SHRP-H-349

Concrete Pavement Repair Manuals of Practice

Materials and Procedures for the Repair of Joint Seals in Concrete Pavements

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Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements

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Preface

This book contains two pavement maintenance manuals intended for use by highway maintenance agencies and contracted maintenance firms in the field and in the office. Each is a compendium of good practices for portland cement concrete (PCC) joint resealing and partial-depth spall repair, respectively, stemming from two Strategic Highway Research Program (SHRP) studies.

In project H-105, Innovative Materials and Equipment for Pavement Surface Repair, the researchers conducted a massive literature review and a nationwide survey of highway agencies to identify potentially cost-effective repair and treatment options. The information and findings from this study were then used in the subsequent field experiments conducted under project H-106, Innovative Materials Development and Testing.

In the H-106 project, the installation and evaluation of many different test sections were conducted to determine the cost-effectiveness of maintenance materials and procedures. Test sections were installed at 22 sites throughout the United States and Canada between March 1991 and February 1992, under the supervision of SHRP representatives. The researchers collected installation and productivity information at each site and periodically evaluated the experimental repairs and treatments for 18 months following installation.

Long-term performance and cost-effectiveness information for the various repair and treatment materials and procedures was not available at the time these manuals were prepared. However, subsequent performance evaluations may lead to future editions of these manuals to address performance and cost-effectiveness more thoroughly.

For the reader's convenience, potentially unfamiliar terms are italicized at their first occurrence in the manuals and are defined in glossaries. Readers who want more information on topics included in the manuals should refer the reference lists for each manual. The final report for the H-106 project may be of particular interest to many readers.[2] It details the installation procedures, laboratory testing of the materials, and field performance of each of the repair and treatment types.

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Manual for joint repair:
- Arizona Department of Transportation
- Colorado Department of Transportation
- Iowa Department of Transportation
- Kentucky Transportation Cabinet
- South Carolina Department of Highways and Public Transportation

Manual for spall repair:
- Arizona Department of Transportation
- Commonwealth of Pennsylvania Department of Transportation
- South Carolina Department of Highways and Public Transportation
- Utah Department of Transportation

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Materials and Procedures for the Repair of Joint Seals in Concrete Pavements

Manual of Practice

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1.0 Introduction

This manual has been prepared for use by maintenance engineers, maintenance field supervisors, crew persons, maintenance contractors, and inspectors as an easy reference for *resealing** transverse and longitudinal joints in portland cement concrete (PCC) pavements.

1.1 Scope of Manual

Included in this manual are descriptions of procedures and materials recommended for resealing joints in PCC pavements. Guidelines for planning a resealing project as well as steps for installing joint seals and inspecting the process are presented. The resealing of concrete-asphalt shoulder joints or sealing cracks in PCC pavements is not addressed. The information contained in this manual is based on the most recent research, obtained through reviews of literature and of current practice as well as from the field results of an ongoing study.[1,2] This study investigates the performance in PCC joints of various hot- and cold-applied sealants using several methods of installation.

1.2 Overview

Several steps are required for successful resealing of joints in PCC pavements. The first is determining the need for resealing the joints. Chapter 2 contains a general procedure for deciding whether to reseal. This procedure can be easily modified to meet the needs of each highway agency.

* Italicized words are defined in the glossary.

Once the need for resealing is determined, the next step is planning the operation. Chapter 3 leads the maintenance planner through the steps for selecting sealant and accessory materials, choosing preparation and installation procedures, specifying equipment, and estimating material and labor requirements.

The construction phase of joint resealing is described in chapter 4. Details of each step of the preparation and installation operations are listed along with troubleshooting procedures for each operation.

In addition, the appendices provide material testing specifications, sample cost-effectiveness calculations, safety precautions, and inspection checklists to help ensure good resealing practices and high-quality results.

2.0 Need for Joint Resealing

Excessive delay in replacing a failing *sealant system* in concrete pavement joints can result in more rapid deterioration of the pavement. However, if sealant is replaced too early, precious maintenance funds may not have been used in the most cost-effective manner. How, then, can those responsible for maintenance determine when is the best time to reseal joints in concrete pavements? Some states specify that joints be resealed when a specified amount of sealant material (25 to 50 percent) has failed, allowing moisture and/or *incompressible* materials to progress past the sealant to the underlying layers. Other agencies base their decision on pavement type, pavement and sealant condition, and available funding.

Another more complete method to determine whether or not a pavement needs to be resealed is to calculate rating numbers based on the sealant and pavement condition, traffic levels, and climatic conditions. Figure 1 presents a worksheet that can be used to estimate these properties, and table 1 gives the user recommendations about the need to reseal, based on these properties. The following sections assist in determining the necessary ratings and conditions.

2.1 Seal Condition

Joint-sealant system effectiveness is judged by the sealant's ability to resist *embedment* of incompressible materials and the sealant system's success in preventing entry of water and incompressibles into the joint. To evaluate pavement seal condition, the following steps should be completed and results recorded on figure 1:

Sealant Condition			
	Low	Med	High
Water entering, % length	< 10	10-30	> 30
Stone intrusion	Low	Med	High
Sealant Rating	**Good**	**Fair**	**Poor**

Environmental Conditions[c]		
Avg. annual precip., in		
Days ≤ 32°F (0°C)		
Avg. low / high temp, °F		
Climatic region [a]	WF DF	WNF DNF

Traffic Conditions			
ADT (vpd); % Trucks			
Traffic level [b]	**Low**	**Med**	**High**

Pavement Condition[c]			
	Low	Med	High
Expected pavement life, yrs	> 10	5-10	< 5
Avg. faulting, in	<0.06	0.06-0.12	>0.12
Corner breaks, % slabs	< 1	1-5	> 5
Pumping, % joints	< 1	1-5	> 5
Spalls > 1 in, % slabs	< 5	5-10	>10
Pavement rating	**Good**	**Fair**	**Poor**

Current Joint Design[c]	
Sealant age, yrs	
Avg. sealant depth, in	
Avg. joint width, in	
Avg. joint depth, in	
Max. joint spacing, ft	

[a] See table 2.
[b] See table 3.
[c] 1 inch = 25.4 mm; 1 ft = 0.305 m

Figure 1. Pavement survey form

Table 1. Decision table for resealing PCC joints

Sealant Rating [a]	Pvmt. Rating	Traffic Rating	Climatic Region			
			Freeze		Nonfreeze	
			Wet	Dry	Wet	Dry
Fair	Good	Low	Possibly	Possibly	Possibly	Possibly
Fair	Good	Med	Yes	Possibly	Possibly	Possibly
Fair	Good	High	Yes	Yes	Yes	Possibly
Fair	Fair	Low	Yes	Possibly	Possibly	Possibly
Fair	Fair	Med	Yes	Yes	Yes	Possibly
Fair	Fair	High	Yes	Yes	Yes	Possibly
Fair	Poor	Low	Possibly	Possibly	Possibly	Possibly
Fair	Poor	Med	Yes	Yes	Yes	Possibly
Fair	Poor	High	Yes	Yes	Yes	Yes
Poor	Good	Low	Yes	Possibly	Possibly	Possibly
Poor	Good	Med	Yes	Yes	Yes	Possibly
Poor	Good	High	Yes	Yes	Yes	Yes
Poor	Fair	Low	Yes	Yes	Yes	Possibly
Poor	Fair	Med	Yes	Yes	Yes	Yes
Poor	Fair	High	Yes	Yes	Yes	Yes
Poor	Poor	Low	Yes	Yes	Yes	Possibly
Poor	Poor	Med	Yes	Yes	Yes	Yes
Poor	Poor	High	Yes	Yes	Yes	Yes

[a] Sealants rated in "Good" condition do not require replacement.

- Choose 10 or more joints whose sealant condition is representative of the entire site. If large variations in condition are evident, subdivide the site into sections having similar seal condition and evaluate 5 to 10 joints from each section.
- Cut 2-in (51-mm) samples of sealant from a few joints and measure the joint width, depth, and sealant thickness.
- Determine from the construction records the type and age of the sealant and the design joint width and sealant thickness.
- Record the maximum spacing between joints.

Carefully inspect each of the 10 or more chosen joints, recording the following items on figure 1:

- Water resistance is the percent of overall joint length where water can bypass the sealant and enter the joint.
- Stone intrusion is the amount of stones, sand, and debris that is embedded in the sealant.

Loss of bonding to the concrete sidewall, shown in figure 2, full-depth spalls, shown in figure 3, and torn or missing sealant are common joint seal distresses. They reduce water resistance and allow moisture, sand, and dirt to enter the joint. Bond failure can be determined by pulling the sealant away from the joint edge and inspecting for *adhesion failure*. Full-depth spalls can be identified by gently inserting a dull knife into the spall and observing whether the knife tip can pass below the sealant. Another method for locating areas of bond failure is with a vacuum tester as developed by the Iowa Department of Transportation. The percent of water resistance loss can be computed using equation 1.

$$\%L = \left[\frac{L_f}{L_{tot}}\right] x\ 100 \qquad (1)$$

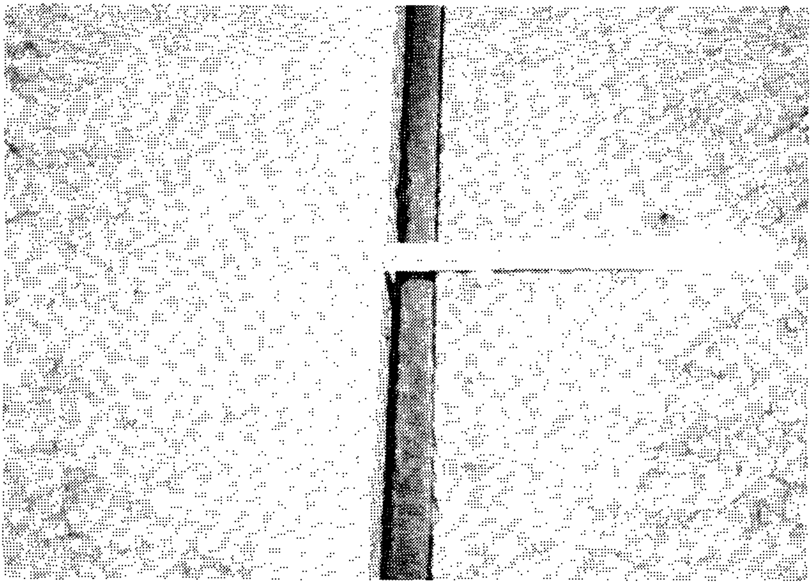

Figure 2. Sealant adhesion failure

where:

%L	=	Percent length allowing water to enter joint (%)
L_f	=	Total length of joint sections allowing the entrance of water (in)
L_{tot}	=	Total length of joint sections evaluated (in)

Stone intrusion can be rated using the following criteria, and the rating should be recorded on figure 1:

Low	=	Occasional stones and/or sand are stuck to the top of the sealant (or material embedded on the surface of the *sealant/channel interface*).
Medium	=	Sand or debris is stuck to sealant and some debris deeply embedded in the sealant (or material embedded between the sealant and the *channel face* but not entering the joint below the sealant).

High	=	Much sand and debris is stuck to and deeply embedded in the sealant or filling the joint (or material embedded between the sealant and the channel face and entering the joint below the sealant).

Next, determine the sealant rating by calculating the sealant condition number (SCN). This number can be computed using the following equation:

$$SCN = 1(L) + 2(M) + 3(H) \tag{2}$$

where:

SCN	=	Sealant condition number
L	=	The number of low-severity sealant conditions from figure 1
M	=	The number of medium-severity conditions
H	=	The number of high-severity sealant conditions

Use the SCN and the following chart to determine whether the existing joint seal is in good, fair, or poor condition, and circle the correct sealant rating on figure 1.

Sealant Rating	**SCN**
Good	0 to 1
Fair	2 to 3
Poor	4 to 6

Results of a sealant condition rating can also be used to monitor the performance of joint seals and to assist in follow-up rehabilitation planning.

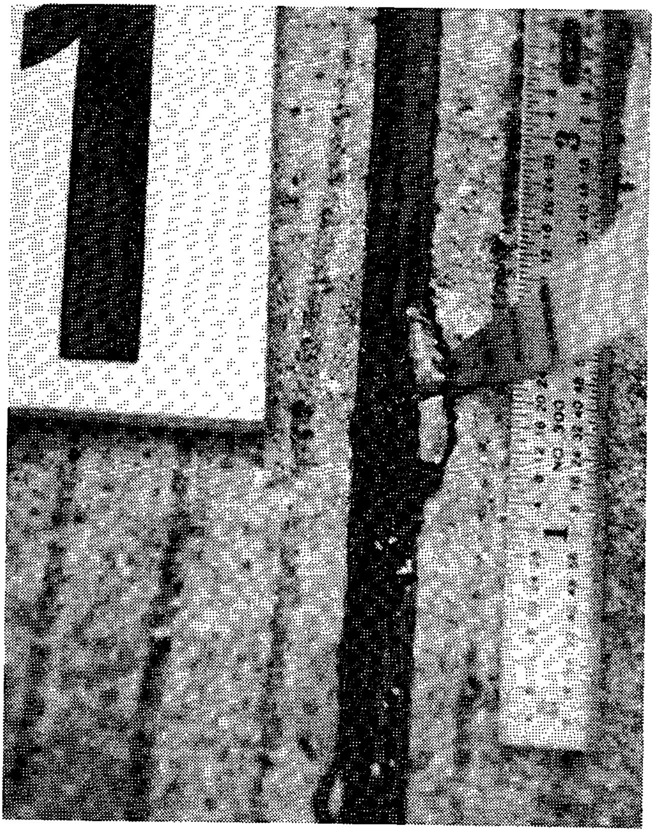

Figure 3. Full-depth spall distress

2.2 Pavement Condition

A pavement will provide several indicators that the joint seal is not performing adequately and is allowing too much water to reach the underlying layers. These indicators include:

- Surface staining or the accumulation of fine material on the surface close to joints or cracks indicates *pumping* of the base or subbase. This results, in part, from excess moisture and it contributes to formation of voids beneath the pavement, cracks, and corner breaks.

- *Faulting,* or dropoff between adjacent slabs, possibly indicates that excess moisture is reaching a water-susceptible base and/or subgrade, and that voids are forming beneath one side of the pavement as a result of continual traffic.

- *D-cracking* of susceptible pavement can result from excess moisture beneath a pavement.

A pavement system can also manifest the effects of the entrance of stones and other incompressible materials into pavement joints by the following:

- Compression-related spalls are present of the walls of joints that are filled with sand and stones.

- *Blowups* have occurred and slab edges have shattered. There has been a permanent increase in joint width causing movement of nearby bridge supports.

To evaluate the condition of a pavement considered for resealing, record the following items in the pavement condition section of figure 1. These items should be based on field inspection and the maintenance schedule.

1. The estimated number of years before the pavement requires major rehabilitation
2. The average vertical faulting movement
3. The percent of slabs containing corner breaks
4. The percent of joints visually indicating pumping
5. The percent of slabs containing full-depth spalls extending greater than 1 in (25.4 mm) or more from the face of the joint

To determine a pavement condition number (PCN), use figure 1 and equation 3.

$$PCN = 1(L) + 2(M) + 3(H) \tag{3}$$

where:

PCN	=	Pavement condition number
L	=	The number of low-severity pavement condition indicators from figure 1
M	=	The number of medium-severity pavement condition indicators
H	=	The number of high-severity pavement condition indicators

Use the PCN and the following chart to determine whether the existing pavement is in good, fair, or poor condition, and circle the correct pavement rating on figure 1:

Pavement Rating	**PCN**
Good	0 to 3
Fair	4 to 5
Poor	6 to 15

2.3 Climatic Conditions

The effects of extreme temperatures and precipitation on joint seal and pavement performance cannot be minimized. In extreme cold, sealants are stretched the most as pavements shrink and joints widen. Extreme heat results in expanding slabs and shrinking joints. This can compress improperly placed sealant so that it is forced above the pavement surface and may be pulled out by passing traffic.

