in)	Low (%)	Med (in)	Med (%)	High (in)	High (%)
C-221	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	61	61	4.2	3	0.2	44	3.1	25	1.7
C-221	1	2	10	0	0.0	0	0.0	0	0.0	0	0.0	17	18	1.3	0	0.0	7	0.5	3	0.2
C-221	2	1	5	540	37.5	324	22.5	0	0.0	0	0.0	211	75	5.2	2	0.1	818	56.8	620	43.1
C-221	2	2	5	744	51.7	492	34.2	144	10.0	180	12.5	111	716	49.7	0	0.0	889	61.7	515	35.8
C-221	4	1	12	0	0.0	0	0.0	0	0.0	0	0.0	230	13	0.9	124	8.6	187	13.0	14	1.0
C-221	4	2	12	0	0.0	0	0.0	0	0.0	0	0.0	44	23	1.6	0	0.0	15	1.0	23	1.6
C-231	1	1	14	0	0.0	0	0.0	0	0.0	0	0.0	27	101	7.0	9	0.6	36	2.5	31	2.2
C-231	1	2	14	0	0.0	0	0.0	0	0.0	0	0.0	8	141	9.8	0	0.0	5	0.3	79	5.5
C-231	2	1	8	864	60.0	300	20.8	0	0.0	0	0.0	70	113	7.8	570	39.6	37	2.6	23	1.6
C-231	2	2	8	456	31.7	168	11.7	0	0.0	0	0.0	51	88	6.1	3	0.2	142	9.9	19	1.3
C-231	4	1	1	0	0.0	0	0.0	0	0.0	0	0.0	75	128	8.9	2	0.1	17	1.2	36	2.5
C-231	4	2	1	0	0.0	0	0.0	0	0.0	0	0.0	13	54	3.8	59	4.1	71	4.9	44	3.1
K-9005	1	1	3	0	0.0	0	0.0	0	0.0	0	0.0	134	296	20.6	0	0.0	8	0.6	198	13.8
K-9005	1	2	3	0	0.0	0	0.0	0	0.0	0	0.0	85	4	0.3	0	0.0	0	0.0	7	0.5
K-9005	2	1	11	24	1.7	1272	88.3	648	45.0	648	45.0	71	15	1.0	248	17.2	10	0.7	35	2.4
K-9005	2	2	11	0	0.0	1440	100.0	714	49.6	720	50.0	51	7	0.5	0	0.0	17	1.2	26	1.8
K-9005	4	1	13	0	0.0	0	0.0	0	0.0	0	0.0	186	47	3.3	12	0.8	12	0.8	28	1.9
K-9005	4	2	13	0	0.0	0	0.0	0	0.0	0	0.0	20	3	0.2	0	0.0	1	0.1	14	1.0
M-HS	1	1	7	0	0.0	0	0.0	0	0.0	0	0.0	1	17	1.2	1	0.1	0	0.0	28	1.9
M-HS	1	2	7	0	0.0	0	0.0	0	0.0	0	0.0	1	6	0.4	0	0.0	0	0.0	12	0.8
M-HS	2	1	15	600	41.7	300	20.8	9	0.6	4	0.3	22	88	6.1	976	67.8	125	8.7	122	8.5
M-HS	2	2	15	780	54.2	348	24.2	30	2.1	0	0.0	8	94	6.5	445	30.9	110	7.6	37	2.6
M-HS	4	1	9	0	0.0	0	0.0	0	0.0	0	0.0	11	29	2.0	0	0.0	4	0.3	21	1.5
M-HS	4	2	9	0	0.0	0	0.0	0	0.0	0	0.0	15	34	2.4	0	0.0	1	0.1	19	1.3
D-888	1	1	4	0	0.0	0	0.0	0	0.0	0	0.0	0	26	1.8	1	0.1	0	0.0	0	0.0
D-888	1	2	4	0	0.0	0	0.0	0	0.0	0	0.0	2	88	6.1	0	0.0	1	0.1	0	0.0
D-888-SL	1	1	2	0	0.0	0	0.0	0	0.0	0	0.0	0	237	16.5	7	0.5	0	0.0	1	0.1
D-888-SL	1	2	2	0	0.0	0	0.0	0	0.0	0	0.0	2	46	3.2	3	0.2	26	1.8	23	1.6
M-960-SL	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	269	18.7	8	0.6	27	1.9	80	5.6
M-960-SL	1	2	6	0	0.0	0	0.0	0	0.0	0	0.0	0	136	9.4	4	0.3	13	0.9	37	2.6
C-903-SL	1	1	B	0	0.0	0	0.0	0	0.0	0	0.0	0	27	1.9	0	0.0	8	0.6	12	0.8
C-903-SL	1	2	B	0	0.0	0	0.0	0	0.0	0	0.0	1	8	0.6	0	0.0	2	0.1	0	0.0

Table D-2. Summary of distresses at Colorado I-25 site

				Adhesion Distress									Spall Distress							
Material	Rep	Cnfg	Test Sectn	Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	A-Loss Rating (in)	Total Partl (in)	Total Partl (%)	Total Full (in)	Total Full (%)	Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	Total Prtl (in)	Total Prtl (%)	Total Full (in)	Total Full (%)
C-231	1	1	8	12	1	2	4	12.5	13	0.5	6	0.4	38	18	12	1	56	3.9	13	0.9
C-231	2	1	8	34	117	0	14	89.5	151	5.2	14	1.0	39	23	16	0	62	4.3	16	1.1
C-231	1	2	4	90	4	1	0	48	94	3.3	1	0.1	11	1	36	0	12	0.8	36	2.5
C-231	2	2	4	14	4	0	1	10	18	0.6	1	0.1	16	3	14	3	19	1.3	17	1.2
C-231	1	4	3	201	5	3	0	106	206	7.2	3	0.2	56	17	15	5	73	5.1	20	1.4
C-231	2	4	3	2	0	0	0	1	2	0.1	0	0.0	9	1	7	0	10	0.7	7	0.5
K-9005	1	1	1	833	874	20	45	918.5	1707	59.3	65	4.5	49	8	9	4	57	4.0	13	0.9
K-9005	2	1	1	297	1237	0	0	767	1534	53.3	0	0.0	23	2	1	2	25	1.7	3	0.2
K-9005	1	2	11	0	98	0	0	49	98	3.4	0	0.0	27	12	3	0	39	2.7	3	0.2
K-9005	2	2	11	0	47	0	0	23.5	47	1.6	0	0.0	17	2	1	4	19	1.3	5	0.3
K-9005	1	4	7	108	272	0	4	194	380	13.2	4	0.3	17	13	4	0	30	2.1	4	0.3
K-9005	2	4	7	36	136	0	0	86	172	6.0	0	0.0	31	22	3	0	53	3.7	3	0.2
K-9030	1	1	5	307	1113	27	110	847	1420	49.3	137	9.5	27	11	30	11	38	2.6	41	2.8
K-9030	2	1	5	658	694	47	53	776	1352	46.9	100	6.9	19	23	10	4	42	2.9	14	1.0
K-9030	1	2	9	562	75	37	9	364.5	637	22.1	46	3.2	31	11	21	12	42	2.9	33	2.3
K-9030	2	2	9	388	400	73	36	503	788	27.4	109	7.6	15	16	16	6	31	2.2	22	1.5
K-9030	1	4	13	485	176	35	32	397.5	661	23.0	67	4.7	42	21	17	8	63	4.4	25	1.7
K-9030	2	4	13	137	103	17	22	159	240	8.3	39	2.7	27	21	33	14	48	3.3	47	3.3
M-SS	1	1	6	203	1057	0	28	658	1260	43.8	28	1.9	45	22	19	6	67	4.7	25	1.7
M-SS	2	1	6	441	933	9	41	737	1374	47.7	50	3.5	22	13	6	2	35	2.4	8	0.6
M-SS	1	2	2	498	209	15	17	385.5	707	24.5	32	2.2	57	46	25	16	103	7.2	41	2.8
M-SS	2	2	2	94	54	2	4	80	148	5.1	6	0.4	9	4	26	2	13	0.9	28	1.9
M-SS	1	4	14	13	15	8	9	31	28	1.0	17	1.2	59	37	14	8	96	6.7	22	1.5
M-SS	2	4	14	2	24	2	5	20	26	0.9	7	0.5	51	36	31	12	87	6.0	43	3.0
D-888	1	1	10	4	4	0	0	4	8	0.3	0	0.0	97	63	11	2	160	11.1	13	0.9
D-888	2	1	10	0	0	0	0	0	0	0.0	0	0.0	33	40	18	7	73	5.1	25	1.7
D-888-SL	1	1	15	0	0	0	0	0	0	0.0	0	0.0	55	31	12	2	86	6.0	14	1.0
D-888-SL	2	1	15	1	0	0	0	0.5	1	0.0	0	0.0	35	39	8	7	74	5.1	15	1.0
M-960-SL	1	1	12	8	9	0	2	10.5	17	0.6	2	0.1	52	42	5	0	94	6.5	5	0.3
M-960-SL	2	1	12	0	0	0	0	0	0	0.0	0	0.0	39	33	46	12	73	5.1	58	4.0
K-9050	1	1	16	1	45	88	455	566	46	1.6	543	37.7	43	15	5	0	58	4.0	5	0.3
K-9050	2	1	16	1	19	22	290	322	20	0.7	312	21.7	33	25	11	7	58	4.0	18	1.3

Table D-2. Summary of distresses at Colorado I-25 site (cont.)

				Overband Wear								Stone Intrusion			Sunken Sealant					
Material	Rep	Cnfg	Test Sectn	Thick <50% (in)	Thick <50% (%)	Thick <10% (in)	Thick <10% (%)	Edge Left (in)	Edge Left (%)	Edge Right (in)	Edge Right (%)	Single Stones (#)	Filled w/ stns (in)	Filled w/ stns (%)	Low (in)	Low (%)	Med (in)	Med (%)	High (in)	High (%)
C-231	1	1	8	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	1	0.1	2	0.1
C-231	2	1	8	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
C-231	1	2	4	528	36.7	468	32.5	284	19.7	18	1.3	4	0	0.0	6	0.4	2	0.1	0	0.0
C-231	2	2	4	552	38.3	540	37.5	447	31.0	270	18.8	3	0	0.0	6	0.4	0	0.0	1	0.1
C-231	1	4	3	0	0.0	0	0.0	0	0.0	0	0.0	20	0	0.0	0	0.0	0	0.0	6	0.4
C-231	2	4	3	552	38.3	420	29.2	290	20.1	216	15.0	26	0	0.0	0	0.0	0	0.0	0	0.0
K-9005	1	1	1	0	0.0	0	0.0	0	0.0	0	0.0	3	575	39.9	0	0.0	0	0.0	5	0.3
K-9005	2	1	1	0	0.0	0	0.0	0	0.0	0	0.0	25	1029	71.5	0	0.0	0	0.0	9	0.6
K-9005	1	2	11	108	7.5	1332	92.5	1326	92.1	1242	86.3	666	4	0.3	1252	86.9	8	0.6	0	0.0
K-9005	2	2	11	36	2.5	1404	97.5	1316	91.4	1304	90.6	846	7	0.5	1299	90.2	32	2.2	8	0.6
K-9005	1	4	7	0	0.0	0	0.0	0	0.0	0	0.0	528	84	5.8	0	0.0	0	0.0	0	0.0
K-9005	2	4	7	0	0.0	8	0.6	0	0.0	0	0.0	1044	3	0.2	30	2.1	19	1.3	23	1.6
K-9030	1	1	5	0	0.0	0	0.0	0	0.0	0	0.0	0	169	11.7	0	0.0	0	0.0	0	0.0
K-9030	2	1	5	0	0.0	0	0.0	0	0.0	0	0.0	0	178	12.4	0	0.0	0	0.0	0	0.0
K-9030	1	2	9	120	8.3	1272	88.3	830	57.6	341	23.7	1	0	0.0	6	0.4	0	0.0	0	0.0
K-9030	2	2	9	132	9.2	1308	90.8	1132	78.6	1034	71.8	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9030	1	4	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	6	0.4	5	0.3	2	0.1
K-9030	2	4	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	2	0.1	3	0.2
M-SS	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	490	34.0	0	0.0	0	0.0	0	0.0
M-SS	2	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	170	11.8	0	0.0	2	0.1	3	0.2
M-SS	1	2	2	0	0.0	1404	97.5	1132	78.6	962	66.8	0	0	0.0	1426	99.0	12	0.8	2	0.1
M-SS	2	2	2	84	5.8	1344	93.3	847	58.8	739	51.3	4	3	0.2	79	5.5	220	15.3	1006	69.9
M-SS	1	4	14	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	114	7.9	198	13.8	81	5.6
M-SS	2	4	14	0	0.0	0	0.0	0	0.0	0	0.0	0	10	0.7	708	49.2	225	15.6	97	6.7
D-888	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	0	0.0	0	0.0	0	0.0
D-888	2	1	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	2	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
M-960-SL	1	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	24	1.7	1	0.1	0	0.0
M-960-SL	2	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9050	1	1	16	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9050	2	1	16	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	0	0.0	2	0.1	0	0.0

Table D-3. Summary of distresses at Iowa I-80 site

Material	Cnfg	Rep	Test Sectn	Adhesion Loss: Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	A-Loss Rating (in)	A-Loss Rating (%)	Total Partl (in)	Total Partl (%)	Total Full (in)	Total Full (%)	Spall Failure: Partl Left (in)	Partl Right (in)	Full Left (in)	Full Right (in)	Total Partl (in)	Total Partl (%)	Total Full (in)	Total Full (%)
C-231	1	1	9	0	9	0	0	4.5	0.3	9	0.3	0	0.0	47	44	1	0	91	6.3	1	0.1
C-231	1	2	9	74	13	7	1	1	0.1	87	3.0	8	0.6	37	44	6	4	81	5.6	10	0.7
C-231	2	1	5	7	6	4	1	3	0.2	13	0.5	5	0.3	16	9	1	2	25	1.7	3	0.2
C-231	2	2	5	3	2	1	0	0	0.0	5	0.2	1	0.1	10	9	3	0	19	1.3	3	0.2
C-231	3	1	3	8	4	2	0	4.5	0.3	12	0.4	2	0.1	15	11	0	0	26	1.8	0	0.0
C-231	3	2	3	0	0	0	0	0	0.0	0	0.0	0	0.0	8	4	0	0	12	0.8	0	0.0
K-9005	1	1	1	910	725	4	0	167	11.6	1635	56.8	4	0.3	9	15	3	4	24	1.7	7	0.5
K-9005	1	2	1	828	828	0	0	27.5	1.9	1656	57.5	0	0.0	0	5	2	0	5	0.3	2	0.1
K-9005	2	1	12	0	0	0	0	0	0.0	0	0.0	0	0.0	16	27	0	0	43	3.0	0	0.0
K-9005	2	2	12	0	0	0	0	0	0.0	0	0.0	0	0.0	8	15	1	3	23	1.6	4	0.3
K-9005	3	1	8	0	0	0	0	0	0.0	0	0.0	0	0.0	18	23	0	3	41	2.8	3	0.2
K-9005	3	2	8	0	0	1	1	0	0.0	0	0.0	2	0.1	15	26	1	2	41	2.8	3	0.2
K-9030	1	1	6	87	80	0	0	0	0.0	167	5.8	0	0.0	68	91	0	1	159	11.0	1	0.1
K-9030	1	2	6	140	28	1	1	0	0.0	168	5.8	2	0.1	35	67	6	3	102	7.1	9	0.6
K-9030	2	1	10	39	9	11	3	9	0.6	48	1.7	14	1.0	24	25	20	16	49	3.4	36	2.5
K-9030	2	2	10	8	0	0	1	0	0.0	8	0.3	1	0.1	6	10	16	24	16	1.1	40	2.8
K-9030	3	1	14	1	1	21	14	1	0.1	2	0.1	35	2.4	13	6	6	6	19	1.3	12	0.8
K-9030	3	2	14	2	0	17	4	0	0.0	2	0.1	21	1.5	7	7	11	8	14	1.0	19	1.3
M-SS	1	1	7	451	255	22	12	235.5	16.4	706	24.5	34	2.4	76	87	7	7	163	11.3	14	1.0
M-SS	1	2	7	438	21	33	0	39.5	2.7	459	15.9	33	2.3	49	90	3	5	139	9.7	8	0.6
M-SS	2	1	2	114	12	0	0	2	0.1	126	4.4	0	0.0	48	78	1	1	126	8.8	2	0.1
M-SS	2	2	2	71	12	1	3	0.5	0.0	83	2.9	4	0.3	72	45	9	7	117	8.1	16	1.1
M-SS	3	1	15	22	9	8	10	1	0.1	31	1.1	18	1.3	20	18	3	5	38	2.6	8	0.6
M-SS	3	2	15	0	1	0	0	0	0.0	1	0.0	0	0.0	19	18	13	5	37	2.6	18	1.3
D-888	1	1	11	0	1	0	0	0	0.0	1	0.0	0	0.0	88	102	11	10	190	13.2	21	1.5
D-888	1	2	11	0	0	0	0	0	0.0	0	0.0	0	0.0	60	103	4	3	163	11.3	7	0.5
D-888-SL	1	1	16	50	25	0	0	0	0.0	75	2.6	0	0.0	33	44	13	22	77	5.3	35	2.4
D-888-SL	1	2	16	0	0	0	0	0	0.0	0	0.0	0	0.0	69	66	4	4	135	9.4	8	0.6
M-960-SL	1	1	13	0	0	3	10	5	0.3	0	0.0	13	0.9	41	67	29	33	108	7.5	62	4.3
M-960-SL	1	2	13	1	1	3	1	4	0.3	2	0.1	4	0.3	55	65	6	19	120	8.3	25	1.7
M-960	1	1	17	45	8	1	2	0	0.0	53	1.8	3	0.2	74	59	8	7	133	9.2	15	1.0
M-960	1	2	17	0	0	0	0	0	0.0	0	0.0	0	0.0	110	136	3	8	246	17.1	11	0.8
D-888-P	1	2	4	0	0	0	0	0	0.0	0	0.0	0	0.0	158	118	5	6	276	19.2	11	0.8
D-888-SL-P	1	1	4	0	0	0	0	0	0.0	0	0.0	0	0.0	62	83	1	5	145	10.1	6	0.4

Table D-3. Summary of distresses at Iowa I-80 site (cont.)

				Overband Wear								Stone Intrusion			Sunken Sealant					
Material	Cnfg	Rep	Test Sectn	Thick < 50% (in)	Thick < 50% (%)	Thick < 10% (in)	Thick < 10% (%)	Edge Left (in)	Edge Left (%)	Edge Right (in)	Edge Right (%)	Single Stones (#)	Filled w/ stns (in)	Filled w/ stns (%)	Low (in)	Low (%)	Med (in)	Med (%)	High (in)	High (%)
C-231	1	1	9	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
C-231	1	2	9	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
C-231	2	1	5	444	30.8	816	56.7	556	38.6	244	16.9	2	0	0.0	83	5.8	0	0.0	0	0.0
C-231	2	2	5	396	27.5	519	36.0	169	11.7	113	7.8	1	0	0.0	16	1.1	20	1.4	1	0.1
C-231	3	1	3	372	25.8	900	62.5	789	54.8	615	42.7	2	0	0.0	4	0.3	13	0.9	1	0.1
C-231	3	2	3	288	20.0	732	50.8	325	22.6	250	17.4	4	0	0.0	4	0.3	5	0.3	0	0.0
K-9005	1	1	1	0	0.0	0	0.0	1	0.1	0	0.0	19	121	8.4	0	0.0	0	0.0	19	1.3
K-9005	1	2	1	0	0.0	0	0.0	0	0.0	0	0.0	11	1	0.1	0	0.0	0	0.0	2	0.1
K-9005	2	1	12	0	0.0	1440	100.0	1200	83.3	1200	83.3	62	33	2.3	22	1.5	281	19.5	1080	75.0
K-9005	2	2	12	0	0.0	1440	100.0	1200	83.3	1200	83.3	38	21	1.5	115	8.0	250	17.4	1016	70.6
K-9005	3	1	8	156	10.8	1284	89.2	1165	80.9	1105	76.7	26	0	0.0	344	23.9	340	23.6	272	18.9
K-9005	3	2	8	216	15.0	1080	75.0	900	62.5	900	62.5	29	2	0.1	118	8.2	619	43.0	512	35.6
K-9030	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	21	1.5	36	2.5	0	0.0
K-9030	1	2	6	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
K-9030	2	1	10	288	20.0	1152	80.0	957	66.5	598	41.5	0	0	0.0	18	1.3	0	0.0	0	0.0
K-9030	2	2	10	252	17.5	1176	81.7	659	45.8	556	38.6	0	0	0.0	12	0.8	31	2.2	11	0.8
K-9030	3	1	14	288	20.0	1152	80.0	666	46.3	403	28.0	0	0	0.0	0	0.0	1	0.1	2	0.1
K-9030	3	2	14	360	25.0	948	65.8	385	26.7	370	25.7	0	0	0.0	0	0.0	0	0.0	0	0.0
M-SS	1	1	7	0	0.0	0	0.0	0	0.0	0	0.0	0	14	1.0	0	0.0	0	0.0	0	0.0
M-SS	1	2	7	0	0.0	0	0.0	0	0.0	0	0.0	0	8	0.6	22	1.5	23	1.6	1	0.1
M-SS	2	1	2	84	5.8	1356	94.2	1080	75.0	952	66.1	0	0	0.0	26	1.8	1380	95.8	0	0.0
M-SS	2	2	2	216	15.0	1224	85.0	696	48.3	471	32.7	2	0	0.0	22	1.5	1370	95.1	4	0.3
M-SS	3	1	15	264	18.3	1176	81.7	973	67.6	865	60.1	0	0	0.0	0	0.0	1428	99.2	6	0.4
M-SS	3	2	15	180	12.5	1260	87.5	747	51.9	682	47.4	1	0	0.0	1411	98.0	24	1.7	1	0.1
D-888	1	1	11	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888	1	2	11	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	16	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	1	0.1	0	0.0
D-888-SL	1	2	16	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	2	0.1
M-960-SL	1	1	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
M-960-SL	1	2	13	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	1	0.1	0	0.0
M-960	1	1	17	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
M-960	1	2	17	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-P	1	2	4	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL-P	1	1	4	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0

Table D-4. Summary of distresses at Kentucky Rte 127 site

				Overband Wear								Stone Intrusion			Sunken Sealant					
			Test	Thick < 50%	Thick < 50%	Thick < 10%	Thick < 10%	Edge Left	Edge Left	Edge Right	Edge Right	Single Stones	Filled w/ stns	Filled w/ stns	Low	Low	Med	Med	High	High
Material	Confg	Rep	Sectn	(in)	(%)	(in)	(%)	(in)	(%)	(in)	(%)	(#)	(in)	(%)	(in)	(%)	(in)	(%)	(in)	(%)
C-231	1	1	7	0	0.0	0	0.0	0	0.0	0	0.0	25	31	2.2	0	0.0	2	0.1	0	0.0
C-231	1	2	7	0	0.0	0	0.0	0	0.0	0	0.0	75	26	1.8	0	0.0	3	0.2	0	0.0
C-231	2	1	3	228	15.8	0	0.0	63	4.4	0	0.0	318	0	0.0	4	0.3	1	0.1	0	0.0
C-231	2	2	3	684	47.5	24	1.7	8	0.6	0	0.0	97	1	0.1	135	9.4	105	7.3	0	0.0
C-231	3	1	5	24	1.7	0	0.0	0	0.0	0	0.0	171	0	0.0	28	1.9	20	1.4	0	0.0
C-231	3	2	5	360	25.0	0	0.0	0	0.0	0	0.0	229	0	0.0	0	0.0	19	1.3	0	0.0
K-9005	1	1	1	0	0.0	0	0.0	0	0.0	0	0.0	189	54	3.8	8	0.6	7	0.5	6	0.4
K-9005	1	2	1	0	0.0	0	0.0	0	0.0	0	0.0	375	10	0.7	0	0.0	12	0.8	104	7.2
K-9005	2	1	11	672	46.7	660	45.8	0	0.0	182	12.6	508	418	29.0	162	11.3	224	15.6	1	0.1
K-9005	2	2	11	312	21.7	1044	72.5	18	1.3	0	0.0	305	0	0.0	659	45.8	486	33.8	0	0.0
K-9005	3	1	8	636	44.2	636	44.2	376	26.1	0	0.0	385	0	0.0	720	50.0	573	39.8	0	0.0
K-9005	3	2	8	372	25.8	792	55.0	358	24.9	12	0.8	465	18	1.3	820	56.9	139	9.7	0	0.0
K-9030	1	1	4	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	6	0.4
K-9030	1	2	4	0	0.0	0	0.0	0	0.0	0	0.0	30	8	0.6	119	8.3	5	0.3	0	0.0
K-9030	2	1	9	108	7.5	1032	71.7	671	46.6	570	39.6	26	0	0.0	370	25.7	48	3.3	1	0.1
K-9030	2	2	9	276	19.2	264	18.3	119	8.3	0	0.0	15	0	0.0	94	6.5	81	5.6	0	0.0
K-9030	3	1	13	258	17.9	816	56.7	6	0.4	249	17.3	13	0	0.0	22	1.5	0	0.0	0	0.0
K-9030	3	2	13	204	14.2	454	31.5	175	12.2	20	1.4	48	0	0.0	0	0.0	0	0.0	0	0.0
M-SS	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	4	0.3	98	6.8
M-SS	1	2	6	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	4	0.3	34	2.4
M-SS	2	1	2	84	5.8	1284	89.2	101	7.0	21	1.5	21	754	52.4	65	4.5	203	14.1	0	0.0
M-SS	2	2	2	336	23.3	972	67.5	505	35.1	307	21.3	12	167	11.6	227	15.8	370	25.7	0	0.0
M-SS	3	1	14	372	25.8	468	32.5	0	0.0	319	22.2	34	46	3.2	114	7.9	738	51.3	0	0.0
M-SS	3	2	14	48	3.3	516	35.8	0	0.0	0	0.0	23	11	0.8	293	20.3	7	0.5	0	0.0
D-888	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	1	0.1
D-888	1	2	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	3	0.2	2	0.1
D-888-SL	1	2	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	1	0.1	1	0.1
M-960-SL	1	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	14	1.0	2	0.1
M-960-SL	1	2	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	2	0.1	8	0.6		0.0
K-9050	1	1	17	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	2	0.1	1	0.1		0.0
K-9005-P	1	1	16	0	0.0	0	0.0	0	0.0	0	0.0	161	50	3.5	0	0.0	47	3.3		0.0

Table D-4. Summary of distresses at Kentucky Rte 127 site (cont.)

				Overband Wear								Stone Intrusion			Sunken Sealant					
Material	Confg	Rep	Test Sectn	Thick < 50% (in)	Thick < 50% (%)	Thick < 10% (in)	Thick < 10% (%)	Edge Left (in)	Edge Left (%)	Edge Right (in)	Edge Right (%)	Single Stones (#)	Filled w/ stns (in)	Filled w/ stns (%)	Low (in)	Low (%)	Med (in)	Med (%)	High (in)	High (%)
C-231	1	1	7	0	0.0	0	0.0	0	0.0	0	0.0	25	31	2.2	0	0.0	2	0.1	0	0.0
C-231	1	2	7	0	0.0	0	0.0	0	0.0	0	0.0	75	26	1.8	0	0.0	3	0.2	0	0.0
C-231	2	1	3	228	15.8	0	0.0	63	4.4	0	0.0	318	0	0.0	4	0.3	1	0.1	0	0.0
C-231	2	2	3	684	47.5	24	1.7	8	0.6	0	0.0	97	1	0.1	135	9.4	105	7.3	0	0.0
C-231	3	1	5	24	1.7	0	0.0	0	0.0	0	0.0	171	0	0.0	28	1.9	20	1.4	0	0.0
C-231	3	2	5	360	25.0	0	0.0	0	0.0	0	0.0	229	0	0.0	0	0.0	19	1.3	0	0.0
K-9005	1	1	1	0	0.0	0	0.0	0	0.0	0	0.0	189	54	3.8	8	0.6	7	0.5	6	0.4
K-9005	1	2	1	0	0.0	0	0.0	0	0.0	0	0.0	375	10	0.7	0	0.0	12	0.8	104	7.2
K-9005	2	1	11	672	46.7	660	45.8	0	0.0	182	12.6	508	418	29.0	162	11.3	224	15.6	1	0.1
K-9005	2	2	11	312	21.7	1044	72.5	18	1.3	0	0.0	305	0	0.0	659	45.8	486	33.8	0	0.0
K-9005	3	1	8	636	44.2	636	44.2	376	26.1	0	0.0	385	0	0.0	720	50.0	573	39.8	0	0.0
K-9005	3	2	8	372	25.8	792	55.0	358	24.9	12	0.8	465	18	1.3	820	56.9	139	9.7	0	0.0
K-9030	1	1	4	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	6	0.4
K-9030	1	2	4	0	0.0	0	0.0	0	0.0	0	0.0	30	8	0.6	119	8.3	5	0.3	0	0.0
K-9030	2	1	9	108	7.5	1032	71.7	671	46.6	570	39.6	26	0	0.0	370	25.7	48	3.3	1	0.1
K-9030	2	2	9	276	19.2	264	18.3	119	8.3	0	0.0	15	0	0.0	94	6.5	81	5.6	0	0.0
K-9030	3	1	13	258	17.9	816	56.7	6	0.4	249	17.3	13	0	0.0	22	1.5	0	0.0	0	0.0
K-9030	3	2	13	204	14.2	454	31.5	175	12.2	20	1.4	48	0	0.0	0	0.0	0	0.0	0	0.0
M-SS	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	4	0.3	98	6.8
M-SS	1	2	6	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	4	0.3	34	2.4
M-SS	2	1	2	84	5.8	1284	89.2	101	7.0	21	1.5	21	754	52.4	65	4.5	203	14.1	0	0.0
M-SS	2	2	2	336	23.3	972	67.5	505	35.1	307	21.3	12	167	11.6	227	15.8	370	25.7	0	0.0
M-SS	3	1	14	372	25.8	468	32.5	0	0.0	319	22.2	34	46	3.2	114	7.9	738	51.3	0	0.0
M-SS	3	2	14	48	3.3	516	35.8	0	0.0	0	0.0	23	11	0.8	293	20.3	7	0.5	0	0.0
D-888	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	1	0.1
D-888	1	2	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	3	0.2	2	0.1
D-888-SL	1	2	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	1	0.1	1	0.1
M-960-SL	1	1	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	14	1.0	2	0.1
M-960-SL	1	2	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	2	0.1	8	0.6		0.0
K-9050	1	1	17	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	2	0.1	1	0.1		0.0
K-9005-P	1	1	16	0	0.0	0	0.0	0	0.0	0	0.0	161	50	3.5	0	0.0	47	3.3		0.0

Table D-5. Summary of distresses at South Carolina I-77 site

Material	Cnfg	Rep	Test Secn	Overband Wear: Thick < 50% (in)	Overband Wear: Thick < 50% (%)	Overband Wear: Thick < 10% (in)	Overband Wear: Thick < 10% (%)	Overband Wear: Edge Left (in)	Overband Wear: Edge Left (%)	Overband Wear: Edge Right (in)	Overband Wear: Edge Right (%)	Stone Intrusion: Single Stones (#)	Stone Intrusion: Filled w/ stns (in)	Stone Intrusion: Filled w/ stns (%)	Sunken Sealant: Low (in)	Sunken Sealant: Low (%)	Sunken Sealant: Med (in)	Sunken Sealant: Med (%)	Sunken Sealant: High (in)	Sunken Sealant: High (%)
C-231	1	1	8	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	2	0.1	19	1.3
C-231	1	2	8	0	0.0	0	0.0	0	0.0	0	0.0	4	0	0.0	0	0.0	2	0.1	2	0.1
C-231	2	1	4	732	50.8	216	15.0	297	20.6	45	3.1	6	0	0.0	11	0.8	8	0.6	0	0.0
C-231	2	2	4	600	41.7	552	38.3	516	35.8	131	9.1	9	0	0.0	0	0.0	3	0.2	0	0.0
C-231	3	1	3	480	33.3	888	61.7	839	58.3	419	29.1	7	0	0.0	232	16.1	168	11.7	66	4.6
C-231	3	2	3	252	17.5	480	33.3	403	28.0	99	6.9	10	0	0.0	0	0.0	8	0.6	13	0.9
K-9005	1	1	1	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	2	0.1	13	0.9
K-9005	1	2	1	0	0.0	0	0.0	0	0.0	0	0.0	19	0	0.0	0	0.0	5	0.3	11	0.8
K-9005	2	1	11	96	6.7	1308	90.8	0	0.0	0	0.0	12	0	0.0	263	18.3	1046	72.6	131	9.1
K-9005	2	2	11	216	15.0	1224	85.0	1179	81.9	550	38.2	17	0	0.0	960	66.7	424	29.4	26	1.8
K-9005	3	1	7	384	26.7	984	68.3	108	7.5	60	4.2	8	0	0.0	234	16.3	233	16.2	150	10.4
K-9005	3	2	7	228	15.8	1152	80.0	1109	77.0	420	29.2	4	0	0.0	564	39.2	249	17.3	60	4.2
K-9030	1	1	5	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	6	0.4	4	0.3
K-9030	1	2	5	0	0.0	0	0.0	0	0.0	0	0.0	2	0	0.0	0	0.0	0	0.0	1	0.1
K-9030	2	1	9	312	21.7	1116	77.5	0	0.0	0	0.0	1	0	0.0	1421	98.7	17	1.2	2	0.1
K-9030	2	2	9	552	38.3	744	51.7	752	52.2	437	30.3	4	0	0.0	344	23.9	44	3.1	6	0.4
K-9030	3	1	13	528	36.7	781	54.2	887	61.6	592	41.1	0	0	0.0	366	25.4	56	3.9	0	0.0
K-9030	3	2	13	420	29.2	696	48.3	873	60.6	551	38.3	1	0	0.0	162	11.3	3	0.2	8	0.6
M-SS	1	1	6	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	4	0.3
M-SS	1	2	6	0	0.0	0	0.0	0	0.0	0	0.0	4	0	0.0	0	0.0	28	1.9	2	0.1
M-SS	2	1	2	132	9.2	1284	89.2	1044	72.5	475	33.0	0	0	0.0	162	11.3	1278	88.8	0	0.0
M-SS	2	2	2	636	44.2	780	54.2	508	35.3	257	17.8	0	0	0.0	0	0.0	1440	100.0	0	0.0
M-SS	3	1	14	108	7.5	1380	95.8	1327	92.2	1292	89.7	0	0	0.0	1296	90.0	0	0.0	0	0.0
M-SS	3	2	14	192	13.3	1176	81.7	1180	81.9	967	67.2	2	0	0.0	1284	89.2	8	0.6	6	0.4
D-888	1	1	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	2	0.1	0	0.0	0	0.0
D-888	1	2	10	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	0	0.0	0	0.0
D-888-SL	1	1	15	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	38	2.6	2	0.1	14	1.0
D-888-SL	1	2	15	0	0.0	0	0.0	0	0.0	0	0.0	4	0	0.0	2	0.1	18	1.3	0	0.0
M-960-SL	1	1	12	0	0.0	0	0.0	0	0.0	0	0.0	1	0	0.0	0	0.0	10	0.7	0	0.0
M-960-SL	1	2	12	0	0.0	0	0.0	0	0.0	0	0.0	0	0	0.0	0	0.0	7	0.5	1	0.1

Table D-5. Summary of distresses at South Carolina I-77 site (cont.)