Wet climatic regions need highly effective seals, approaching 100 percent effectiveness to prevent water damage to the base and pavement structures. Similarly, dry climates also require highly effective seals in order to prevent the intrusion of incompressible material into the joint, which can result in *joint growth*, blowups, and structural damage.

When evaluating the climatic conditions that a pavement will experience, determine for that location the following information and enter it in the environmental condition section of figure 1:

- The normal annual total precipitation for the location
- The mean number of days in a year with a minimum temperature of 32°F (0°C) or below
- The highest and lowest recorded temperatures

This information is available from the National Climatic Data Center in Asheville, N.C., or from local weather recording stations. Then, using the information on figure 1 and table 2, identify the climatic region in which the pavement is located. Circle the correct climatic region on figure 1.

Table 2. Climatic region parameters

Climatic Region	Mean Annual Days ≤ 32°F (0°C)	Average Annual Precipitation
Wet-freeze	> 100	> 25 in (635 mm)
Wet-nonfreeze	≤ 100	> 25 in (635 mm)
Dry-freeze	> 100	≤ 25 in (635 mm)
Dry-nonfreeze	≤ 100	≤ 25 in (635 mm)

2.4 Traffic Level

To identify traffic conditions, obtain the *average daily traffic* (ADT) level in vehicles per day (vpd) and the percent truck traffic. Determine the traffic level rating from table 3. If the percent truck traffic is greater than 10 percent or the expected growth rate is greater than 5 percent, borderline traffic level ratings should be increased one level.

Table 3. Traffic level rating

Traffic Level	ADT, vpd all lanes
Low	< 5,000
Medium	5,000 to 35,000
High	> 35,000

2.5 Determining the Need to Reseal

After completing the pavement evaluation worksheet, use table 1 and the calculated sealant rating (SCN), pavement rating (PCN), the traffic rating, and the climatic region to evaluate the need for resealing. The table makes recommendations about the need for resealing based on the ratings of the evaluation worksheet. The basis for the table is engineering experience; however, it can be adjusted to the needs and policies of individual state agencies. Choose the row with the combination of sealant, pavement, and traffic rating from the three left-hand columns that match the pavement being evaluated. Then, find the intersection of that row with the appropriate climatic region to obtain the recommendation on the need for resealing.

If the recommendation is that sealing is "possibly" needed, then the case is borderline, and good judgment based on experience should be used in determining the need to reseal. When an overlay or rehabilitation is scheduled within 3 to 5 years, sealing could be delayed unless pavement or base damage would result.

3.0 Planning and Design

3.1 Primary Considerations

After determining the need to reseal the joints in a concrete pavement section, it is important to plan the sealing operation to ensure that a proper resealing job is completed. Proper planning should take into account these factors:

- The long- and short-term objectives for resealing
- The current sealant and pavement condition and the place of the resealing effort in an overall maintenance plan
- The applicability and documented performance of the sealant materials chosen for use
- The effectiveness of the equipment and installation methods chosen for use
- The level of strain placed on the sealant system as a result of the dimensions of the joint reservoir
- The minimization of traffic disruption, increased worker safety, and efficient installation rates

3.2 Objective for Resealing

When beginning, it is important to determine the objective of the resealing project. Possible objectives include:

- Temporarily sealing pavement joints for 1 to 2 years until the pavement is overlaid or replaced.
- Sealing and maintaining watertight joints for 3 to 5 years.
- Sealing and maintaining watertight joints for a period extending more than 5 years.

Each of these objectives may be correct for a different situation, depending primarily on the pavement condition and the traffic level, as illustrated in table 4.

In dry climates, it is more important to keep sand and dirt out of the joints to prevent spalling and blowups. A sealant should then be chosen that does not allow sand to penetrate the sealant surface. In hot climates, some sealants *flow* down into the joint, or *track* on the surface, or allow stones to become embedded in the sealant. In some situations, a jet-fuel-resistant sealant material is required. In some pavements, only certain areas of sealant are failed, and selective replacement is needed. Consequently, when choosing sealant materials and installation methods, the objectives must match the requirements of the situation.

3.3 Accounting for Existing Conditions

The condition of a pavement when it is resealed can greatly affect the performance of the seal. Corner breaks, large spalls, voids beneath the pavement, faulting, and poor *load transfer* can all reduce the effective life of resealed joints. Depending on existing conditions, some of these pavement distresses should be repaired before sealant is installed.[3] Specifically, prior to resealing, the following repairs should be considered:[4]

- Full-depth repair of corner breaks and deep spalls
- Partial-depth repair of spalls that extend more than 1 in (25.4 mm) from the face of the joint
- Improving *subdrainage* and/or roadside drainage
- Restoring load transfer at joints and cracks where poor load transfer exists
- *Undersealing* the pavement where voids exist

Table 4. Relationship between pavement condition and sealing objectives

Condition	Objective
Pavement is to be overlaid in 1 to 2 years.	Temporarily seal the pavement.
Pavement is in fair condition. Major rehabilitation in 5 years.	Maintain the seal until rehabilitation.
Pavement is in good condition and carries a high level of traffic.	Maintain the seal as long as possible.

- Grinding the pavement surface to restore a smooth ride or to improve traction

Each of these repairs, if needed, should be completed before resealing begins. The condition of the sealant in longitudinal joints and transverse cracks should also be evaluated to determine whether resealing them is appropriate.[5] Studies have shown that extensive pavement damage can occur due to the large amount of water entering a pavement system through open transverse cracks and longitudinal joints.

The condition of the joints and sealant can reveal much about the conditions under which it failed. Several of these indicators are listed in table 5. When these or other conditions are evident, care should be taken to address and eliminate these problems for the resealing project.

3.4 Selecting a Sealant Material

Sealant materials are subjected to very harsh conditions. Selected sealants must have the capability to:

Table 5. Indicators learned from original sealant

Observed Sealant Condition	Possibly Indicates...
Sealant is pulled away from edge(s) along majority of the site.	Joint movement was large. Sealant material or placement methods were poor.
Sealant is pulled away from edge(s) at random positions along joints.	Joint may not have been cleaned properly.
Sealant is tracked on pavement.	Sealant was overheated or contaminated or has a low softening point.

- Withstand *horizontal movement* and *vertical shear* at all temperatures to which they are exposed
- Withstand environmental effects such as *weathering*, extreme temperatures, and excess moisture
- Resist stone and sand penetration at all temperatures
- Maintain complete bond to concrete *joint sidewalls* at all temperatures

There are a wide variety of sealant materials on the market, each with its own inherent characteristics and with costs ranging from less than $2.00 per gallon to more than $35.00 per gallon. However, there is no one sealant that can meet the demands of every resealing project. Sealant selection should be based on the objectives of the resealing project.

Table 6 contains a listing of sealant materials commonly used in resealing joints in PCC pavements. Example products for each sealant type are included, along with applicable specifications. To help the designer in choosing a sealant material, the *allowable extension* and cost range are included. The allowable extension is the manufacturer recommended maximum in-place sealant extension.

Table 6. Summary of sealant materials

Sealant Material	Example Product	Applicable Specification(s)	Design Extension [a]	Cost Range ($/gal) [b]
PVC coal tar	Crafco Superseal 444, Koch NEA 3406	ASTM D3406	10 to 20%	$5.50 to $8.00
Rubberized asphalt	Koch 9005, Crafco 221, Meadows Hi-Spec	ASTM D1190, D3405 AASHTO M173, M301-851, Fed SS-S-164	15 to 30%	$1.85 to $3.75
Low-modulus rubberized asphalt	Crafco 231, Meadows Sof-Seal, Koch 9030	Modified ASTM D 3405	30 to 50%	$3.15 to $5.40
Polysulfide (1 & 2 part)	Koch 9015, 9020, 9050	Fed SS-S-200E	10 to 20%	$13.00 to $14.50
Polyurethane	Mameco Vulkem 245, Sikaflex, Burke U-Seal, Tremco	Fed SS-S-200E	10 to 20%	$19.00 to $28.00
Silicone (non-self-leveling)	Dow 888, Mobay 960, Crafco 902	State specifications	30 to 50%	$25.00 to $30.00
Silicone (self-leveling)	Dow 888-SL, Mobay 960-SL, Crafco 903	State specifications	30 to 50%	$30.00 to $35.00
Preformed neoprene compression seal	DS Brown - Delastic, Watson-Bowman - WG-300	ASTM D2628 AASHTO M220	Compress 45 to 85%	-

[a] Consult manufacturers for specific design extensions.

[b] Based on 1991 and 1992 costs (1 gal = 3.79 L)

Resealing with *compression seals* is not typically done when the pavement joints are spalled, since the seals tend to twist or move up or down in the joint at locations where the joint edge is not vertical and completely smooth.

Many agencies have full-scale testing programs to determine the performance of potential materials under local conditions. Thorough field and laboratory testing is recommended before any sealant is used on a large-scale project. Commonly used lab specifications are shown in appendix A.

A *life-cycle cost analysis* should be performed to determine the material with the least average annual cost over the expected life of the pavement. Section 3.11 includes a worksheet to assist in life-cycle cost analysis.

3.5 Selecting Backer Materials

Backer rod is typically inserted in PCC joints prior to resealing to keep the sealant from sinking into the reservoir. It also keeps the sealant from bonding to the bottom of the reservoir and, if properly selected and installed, it helps maintain the proper sealant thickness. The rod must be flexible, compressible, non-shrinking, non-reactive, and non-absorptive. Shrinking rod may allow sealant to flow past the rod before the sealant sets. Backer rod that reacts with certain sealants may produce bubbles in or staining of the sealant. Finally, backer rod that absorbs water may shorten the life of the sealant material.

Several currently available types of backer rod are described in table 7. Each type has specific properties and intended uses. For example, several backer-rod types are designed to withstand the extreme temperatures of hot-applied sealants, while others are intended only for cold-applied sealants.

Table 7. Backer-rod materials

Backer Material Type	Example Products	Properties*	Compatibility
Extruded closed-cell polyethylene foam rod	AET-HBR, ITP-SBR	NMA, ECI, NS	Most cold-applied sealants
Cross-linked extruded closed-cell polyethylene foam rod	AET- HBR-XL, ITP- Hot Rod-XL	HR, NMA, ECI, NS	Most hot- and cold-applied sealants
Extruded polyolefin foam rod	AET- Sof-Rod, ITP-Soft-Type Rod	NMA, NS, NG, CI, IJ	Most cold-applied sealants

* CI - Chemically inert; ECI - Essentially chemically inert; IJ - Fills irregular joints well; NMA - Non-moisture-absorbing; NG - Non-gassing; NS - Non-staining; HR - Heat resistant

Recently, softer, *extruded* foam rods have been developed to better seal joints with irregular edges. Backer tapes that require a shallower joint have also been used.

The manufacturers' recommendations should be followed when selecting rod type, since sealant and backer rod must be compatible. The more commonly used backer-rod materials for hot-applied sealants are cross-linked, expanded foam rods. For cold-applied sealants, extruded closed-cell polyethylene foam or extruded polyolefin foam rod is typically used. The rod diameter should be at least 25 percent larger than the joint width. Backer rod is available in diameters ranging from 0.38 to 3.0 in (10 to 76 mm) or more. Since joint widths may vary within a rehabilitation project, a sufficient range of rod sizes should be on hand to obtain a tight seal in all joints.

3.6 Selecting Primer Materials

In areas where high humidity and moisture make it difficult to obtain a good bond between the sealant and the concrete, primer may be recommended by the planner or the sealant manufacturer. The purpose of a primer is to bond to the concrete surface and provide a surface to which the new sealant can bond well. Primer may be used when past experience indicates that it is difficult to obtain a good bond with the specified sealant.

Primers are currently used in only a small percentage of major PCC resealing operations, with most of the use occurring in wet or cold climates. Consult sealant manufacturers for primer type recommendations when the need for priming the joints exists.

3.7 Selecting Joint Reservoir Dimensions

The width of a joint and the thickness of the sealant in that joint can significantly affect the performance of the seal.[6,7] If a joint is too narrow and temperature changes cause the joint to widen significantly, the sealant may be stretched beyond its breaking point or pulled away from the concrete. In addition, if a thick sealant is stretched, it may tear or not stick to the concrete, in the same way that a thick rubber band cannot be stretched as far as a thin one before tearing.

In designing the dimensions of a joint sealant and the sealant reservoir, two major items must be determined: the shape factor and the expected joint movement. Figure 4 shows the

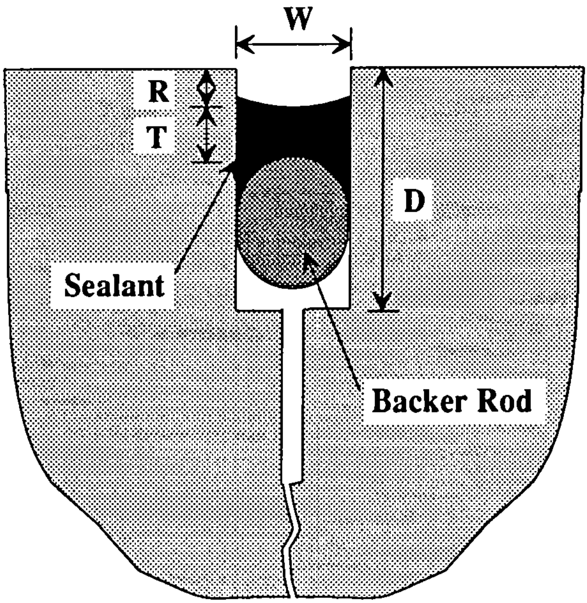

Figure 4. Typical joint cross-section.

dimensions of a typical *sealant reservoir* containing sealant material and backer rod. The shape factor, W:T, is the ratio of the sealant width (W) and the sealant thickness (T). The sealant recess is designated as "R" and the joint channel depth is "D".

Manufacturers' recommendations should be followed when choosing a shape factor. Typical recommended shape factors are shown in table 8. Silicone manufacturers recommend a minimum thickness of 0.25 in (6 mm) and a maximum of 0.5 in (13 mm).

Table 8. Typical recommended shape factors (W:T)

Sealant Material Type	Typical Shape Factor (W:T)
Rubberized asphalt	1:1
Silicone	2:1
PVC coal tar	1:2
Polysulfide and polyurethane	1:1

The maximum joint opening movement can be estimated using equation 4.

$$M = CL\,(\alpha T) \tag{4}$$

where:

- M = Joint opening movement caused by temperature change of PCC (in)
- C = Subbase/slab friction resistance adjustment factor (0.65 for stabilized subbase, 0.80 for granular subbase)
- L = Joint spacing (in)
- α = Thermal coefficient of contraction for PCC (5 to 6 x 10^{-6}/°F [9.0 to 10.8 x 10^{-6}/°C)
- T = Temperature range: temperature at placement minus lowest mean monthly temperature

Based on this equation, the percent elongation that the new sealant must allow is:

$$\%E_{max} = 100\left(\frac{M_{max}}{W_{init}}\right) \tag{5}$$

where:

- $\%E_{max}$ = Estimated elongation (percent)

M_{max} = Joint opening movement caused by change of PCC temperature (in)
W_{init} = Joint width at the time of sealant placement (in)

Some engineers prefer to determine M_{max} using the safer assumption that a joint between two slabs may be called upon to take the total movement of both slabs. In this assumption:

$$M_{max} = 2(M) \qquad (6)$$

The initial joint width, W^{init}, should be wide enough to keep the sealant from being stretched in cold weather more than the design amount, typically 20 percent. However, joints should not typically be wider than 0.75 in (19 mm).[3,6]

Suggested sealant thicknesses and minimum joint widths for various joint spacings are listed in table 9 as a check for more detailed joint design. This table is based on limiting the sealant stress to less than 20 percent.