Material	Cnfg	Rep	Test Sectn	Adhesion Loss Partl Left (in)	Adhesion Loss Partl Right (in)	Adhesion Loss Full Left (in)	Adhesion Loss Full Right (in)	Adhesion Loss A-Loss Rating (in)	Adhesion Loss A-Loss Rating (%)	Adhesion Loss Total Partl (in)	Adhesion Loss Total Partl (%)	Adhesion Loss Total Full (in)	Adhesion Loss Total Full (%)	Spall Distress Partl Left (in)	Spall Distress Partl Right (in)	Spall Distress Full Left (in)	Spall Distress Full Right (in)	Spall Distress Total Prtl (in)	Spall Distress Total Prtl (%)	Spall Distress Total Full (in)	Spall Distress Total Full (%)
C-231	1	1	8	817	827	0	0	0	0.0	0	57.1	0	0.0	0	2	0	0	2	0.1	0	0.0
C-231	1	2	8	82	68	0	0	75	5.2	150	5.2	0	0.0	1	1	0	0	2	0.1	0	0.0
C-231	2	1	4	0	0	0	0	0	0.0	0	0.0	0	0.0	0	0	0	0	0	0.0	0	0.0
C-231	2	2	4	3	1	0	0	2	0.1	4	0.1	0	0.0	0	0	0	0	0	0.0	0	0.0
C-231	3	1	3	54	43	90	40	175	12.2	98	3.4	126	8.8	3	1	3	0	4	0.3	3	0.2
C-231	3	2	3	5	0	3	2	8	0.5	5	0.2	5	0.3	0	0	12	7	0	0.0	19	1.3
K-9005	1	1	1	805	686	7	11	766	53.2	1491	51.8	20	1.4	2	2	3	0	4	0.3	3	0.2
K-9005	1	2	1	1138	951	33	0	1078	74.8	2089	72.5	33	2.3	0	1	4	5	1	0.1	9	0.6
K-9005	2	1	11	0	0	1	0	0	0.0	0	0.0	0	0.0	0	0	6	0	0	0.0	6	0.4
K-9005	2	2	11	1	1	0	0	1	0.0	1	0.1	0	0.0	0	0	0	1	0	0.0	1	0.1
K-9005	3	1	7	3	6	150	138	331	23.0	0	0.3	331	23.0	0	0	1	0	0	0.0	1	0.1
K-9005	3	2	7	3	1	129	90	221	15.3	4	0.1	219	15.2	2	0	1	0	2	0.1	1	0.1
K-9030	1	1	5	1278	1249	20	16	1302	90.4	2537	87.7	33	2.3	2	0	0	0	2	0.1	0	0.0
K-9030	1	2	5	939	805	57	43	971	67.4	1744	60.6	99	6.9	3	1	0	0	4	0.3	0	0.0
K-9030	2	1	9	10	4	7	18	24	1.6	9	0.5	19	1.3	0	0	0	0	0	0.0	0	0.0
K-9030	2	2	9	115	23	48	32	147	10.2	131	4.8	81	5.6	0	0	9	0	0	0.0	9	0.6
K-9030	3	1	13	3	0	287	193	489	33.9	3	0.1	487	33.8	0	0	0	0	0	0.0	0	0.0
K-9030	3	2	13	0	0	522	226	705	49.0	0	0.0	705	49.0	0	0	6	8	0	0.0	14	1.0
M-SS	1	1	6	899	917	0	2	909	63.1	1813	63.1	2	0.1	0	3	0	0	3	0.2	0	0.0
M-SS	1	2	6	1056	925	22	5	1013	70.3	1971	68.8	27	1.9	4	0	7	0	4	0.3	7	0.5
M-SS	2	1	2	28	14	21	9	30	2.0	31	1.5	14	1.0	0	0	1	0	0	0.0	1	0.1
M-SS	2	2	2	266	63	33	1	199	13.8	329	11.4	34	2.4	1	1	0	0	2	0.1	0	0.0
M-SS	3	1	14	47	47	75	34	190	13.2	171	3.3	104	7.2	2	0	0	0	2	0.1	0	0.0
M-SS	3	2	14	1	0	208	39	230	16.0	0	0.0	230	16.0	0	0	0	1	0	0.0	1	0.1
D-888	1	1	10	0	0	2	0	0	0.0	0	0.0	0	0.0	4	2	5	5	6	0.4	10	0.7
D-888	1	2	10	0	0	0	0	0	0.0	0	0.0	0	0.0	0	2	4	3	2	0.1	7	0.5
D-888-SL	1	1	15	0	0	0	0	0	0.0	0	0.0	0	0.0	1	1	0	0	2	0.1	0	0.0
D-888-SL	1	2	15	0	0	0	0	0	0.0	0	0.0	0	0.0	1	0	0	7	1	0.1	7	0.5
M-960-SL	1	1	12	0	0	0	0	0	0.0	0	0.0	0	0.0	5	2	7	0	7	0.5	7	0.5
M-960-SL	1	2	12	0	0	1	1	2	0.1	0	0.0	2	0.1	0	0	0	15	0	0.0	15	1.0