Table 9. Typical joint design dimensions

Maximum Joint Spacing, ft (m)	Minimum Joint Width, in (mm) [a]	
	Nonfreeze Region [b]	Freeze Region [c]
≤ 15 (≤ 4.6)	0.25 (6)	0.38 (10)
16-25 (4.9-7.6)	0.25-0.38 (6-10)	0.38-0.5 (10-13)
26-40 (7.7-12.2)	0.38-0.5 (10-13)	0.5-0.75 (13-19)
41-60 (12.3-18.3)	0.5-0.75 (13-19)	0.75-1.13 (19-29)

[a] Installation temperature is 80°F (27°C), base is stabilized, $\%E_{max} \leq 20\%$.
[b] Minimum nonfreeze region temperature is 20°F (-7°C).
[c] Minimum freeze region temperature is -15°F (-26°C).

The joint reservoir depth, D, should be the sum of the selected sealant thickness, the compressed backer-rod thickness, and the depth that the sealant surface is to be recessed. Some manufacturers recommend that an extra 0.25 in (6 mm) be added when resealing joints to prevent water and material beneath the sealant from pushing the sealant up and out of the joint.

3.8 Selecting Preparation and Installation Procedures

The type of joint cleaning procedures and the final cleanliness of the concrete joint walls prior to sealant installation can significantly affect the performance of sealant materials. As a rule, the cleaner and dryer the joint surfaces are, the better a sealant will adhere, and the more effective it will be. Therefore, preparation and installation procedures should be chosen as carefully as sealant materials.

The selection of which combination of preparation and installation procedures to use should be based on the condition and requirements of each individual resealing project. Four combinations are shown in table 10. Each option, if followed completely, should result in clean joint surfaces and increase the chances for good performance.

Option 1 should be considered when:

- The resealing project carries a high volume of traffic.
- A high-quality sealant is being used.
- Joint widths or depths do not meet the minimum design requirements.
- The existing sealant is hardened and will not melt and "gum up" the saw blades.

Table 10. Joint preparation/installation procedures

Opt	Plow	Saw	Water Wash	Initial Airblast	Sand Blast	Final Airblast	Backer Rod	Recessed Sealant
1		✓	✓	✓	✓	✓	✓	✓
2		✓		✓	✓	✓	✓	✓
3	✓	✓		✓	✓	✓	✓	✓
4	✓				✓	✓	✓	✓

Option 2 differs from option 1 only by the elimination of waterwashing. This option can be used only when it can be demonstrated that:

- Sufficient joint surface cleanliness can be achieved without waterwashing.

Option 3 adds a plowing operation to the option 2 procedures. It should be used when:

- The saw blade is melting the existing sealant and sawing cannot remove the sealant efficiently by itself.

- The joint dimensions are not adequate.

Option 4 replaces the sawing operation with an effective plowing operation. It can significantly reduce the preparation time and, since it is a dry operation, it allows immediate cleaning and resealing. But it may only be used if:

- The joint dimensions are adequate.
- The plowing equipment removes more than 95 percent of the sealant from the joint faces, leaving fresh, unspalled concrete.

- The sandblaster is able to efficiently remove any remaining sealant.

If compression seals are being replaced with formed-in-place sealant, sawing is not required when sandblasting can completely remove the old lubricant from the joint walls.[3]

Several methods of sealant installation have also been used with varying results.[1,2] These include:

- Recessing the sealant below the pavement surface
- Keeping the sealant surface level with the pavement surface
- *Overbanding* sealant onto the pavement surface

The slightly recessed sealant has better potential for long-term performance. The overbanded sealant material is typically worn away by traffic in less than one year. After it is worn, traffic tires tend to pull the sealant from the joint edge. This pulling away has also been noted on some sealants that were installed level with the pavement surface.

3.9 Selecting Equipment

Selection of equipment for the resealing process should be based on its ability to complete the task. This ability should be proven prior to beginning the resealing operation by constructing a test resealing section.

A contractor or highway maintenance crew should be allowed to choose the equipment that will effectively clean and reseal concrete joints in the most efficient manner. However, several items have been shown to be important to successful use of each piece of equipment. These requirements are listed in table 11, together with a partial list of equipment manufacturers.

Table 11. Joint resealing equipment requirements

Equipment	Example Manufacturers	Requirements
Joint plow	RC Company, Major joint sealing contractors	Non-tapered, carbide-tipped blades. Sufficient blade sizes. Ability to control blade height. Ability to force blade against sidewall.
Concrete saw (includes saw, hose, and water truck)	Target, Cimline, Magnum, Diamond Core Cut	Self-propelled, water-cooled saw $\geq$ 35 hp. Diamond saw blades designed to cut hardened PCC to uniform width. Controllable, does not pull to one side.
Sandblast equipment (includes sandblast unit, air compressor, hoses, nozzles, and safety equipment)	Clemco, P. K. Lindsay, Ingersoll-Rand, Reumelin	Acceptable air compressor. Recommend venturi tungsten nozzles.
Airblast equipment (includes air compressor, hose, wand, and safety equipment)	P. K. Lindsay, Ingersoll-Rand, Smith, Joy, Leroi-Dresser, Sullivan Industries	Functional oil and water removal filter on compressor. Minimum 90 lb/in^2 (621 kPa) at 150 ft^3/min (71 L/sec). $\geq$ 0.75 in (19 mm) ID hose. Nozzle with shut-off valve. Face shield, ear protectors.
Hot air lance	Linear Dynamics, LA Mfg., Cimline, Seal-All, P.A. Torch	Air outlet temperature: $\leq$ 2,000 °F (1,093°C). Stream Velocity: $\geq$ 1,000 ft/s (1,328 m/s). No direct flame on pavement.
Backer-rod installation tools	Control Tool, O.J.S. Machines, sealing contractors	Maintains proper recess, $\pm$1/8 in (3 mm). Does not damage backer rod.
Hot-applied sealant installation equipment (includes portable melter/applicator, hose, wand and safety equipment)	Crafco, Stepp's, Cimline, Cleasby, Aeroil, Bearcat, Berry, Western Industries, White, Ghausse	Mechanical agitator. (recommend full-sweep agitator). Separate automatic temperature controls for oil and melting chamber. Sealant heating range to 500°F (260°C). Sealant recirculation system.
Silicone sealant installation equipment (includes pump, compressor, hose, wand)	Pyles-Graco, Inc, Aro Corporation, Semco	Minimum flow rate 0.4 gal/min (0.025 L/sec). Recommend: hose lined with Teflon, all seals and packing made with Teflon.

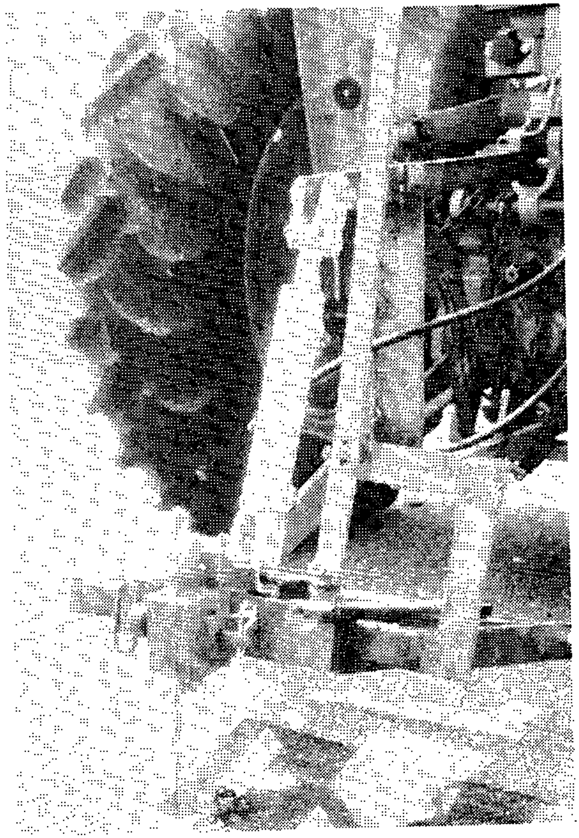

Figure 5. Rear-mounted joint plow

3.9.1 Joint Plow

A joint plow used only to remove sealant prior to sawing must remove enough sealant to keep the saw blades from gumming up. A shop-made, rear-mounted joint plow for this purpose is shown in figure 5. If the plow is used without resawing, it must be able to efficiently remove at least 95 percent of the old sealant from the joint walls and not spall the joint sidewalls. Plowing has also been successfully accomplished by attaching a hydraulically-controlled carbide-tipped blade to the underbody of a small, 18 to 24 hp (13.4 to 17.9 kW) tractor, as shown in figure 6. Multiple blade

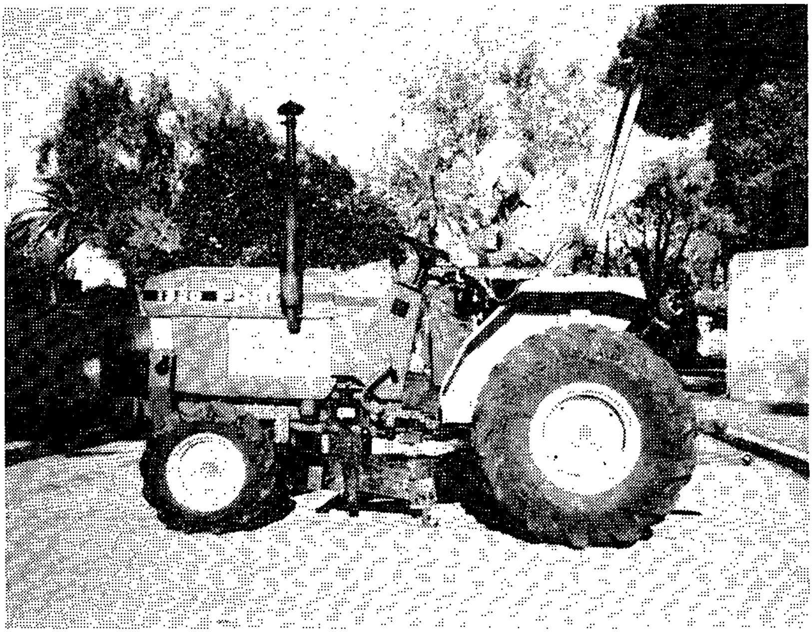

Figure 6. Belly-mounted joint plow

sizes should be on hand to keep the blades from binding in narrow joints.

Plow blades generally have straight sides, but may be tapered. Tapered blades tend to spall the joint edges, especially at intersections with other joints, at pavement edges, and at locations where the joint width changes quickly. Straight-sided blades must be forced against the side of the joints to clean them more thoroughly, but the risk of spalling is greatly reduced when the blade width is narrower than the joint width.

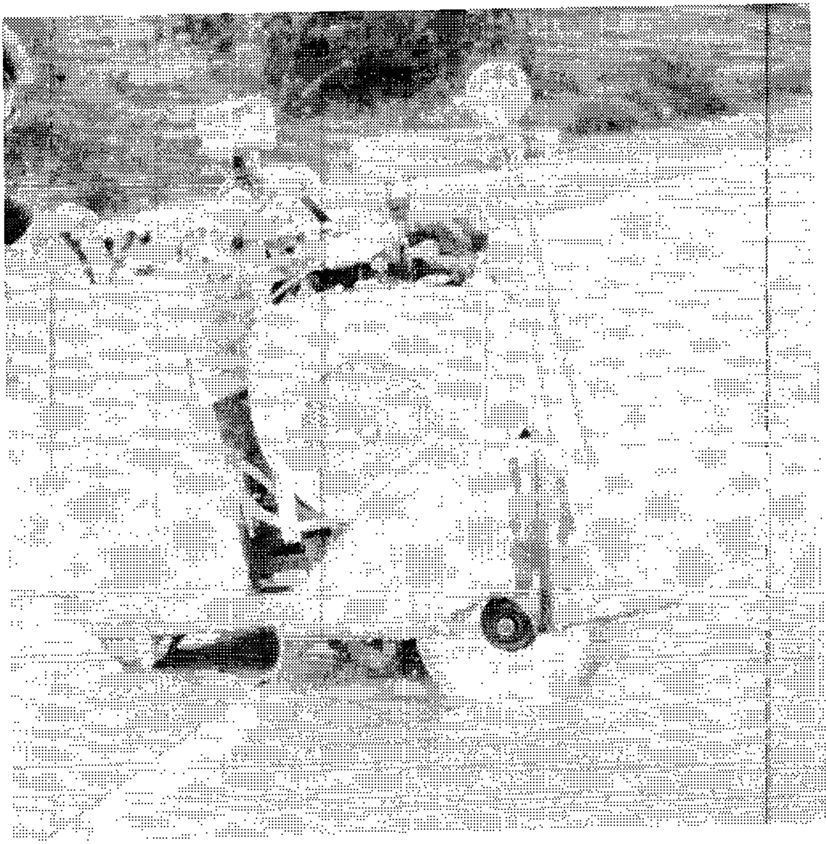

Figure 7. Concrete joint saw

3.9.2 Concrete Saw

Saws used for refacing the joint should remove the minimum amount of concrete to achieve the design width and produce freshly sawn, clean joints of uniform width and depth. Self-propelled, water-cooled power saws with diamond blades, as shown in figure 7, are typically used for joint refacing.

In many cases, blades are ganged side-by-side on the blade arbor with a solid metal spacer to allow the saw to *reface* the joint to a proper, uniform width in one pass.[4] The spacer diameter must be sized to prevent sealant from building up between the blades. Ganged blades can be exchanged on the arbor to provide more even wear, more uniform sawing widths, and longer blade life. Single, full-width blades are also used to resaw joints for resealing.

Since smaller blades are less expensive and make the saw easier to maneuver, blades should be no larger than necessary to achieve the required depth. Blades specifically designed for resawing hardened concrete should be used, and the body of these blades must be thick enough to resist warping.

3.9.3 Abrasive Blasting Equipment

Sandblasting equipment must be able to completely remove dried sawing *slurry*, dirt, and any old sealant from the joint faces. To efficiently accomplish this for a medium to large resealing project, an abrasive blasting unit, as shown in figure 8, should maintain a minimum nozzle pressure of 90 lb/in^2 (621 kPa) at 150 ft^3/min (71 L/sec). The air supply must be clean, dry, and free from oil. This may require the installation of an oil and moisture filter on the air compressor.

Tungsten carbide nozzles should be used for larger projects, and ceramic nozzles are more useful for 3- to 4-hour projects. Tungsten carbide and ceramic nozzles are available in several diameters, lengths, and shapes. A 0.19- to 0.25-in (5- to 6-mm) diameter venturi nozzle has been used successfully for sandblasting joints. A sandblast chamber that allows continuous loading increases production rates.

Attaching an adjustable guide to the nozzle to keep it 1 to 2 in (25.4 to 50.8 mm) from the pavement promotes consistent results and reduces operator fatigue.