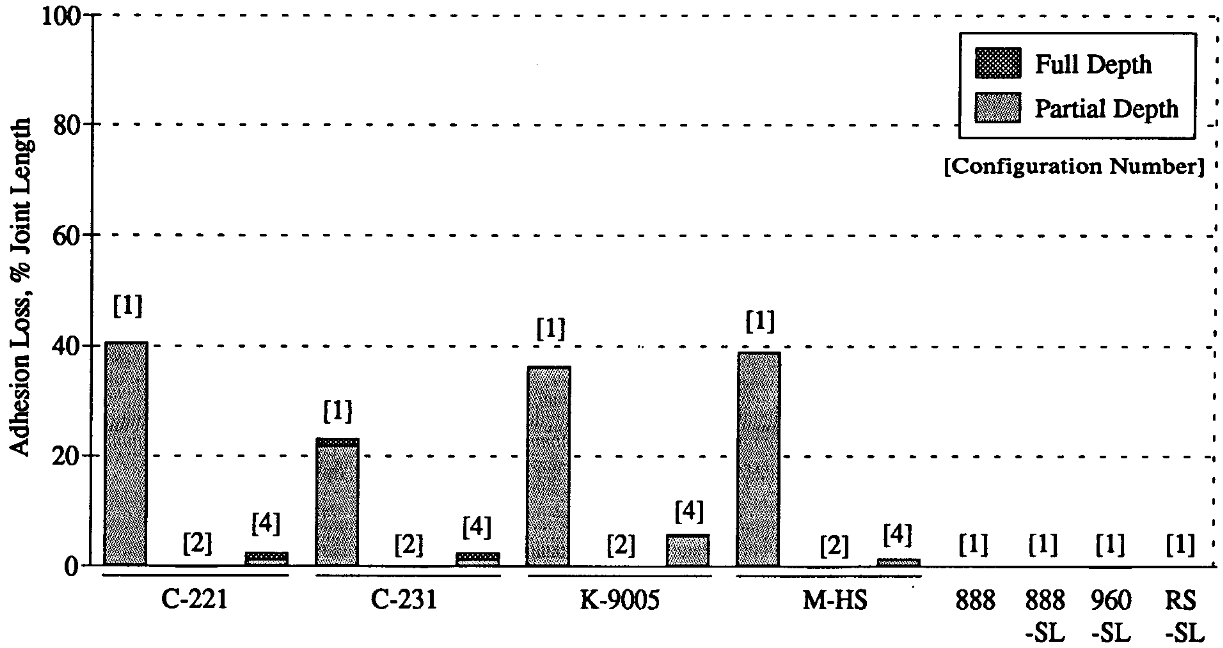

Figure D-2. Joint seal adhesion loss at Arizona I-17 site after 18 months

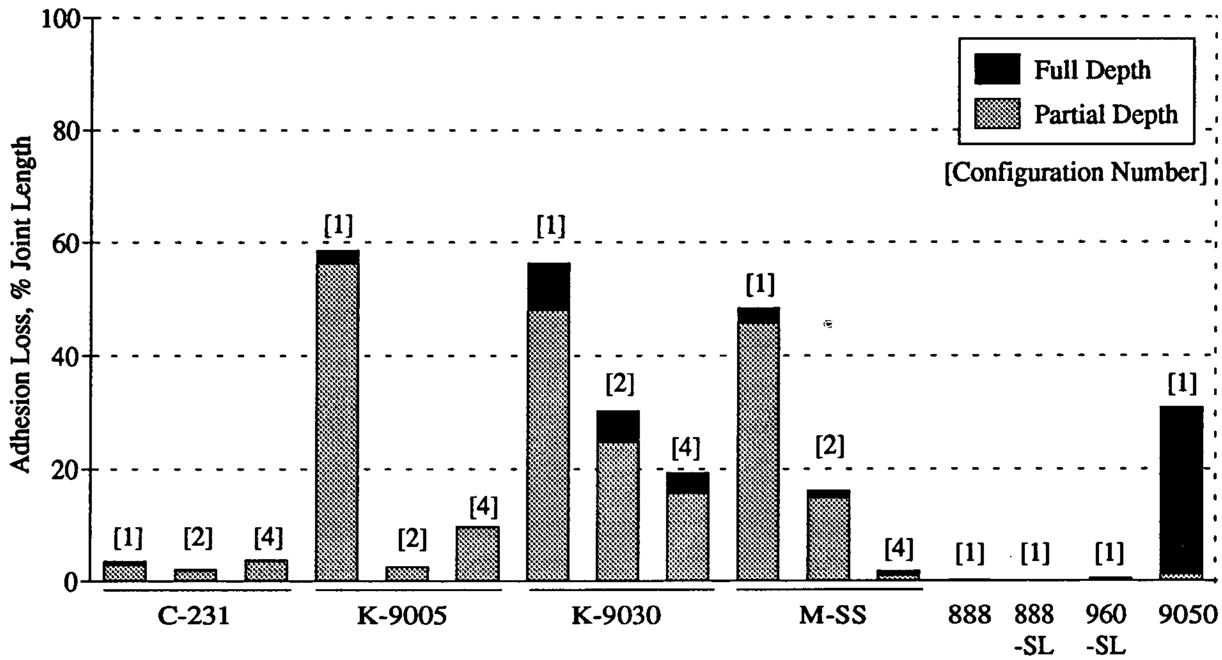

Figure D-3. Joint seal adhesion loss at Colorado I-25 site after 18 months

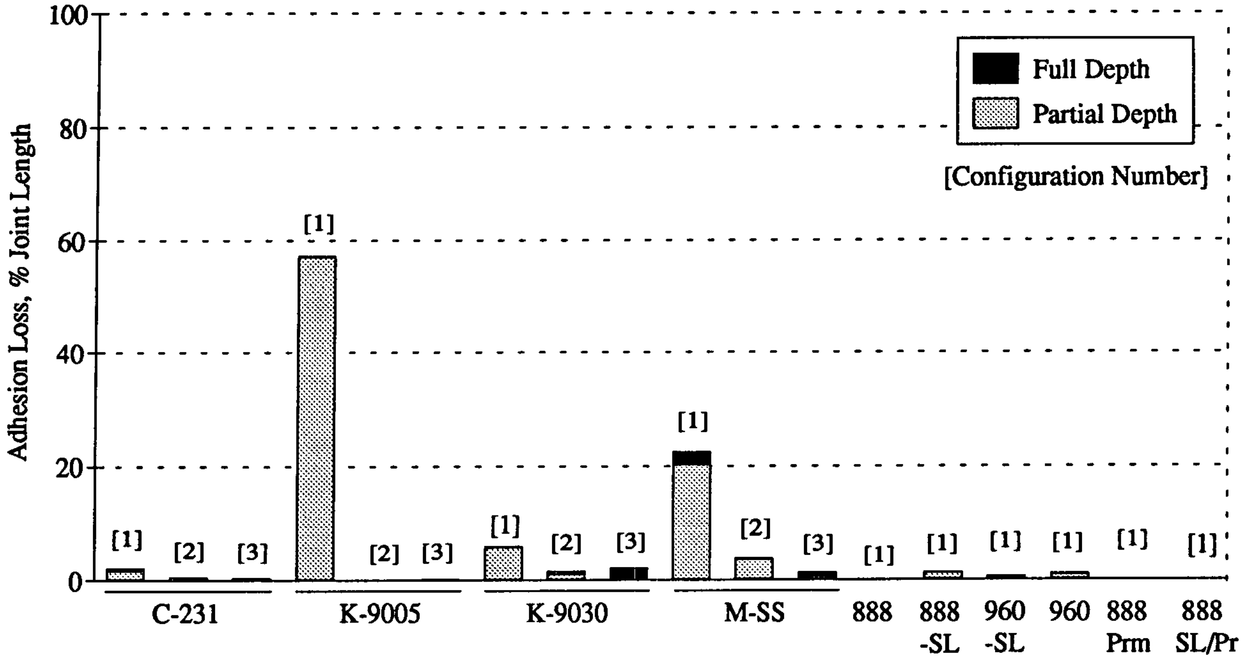

Figure D-4. Joint seal adhesion loss at Iowa I-80 site after 18 months

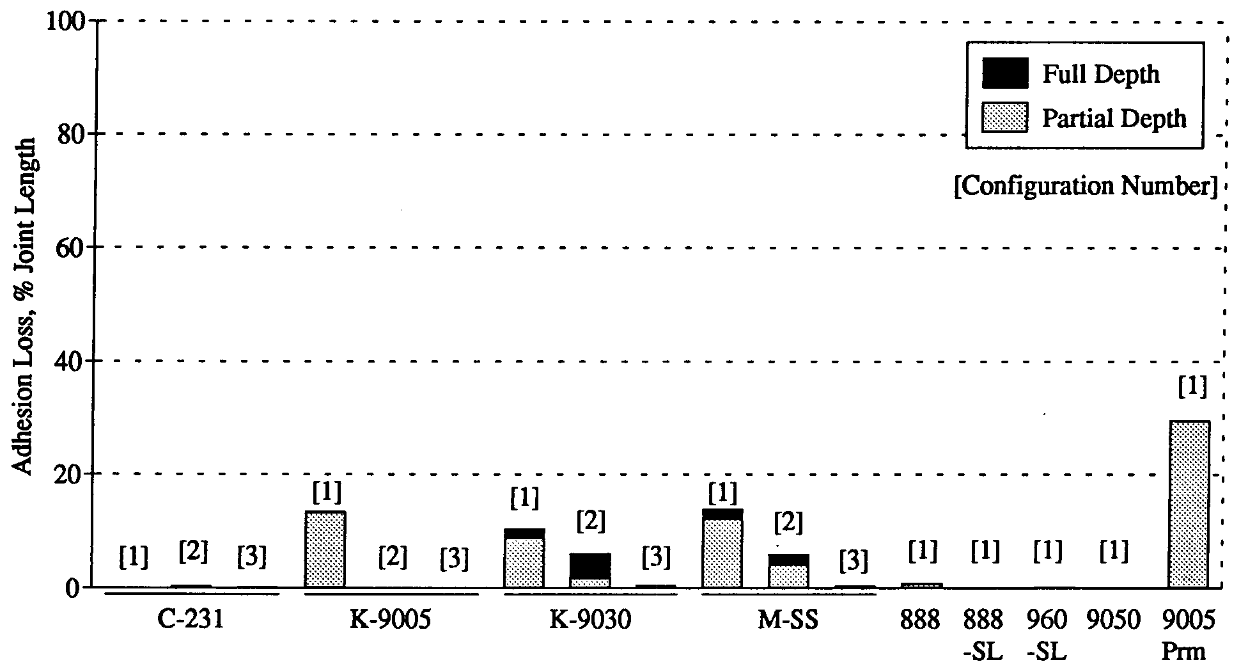

Figure D-5. Joint seal adhesion loss at Kentucky Rte 127 site after 18 months

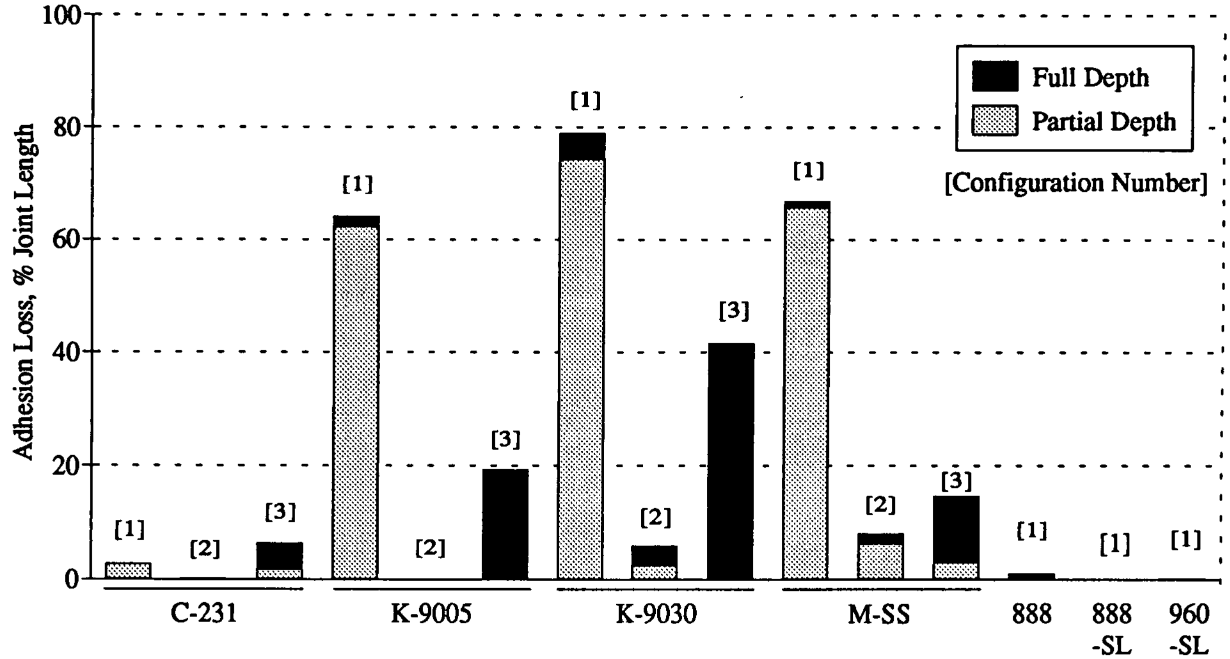

Figure D-6. Joint seal adhesion loss at South Carolina I-77 site after 18 months

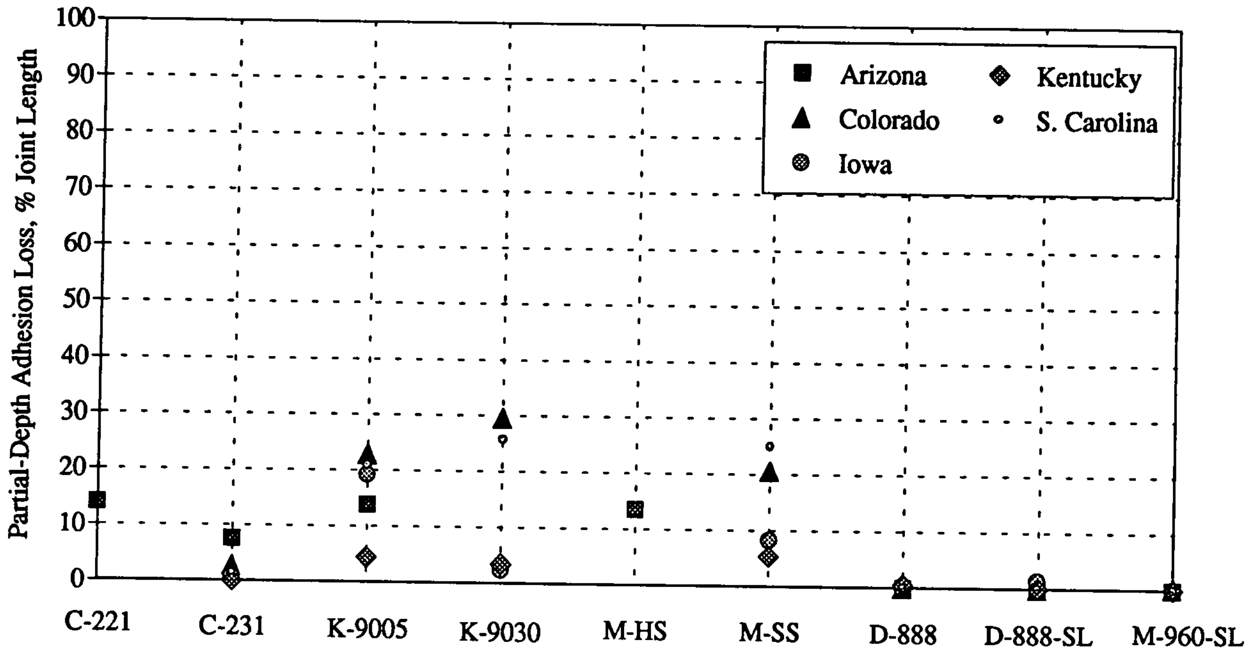

Figure D-7. Partial-depth adhesion loss for recessed joint seals after 18 months

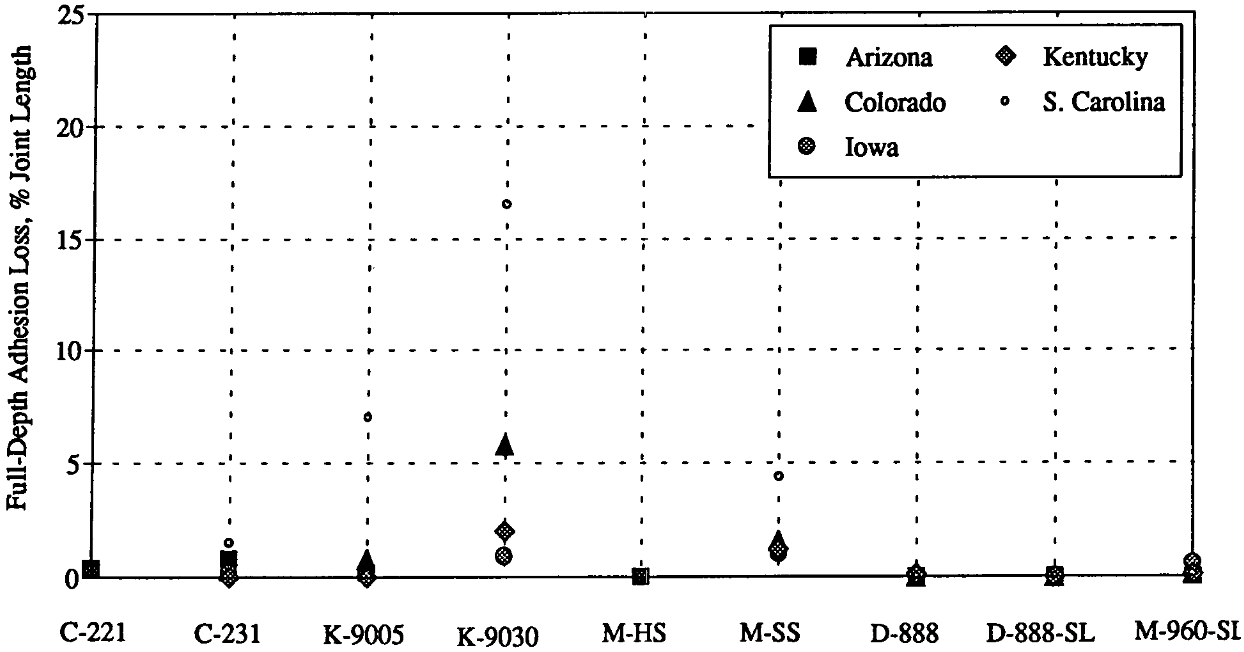

Figure D-8. Full-depth adhesion loss for recessed joint seals after 18 months.

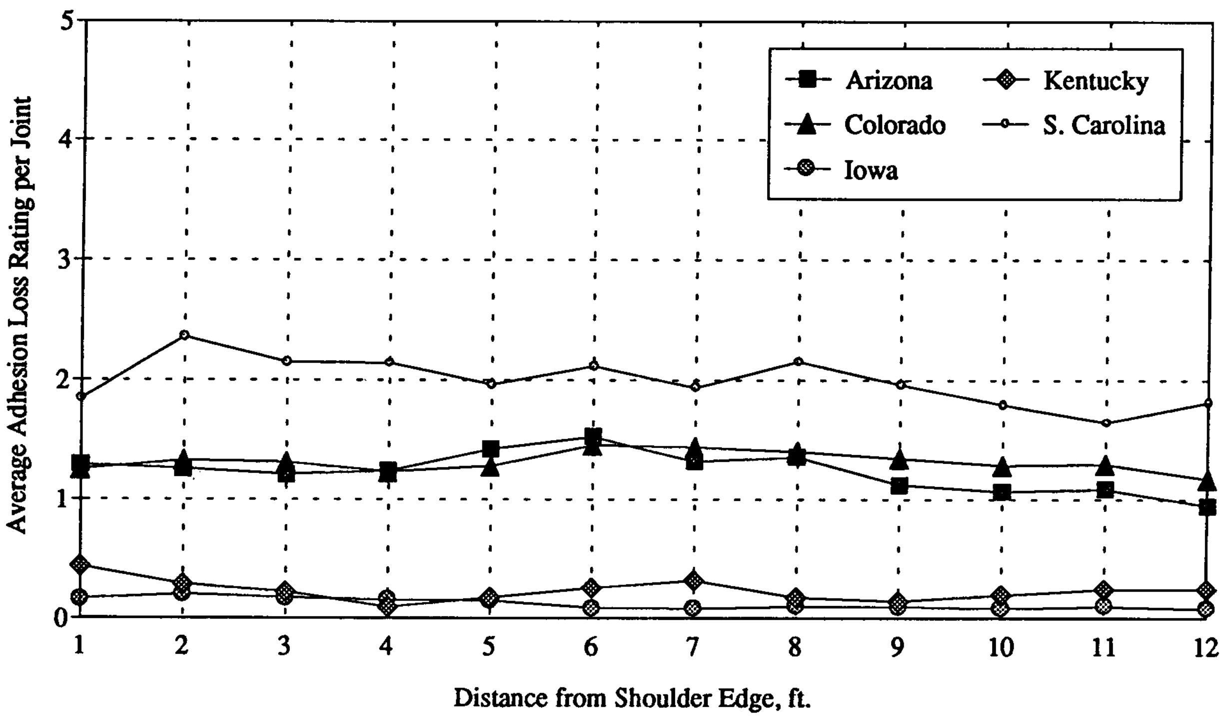

Figure D-9. Adhesion loss rating (ALR) vs. distance from shoulder edge

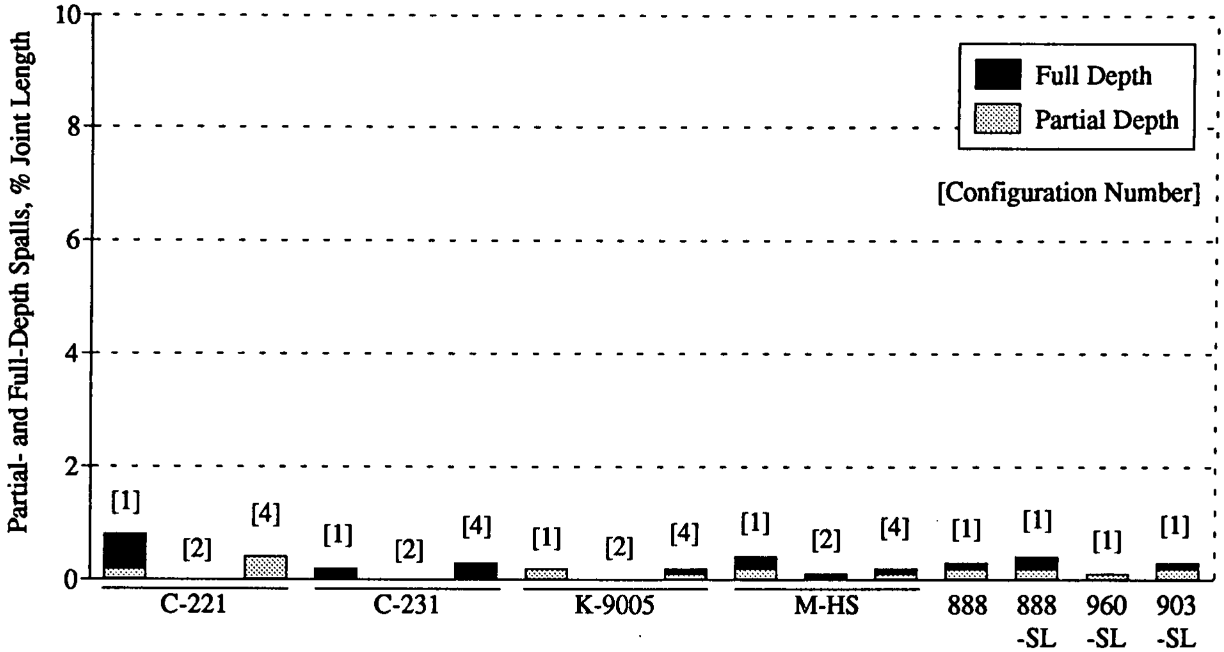

Figure D-10. New spall distress at Arizona I-17 site after 18 months

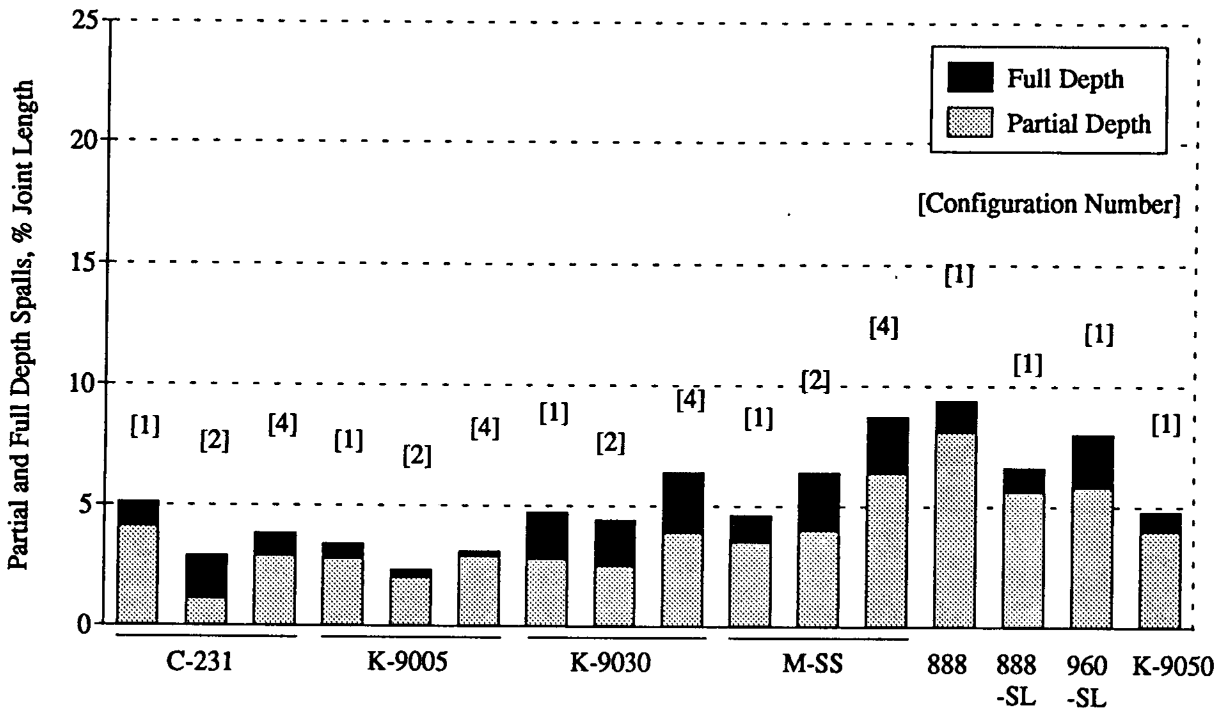

Figure D-11. New spall distress at Colorado I-25 site after 18 months

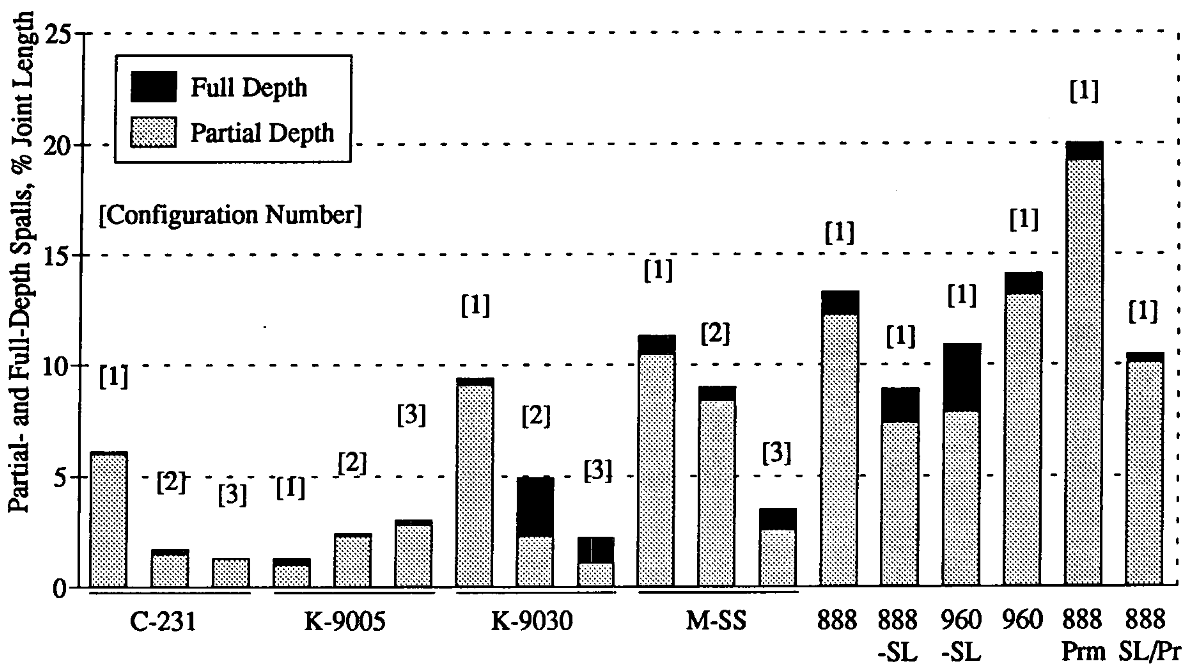

Figure D-12. New spall distress at Iowa I-80 site after 18 months

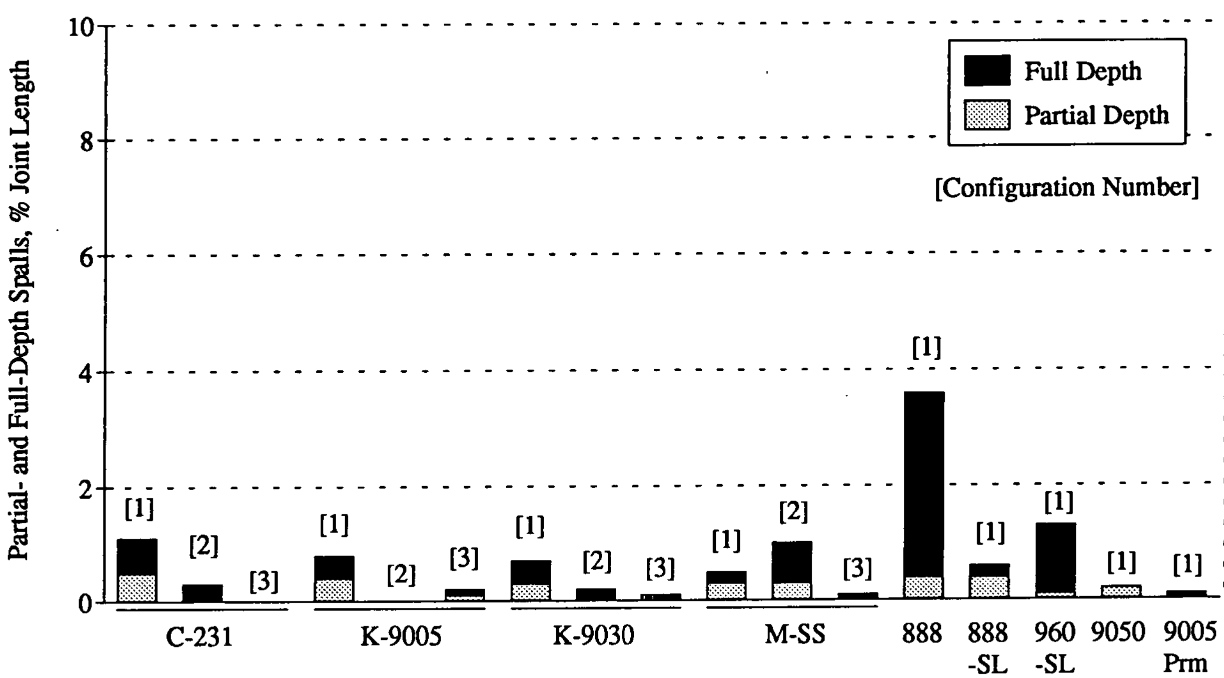

Figure D-13. New spall distress at Kentucky Rte 127 site after 18 months

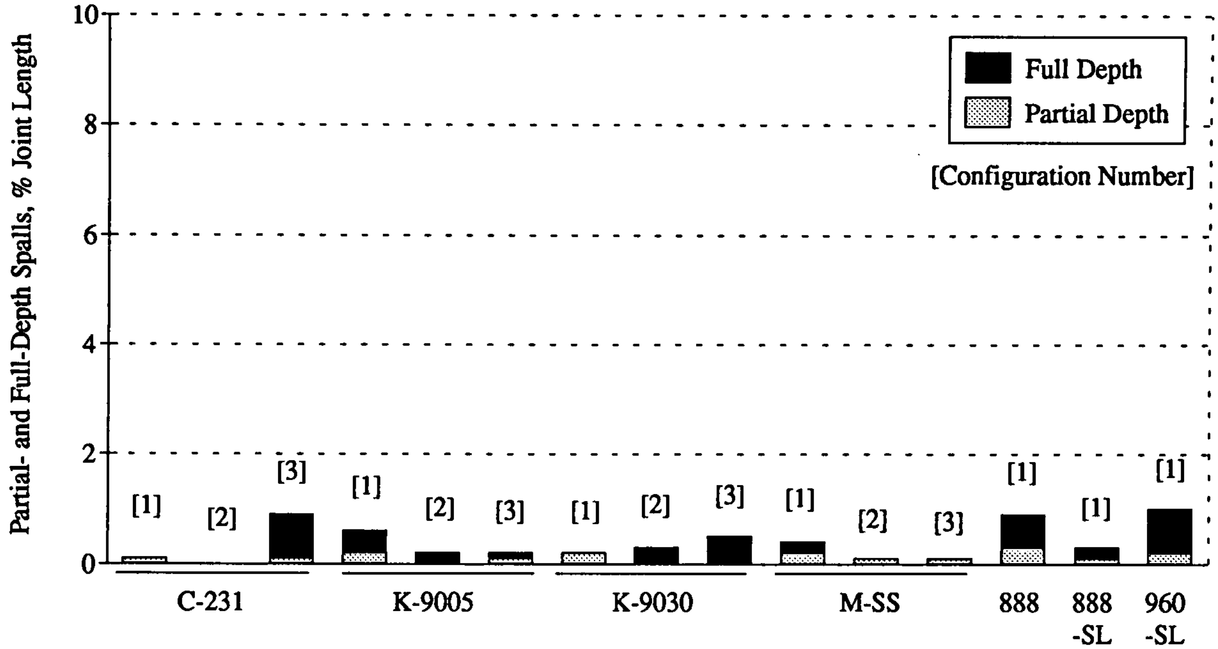

Figure D-14. New spall distress at South Carolina I-77 site after 18 months

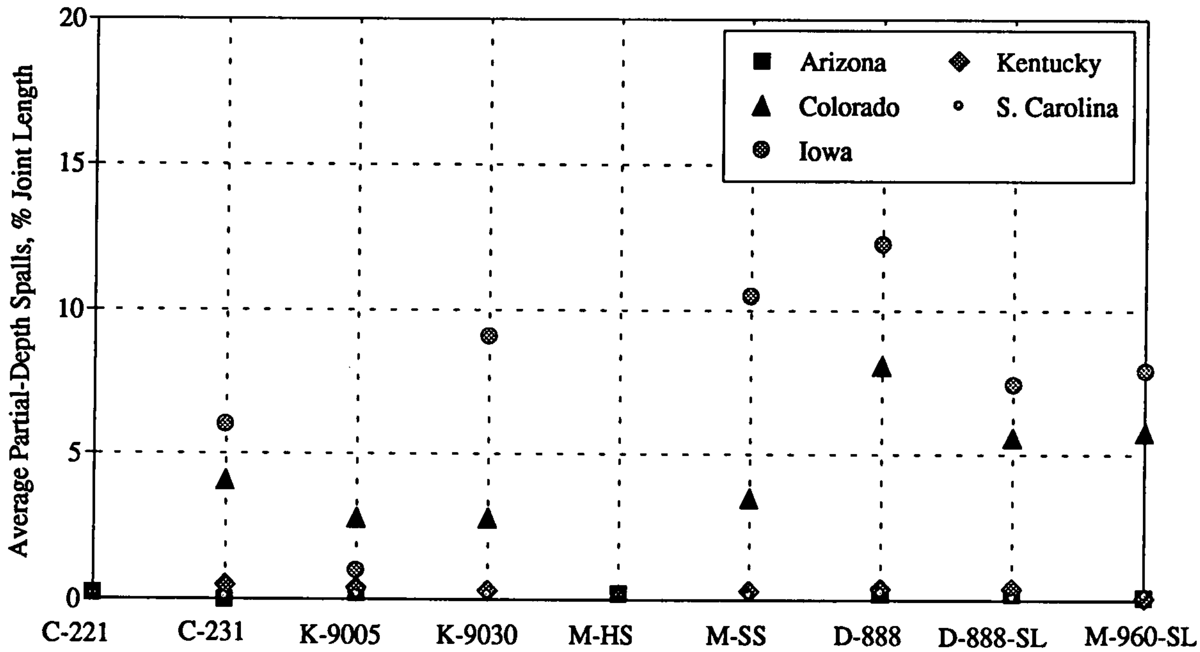

Figure D-15. Partial-depth spalls in recessed joints after 18 months

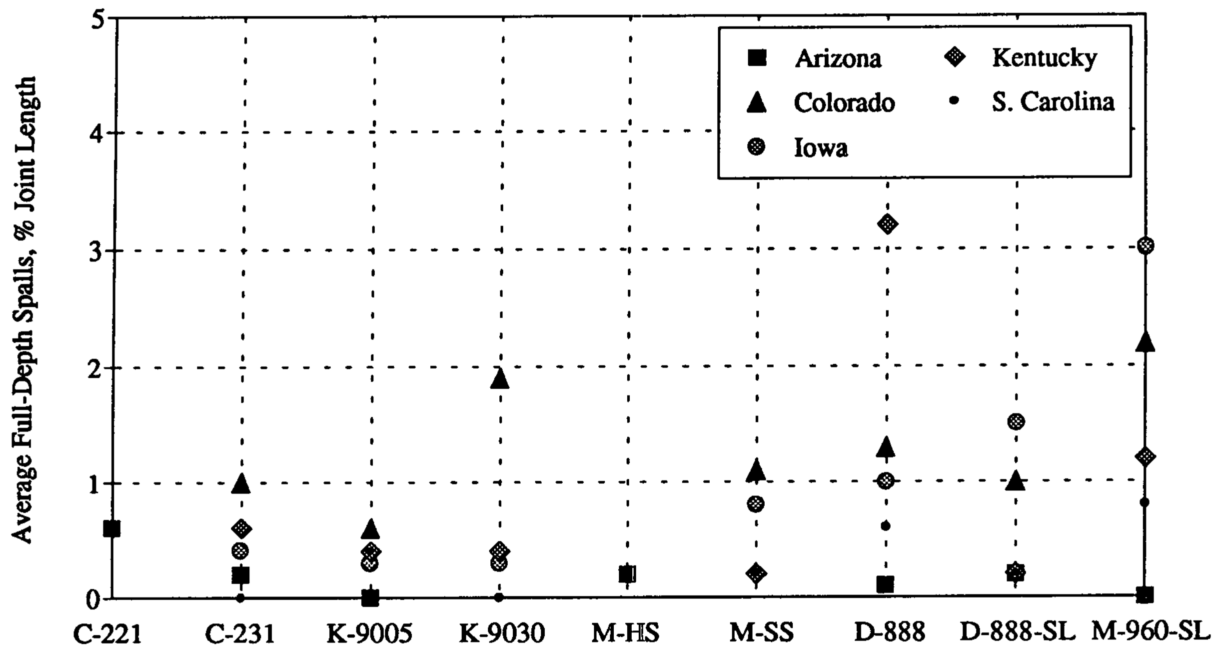

Figure D-16. Full-depth spalls in recessed joints after 18 months

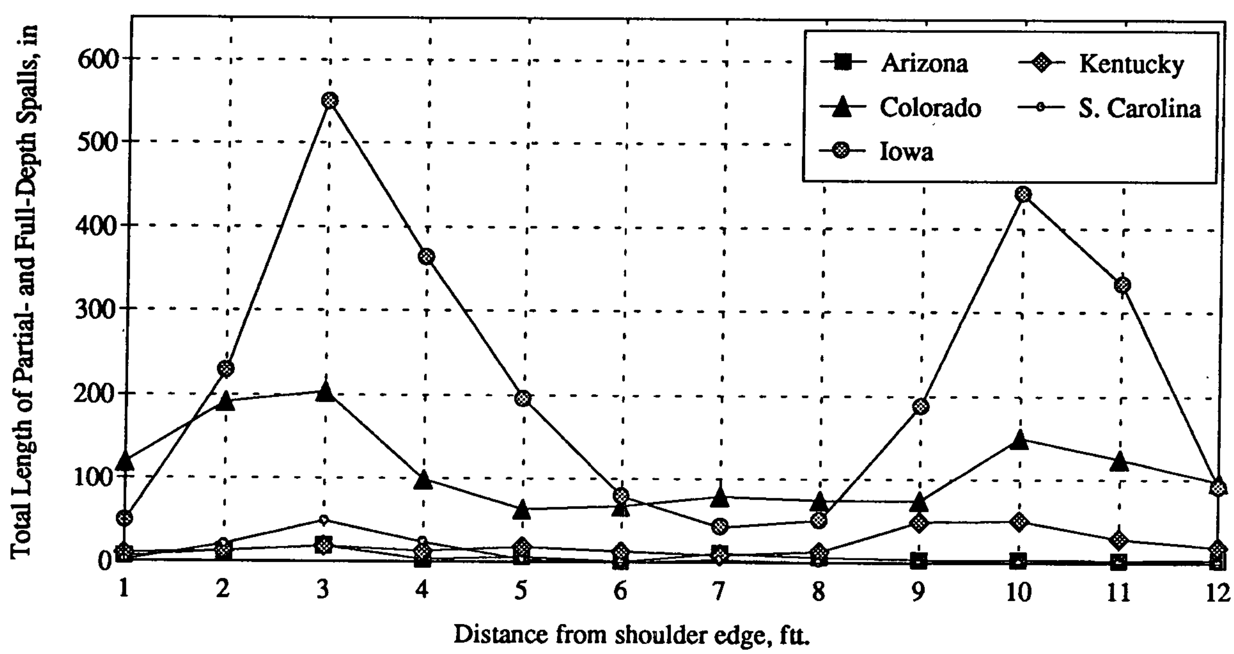

Figure D-17. New partial- and full-depth spalls vs. position along joint

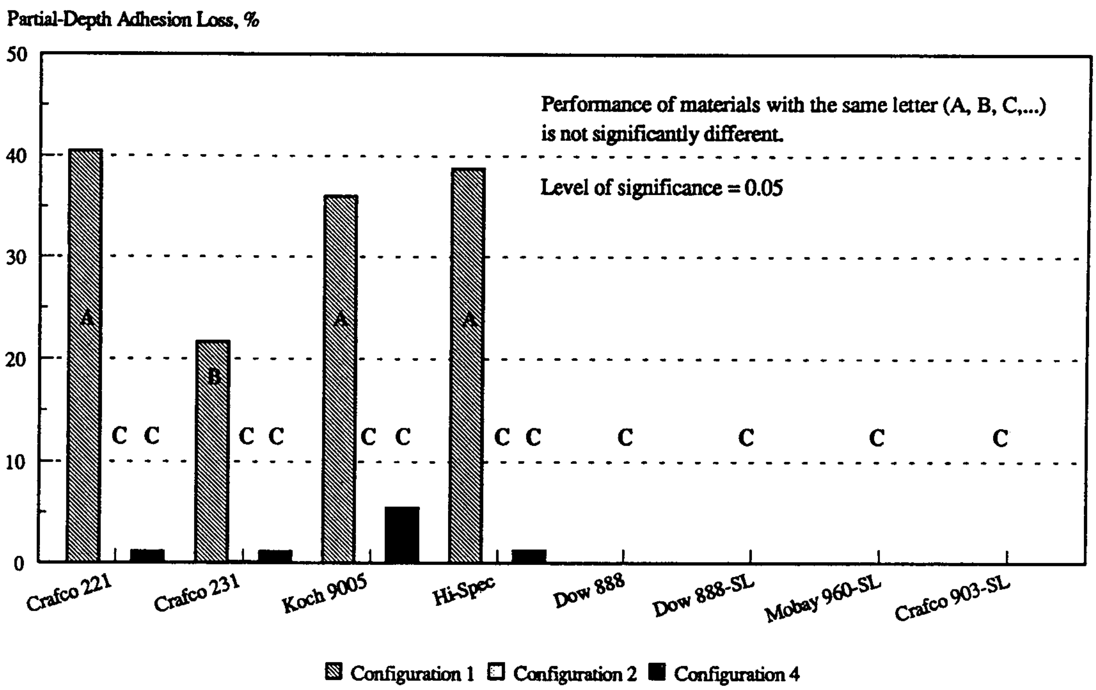

Figure D-18. HSD ranking of partial-depth adhesion loss at AZ site, by material

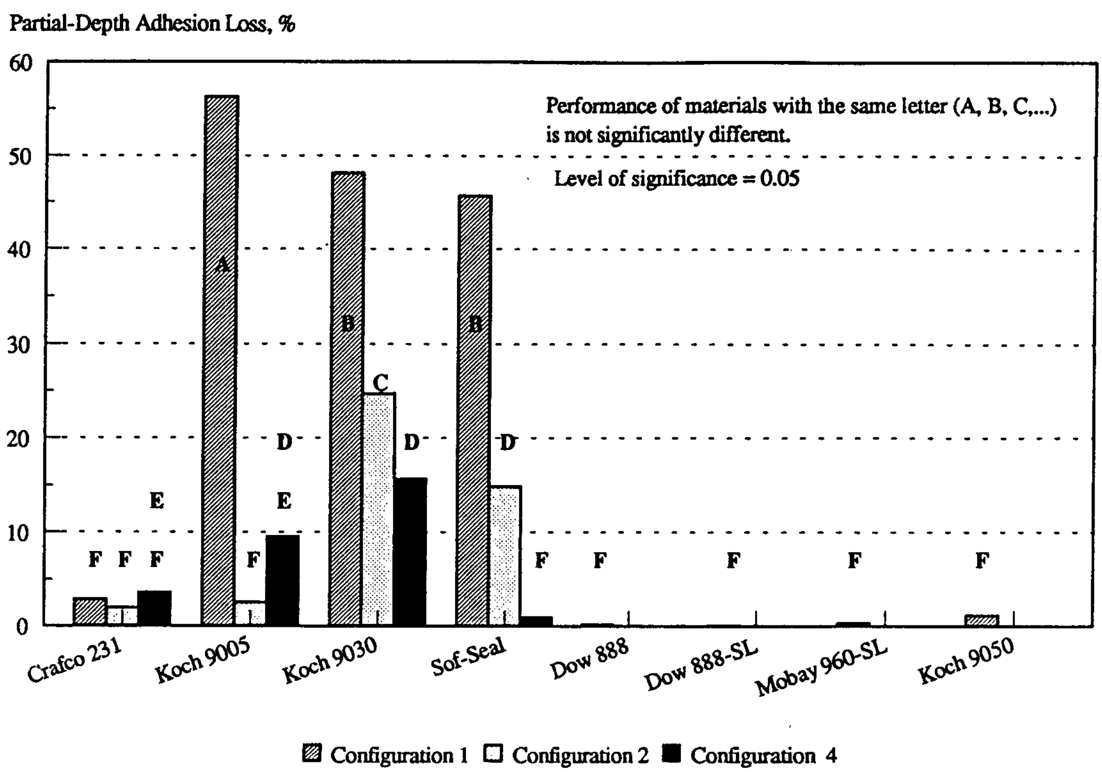

Figure D-19. HSD ranking of partial-depth adhesion loss at CO site, by material

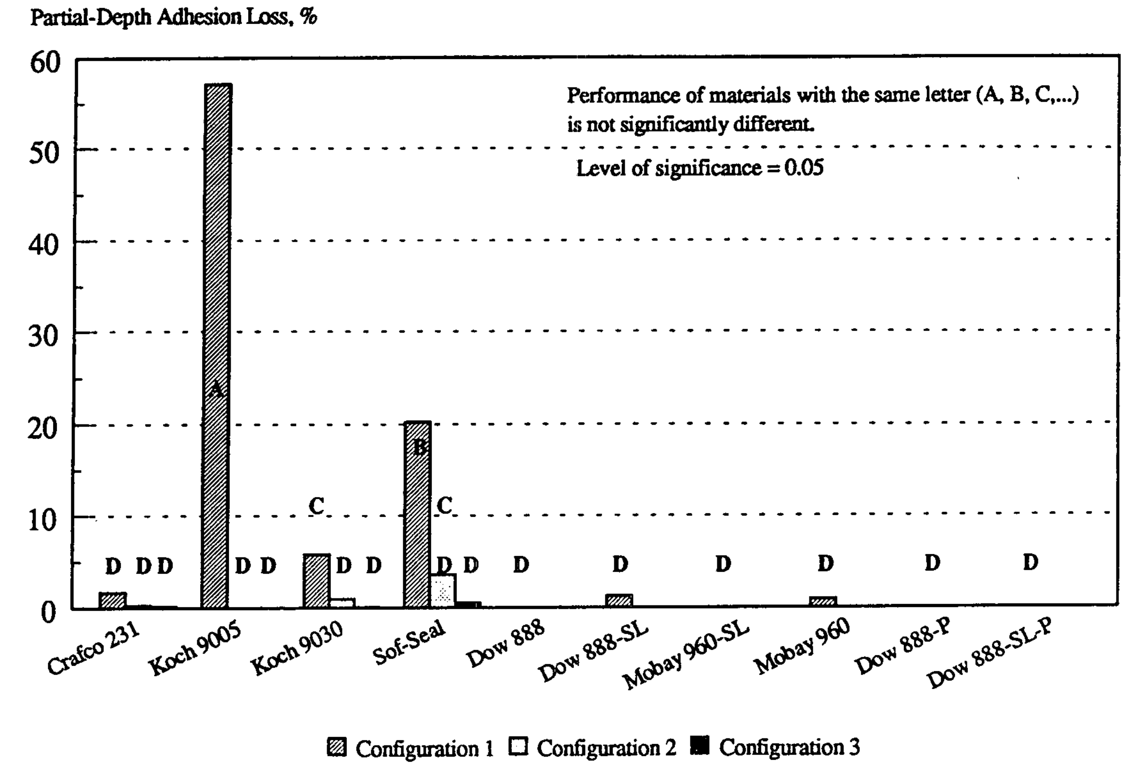

Figure D-20. HSD ranking of partial-depth adhesion loss at IA site, by material

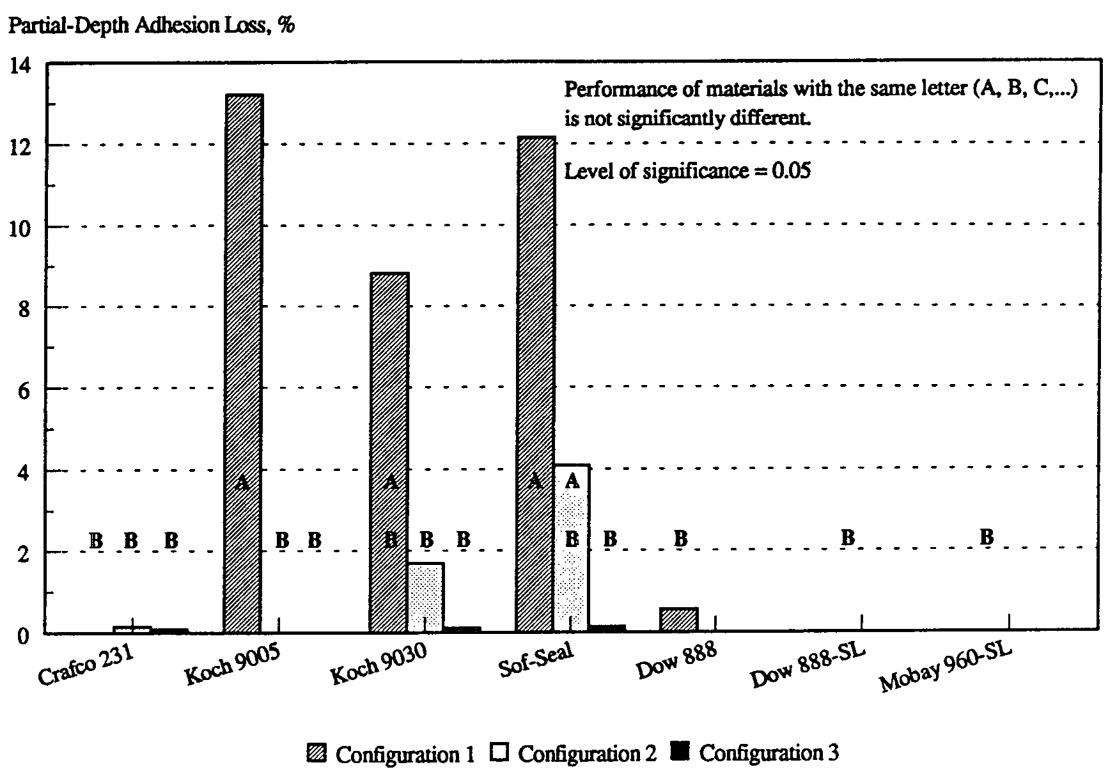

Figure D-21. HSD ranking of partial-depth adhesion loss at KY site, by material

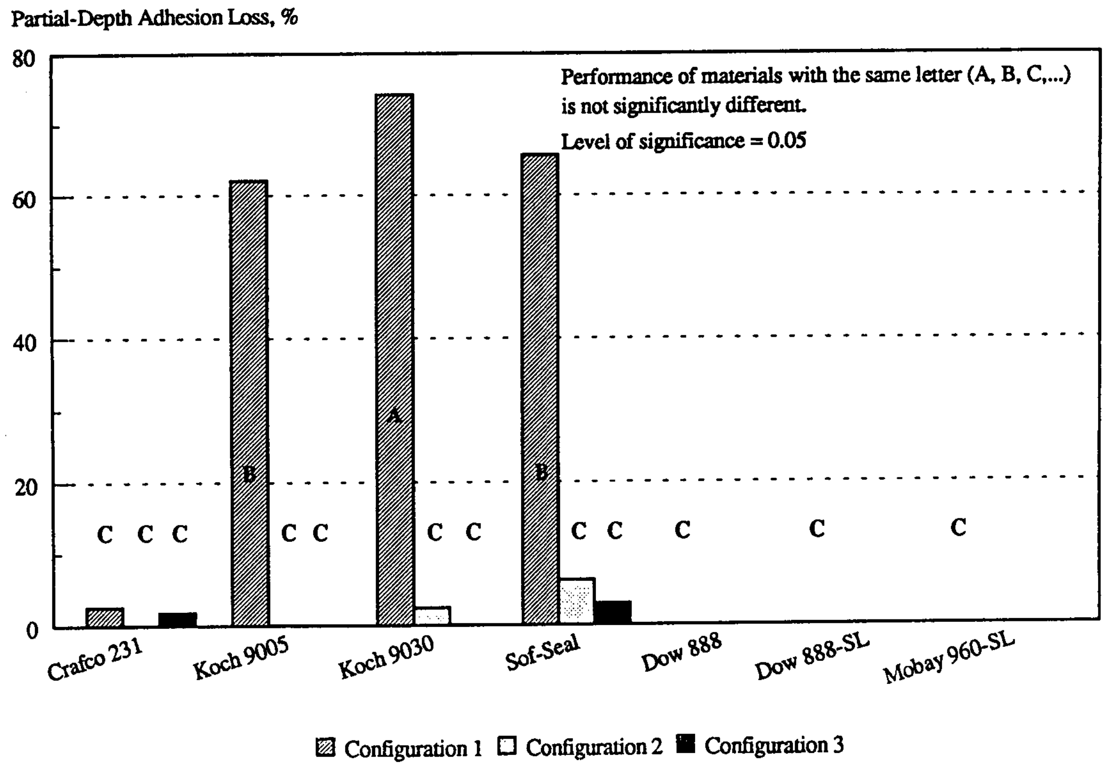

Figure D-22. HSD ranking of partial-depth adhesion loss at SC site, by material

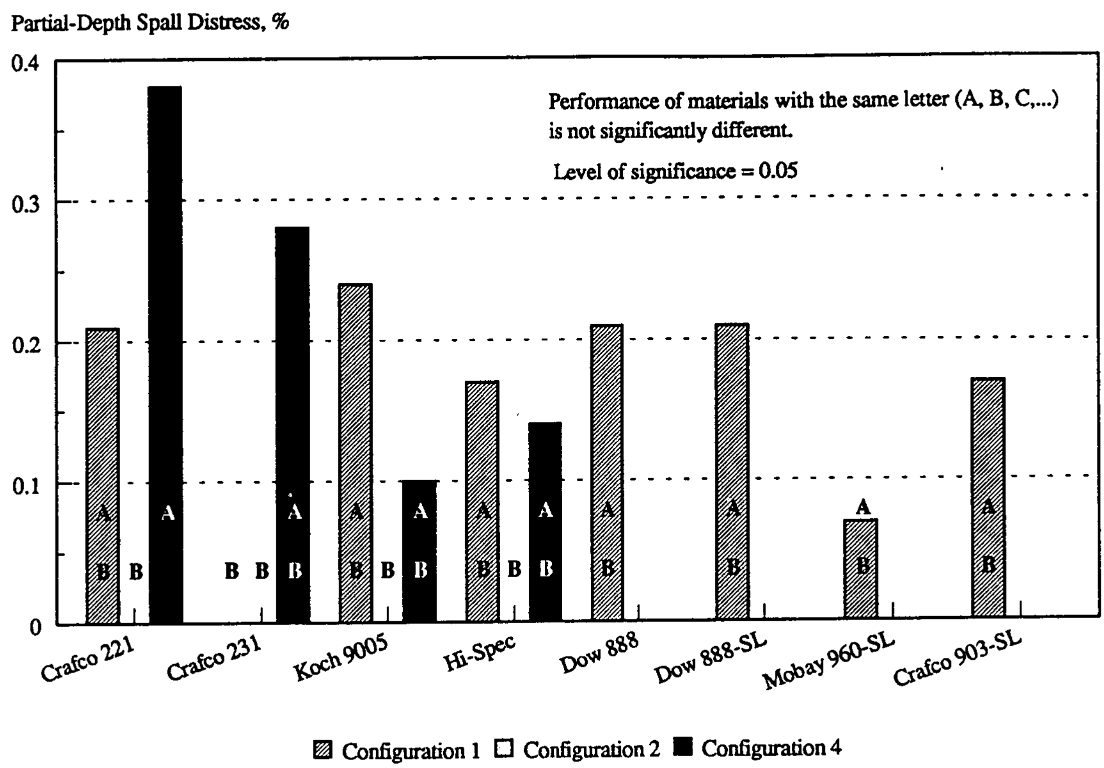

Figure D-23. HSD ranking of partial-depth spalls at AZ site, by material

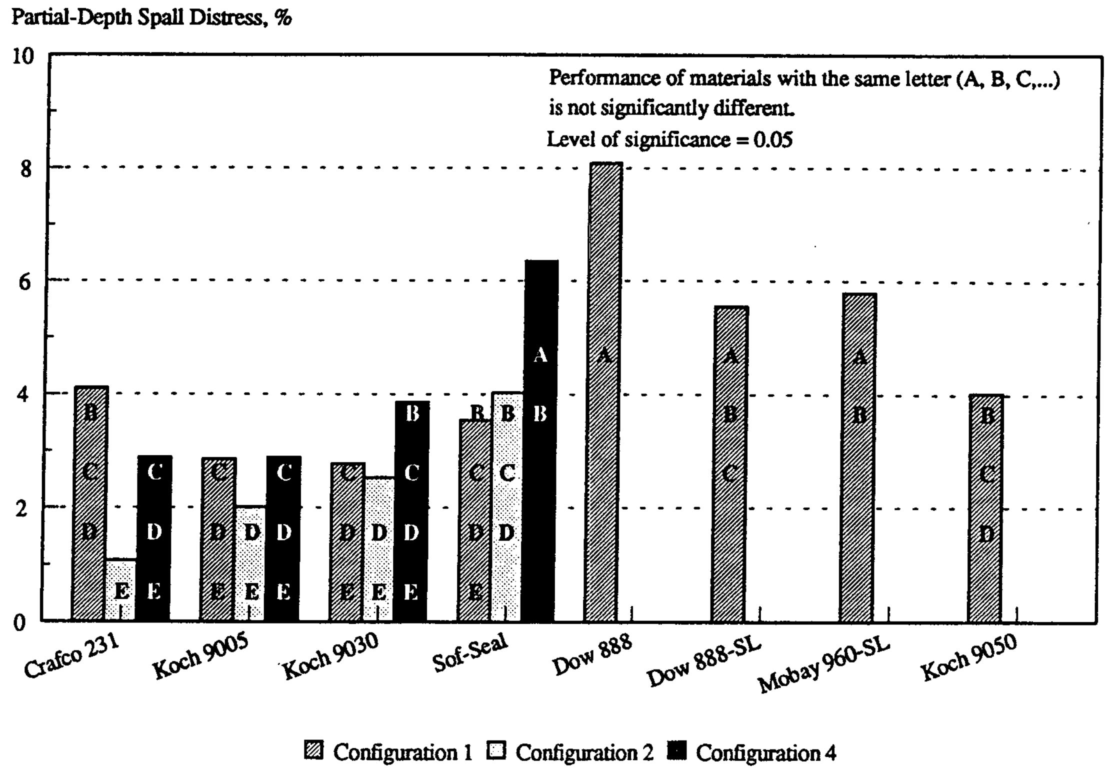

Figure D-24. HSD ranking of partial-depth spalls at CO site, by material

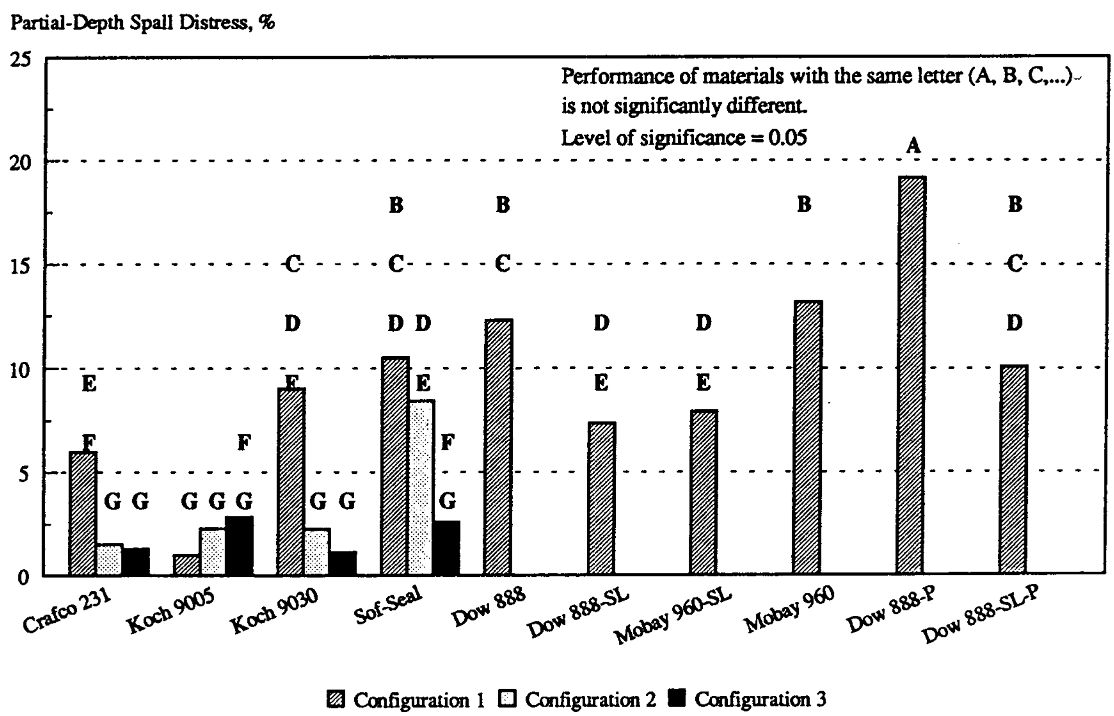

Figure D-25. HSD ranking of partial-depth spalls at IA site, by material

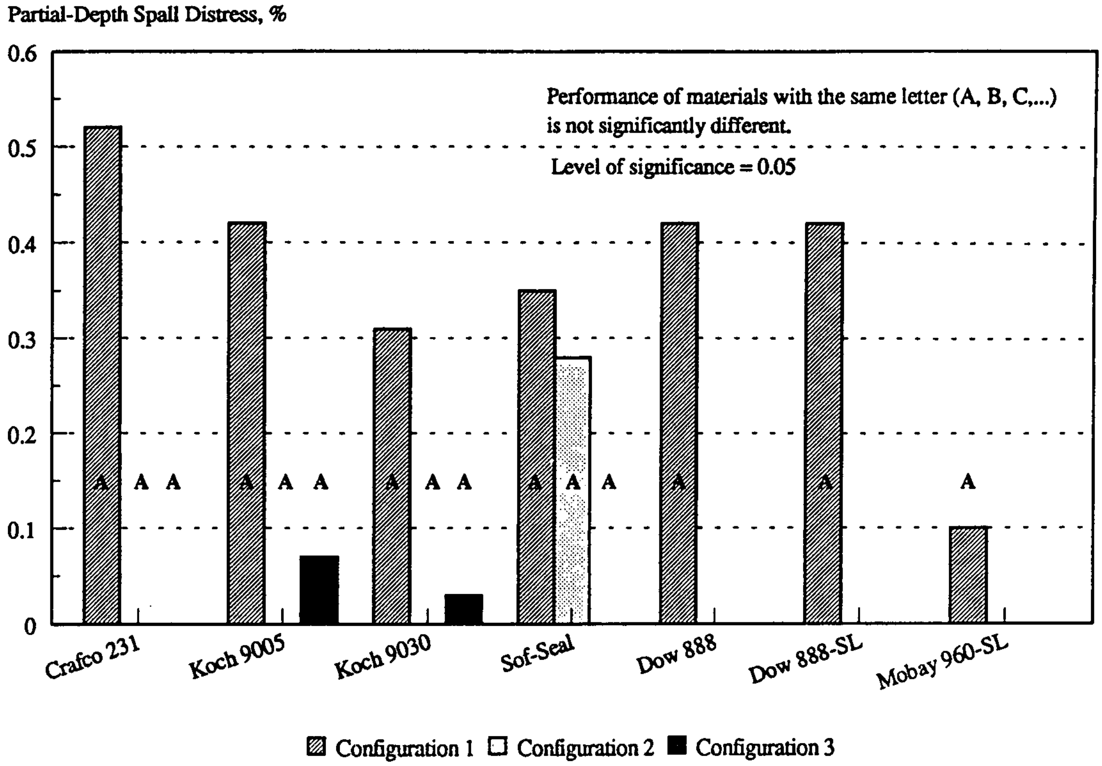

Figure D-26. HSD ranking of partial-depth spalls at KY site, by material

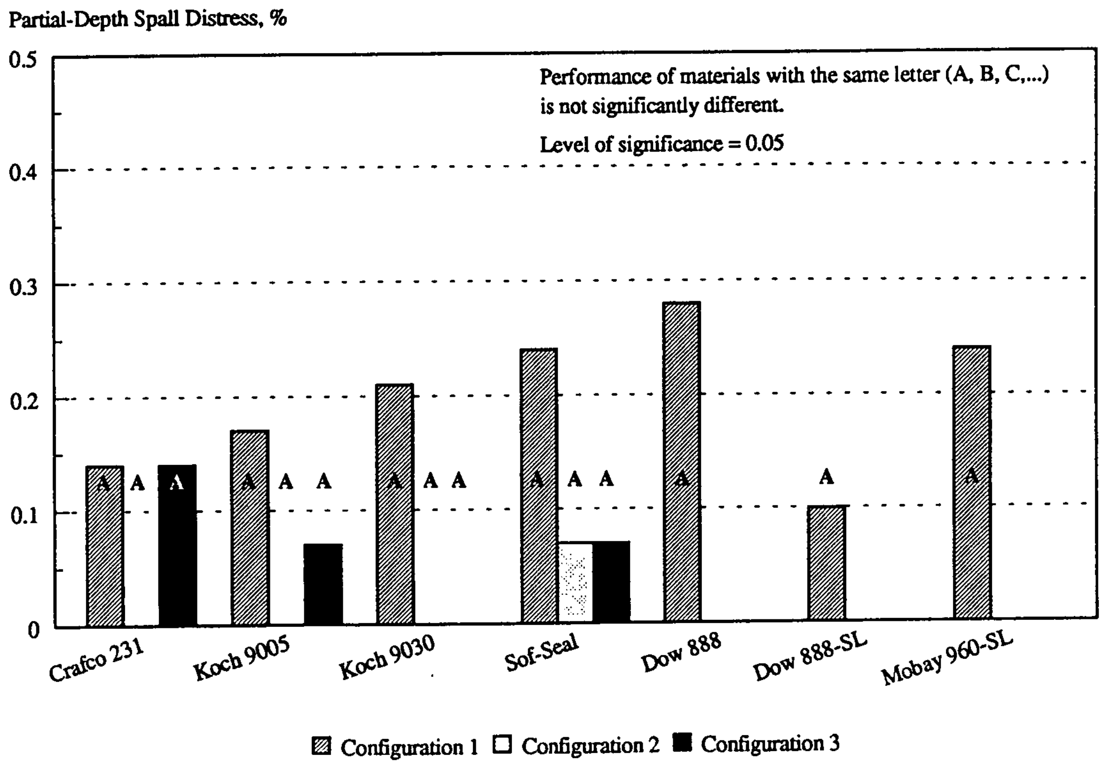

Figure D-27. HSD ranking of partial-depth spalls at SC site, by material

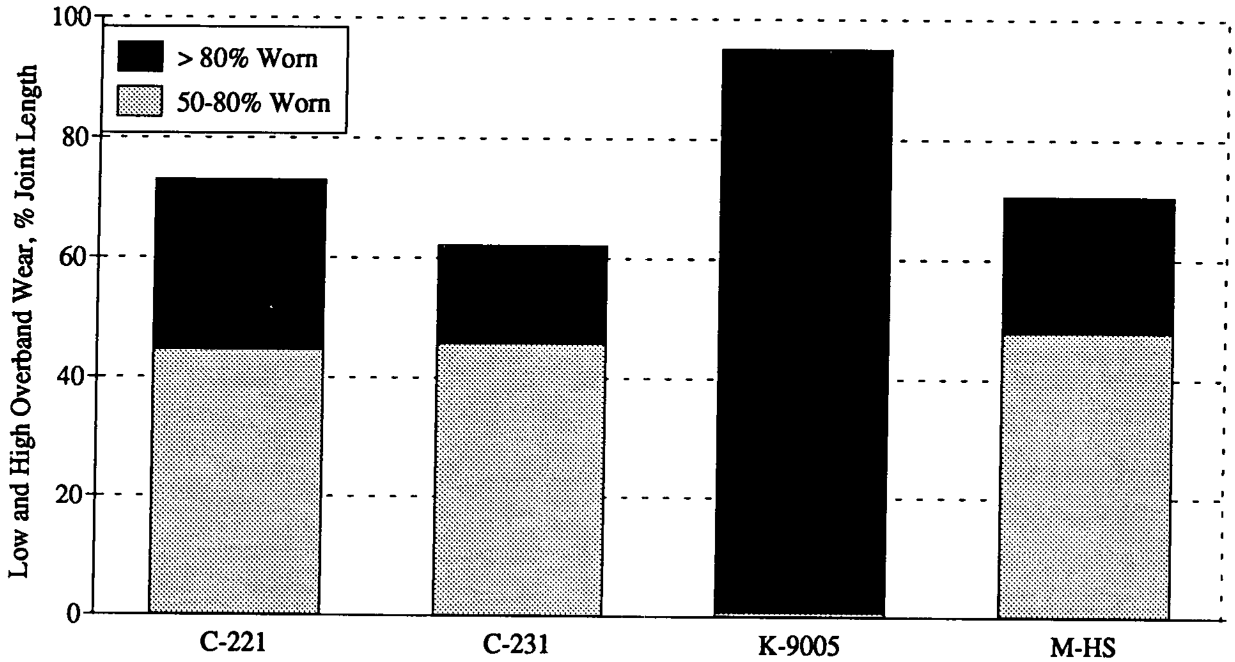

Figure D-28. Joint seal overband wear at Arizona I-17 site after 18 months

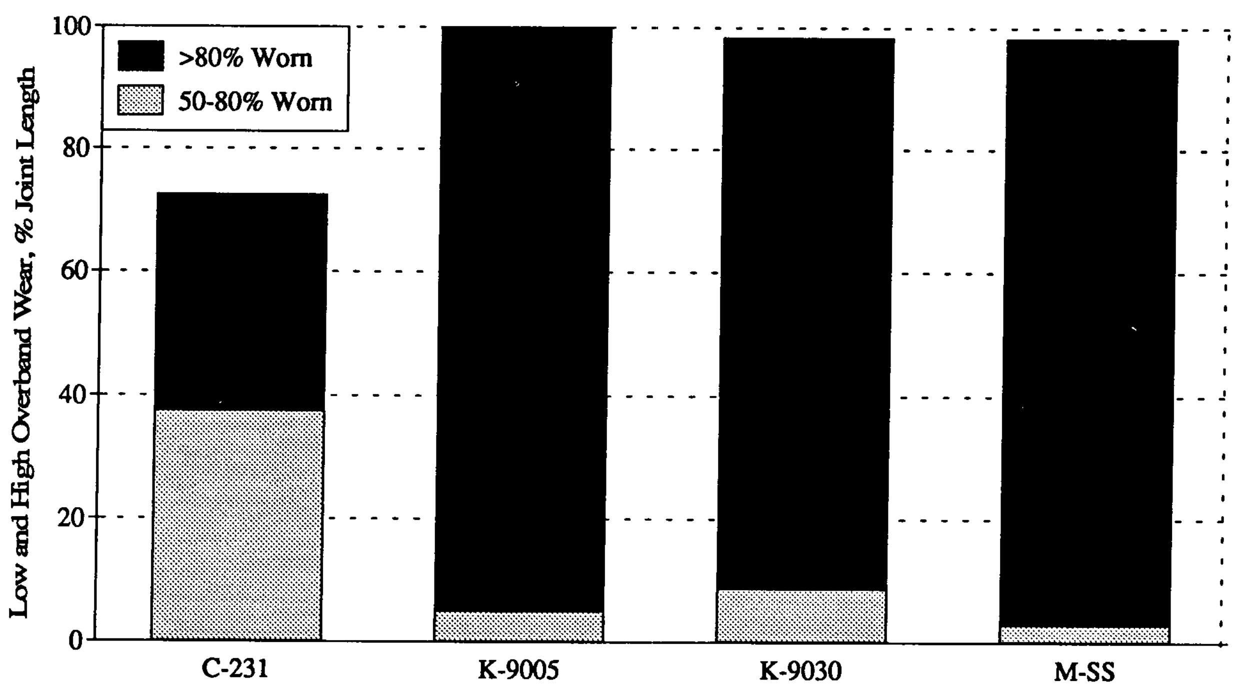

Figure D-29. Joint seal overband wear at Colorado I-25 site after 18 months

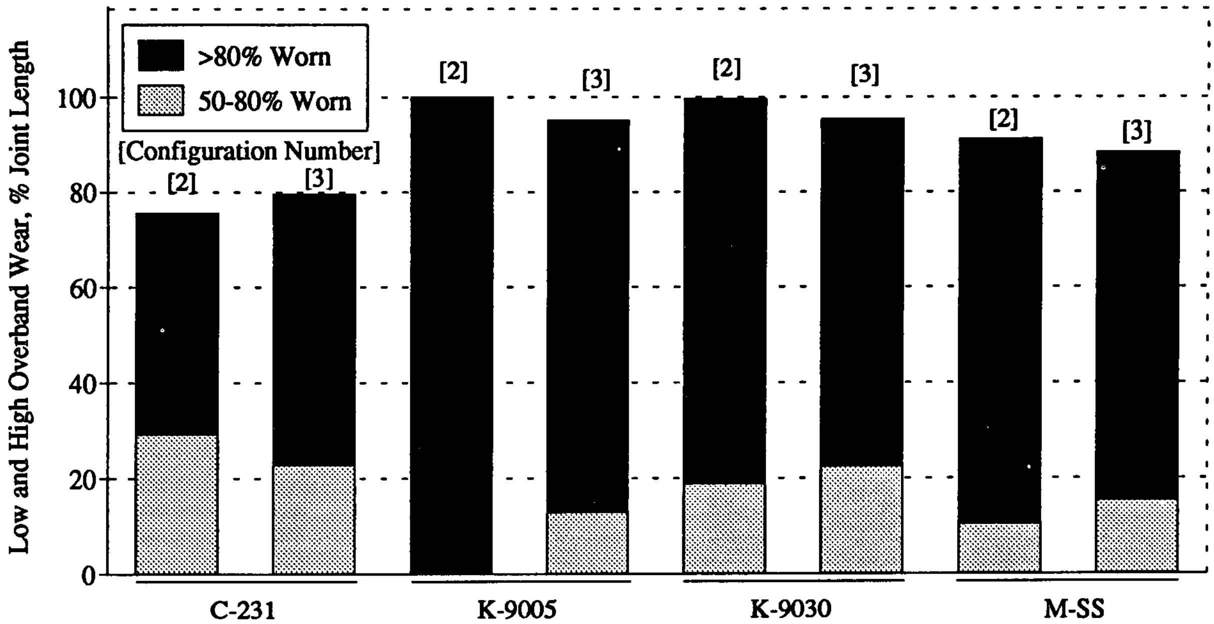

Figure D-30. Joint seal overband wear at Iowa I-80 site after 18 months

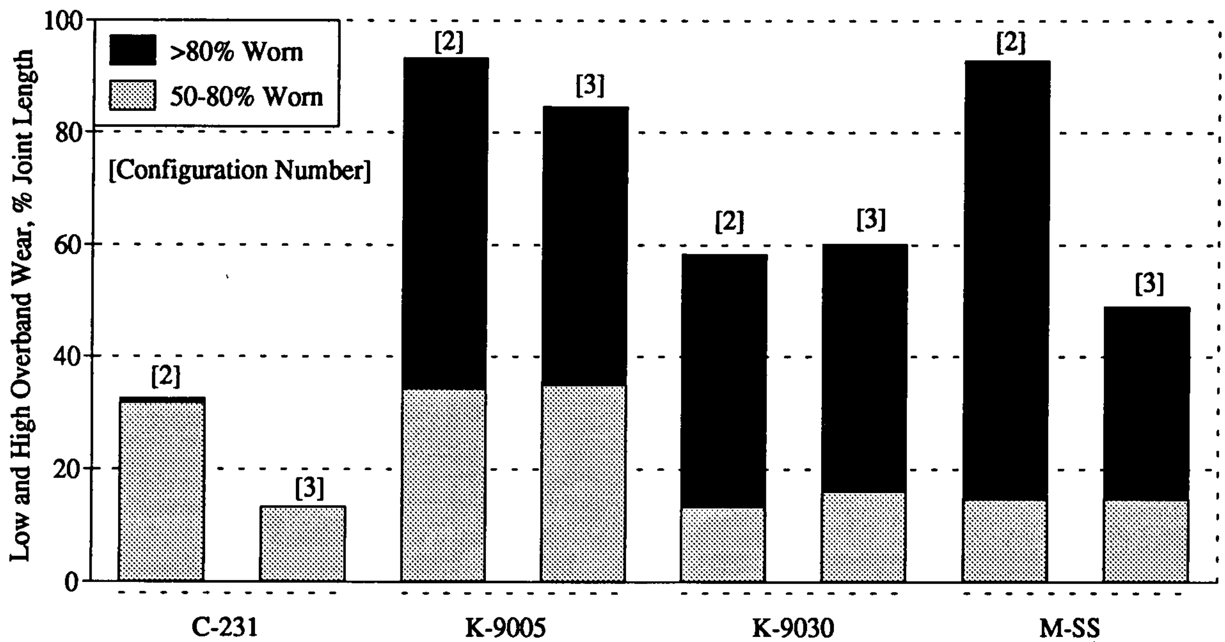

Figure D-31. Joint seal overband wear at Kentucky Rte 127 site after 18 months

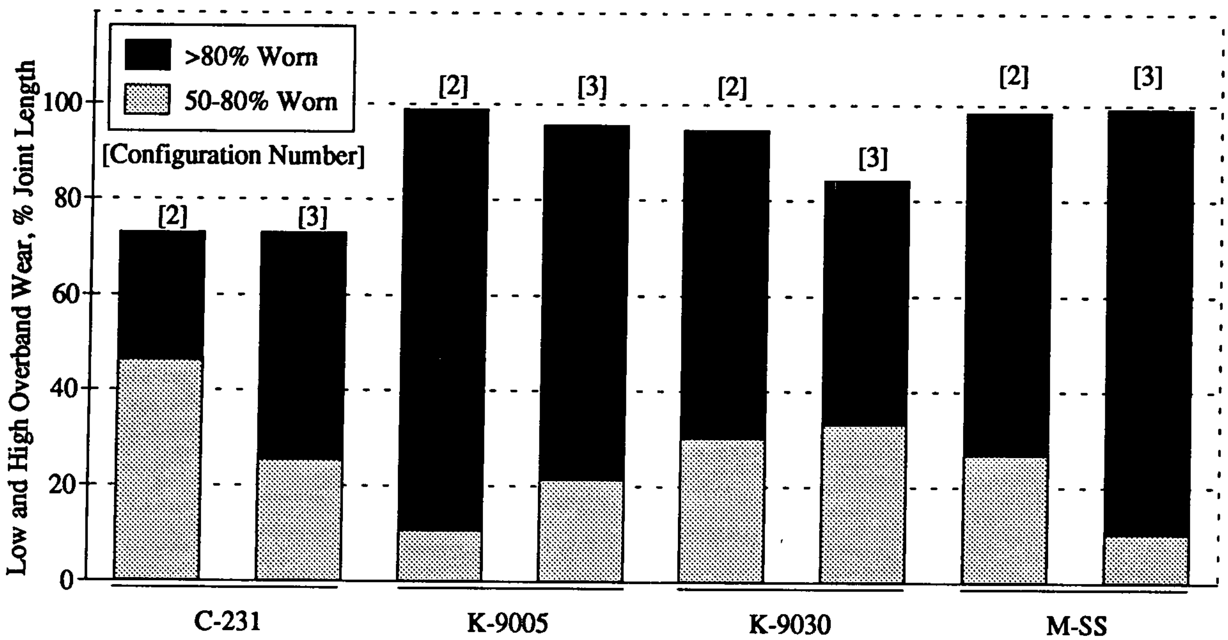

Figure D-32. Joint seal overband wear at South Carolina I-77 site after 18 months

Appendix E

Cost-Effectiveness

Choosing maintenance materials and methods that provide the most effective balance of performance and cost is becoming increasingly important to maintenance planners. Described in this appendix is the information required to compare the cost-effectiveness of joint seal materials and installation procedures. Tables to assist in the calculations are included, along with a set of example calculations. Steps for determining the cost-effectiveness of methods and materials for resealing joints in PCC pavements include:

1. Determining the amounts and costs of materials needed.