Figure 8. Abrasive blasting equipment

For worker protection and to conform to state and OSHA requirements, all necessary safety equipment must be present and in good working condition. This equipment may include:

- A remote shutoff valve
- An air-fed protective helmet
- An air supply purifier
- Protective clothing for the operator
- Portable protective barriers between the sandblaster and adjacent traffic

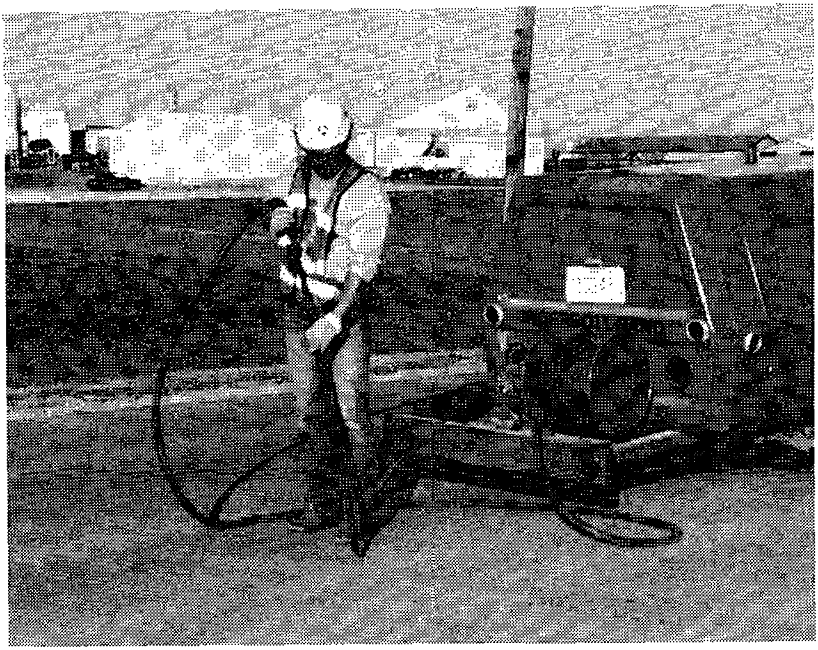

Figure 9. Air compressor

3.9.4 Airblasting Equipment

An air compressor, as shown in figure 9, is used for final cleaning, and must produce sufficient air quality, pressure, and volume to thoroughly clean the joints. This requires the following:

- The air supply must be clean, dry, and contain no oil.
- A compressor with a minimum of 150 ft^3/min (71 L/sec) at the nozzle and 100 lb/in^2 (690 kPa) must be used.

Many modern compressors automatically insert oil into the air lines to lubricate air-powered tools. For joint cleaning, this must be disconnected and an effective oil and moisture trap must be installed. In most cases, the inside of the hose for a lubricating air compressor is coated with oil. This oil must be removed or the hose be replaced to keep oil from reaching the joints. Attaching a balanced wand with a shutoff control increases safety and improves worker comfort. Proper eye and ear protection should also be used to protect the operators.

3.9.5 Hot Airblasting Equipment

A hot compressed air lance, or heat lance, used to dry slightly damp joints must supply heated air at about 2,000°F (1,093°C) with a supply velocity of more than 1,000 ft/s (328 m/s). The temperature and movement rate must be closely controllable to reduce the possibility of overheating the pavement, since overheating can produce chalking and temperature/steam-induced stress fractures.

Several heat lance options are available, including push button ignition, wheels, and balancing straps. Eye, ear, and body protection devices must be used, due to the heat and noise produced by this equipment.

3.9.6 Backer-Rod Installation Tools

A backer-rod installation tool must be able to push the backer rod into a joint to the specified depth without tearing, stretching, or damaging the rod. Most sealant contractors make their own installation tools. However, a lightweight, adjustable tool is commercially available, as well as an automated, self-guiding unit that is shown in figure 10.

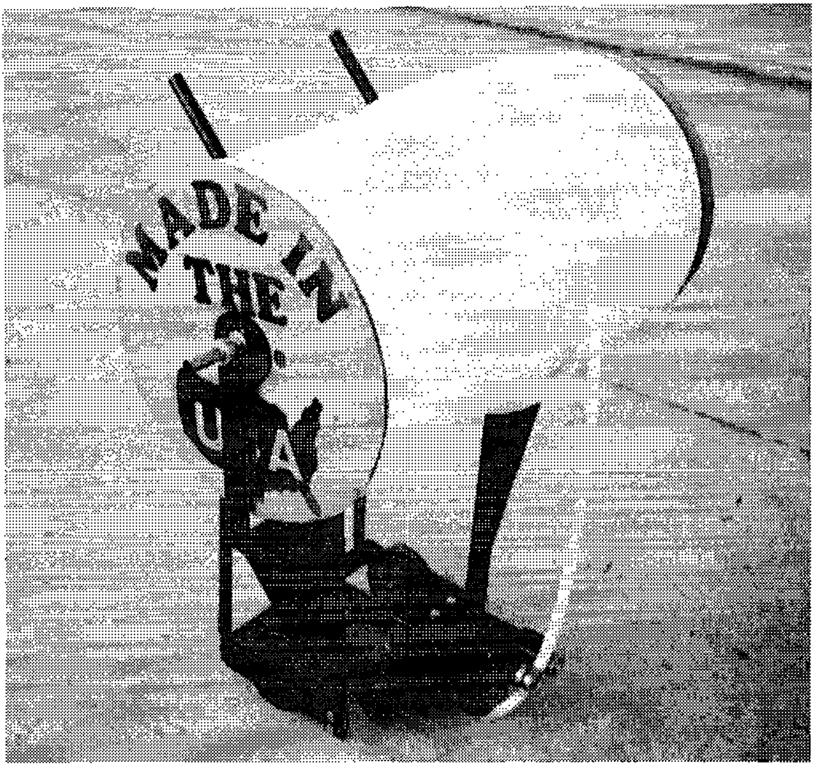

Figure 10. Automated backer rod installation tool

3.9.7 Hot-Applied Sealant Installation Equipment

The equipment used for installing sealant materials that must be heated should be able to:

- Effectively raise the temperature of the sealant without overheating portions of the sealant
- Allow the operator to maintain exact sealant temperatures in the range of 325 to 480°F (163 to 249°C)
- Be large and powerful enough to heat a sufficient amount of sealant so that installation is not delayed

Many companies manufacture mobile equipment that will melt and pump sealant into pavement joints. Several such companies are listed in table 11. The sealant capacity of most melter/applicators ranges from 50 to 350 gal (189 to 1,325 L). Characteristics of the melter/applicator equipment should include:

- A double-walled heating chamber with heating oil between the walls as the heat transfer medium
- A mechanical agitator
- Accurate thermostats to monitor both the sealant and the heating oil temperatures (these thermostats should control the operation of the burners)
- A reversible pump that can feed sealant to the applicator wand or recirculate the sealant into the melter vat
- A nozzle with an outside diameter that is small enough to allow it to be pulled through the narrowest joint without binding, yet large enough to maintain a good installation rate

Options that may be helpful include electronic ignition, diesel heating fuel, wand nozzles that maintain the sealant at a certain depth,[8] and hoses and wands that are insulated and/or heated.

3.9.8 Silicone Sealant Applicators

Silicone pumps and applicators should provide sealant to the joint at a rate that does not slow the operator. The applicator equipment should:

- Not introduce bubbles into the sealant
- Not allow air to reach the sealant before it enters the joint, to prevent premature curing

- Maintain a feed rate of at least 0.4 gal/min (1.5 L/min)
- Have a nozzle designed to fill the joint from the bottom up

Applicators that have Teflon-lined hoses and Teflon seals are less likely to allow the sealant to cure in the pump or hose than those that use neoprene seals and standard hose.

3.9.9 Other Equipment

Under some conditions, a self-propelled vacuum sweeper or portable air blower may be useful for removing sand and dust from the pavement surface prior to backer rod installation. Rotary wire brushes have been used for joint wall cleaning with very limited success, due to their tendency to scrape the cement (which produces dust) and to smear old joint sealant over the dust.[6] They are not generally recommended.

3.10 Estimating Material, Labor, and Equipment Requirements

To help with estimating the material, labor, and equipment requirements, the information in table 12 is provided. This table contains estimated material amounts and preparation and installation rates. Costs and rates for two scenarios are shown. The first is a self-leveling silicone with a shape factor of 2:1, and the second is a hot-applied low-modulus, rubberized asphalt.

The plowing rate can be influenced by the number of passes required and the difficulty in aligning the blade with the joint. Sawing rates are influenced by the power of the saw,

Table 12. Production rates and material amounts

	Number of Workers	Amounts/Rates (per 1,000 ft)[b]	
		Silicone	Hot-Applied
Average sealant amount [a]	-	7-10 gal	13-15 gal
Average plowing rate	2	2-3 hr	2-3 hr
Average sawing rate	1	3.5-7.5 hr	3.5-7.5 hr
Average sandblast rate	2	1.5-4 hr	1.5-4 hr
Final airblast rate	2	1.5-4 hr	1.5-4 hr
Backer-rod installation rate	2	1-3 hr	1-3 hr
Sealant installation rate	2	1.5-2.5 hr	1.5-2.5 hr

[a] Based on 0.5-in (12.7-mm) joint width.
[b] 1 ft = 0.305 m; 1 gal = 3.79 L

the blade speed, the type and width of blade, the cutting depth and pressure, the hardness of the concrete, and the size of the aggregate in the concrete.

Production rates for initial and final airblasting can vary with the capacity and pressure provided by the air compressor. Large amounts of debris in the joint or on the pavement surface will slow the airblasting operation. The rate of sandblasting is a function of the equipment, nozzle, and abrasive type used. Where old sealant remains on the joint walls, the rate of sandblasting will decrease. A 600-lb (272-kg) capacity sandblast unit with a 0.25-in (6.4-mm) nozzle and 1-in (25.4-mm) inside diameter sandblast hose can use about 600 lb (272 kg) of abrasive per hour.

The rate of primer installation varies greatly with the application method. Large-volume spray units result in much greater production rates than brushing the sealant on by hand. The speed of backer-rod installation is dependent upon the consistency of joint width. If joint widths vary significantly, backer rod of different diameters must be used to fill the joints. This, in turn, requires the installer to carry backer rod of various sizes, and to sometimes install very short lengths of rod.

The rate of sealant application is controlled by the skill of the operator, the distance between joints, the dimensions of the sealant reservoir, and the production rate of the melter/applicator (hot-applied) or pump (silicone). High rainfall frequency can significantly reduce the rate of sealant installation, since time must be allowed for the concrete to dry.

3.11 Determining Cost-Effectiveness

Steps for determining the cost-effectiveness of methods and materials for resealing joints in PCC pavements include:

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

Example calculations are included in appendix B.

3.11.1 Material and Shipping Costs

Material and shipping costs can be determined using table 13. Material costs for sealant, backer rod, blasting abrasive, primer, and other required materials can be obtained from local suppliers or manufacturers. Coverage rates for sealant can be estimated by using equation 7 or by consulting manufacturers' literature. 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.

$$CR = \left(\frac{12}{231}\right)(WF)(ST)(W)(T) \tag{7}$$

where:

CR	=	Sealant coverage rate, ft/gal (1 ft/gal = 0.08057 m/L)
WF	=	Waste factor (WF = 1.2 for 20 percent waste)
ST	=	Surface type constant (tooled surface: ST = 1.1; non-tooled surface: ST = 1.0)
W	=	Joint width, in (see figure 4)
T	=	Thickness of sealant, in (see figure 4)

3.11.2 Labor Costs

Labor costs can be determined using table 14. Using the wages for each worker, the number of workers required for each operation, and the expected time necessary to complete each operation, the total labor costs can be estimated. The production rates and amounts in table 12 should be helpful in determining labor requirements. In addition to wage rates, labor costs are greatly influenced by crew productivity and the need for night work or extra traffic control.

3.11.3 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 needed also greatly influences equipment costs. By completing table 15 and multiplying the daily equipment costs by the number of pieces of equipment required and 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 12 may be used to obtain rough estimates.

3.11.4 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. It 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.

3.11.5 Cost-Effectiveness Comparisons

After the material, labor, equipment, and user costs have been determined, the worksheet in table 16 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.

Table 13. Material and shipping costs

Material, Unit	Material Cost, $/unit	Coverage Rate, ft/unit	Length Required, ft	Total Cost, $
	a	b	c	abc
Sealant, gal				
Backer rod, ft				
Blasting sand, lb				
Primer, gal				
Total material cost:				

Table 14. Labor costs

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

Table 15. Equipment costs

Equipment	Cost, $/day	Number of Units	Number of Days	Total Cost, $
	g	h	i	ghi
Traffic control				
Joint plow				
Concrete saw				
Air compressor				
Sandblast equip.				
Installation equip.				
Other trucks				
Total equipment cost:				

Table 16. Cost-effectiveness worksheet

Total material cost [table 13]	$ ________	
Total labor cost [table 14]	$ ________	
Total equipment cost [table 15]	$ ________	
Total user delay cost	$ ________	
	==========	
Total resealing cost	$ ________	(A)
Project length, lane-mi (lane-km)	________	(B)
Average cost, $/lane-mi ($/lane-km)	$ ________	(C)
Estimated lifetime of seal, yrs	________	(D)
Interest rate (typically 0.05)	________	(E)

$$\textit{Average Annual Cost} = C\left[\frac{(E)[(1+E)^{D}]}{(1+E)^{D}-1}\right] \qquad \textbf{(8)}$$

Average annual cost,
$/lane-mi ($/lane-km) $ ________

4.0 Construction

Once the design and planning stages are completed, joints can be prepared in the chosen manner and sealant installed. This construction stage is just as critical as the design stage, since preparing clean joints and correctly installing the sealant material in an effective manner will largely determine the overall performance of the sealant system design.

This chapter presents the objectives and steps required for cleaning and resealing joints in concrete pavements. Troubleshooting procedures for solving the problems potentially encountered in each operation are also included.

4.1 Traffic Control

Whenever a joint resealing operation is performed, it is critical that adequate traffic control be in place to provide a safe working environment for the installation crew and a safe travel lane for vehicles. The operation should also cause the least amount of disturbance possible to the flow of traffic.

Besides normal signs, arrowboards, cones, and attenuators, flaggers may be required to accompany the sawing and/or plowing operations if the plow or saw must extend into the lane carrying traffic.

4.2 Safety Precautions

The equipment and materials used in a joint resealing operation can present safety hazards to workers if appropriate precautions are not taken. All guards must be in place, operational worker protection devices must be used, and appropriate clothing should be worn.

Material safety data sheets should be obtained for each sealant material to be installed, and proper care should be taken to protect workers from any potentially harmful materials. A more detailed description of safety precautions required for each sealing operation is included in appendix C.

4.3 Preparing the Joints

Objective: To provide clean, dry, properly dimensioned joints that are free from sawing dust, old sealant, or any other contamination, and to which sealant material can adequately bond.

Good joint preparation is essential to good sealant performance. No matter what the sealant material quality is, if the joint faces are not clean and dry, the sealant will pull away from the joint walls prematurely. Appropriate sealants placed in joints that are clean and dry should provide effective, long-term performance. Successful steps for preparing joints for sealant installation include removing old sealant, refacing joint sidewalls, abrasive blasting, airblasting, and installing primer.

4.3.1 Removing the Old Sealant

Plows can be used to remove old sealant from concrete joints prior to or in place of sawing. Preformed compression seals should be removed by hand or by pulling out longer sections with a tractor. Plowing involves pulling a thin blade through a joint to remove old sealant and backer material from the reservoir and to clean sealant from the sides of the joint.

To effectively remove sealant prior to sawing, the plowing operation must achieve the following results:

- Sufficient sealant and debris must be removed so that saw blades are not "gummed up" during sawing.
- Joint walls must not be spalled by the plow.

If sawing will not follow the plowing operation, the following additional results must be achieved:

- At least 95 percent of old sealant must be removed from the joint sidewalls.
- All sealant remaining on joint sidewalls must be easily removable by sandblasting.

Several types of plows have been used, and a few have functioned successfully. Descriptions of joint plows are given in section 3.9.1. Successful use of a joint plow typically requires the following equipment and procedures:

- A rear- or front-mounted, carbide-tipped plow blade for partial sealant removal (shown in figure 11), or an undercarriage-mounted carbide blade with hydraulic controls for complete sealant removal
- Multiple passes of a blade that is narrower than the joint, cleaning each channel face individually
- Carbide-tipped steel plow blades
- Sufficient tractor weight to maintain blade depth and remove the old sealant
- Effective traffic control and equipment guards to protect workers from flying debris and moving traffic

Operators must use special care or an alternative procedure if difficulties with spalling or improper cleaning are encountered. Several common plowing problems and possible solutions are listed in table 17.