2. Estimating the labor needs and costs.
3. Determining the equipment requirements and costs.
4. Estimating the effective lifetime of each resealing option.
5. Calculating the average annual cost for each method under consideration.

Material and Shipping Costs

Material costs for sealant, backer rod, blasting abrasive, primer, and other required materials can be obtained from local suppliers or manufacturers. Shipping costs can range up to 40 percent or more of the material costs, depending on the amount of material purchased and the required shipping distance. Overall material and shipping costs can be computed using table E-2. Sealant coverage rates used in table E-3 can be estimated by using the following equation or by consulting manufacturers' literature.

$$CR = \left(\frac{12}{231}\right)(WF)(ST)(W)(T) \qquad \text{(E-1)}$$

where:

- CR = Sealant coverage rate, ft/gal (1 ft/gal = 0.08057 m/L)
- WF = Waste factor (WF = 1.2 for 20 percent waste)
- W = Joint width, in
- T = Thickness of sealant, in
- ST = Surface type constant (tooled surface: ST = 1.1; non-tooled surface: ST = 1.0)

By multiplying the material cost, the coverage rate, and the length of the joint to be resealed, the total cost for each material and the overall material cost can be estimated.

Labor Costs

Total labor costs can be estimated by entering the wages for each worker, the number of workers required for each operation, and the expected time necessary to complete each operation into table E-3. The production rates listed in table E-1 should be helpful in determining labor requirements. However, in addition to wage rates, labor costs are greatly influenced by crew productivity and the need for night work or extra traffic control. Therefore, local conditions should be considered when estimating production rates.

Table E-1. Production rates

Resealing Operation	Number of Workers	Average Production Rates (hrs/1,000 ft [hrs/328 m])
Joint plowing	2	2 to 3
Joint resawing	1	3.5 to 7.5
Sandblasting	2	1.5 to 4
Final airblasting	2	1.5 to 4
Backer rod installation	2	1 to 3
Sealant installation	2	1.5 to 2.5

Equipment Costs

The cost of equipment will be affected by the availability of adequate equipment and the need for equipment rental. The amount of time that each piece of equipment is required also greatly influences equipment costs. By completing table E-4 and multiplying the daily equipment costs by the number of pieces of equipment required and by the number of days the equipment is needed, the cost of resealing equipment can be estimated. Production rates should be based on local experience, although the rates shown on table E-1 may be used to obtain rough estimates.

User Delay Costs

Although difficult to determine, there is a cost of delay to roadway users during the time that joints are cleaned and resealed. This delay cost should be included in cost-effectiveness calculations, if the options being evaluated require significantly different amounts of lane closure. Experienced traffic engineers or agency guidelines should be consulted in defining the cost of user delay.

Cost-Effectiveness Comparisons

After the material, labor, equipment, and user costs have been determined, the worksheet in table E-5 can be used to determine the annual cost of each resealing option. The expected rate of inflation and the estimated lifetime of each material-placement method option are required inputs for the worksheet. By comparing the average annual cost of various materials and repair procedures, the most cost-effective resealing option can be determined. Sample cost-effectiveness comparison is included in the following section.

Table E-2. Material and shipping costs

Material, unit[a]	Material Cost ($/unit)	Coverage Rate (ft/unit)	Length Required (linear ft)	Total Cost ($/mtrl)
	a	b	c	a x b x c
Sealant, gal				
Backer rod, ft				
Blasting sand, lb				
Primer, gal				
Total Material Cost:				

[a] 1 gal = 3.785 L; 1 ft = 0.305 m; 1 lb = 0.454 kg

Table E-3. Labor costs

Crew Labor	Wages ($/day)	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor				
Traffic control				
Plowing				
Sawing				
Initial airblast				
Sandblast				
Final airblast				
Backer rod				
Sealant installation				
Total Labor Cost:				

Table E-4. Equipment costs

Equipment	Daily Cost	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic control				
Joint plow				
Concrete saw				
Air compressor				
Sandblast equip.				
Installation Equip.				
Other trucks				
Total Equipment Cost:				

Table E-5. Cost-effectiveness worksheet

Cost Item	Source	Total Cost ($)		Eqn. Code
		Option 1	Option 2	
Materials and shipping	Table E-2			
Labor	Table E-3			
Equipment	Table E-4			
User delay				
Total Resealing Cost ($)				A
Project length (lane-mi [lane-km])				B
Average cost ($/lane-mi [$/lane-km])	A x B			C
Estimated lifetime of joint seal (years)				D
Rate of inflation				E
Average Annual Cost ($/lane-mi [$/lane-km])	Equation E-2			

$$\textit{Average Annual Cost} = C\left[\frac{(E)[(1+E)^{D}]}{(1+E)^{D}-1}\right] \qquad \text{(E-2)}$$

Sample Cost-Effectiveness Calculations

An engineer has decided to compare the cost-effectiveness of two sealant materials, a silicone and a rubberized asphalt, for a 2.5-mi (4.0 km) resealing project containing 20,000 linear ft (6.1 km) of joints. The preparation methods and labor and installation rates are nearly the same for each material and are listed in table E-6. Based on local experience and manufacturers' recommendations, information relative to each material has been compiled in table E-7. Using this information, coverage rates can be computed, and material, equipment, and labor costs can be estimated, as shown in tables E-8, E-9, and E-10. Sample equipment cost and cost-effectiveness calculations are given in tables E-11 and E-12.

Table E-6. Production and labor rates

Operation / Operator	Production & Labor Rates	
	English Units	Metric Units
Joint plowing	525 ft/hr	160 m/hr
Joint resawing	275 ft/hr	84 m/hr
Airblasting	500 ft/hr	152 m/hr
Sandblasting	375 ft/hr	114 m/hr
Backer rod installation	540 ft/hr	165 m/hr
Sealant installation	540 ft/hr	165 m/hr
Labor	$120/day	
Maintenance supervisor	$200/day	

Table E-7. Sealant material information

	Option 1	Option 2
Material type	Self-leveling silicone	Rubberized asphalt
Shape factor (W:T)	2:1	1:1
Joint width (W)	0.5 in (13 mm)	0.5 in (13 mm)
Sealant thickness (T)	0.25 in (6.5 mm)	0.5 in (13 mm)
Primer required	None	None
Estimated lifetime	8 years	5 years
Wastage factor (WF)	1.2	1.2
Surface type constant (ST)	1	1

The sealant coverage rate for option 1 is calculated in the following equation:

$$CR = \left(\frac{12}{231}\right)(1.2)(1.0)(0.5)(0.25) = 0.007792 \qquad \text{(E-3)}$$

where:

CR = Coverage rate, gal/ft
WF = Wastage factor = 1.2
W = Joint width = 0.5 in
T = Thickness of sealant = 0.25 in
ST = Surface type constant = 1.0