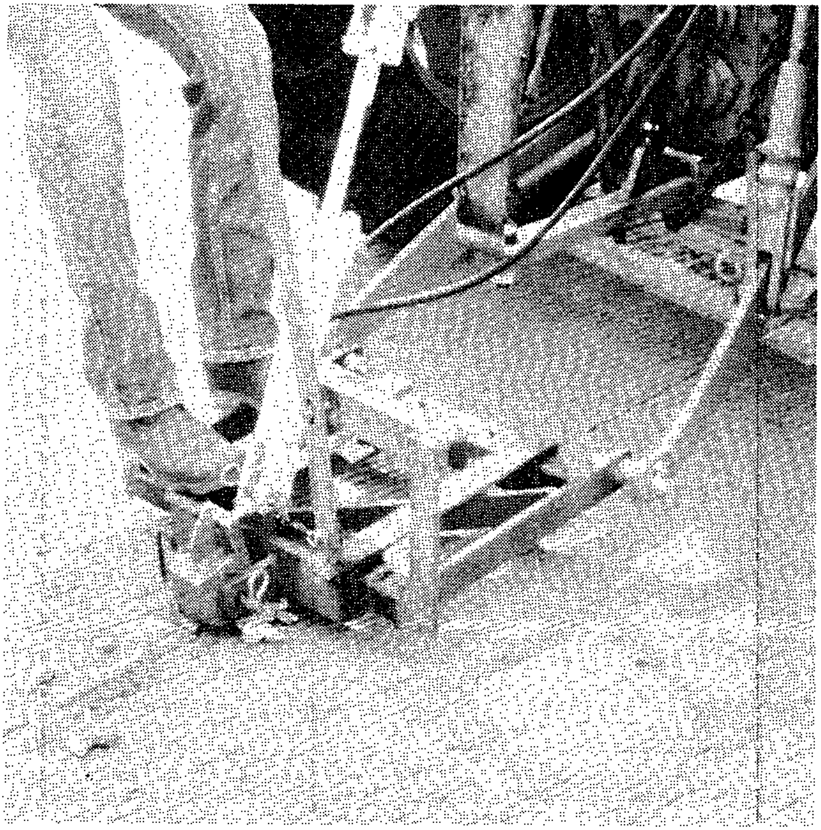

Figure 11. Joint plowing operation

Removing old joint material and other debris should be a continual process during joint preparation. The following concurrent work is recommended with the plowing operation:

- Blowing sealant and debris from the plowed joints
- Vacuuming, blowing away, or picking up debris from the plowing operation
- Removing the old sealant and properly disposing of it (Some materials may require hazardous or specialized waste disposal methods.)

Table 17. Troubleshooting procedures for plowing

Problems Encountered	Possible Solutions
Plow is spalling joint edges.	Use an untapered plow bit or a narrower blade.
Plow is not completely removing sealant.	Increase pressure on the joint sidewall. Use hand tools.
Belly-mounted plow places tractor in traffic.	Use rear- or front-mounted blades, hand tools, or a router.
Guardrail or curb keeps plow from reaching the entire joint.	Use rear/front-mounted blades. Reverse the plowing direction. Use hand tools or a router.
Lining up the plow with a joint is difficult.	Use a belly-mounted plow. Use an assistant.
Original saw cuts are offset.	Use additional care in plowing. Use hand tools or a router.

4.3.2 Refacing the Joint Sidewalls

Sawing, or refacing, joints in concrete pavements, shown in figure 12, is done either to increase the joint width and depth to the design requirements, or to expose clean, fresh concrete to which new sealant can adhere. Recommendations for water-cooled saws and blades are discussed in section 3.9.2. The following results of sawing must be achieved for the entire project:

- Uniform width and depth of joint in compliance with the design dimensions
- No spalls resulting from resawing
- Sealant completely removed and concrete freshly exposed on both sides of each joint

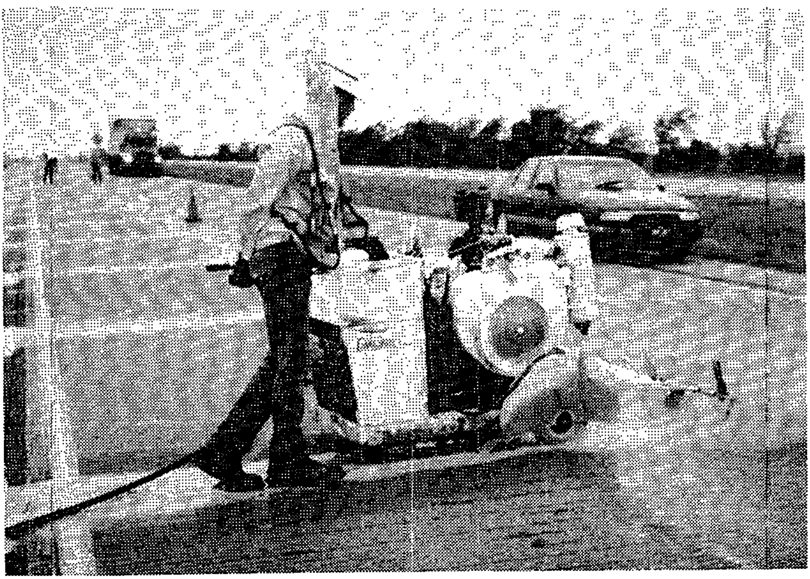

Figure 12. Joint sawing operation

If the resawing operation is properly completed, the remainder of the preparation tasks are greatly simplified. Therefore, care should be taken to ensure accurate and complete sawing, and if poor results are noticed they should be corrected promptly. Several common problems encountered in resawing are noted in table 18 along with recommended solutions. Consult saw manufacturers for other problems and solutions.

Wet-sawing leaves behind old sealant and a slurry of water and concrete dust in the joint. If this slurry dries on the joint walls, it is very difficult to remove; if it is not removed, it will keep new sealant from bonding to the concrete. Therefore, the sealant and slurry must be removed immediately after sawing by one of the following slurry removal methods. The first and second methods are more effective than the third at removing concrete dust slurry.

Table 18. Troubleshooting procedures for resawing

Problems Encountered	Possible Solutions
Blade is pulling to one side.	Change the rate of sawing. Check for rear wheel alignment.
Blade is not cleaning both sides.	Use wider blades. Use smaller diameter blades. Use a more skilled operator.
Sealant is "gumming up" blade.	Remove (plow) sealant before sawing.
One side of the ganged blades is worn.	Switch the inside and outside blades.
The saw cut does not begin in the center of the joint.	Have the saw operator take more care. Replace the saw operator. Provide an assistant to the operator.
Sawing is slow.	Use a more powerful saw. Use a more appropriate blade. Adjust the water feed. Increase the cutting rate.

- Flush the joints with low-pressure water simultaneously blowing the slurry out with high-pressure air until all sawing waste is removed.[4]
- Flush the joints with high-pressure water until all sawing waste is removed.
- Clean the joints with high-pressure air until all sawing waste is removed.

4.3.3 Abrasive Blasting the Joint Sidewalls

An abrasive blasting apparatus is used to direct a mixture of clean, dry air and abrasive material (typically sand) onto the walls of concrete joints. Results of abrasive blasting include the removal of sawing dust, old sealant, and other foreign material from the concrete joint surfaces, as well as the roughening of the concrete surface, creating a better bonding surface. To achieve these results, the abrasive blasting operation must produce the following effects:

1. Joint walls to which sealant must bond must be free from all sawing dust, old sealant, lubricant adhesive, discoloration or stain, or any other form of contamination.
2. Joint walls must be completely clean, newly exposed concrete.

The following procedures can provide successful abrasive-blast cleaning results:

1. Use approved sandblast units, safety equipment, and safety procedures, as described in section 3.9.3.
2. Hold the sandblast nozzle no more than 2 in (51 mm) from the pavement surface. A long handle attached to the hose and extending slightly past the nozzle will allow this to be done from an upright position, as shown in figure 13.
3. Make one complete pass for each joint wall at an angle from the pavement that directs the blast onto the surface to which sealant must bond.
4. Remove any old sealant with repeat passes or with a knife and repeat passes.
5. Protect traffic in nearby lanes from sand and dust by using a portable shield and low-dust abrasive.
6. Remove sand and dust from the joint and nearby pavement to prevent recontamination, using airblasting and/or vacuuming equipment.

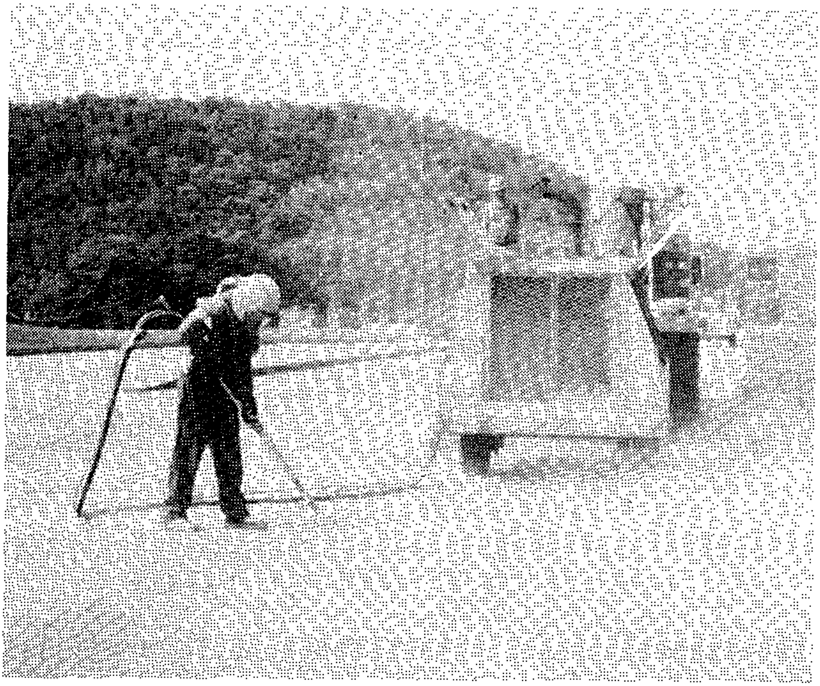

Figure 13. Abrasive blasting operation

Problems that are encountered in sandblasting must be solved quickly. Several common sandblasting problems and possible solutions are listed in table 19.

The sand and dust must be removed from the joints and pavement surfaces before sealing can begin. If this is not done, sand and dust can be blown back into the joints, reducing sealant performance. Self-propelled vacuums and portable blowers can be used for debris removal.

Table 19. Troubleshooting procedures for sandblasting

Problems Encountered	Possible Solutions
Sandblasting is not removing sealant.	Ensure that sandblaster is functioning. Cut old sealant away and reblast. Use a different blaster or abrasive or larger hoses. Improve the accuracy of sawing.
Sandblast quality is not consistent.	Ensure that sandblaster is functioning. Keep the nozzle height and alignment consistent. Use a nozzle guide attachment.
Sandblast progress is too slow.	Ensure that sandblaster is functioning. Use a different blaster or abrasive or a larger hose.
There is oil or moisture in the sandblast stream.	Install a functional oil/moisture filter. Use another compressor that doesn't add oil or moisture. Use drier sand.
The operator is quickly fatigued.	Use a guide and handle for upright sandblasting. Use alternating operators.

4.3.4 Airblasting the Joint Reservoir

After the joints have been sandblasted, and immediately before sealant installation, the dust, dirt, and sand must be blown from the joints and pavement surface using a compressed air stream. The following results of airblasting are desired over the entire project:

- Sand, dust, and dirt must be completely removed from the joint reservoir.
- Any sand, dust, and dirt that may recontaminate the joints must be removed from the surrounding pavement surface.

Figure 14. Airblasting operation

Successful airblasting methods for accomplishing these results, after the joints are dry and have been sandblasted, are listed below. In general, joints should be airblasted immediately prior to backer-rod installation. The airblasting, rod placement, and sealant installation operations must occur on the same day. If rain or dew recontaminate the joints, they must be sandblasted and airblasted again after drying.

1. Use approved air compressors, safety equipment, and safety procedures, as described in section 3.9.4.
2. Hold the nozzle no more than 2 in (51 mm) from the pavement surface, as shown in figure 14.
3. Blow debris in front of the nozzle. Do not walk backwards.

4. Make slower or repeated passes until the joint reservoir is completely clean.
5. Elevate and fan the nozzle across the pavement on the last pass to remove debris from the joint area to a place where it cannot recontaminate the joints.

The most common problems encountered in airblasting are related to contamination of the air stream or lack of air volume and pressure. Methods for addressing these problems are described in table 20.

Table 20. Troubleshooting procedures for airblasting

Problems Encountered	Possible Solutions
Oil in airstream	Ensure oil/moisture filter is functional. Clean or replace the hose.
Moisture in airstream	Ensure oil/moisture filter is functional.
Air not removing dust, dirt, and sand	Use a larger compressor. Use a larger diameter hose. Reduce the nozzle opening diameter.

If the joints are slightly damp, a heat lance may be used to dry the joints prior to installing backer rod.[9] The extreme temperatures that a heat lance can produce (1,500 to 3,000°F [819 to 1,649°C]) can severely spall concrete pavement that is exposed to the heat for more than a very short time. Extreme care must be taken to keep the heat lance from remaining in one location for more than 1 to 2 seconds. Pavement that is saturated must be allowed to dry before resealing. A heat lance may dry the surface of such a pavement for a short time, but capillary action in the concrete will bring the moisture back to the joint very quickly.

4.3.5 Installing Primer

To effectively and economically prime joint surfaces, the primer installation process must achieve the following:

- Primer must very thinly and uniformly coat all joint surfaces to which sealant must bond.
- Primer should not be wasted by applying thick coats or covering nonessential concrete surfaces.

Primer can be installed using a brush or spray equipment. Spray equipment is much more efficient, generally resulting in a thinner coat, and spray nozzles can be designed to coat only the upper joint wall surface. It is critical that the primer be allowed to dry, since as it dries it gives off gas.[7] If hot-applied sealant is installed before the primer has dried, bubbles will form in the sealant as the gas tries to escape. All required operator safety equipment must be used. This may include goggles, gloves, protective clothing, and respirators. Manufacturer's recommendations for installation methods and safety procedures must be followed.

4.4 Material Preparation and Installation

Objective: To properly install backer rod in clean joint channels and to adequately prepare, install, and shape sealant material.

The preparation and sealing operations should be scheduled so that joints are cleaned and left open for a minimum of time before resealing. Prepared joints that are left open overnight must be airblasted again and reinspected for cleanliness and dryness. Primer, installed before backer-rod installation, must be dry and tack-free. Only a minimum amount of time must be allowed to pass between backer-rod installation and sealant placement.

No matter how good the joint preparation has been, improper sealant installation can result in rapid seal failure. Therefore, manufacturer's recommendations must be followed regarding minimum placement temperatures, sealant heating temperatures, extended sealant heating, and pavement moisture conditions. Most sealant manufacturers recommend installing sealant when the pavement is dry and the air temperature is 40°F (5°C) and rising. Recommended application temperatures for rubberized asphalt sealants generally range from 370 to 390°F (187 to 198°C).

Polymers used in some hot-applied sealants are susceptible to damage from overheating and from extended heating. The allowable time such sealants may remain at application temperature ranges from 6 hours to 5 days, depending on the sealant properties. Check with sealant manufacturers for exact heating time and temperature limits.

4.4.1 Installing Backer Rod

Backer rod should be installed immediately after airblasting and immediately before placing the sealant. Joint reservoirs and pavement surfaces must be completely clean before backer rod is inserted.

Backer rod serves two purposes. First, it helps keep the sealant to its design thickness. Second, it keeps sealant from bonding to the bottom of the joint reservoir. Both thicker sealant and sealant bonded to the bottom of the reservoir place additional stress on the sealant. To perform properly and reduce sealant stress, the installed backer rod must meet the following requirements:

- The backer rod must be compatible with and appropriate for the sealant.
- Backer rod must be at the depth required in the plans.

- No gaps should be evident between the backer rod and joint walls.
- The rod must be compressed in the joint enough that the weight of uncured sealant or the tooling operation does not force it down into the reservoir before curing.
- The rod must be dry and clean.
- The surface of the rod must not be damaged during installation.
- No gaps should form between backer rod that is butted together in a joint or at a joint intersection.

Many methods have been used to insert backer rod into joints, ranging from poking it in with a screwdriver to using automated, self-guided installation equipment. Using a screwdriver may damage the surface of the rod and result in bubbles forming in the sealant. Automated equipment is most effective for continuous joints where only one size of backer rod is generally needed. The steps to the most commonly used and successful method of installing backer rod are listed below:

1. Have enough rod sizes available to fit all of the joint widths at the project.
2. Use a long-handled installation tool with a large-diameter central disk that fits into all joints and does not cut or damage the backer rod, as shown in figure 15.
3. Insert one end of the proper size of rod into the end of a joint.
4. Tuck the rod loosely into the joint and push the rod into the joint to the required depth by rolling the installation tool along the joint.
5. Roll over the rod a second time with the installation tool to ensure proper depth.
6. Cut the rod to the proper length, making sure no gaps exist between segments of backer rod.

Figure 15. Backer-rod installation

7. In sections where the rod does not fit tightly to the joint walls, install larger diameter backer rod.

The depth of the installation tool must be slightly greater than the required depth of backer rod.[10] This is because the rod compresses slightly when installed. Certain rod materials are more compressible and require additional tool depth. Stretching and twisting of backer rod must be minimized during installation, since, as the material relaxes, gaps may form at joint intersections and result in sealant failure. When transverse and longitudinal joints are being sealed in one operation, better results are obtained if rod is installed in the entire length of the transverse joints. That rod is then cut at the intersection with longitudinal joints and rod is installed in

Table 21. Troubleshooting procedures for backer-rod installation

Problems Encountered	Possible Solutions
Rod is tearing (slivers forming) when installed.	Use a smaller diameter backer rod. Ensure that installation tool is smooth.
Side gaps are evident or rod is slipping or is easily pushed down in joints.	Use a larger diameter rod.
Rod depth is inconsistent.	Check the installation tool for depth. Repeat passes with the installation tool.
Rod is shrinking in the joint. Gaps are formed between rod ends.	Do not stretch the rod when installing. Use a larger diameter roller.

the longitudinal joints. Possible solutions to common problems encountered when installing backer rod are described in table 21.

If delay occurs before installing the sealant, dirt and sand can be blown into the cleaned joints, or moisture can enter the joints. When dirt has reentered joints after backer rod has been installed, blow out the dirt using a clean, dry, low-pressure airstream, taking care not to force the rod deeper into the joint. Damp or wet backer rod must be removed from the joints and replaced with dry rod after the reservoir is completely dry and has been recleaned.

4.4.2 Sealant Installation

When the joints are clean, the backer rod is installed and, if the temperatures are within the required limits, sealing can begin. If rain interrupts the sealing operation, reclean the open joints before installing the sealant. The sealing operation should progress quickly and result in a seal with the following characteristics:

- Prevents infiltration of water through the joints
- Remains resilient and capable of rejecting incompressible materials at all pavement temperatures
- Maintains a tight bond with the sidewalls of the joint
- Has no bubbles or blisters
- Is not cracked or split
- Cannot be picked up or spread on adjacent pavement surfaces by tires, rubber-tired vehicle traffic, or the action of power-vacuum rotary-brush pavement-cleaning equipment after the specified curing period
- Provides a finished, exposed joint surface that is nontacky and will not permit the adherence or embedment of dust, dirt, small stones, and similar contaminants

4.4.2.1 Hot-Applied Sealant

To install hot-applied sealant that successfully meets the above requirements, proper heating and installation methods must be used. Suitable cleanup and safety procedures, as described in appendix C, must also be followed to ensure worker protection and properly functioning equipment.

Heating the Sealant

Hot-applied sealant performance can be significantly changed by the procedures used to heat and maintain its temperature during installation. Prior to heating sealant, the melter/applicator should be checked for the following properties and modified if necessary:

- Carbon buildup on the sides of the heating chamber should be removed.
- All temperature gauges should be accurately calibrated.

Heating should be scheduled so that the sealant will be at the recommended temperature when sealing is to begin. During initial heating the following guidelines should be adhered to:

1. Keep the heating oil temperature no more than 75°F (24°C) above the safe sealant heating temperature stated on the sealant packaging.
2. Keep sealant temperatures between the recommended pouring temperature and the safe heating temperature printed on the sealant packaging.
3. Start the agitator as soon as possible.
4. Do not hold the sealant at application temperatures for a long period before using it.

If sealant is heated above the safe heating temperature, it should not be used, since rubberized sealants break down and become very thin or very stringy when heated above this temperature. The recommended pouring temperature is the temperature of the sealant that will achieve the best performance. If the sealant is installed below this temperature, it may cool before it fills the voids in the concrete, and a poor bond may result. Recommended pouring temperatures vary between sealant manufacturers and types. Therefore, the pouring and safe heating temperatures of the sealant in use should be obtained from the sealant packaging, and all sealant operators must be made aware of it.

The procedures listed below should be followed during installation:

1. Check to ensure that the pavement temperature is above the minimum recommended installation temperature and above the dew point.
2. Check the temperature of the sealant at the nozzle and adjust the melter controls to obtain the recommended pouring temperature at the nozzle.
3. Regularly check the sealant temperatures and adjust as necessary.
4. Watch for carbon buildup on the sidewalls of the heating chamber. This is a sign of overheating.
5. Do not use sealant that has been overheated or heated for an extended time, or sealant that remains tacky and shows signs of breakdown.

Methods for Installation

Trial installation of at least 15 transverse joints should be completed using the methods scheduled for use in cleaning and installing sealant on each project. The sealed trial joints should be inspected after curing and approved or rejected prior to sealant placement. Upon approval, the remaining joints should be cleaned and resealed in the same manner as the trial joints. Sealing should begin only when the air temperature is 40°F (8°C) and rising and the air temperature is above the dew point. The following installation practices are recommended:

1. Pour the sealant with the nozzle in the joint, so that the joint is filled from the bottom and air is not trapped beneath the sealant.
2. Apply the sealant in one continuous motion while moving the wand in a way that the sealant flows out behind the wand, as shown in figure 16.[4]
3. Apply sealant in one pass, filling the reservoir to the recommended level. If additional sealant is required in low sections, it should be added as soon as possible.

Figure 16. Hot-applied sealant installation

4. Recirculate sealant through the wand into the melting chamber when not applying sealant.
5. Watch for bubbles, areas of sunken sealant, sealant that remains tacky, and sealant that has not bonded to the joint walls, and solve these problems as soon as they are identified. Several solutions are listed in table 22.
6. Use equipment and installation practices that result in consistent sealant thickness, little waste, and low operator fatigue. Support plates on the wand tip may be useful for this purpose.

Table 22. Troubleshooting procedures for hot-applied sealant installation

Problem Encountered	Possible Causes	Possible Solutions
Bubbles in sealant	Reaction with backer rod	Use nonreactive rod.
	Damaged backer rod	Change rod installation method or rod diameter.
	Moisture in joint	Allow joint to dry. Install above dew point.
	Bubbles in melter	Add sealant material. Reduce agitator speed.
	Air trapped by sealant	Fill joint from bottom.
Sealant is deeply sunken in joint.	Gap remain between rod and wall. Rod is slipping into joint.	Use proper rod diameter.
	Gaps remain between backer rod ends.	Do not stretch rod. Install rod carefully.
Sealant recess is not consistent.	Operator control is poor. Operator movement is uneven. Joint width is variable. Hoses are unmanageable.	Use a nozzle with a depth control plate. Use a wand with a shutoff at the nozzle. Use an experienced operator. Provide a hose support.

7. Do not allow traffic onto the pavement until the sealant has set and there is no danger of tracking or stone intrusion.

Table 22. Troubleshooting procedures for hot-applied sealant installation (continued)

Problems Encountered	Possible Causes	Possible Solutions
Sealant is not sticking to concrete walls.	Joint walls are not clean.	Remove all old sealant, oil, dust, dirt, sawing slurry, and other contaminants.
	There is moisture on the walls from rain, dew, or condensate.	Wait for concrete to dry. Use a heat lance if slightly damp. Install above dew point.
	Sealant temperature is too low.	Maintain recommended sealant temperature. Insulate and heat hoses.
	Pavement temperature is too low.	Maintain recommended sealant temperature. Insulate and heat hoses.
Sealant remains tacky after installation.	Kettle is contaminated with asphalt, heat transfer oil, solvent, or other sealant.	Remove sealant. Clean and flush kettle. Replace with uncontaminated sealant.
	Sealant has been overheated or heated too long.	Remove and replace with fresh sealant. Check melter temperatures.

Cleanup Requirements

Follow the melter/applicator manufacturers' instructions as to the frequency of cleaning. If carbon is built up on the heating chamber walls, remove it completely by scraping and flushing. Flush the pump and hose with solvent, if recommended, and waste the first 3 gal (11 L) of the day to remove any traces of solvent. Dispose of the wasted sealant/solvent solution properly.

Safety Precautions

Obtain the material safety data sheets for each sealant material and follow the worker protection and disposal instructions outlined in them. Several safety precautions should be followed before, during, and after installation:

1. Be careful when loading blocks of sealant–splashing can occur.
2. Have operators wear protective gloves and clothing. Sealant and oil temperatures can reach 400°F (204°C), and can cause serious burns.
3. Do not overheat the sealant–it is flammable.
4. Make sure the appropriate hoses (manufacturer recommended) are used.
5. Follow manufacturers' safety instructions when using coal tar compounds. Excessive breathing of fumes or skin contact with coal tar compounds may cause irritation.[7]
6. Follow disposal instructions for cleaning solvent and wasted sealant.

4.4.2.2 Cold-Applied Sealant

Several types of sealant are installed without heating; they include polysulfides, polyurethanes, and silicones. Consult manufacturers' literature for installation recommendations for each sealant type. The discussion in this manual is limited to the installation of one-part cold-applied sealants.

Loading Sealant into the Pumping Apparatus

Typically, silicone sealant is pumped from storage containers through compressed-air-powered pumping equipment to a wand with an application nozzle. The sealant is pumped from 5-gal (19-L) buckets or 55-gal (208-L) drums. Two important precautions should be observed when loading silicone into an approved pumping apparatus.

- Load the sealant into the apparatus in a manner that keeps bubbles from becoming trapped in the sealant.
- Limit the exposure of the sealant to air and moisture, since premature curing can result from such exposure.

Methods for Installation

The following practices have been used successfully and are recommended for installing silicone sealants.

1. Pour the sealant with the nozzle in the joint, so that the joint is filled from the bottom and air is not trapped beneath the sealant.
2. Use a nozzle that applies sealant at a 45° angle, and push the bead along the joint rather than draw it with the gun leading. An applicator like that shown in figure 17 can provide good results.
3. Apply the sealant in one continuous motion, moving steadily along the joint, so that a uniform bead is applied without dragging, tearing, or leaving unfilled joint space.[6]
4. Adjust the pump rate, nozzle type, and nozzle diameter to control the speed of application.
5. Form a concave surface in non-self-leveling sealant using a piece of oversized backer rod, a dowel, or other suitable instrument.

Figure 17. Silicone sealant installation

6. When tooling is required, press the sealant around the backer rod, forming a uniform concave surface with no wasted sealant on the pavement surface. The bottom of the concave surface should be 0.25 in (6 mm) below the pavement surface.
7. The surface of any silicone sealant must be recessed 0.25 in (6 mm) below the pavement surface and must never be exposed to traffic wear.
8. Watch for bubbles, sunken sealant, a nonuniform surface, and other installation deficiencies and solve these problems as soon as they are identified. Several solutions are listed in table 23.

Table 23. Troubleshooting procedures for cold-applied sealant installation

Problem Encountered	Possible Sources	Possible Solutions
Sealant is not sticking to concrete walls.	Joint walls are not clean.	Remove all old sealant, oil, dust, dirt, sawing slurry, and other contaminants.
	Moisture remains on the joint walls from rain, dew, or condensate.	Wait for concrete to dry. Carefully use a heat lance if the pavement surface is slightly damp.
	Tooling was inadequate.	Use more tooling care. Use another striking tool.
Sealant is deeply sunken in the joint.	Gap between rod and wall Rod slipping into joint	Use a larger diameter backer rod.
	Gaps remain between backer rod ends.	Do not stretch rod. Install rod carefully.
Installed sealant contains bubbles.	Reaction with backer rod	Use nonreactive backer rod.
	Damaged backer rod	Change rod installation method or rod diameter.
	Bubbles in pump lines	Set the pump diaphragm into sealant better.
	Air was trapped by sealant	Fill the joint from bottom.

Table 23. Troubleshooting procedures for cold-applied sealant installation (continued)

Problem Encountered	Possible Sources	Possible Solutions
Sealant recess is not consistent.	Operator control is poor. Operator movement is uneven. Joint width is variable.	Use a "dog-leg" applicator. Use an experienced operator.
	Surface tooling is poor.	Use more tooling care. Use another striking tool (large backer rod, plastic or rubber tubing on a flexible handle).

9. Allow non-self-leveling sealant to become tack free and self-leveling sealant to skin over before opening the pavement to traffic. If large pavement deflections are expected, allow a longer cure time.

Cleanup Requirements

Cleaning the applicator equipment apparatus will be required if the sealant begins to cure in the pump or hose. Follow the sealant pump manufacturers' instructions as to cleaning frequency and required solvents.

5.0 Evaluation of Joint Seal Performance

Monitoring the performance of the joint seal repairs is good practice, and it can be done rather quickly (in 1 or 2 hours) with fair accuracy. At least one inspection should be made each year in order to chart the rate of failure and to plan for subsequent maintenance. A midwinter evaluation is highly recommended, since at that time joints will be near their maximum opening and, as a result, adhesion loss can be seen more easily.

As discussed in section 2.1, a small representative sample of the pavement section should be selected for the evaluation. Resistance to the entrance of water and debris to the joint should be measured by noting the percent of water resistance loss using equation 1. The joint seal effectiveness can then be calculated using the following equation.

$$\%L_{eff} = 100 - \%L \qquad (9)$$

where:

$\%L_{eff}$ = Percent joint seal effectiveness
$\%L$ = Percent length allowing water to enter joints..

After a few inspections, a graph of seal effectiveness versus time can be constructed, such as the one in figure 18. A minimum allowable effectiveness level, commonly 50 percent, will help to indicate when additional joint seal repair is required.