Since the recommended shape factor for option 2 is 1:1, the required sealant thickness is 0.5 in (13 mm), resulting in a coverage rate of 0.015584 gal/ft.

Table E-8. Option 1 material and shipping costs

Material, unit[a]	Material/Shipping Cost ($/unit)	Coverage Rate (unit/ft)	Length Required (ft)	Total Cost ($/mtrl)
	a	b	c	a x b x c
Sealant, gal	28.00	0.007792	20,000	4,364
Backer rod, ft	0.10	1.05	20,000	2,100
Blasting sand, lb	0.05	0.20	20,000	200
Primer, gal	-0-	-0-	-0-	0
Total Material Cost:				6,664

[a] 1 gal = 3.785 L; 1 ft = 0.305 m; 1 lb = 0.454 kg

Table E-9. Option 2 material and shipping costs

Material, unit[a]	Material/Shipping Cost ($/unit)	Coverage Rate (unit/ft)	Length Required (ft)	Total Cost ($/mtrl)
	a	b	c	a x b x c
Sealant, gal	5.50	0.015584	20,000	1,715
Backer rod, ft	0.10	1.05	20,000	2,100
Blasting sand, lb	0.05	0.20	20,000	200
Primer, gal	-0-	-0-	-0-	0
Total Material Cost:				4,015

[a] 1 gal = 3.785 L; 1 ft = 0.305 m; 1 lb = 0.454 kg

Table E-10. Labor costs for options 1 and 2

Crew Labor	Wages ($/day)	Number in Crew	Days Required	Total Cost, $
	d	e	f	d x e x f
Supervisor	200	1	14	2,800
Traffic control	120	1	14	1,680
Plowing	120	2	5	1,200
Sawing	120	1	3.5	420
Initial airblast	120	2	3.5	840
Sandblast	120	2	6	1,440
Final airblast	120	2	3.5	840
Backer rod	120	2	4.6	1,104
Sealant installation	120	2	4.6	1,104
Total Labor Cost:				11,428

Table E-11. Sample equipment costs

Equipment	Daily Cost	Number of Units	Number of Days	Total Cost, $
	g	h	i	g x h x i
Traffic control	450	1	14.0	6,300
Joint plow	150	1	5.0	750
Concrete saw	225	2	3.5	1,575
Air compressor	175	1	7.5	1,125
Sandblast equip. (incl. compressor)	200	1	6.0	1,200
Installation equip.	200	1	4.6	920
Other trucks	10	2	14.0	2,800
Total Equipment Cost:				14,670

Table E-12. Sample cost-effectiveness calculations

Cost Item	Source	Total Cost ($)		Eqn. Code
		Option 1	Option 2	
Materials and shipping	Tables E-8, E-9	6,664	4,015	
Labor	Table E-10	11,428	11,428	
Equipment	Table E-11	14,670	14,670	
User delay		2,250	2,250	
Total Resealing Cost ($)		35,012	32,363	A
Project length (lane-mi [lane-km])		2.5 lane-mi	2.5 lane-mi	B
Average cost ($/lane-mi [$/lane-km])	A x B	$14,005/lane-mi	$12,945/lane-mi	C
Estimated lifetime of joint seal (years)		8 yrs	5 yrs	D
Rate of inflation		0.05	0.05	E
Average Annual Cost ($/lane-mi [$/lane-km])	Equation E-2	**$2,167/lane-mi**	**$2,990/lane-mi**	

$$\textit{Option 1 Avg Annual Cost} = \$14{,}005\left[\frac{(0.05)[(1+0.05)^{8}]}{(1+0.05)^{8}-1}\right] = \$2{,}167 \qquad \text{(E-4)}$$

$$\textit{Option 2 Avg Annual Cost} = \$12{,}945\left[\frac{(0.05)[(1+0.05)^{5}]}{(1+0.05)^{5}-1}\right] = \$2{,}990 \qquad \text{(E-5)}$$

Results of this hypothetical engineer's analysis show that, although the material cost of option 2 is less than option 1, the higher expected lifetime of option 1 results in option 1 having a smaller average annual cost. This type of analysis allows a planner to compare resealing materials and methods on an even basis and to choose the most cost-effective option.

References

1. Evans, L.D. et al, "SHRP H-106–Experimental Design and Research Plan," Strategic Highway Research Program, Contract SHRP-89-H-106, February 1991, revised October 1991.

2. Evans, L.D. et al, "SHRP H-106–Evaluation and Analysis Plan," Strategic Highway Research Program, Contract SHRP-89-H-106, February 1991, revised September 1991 and February 1992.

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8/16/93