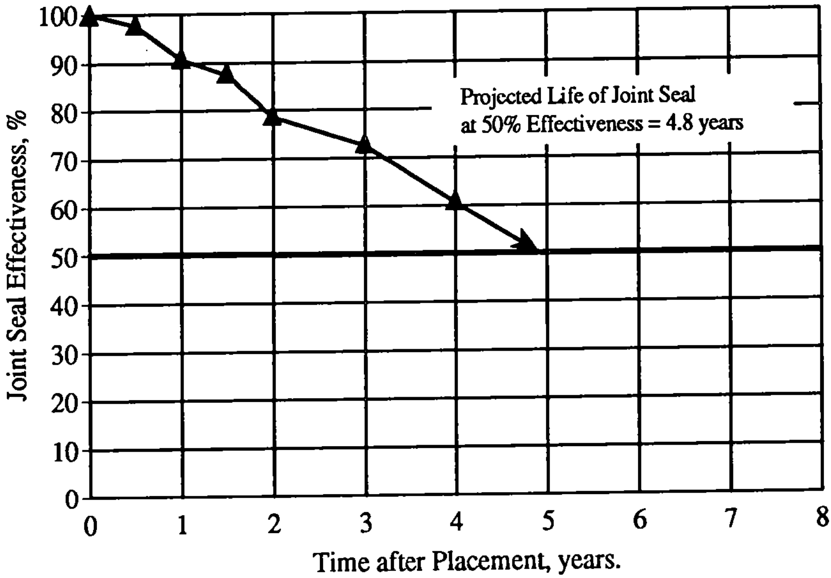

Figure 18. Example joint seal deterioration chart.

Appendix A

Material Testing Specifications

Material testing specifications are listed in tables A-1 to A-3. These specifications are based on specifications prepared by the American Society for Testing and Materials and by states having significant joint resealing experience.

Specifications are revised frequently, and the sponsoring society should be contacted to obtain the latest edition. Information regarding the availability of specifications can be obtained from the agencies listed below.

ASTM Specifications
American Society for Testing and Materials
1916 Race Street
Philadelphia, PA 19103

AASHTO Specifications
The American Association of State Highway and Transportation Officials
917 National Press Building
Washington, DC 20004

Federal Specifications
Business Service Center
General Services Administration
7th & D Streets, SW
Washington, DC 20407

Canadian Specifications
Secretary
Canadian Specifications Board
National Research Council
Ottawa 2, Ontario, Canada

Table A-1. Rubberized asphalt specifications

Test Description[a]	Test Criteria						
	Other			Standard			Low-Modulus
	ASTM D 1190	AASHTO M 173	Federal SS-S-164	ASTM D 3405	AASHTO M 301	Federal SS-S-1401	State Specification
Cone penetration (77°F, dmm)	≤ 90	≤ 90	≤ 90	≤ 90	≤ 90	≤ 90	110-150
Flow (140°F, mm)	≤ 5	≤ 5	≤ 5	≤ 3	≤ 3	≤ 3	≤ 3
Resilience (77°F, % recovery)				≥ 60	≥ 60	≥ 60	≥ 60
Bond (0°F, 50% ext.)	Pass 5 cycles	Pass 5 cycles	Pass 5 cycles				
Bond (0°F, 100% ext.) or (-20°F, 50% ext.)				Pass 3 cycles	Pass 3 cycles	Pass 3 cycles	
Bond (-20°F, 100% ext.) or (-20°F, 200% ext.)							Pass 3 cycles
Asphalt compatibility						Pass	
Cone penetration (0°F, dmm)							≥ 40

[a] °C = 0.556(°F - 32); 1 dmm = 0.1 mm

Table A-2. Nonsag silicone sealant specifications

Test Description [a]	Test Method	State Agency [b]		
		GA DOT	MN DOT	MI DOT
Tensile stress at 150% strain, psi	ASTM D 412(C)	≤ 45		≤ 45
Durometer hardness, Shore A (0 and 77±3°F)	ASTM D 2240	"A" 10-25	"A" 10-25	"A" 5-25
Bond to PCC mortar, psi	State	≥ 50		
Tack-free time, min	Mil S 8802	≤ 90	30-75	35-70
Extrusion rate, g/min	Mil S 8802	≥ 75		90-300
Non-volatiles, %	State	≥ 90		
Shelf life (months from ship date)	Mfg	≥ 6		≥ 6
Specific Gravity	D 792	1.1 - 1.5		1.01-1.515
Bond (-20°F, 100% ext., 3 cycles, IM)	State			Pass
Bond (-20°F, 100% ext., 3 cycles, NI)	State			Pass
Bond (0°F, 10 cycles)	State	Pass		
Elongation, %	ASTM D 412(C)		≥ 1200	≥ 700
Ozone, UV resistance (5,000 hrs)	ASTM C 793	Pass		

[a] °C = 0.556(°F - 32); 1 psi = 6.895 kPa
[b] DOT = Department of Transportation

Table A-3. Self-leveling silicone sealant specifications

Test Description [a]	Test Method(s)	Very low modulus	Ultra low modulus
		GA DOT [b]	GA DOT [b]
Tensile stress at 150% strain, psi	ASTM D 412(C)	$\leq$ 40	$\leq$ 15
Durometer hardness, Shore 00 (0, 77$\pm$3°F)	ASTM D 2240	"00" 40-80	"00" 20-80
Bond to PCC mortar, psi	State	$\geq$ 40	$\geq$ 35
Skin-over time, min	State	$\leq$ 90	$\leq$ 90
Extrusion rate, g/min	Mil S 8802	$\geq$ 90	$\geq$ 100
Nonvolatiles, %	State	$\geq$ 90	$\geq$ 90
Shelf life (months from date of shipment)	Mfg	$\geq$ 6	$\geq$ 6
Specific gravity	D 792	1.1 - 1.5	1.1 - 1.5
Bond (0°F, 10 cycles)	State	Pass	Pass
Ozone, UV Resistance (5,000 hrs)	State	Pass	Pass

[a] °C = 0.556(°F - 32); 1 psi = 6.895 kPa

[b] DOT = Department of Transportation

Appendix B

Sample Cost-Effectiveness Calculations

Sample worksheets for cost-effectiveness calculations are presented in this section. The forms included in section 3.11 are used to illustrate the method discussed in that section. Data used for calculation of cost-effectiveness is listed below and in tables B-1 to B-3.

Sealant Type =	Self-leveling silicone sealant
Shape Factor =	2:1
Joint Width =	0.5 in (12.7 mm)
Joint Length to Seal =	20,000 ft (6.1 km)
Project Length =	2.5 mi (4.0 km)
Primer =	None required
Estimated Lifetime =	8 years
Plow Rate =	525 ft/hr (160 m/hr)
Saw Rate =	275 ft/hr (84 m/hr)
Airblast Rate =	500 ft/hr (152 m/hr)
Sandblast Rate =	375 ft/hr (114 m/hr)
Backer-Rod Install Rate =	540 ft/hr (165 m/hr)
Sealant Installation Rate =	540 ft/hr (165 m/hr)
Labor Rates =	$120/day
Supervisor Rates =	$200/day

The sealant coverage rate is calculated in the following equation.

$$CR = \left(\frac{12}{231}\right)(1.2)(1.0)(0.5)(0.25) = 0.007792$$

where:

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

Table B-1. Example material and shipping costs

Material, unit[a]	Material Cost, $/unit	Coverage rate, unit/ft	Length required, ft	Total cost $/mtrl
	a	b	c	abc
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 B-2. Example labor costs

Crew Labor	Wages, $/day	Number in Crew	Days Required	Total Cost, $
	d	e	f	def
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 B-3. Example equipment costs

Equipment	Daily Cost, $/day	Number of Units	Number of Days	Total Cost, $
	g	h	i	ghi
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 B-4. Example cost-effectiveness calculations

Total material cost [table B-1]	$ 6,664	
Total labor cost [table B-2]	$ 11,428	
Total equipment cost [table B-3]	$ 14,670	
User delay cost	$ 2,250	
	=========	
Total resealing cost	$ 35,012	(A)
Project length, lane-mi	2.5	(B)
Avg. resealing cost, $/lane-mi	$ 14,005	(C)
Estimated lifetime of seal, yrs	$ 8	(D)
Interest rate (typically 0.05)	$ 0.05	(E)

$$Avg.\ Annual\ Cost = C\left[\frac{(E)[(1+E)^{D}]}{(1+E)^{D}-1}\right]$$

$$Avg.\ Annual\ Cost = 14{,}005\left[\frac{(0.05)[(1+0.05)^{8}]}{(1+0.05)^{8}-1}\right] = \$2{,}167$$

Average annual cost, $/lane-mi $ 2,167

Using a modified D-3405 sealant that costs $3.50 per gallon and lasts five years, together with the same preparation methods listed above, the computed average annual cost is $2,932/lane-mi.

$$Avg.\ Annual\ Cost = 12{,}696\left[\frac{(0.05)[(1+0.05)^{5}]}{(1+0.05)^{5}-1}\right] = \$2{,}932$$

Appendix C

Material and Equipment Safety Precautions

Mandated highway safety attire, such as vests and hard hats, should always be worn by crews and supervisors during sealing operations. In addition, individual crews should be made aware of all safety precautions associated with the materials and equipment with which they are working.

C.1 Materials

In order to protect the health and well-being of maintenance workers who handle the various sealant materials, material safety data sheets (MSDS) should be obtained from manufacturers of all materials to be installed and these sheets should be reviewed by those handling the materials. These sheets provide important information about health hazards, fire and explosion data, reactivity data, and safe usage and disposal.

Every effort should also be made to determine the type of sealant material to be removed and to address any safety hazards that it may present.

C.1.1 Hot-Applied Sealants

Hot-applied sealants require that several safety precautions be followed:

1. Be careful when loading blocks of sealant–splashing may occur.

2. Have operators wear protective gloves and clothing. Sealant and oil temperatures can reach 400°F (204°C), and can cause serious burns.
3. Do not overheat the sealant–it is flammable.
4. Follow manufacturers' safety instructions when using coal tar compounds. Excessive breathing of fumes or skin contact with coal tar compounds may cause irritation or possibly more serious health problems.
5. Use care with any solvents required for cleanup.
6. Dispose of diluted or wasted sealant as specified in the MSDS.

C.1.2 Cold-Applied Sealants

When working with cold-applied sealants, care should be taken to protect workers from skin, eye, or internal contact with sealant materials. MSDS and manufacturer's recommendations should be consulted to determine specific safety requirements for each sealant material.

Appendix D

Inspection Checklists for Construction

This section is intended for use by inspectors of resealing processes, as well as by supervisors and contractors. It contains discussions of planning, equipment, and procedures critical to the successful completion of a resealing project. Checklists pertaining to each step of the process, including planning, equipment, material preparation, joint preparation, sealant installation, final inspection, and safety precautions, are included.

Field experience has shown that each step in the resealing process requires careful supervision and inspection. An inspector must continually observe the various operations to ensure that proper procedures are being continually performed. In most cases, it is the contractor's responsibility to effectively clean and reseal the joints, and it is the inspector's responsibility to continually monitor the work and ensure that corrections are made if requirements are not met.

D.1 Preconstruction Plans and Specifications

Plans must be prepared and distributed to the inspector(s) and the supervisor(s) of the installation crew. It is recommended that the inspectors and the construction supervisors meet before work begins to discuss the plans and specifications. Information that must be contained in the **plans** includes the following:

- ☐ 1. Project layout, including stationing and slab lengths
- ☐ 2. Original joint reservoir dimensions, including existing variability
- ☐ 3. Original sealant material type
- ☐ 4. Location and type of required pre-resealing repairs
- ☐ 5. Required reservoir dimensions
- ☐ 6. Required sealant thickness
- ☐ 7. Required sealant recess below pavement surface

Specifications may be based on adherence to designated procedures, on achieving a quality end product, or a combination of the two. Information that must be contained in **procedure-based specifications** includes the following:

- ☐ 1. Lot testing requirements
- ☐ 2. Delivery and storage requirements
- ☐ 3. Repair methods and materials for pre-resealing repairs
- ☐ 4. Equipment requirements
- ☐ 5. Material requirements
- ☐ 6. Preparation procedure requirements
- ☐ 7. Installation procedure requirements
- ☐ 8. Weather condition limitations
- ☐ 9. Traffic shutdown requirements.
- ☐ 10. Safety requirements
- ☐ 11. Material disposal requirements

If **end-result specifications** are used, the following information must be included:

- ☐ 1. Lot testing requirements
- ☐ 2. Delivery and storage requirements
- ☐ 3. Repair methods and materials for pre-resealing repairs
- ☐ 4. Required results of each preparation procedure and acceptance/rejection criteria
- ☐ 5. Required results of the installation process and acceptance/rejection criteria
- ☐ 6. Weather condition limitations
- ☐ 7. Limitations of traffic shutdown
- ☐ 8. Safety requirements
- ☐ 9. Material disposal requirements

An example of installation acceptance criteria is included in section D.4. In most cases, a combination of procedure-based and end-result specifications is used, and the following inspection process is based on a combination of the two.

D.2 Equipment Inspection

All equipment must be inspected and approved before the project begins, as well as during joint preparation and sealant installation. A list of proposed equipment should be submitted before installation for approval. During preinstallation inspection, the inspector should check all equipment to be used on the project, making sure that each piece meets the requirements of the project specifications or the suggested requirements listed in table 11. If questions arise about the suitability of the equipment, a statement from the sealant manufacturer should be supplied indicating that the equipment is acceptable for installing the sealant.

The condition and effectiveness of each piece of equipment should be checked during trial installation and at the beginning of each day of preparation and installation. Criteria for equipment effectiveness are listed in the following sections.

D.3 Field Installation Inspection

After all required spall repair, load transfer restoration, slab stabilization, grinding, and other rehabilitation have been completed and approved, the resealing process can begin. It is recommended that the inspector(s) and supervisor(s) meet before work begins to discuss the following subjects:

1. Exact locations and amounts of all joints to be resealed (Boundaries should be clearly marked.)
2. Traffic control requirements and lane closure time limitations
3. Methods required for cleaning and resealing joints (if procedure-based specification)
4. Criteria for approval of all cleaning and installation equipment and processes
5. Final criteria for approval of resealing work, including procedures and penalties for rejection
6. Any localized variations from the specified methods
7. Safety requirements for all equipment and procedures (including material disposal requirements)
8. Procedures in the event of wet or cold weather
9. Procedures in the event that seal quality requirements are not met

D.3.1 Inspection of Joint Preparation

Joint preparation, as discussed in this manual, refers to sealant removal, joint refacing, final cleaning, primer installation, and backer rod insertion. Sealant manufacturers' instructions should be followed when preparing joints unless noted otherwise in the plans and specifications. The following inspection checklist can be used to ensure that joint preparation is completed properly.[6] Not all of these cleaning processes are used, in many cases.

- ☐ 1. **Joint plowing**:
  - ☐ Plow is removing the required amount of sealant.
  - ☐ Plow is not spalling the joint edges.
  - ☐ Worker and driver safety are not compromised.

- ☐ 2. **Concrete sawing**:
  - ☐ Saw is removing the required amount of concrete and sealant.
  - ☐ Saw is uniformly cutting to the proper width and depth (depth and width can be checked quickly using a metal template).
  - ☐ Saw is refacing both sides of the joint.
  - ☐ All guards and safety mechanisms are functioning properly.
  - ☐ All sawing slurry is immediately removed from the joints.

- ☐ 3. **Waterwashing**:
  - ☐ Equipment is removing all sawing slurry and old sealant from the joints.
  - ☐ No standing water remains in the joints.

- ☐ 4. **Abrasive blasting**:
  - ☐ The nozzle is being held 1 to 2 in (25 to 51 mm) from the pavement.
  - ☐ Two passes are made for each joint, directing the nozzle toward one side of the joint for each pass.
  - ☐ No old sealant, oil, or dried sawing slurry remains on the joint walls.
  - ☐ The blaster does not introduce oil or moisture to the joint.
  - ☐ The operator is using all OSHA or state required protective devices.
  - ☐ Following sandblasting, all joint walls exhibit freshly exposed concrete.[9]

- ☐ 5. **Airblasting**:
  - ☐ Equipment is removing all dirt, dust, and sand from the dry joint reservoir.
  - ☐ The airblaster does not introduce oil or moisture to the joint (check for oil by directing the airstream onto a tire or a piece of paper and noting any discoloration).
  - ☐ The operator is wearing required eye and ear protection.
  - ☐ Following airblasting, the joint is clean and dry.

- ☐ 6. **Vacuum or compressed-air cleaning**:
  - ☐ Cleaning equipment is removing all old sealant, sand, dirt, and dust from the pavement surface.
  - ☐ Debris has no potential for reentering the joints, especially on windy days or when traffic is moving next to the cleaned joints.

☐ 7. **Primer application**:

- ☐ Primer applicator is applying a thin layer of sealant uniformly over joint faces to receive sealant.
- ☐ All required safety protection equipment is in use and operational.
- ☐ Primer is allowed to dry before backer rod is inserted.

☐ 8. **Backer-rod installation**:

- ☐ The rod is inserted into the joint uniformly to the required depth without stretching or tearing it. Depth can be checked using a template (slivers of rod in the joint indicate that the rod is too large).
- ☐ The rod remains tight in the joint without gaps along the sides, at joint intersections, or between rod segments.
- ☐ The rod is compressed in the joint enough that the weight of the uncured sealant or installation equipment or tooling equipment will not force it down into the joint.
- ☐ A larger diameter rod is used in wide joint sections.

☐ 9. **Low-pressure air cleaning**:

- ☐ When needed, all dust or dirt that has reentered clean joints that contain backer rod is blown out.
- ☐ The backer rod is not pushed into the joint by the airstream.

Water on the joint walls during sealing will severely reduce the ability of the sealant to bond to the walls, and can result in bubbles in some sealants. Check frequently for dew that may collect in the joints and remain after the surface is dry, particularly if temperatures and humidity levels have been at or are close to the dew point. If cleaned joints are recontaminated by rain, dew, dirt, or oil, they should be recleaned in a manner that restores cleanliness. This may require sandblasting and airblasting or merely airblasting. Cleaned joints that are left overnight should, at a minimum, be airblasted again. Moist backer rod should be removed and replaced.

One method that an inspector can use to communicate the need for additional preparation at a particular joint is to mark near it with a particular color of paint.[6] A possible pattern that could be used is the following.

1. Yellow - Repairs must be made to joint before sealing.
2. Orange - Joint is not the proper size.
3. Red - Joint is not properly cleaned.
4. Blue - Backer rod is not tight or is not at proper depth.
5. Brown - Improper sealing technique (too full, too low, tacky sealant, not tooled correctly, bubbles in sealant, sealant not bonded, etc.)

The contractor or supervisor can use green spray paint to indicate that the problem is repaired and the inspector should reexamine the joint for approval.

D.3.2 Inspection of Joint Sealant Installation

The inspector should watch for several items prior to and during installation of the sealant material. The following section is a checklist for inspection of joint sealant installation.

D.3.2.1 Hot-Applied Sealant Installation Inspection

When inspecting the installation of hot-applied sealant materials, the following pieces of information must be determined **before heating begins**. This information can be obtained from sealant manufacturers and from the project plans and specifications:

- ☐ 1. The recommended sealant application temperature
- ☐ 2. The safe sealant heating temperature
- ☐ 3. The length of time that a sealant can be heated before it begins to break down
- ☐ 4. The required thickness of sealant
- ☐ 5. The required sealant recess below the pavement surface
- ☐ 6. The air temperatures allowable for sealing
- ☐ 7. The average sealant curing time and the time before traffic can be allowed on the pavement after resealing
- ☐ 8. The material safety data sheets (MSDS)
- ☐ 9. The criteria for acceptance/rejection of resealing work, and the penalties associated with rejection
- ☐ 10. Acceptable test results for all materials to be installed
- ☐ 11. The production date and shelf life of all materials

During installation of hot-applied sealants, the following items should be regularly checked to ensure that they meet the requirements:

- ☐ 1. All joints remain clean and dry.
- ☐ 2. All backer rod remains tight in the joint at the correct height with no gaps.
- ☐ 3. The melter/applicator maintains the sealant at the required temperature without overheating.
- ☐ 4. Sealant leaving the nozzle is at the application temperature.
- ☐ 5. The agitator is functioning properly.
- ☐ 6. No carbon is built up on the melting chamber walls.
- ☐ 7. All thermometers and temperature controls are monitored and functioning properly.
- ☐ 8. The operator is not trapping bubbles in the sealant or overfilling or underfilling the joints.
- ☐ 9. Spilled sealant is removed from the pavement surface.
- ☐ 10. Areas of low sealant are not present or are quickly filled. Steps are taken to eliminate the cause of the low sealant.
- ☐ 11. All required operator safety equipment is in use. This applies especially to D-3406 materials.

Warning: If white smoke is seen rising from the kettle, stop the operation immediately and check the sealant temperature. If the sealant remains tacky in the joint long after placement, or the sealant becomes stringy inside the melting chamber, the sealant has been overheated and should be completely removed from the chamber and wasted.

D.3.2.2 Silicone Sealant Installation Inspection

Prior to installation of silicone sealants, the following information should be obtained by the inspector:

- ☐ 1. The expiration date of the sealant material
- ☐ 2. The air temperatures allowable for sealing
- ☐ 3. The required thickness of sealant
- ☐ 4. The required sealant recess below the pavement surface
- ☐ 5. The need for tooling the surface of the sealant
- ☐ 6. The average sealant curing time and the time before traffic can be allowed on the pavement after resealing
- ☐ 7. Safety data from the MSDS
- ☐ 8. The criteria for acceptance/rejection of resealing work and penalties for rejection
- ☐ 9. The acceptable results of lot tests for all materials
- ☐ 10. The production dates and shelf life of all materials

As sealant installation continues, the following items should be regularly checked for compliance with the plans and specifications:

- ☐ 1. All joints remain clean and dry.
- ☐ 2. Backer rod remains tight in the joint at the correct height with no gaps.
- ☐ 3. The silicone applicator system is not introducing bubbles to the sealant.
- ☐ 4. The applicator, wand, and controls allow the operator to fill the joint uniformly to the correct level.
- ☐ 5. The operator is not trapping bubbles in the sealant.

☐ 6. The operator is not overfilling or underfilling the joints (sealant thickness and recess can be checked by inserting a thin ruler through the uncured sealant to the top of the backer rod).

☐ 7. Non-self-leveling silicone sealant is tooled immediately, forcing sealant against the joint walls and creating a smooth concave surface.

☐ 8. Any sealant that remains on the pavement surface is removed.

☐ 9. Areas of low sealant are not present or are quickly filled. Steps are taken to eliminate the cause of the low sealant.

☐ 10. All required operator safety equipment is in use.

☐ 11. Traffic is not allowed on the pavement until the sealant is skinned over and cannot be damaged.

D.4 Final Inspection

During installation and prior to approval, the resealed joints should be individually inspected, ensuring that the sealant meets the following criteria, and noting the presence and severity of any distresses.[4,6]

☐ 1. Sealant is bonded firmly to the joint sidewalls (cured sealant material should not separate from the sidewalls when pulled lightly with the fingertips across the joint).

☐ 2. Sealant is not tacky after curing and will not permit adherence of dust, dirt, or small stones.

☐ 3. Sealant material contains no cracks, bubbles, or blisters.

☐ 4. Sealant cannot be picked up or spread on adjacent pavement surfaces by tires, rubber-tired vehicle traffic, or the action of power-vacuum rotary-brush pavement-cleaning equipment after the specified curing period.

- ☐ 5. Sealant is resilient and capable of rejecting stones at high pavement temperatures.
- ☐ 6. Sealant is recessed to the correct depth below the pavement surface (this is critical for silicone sealants, as they are not resistant to traffic wear).
- ☐ 7. Sealant spilled on the pavement surface has been removed.
- ☐ 8. No debris remains on the pavement surface.

Appendix E

Partial List of Material and Equipment Sources

This section contains information for contacting several manufacturers of sealant materials, backer rod, and installation equipment. Addresses and phone numbers are given for manufacturers and/or suppliers who can provide the inquirer with information regarding material properties, recommended installation practices, safety procedures, and local suppliers.

Material safety data sheets that describe the material components, any hazardous properties, and any required protective equipment, should be available from all sealant manufacturers.

Sealant Materials

Manufacturers of D-3405 and Modified D-3405 Hot-Applied Sealant

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(602) 276-0406
(800) 528-8242

W.R. Meadows, Inc.
P.O. Box 543
Elgin, IL 60121
(708) 683-4500

Koch Materials Company
4334 NW Expressway, Ste. 281
Oklahoma City, OK
(405) 848-0460
(800) 654-9182

Manufacturers of Self-Leveling and Non-self-Leveling Silicone Sealant

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(602) 276-0406
(800) 528-8242

Dow Corning Corporation
Midland, MI 48686-0094
(517) 496-4000

Mobay Corporation
Mobay Road
Pittsburgh, PA 15205-9741
(412) 777-2000

Backer Material

Manufacturers of Expanded Closed-Cell Foam Rod

Applied Extrusion Technologies, Inc.
P.O. Box 582
Middletown, DE 19709
(302) 378-8888
(800) 521-6713

Industrial Thermo Polymers Limited
1255 Lorimar Drive
Mississauga, ON, Canada L5S 1R2
(416) 795-1254
(800) 387-3847

Sealant Installation Equipment

Manufacturers of Melter/Applicators for Hot-Applied Sealants

Cimline, Inc.
7454 Washington Avenue South
Eden Prairie, MN 55344
(800) 328-3874

Crafco Incorporated
6975 W. Crafco Way
Chandler, AZ 85226
(800) 528-8242

Stepp Manufacturing Company, Inc.
North Branch, MN 55056
(612) 674-4491

White Asphalt Equipment
Midwest Tank and Mfg. Co., Inc.
2075 S. Belmont Avenue
Indianapolis, IN 46221
(317) 632-9326

Manufacturer of Pump Applicators for Cold-Applied Sealants

Pyles Business Unit
Graco, Inc.
28990 Wixom Road
Wixom, MI 48096
(313) 349-5500

Manufacturers of Automated Backer-Rod Installation Devices

O.J.S. Machines
5842 Sackville Close
Humble, Texas 77346
(713) 853-7072

Manufacturers of Joint Plows

RC Company
7207 Stutz Lane
Bethalo, IL 62010
(618) 258-1044

Glossary

Adhesion failure–Complete loss of bond between a sealant material and the concrete joint wall.

Allowable extension–The amount of stretching of a sealant material under which performance is estimated to be adequate.

Average daily traffic (ADT)–The total traffic volume carried by a pavement during a given period (in whole days), greater than 1 day and less than 1 year, divided by the number of days in that period.

Blowups–The result of localized upward movement or shattering of a slab along a transverse joint or crack.

Channel face–The vertical concrete sidewall of a sawed joint sealant reservoir.

Compression seals–Preformed seals, generally made from neoprene, that can be compressed and inserted into concrete joints for sealing purposes.

Corner break–A diagonal crack forming between transverse and longitudinal joints that extends through the slab, allowing the corner to move independently from the rest of the slab.

D-cracking–The breakup of concrete due to freeze-thaw expansive pressures within certain susceptible aggregates (also called durability cracking).

Embedment–To become fixed firmly in a surrounding mass, as stones sink into and become fixed in soft sealant material.

Extruded–Forced through a die to give the material a certain shape.

Flow–The sinking of unstable sealant into a sealant reservoir.

Horizontal movement–Opening and closing of joints resulting from pavement expansion and contraction.

Incompressible–Material that resists compression, as stones, sand, and dirt in a crack or joint reservoir that is closing.

Joint growth–The gradual increase in joint width resulting from the filling of joints with incompressible materials during cold cycles.

Joint sidewalls–The vertical concrete edges of a sawed joint reservoir.

Life-cycle cost analysis–An investigation of the present and future costs of each repair alternative, taking into account the effects of both inflation and interest rates on expenses over the life of the project.

Load transfer–The transfer of load across a joint or crack in concrete pavement resulting from aggregate interlock, dowels, or other load-carrying devices.

Overbanding–Spreading a thin layer of sealant (about 1.5 in [38 mm] wide) onto a pavement surface centered over a joint or crack at the same time that the sealant reservoir is filled.

Pumping–The ejection of water and fine materials from beneath a concrete pavement through cracks or joints under pressure from moving loads.

Refacing–Removing about 1/16 in (1.6 mm) of concrete from each wall of a sealant reservoir using diamond saw blades.

Resealing–Replacing sealant in joints or cracks, preferably using good-quality methods and materials.

Sealant/channel interface–The vertical edge of a sealed joint where sealant material and concrete joint face meet.

Sealant reservoir–The channel along a joint or crack that has been widened by sawing to allow sealant to be placed in it.

Sealant system–All components that function to seal joints, i.e., sealant material, surrounding concrete, and sealant/concrete interface.

Slurry–The mixture of water, concrete dust, old sealant, and dirt that results from resawing a joint in concrete pavement.

Subdrainage–Drainage of moisture from beneath a pavement by means of a porous subbase material connected to outlet drain lines.

Track–The spreading of unstable sealant material along the pavement surface by traffic tires.

Undersealing–Filling voids beneath a concrete pavement using a pressurized slurry or hot asphalt material.

Vertical shear–Vertical stress along the sealant/concrete interface resulting from traffic loading, curling, and pavement faulting.

Weathering–Breakdown of sealant material resulting from the effects of moisture, ultraviolet rays, and time.

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Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements

Manual of Practice

shrp

Strategic Highway Research Program
National Research Council

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1.0 Introduction

*Spalling** is a common distress in jointed concrete pavements that decreases pavement serviceability and can be hazardous to highway users. When left unrepaired, it results in accelerated pavement deterioration. This manual has been prepared for maintenance engineers, maintenance field supervisors, crew members, maintenance contractors, and inspectors to use as an easy reference for the rapid repair of *partial-depth spalls* in jointed portland cement concrete (PCC) pavements.

1.1 Scope of Manual

This manual describes procedures and materials recommended for partial-depth *spall* repair in jointed PCC pavements. Only *rapid-setting materials* are discussed. The manual presents detailed guidelines on design, construction, and inspection. The information in this manual is based on the most recent research, obtained through reviews of literature and current practices, and the field results of an ongoing study. This study investigates the performance of various rapid-setting spall repair materials and partial-depth spall repair methods for jointed PCC pavements.[1,2]

1.2 Purpose of Partial-Depth Spall Repair

In brief, partial-depth spall repair is removing an area of deteriorated concrete that is generally limited to the top third of a concrete pavement slab, and replacing it with a repair material and perhaps a new *joint sealant system*. Partial-

* Italicized words are defined in the glossary.

depth spall repairs may be placed along transverse and longitudinal joints, and anywhere in the slab.

Partial-depth patches improve the ride of jointed concrete pavements by repairing surface spalls, scaling, and popouts. When placed along joints and combined with an appropriate joint maintenance and resealing program, they reduce the infiltration of moisture and the intrusion of *incompressibles* into the joint. Properly placed partial-depth patches should last as long as the rest of the pavement.

Partial-depth spall repair should also be considered before a pavement is overlaid. If spalls are not repaired, the overlay is likely to deteriorate and fail prematurely. Partial-depth spall repairs should be completed after any *undersealing* or *slab jacking*, but before *diamond grinding* and joint sealing.

1.3 Partial-Depth Patch Performance

Studies have shown that when partial-depth patches are properly installed with good quality control, 80 to 100 percent of the repairs perform well after 3 to 10 years of service.[3,4,5] In an ongoing study, partial-depth patches are showing a failure rate of less than 2 percent after 1.5 years of service.[2]

However, improper design and construction practices, combined with poor quality control and inspection, result in poor performance. The most frequent causes of partial-depth patch failure are:

- Improper selection of repair materials
- Lack of bond between the patch and the pavement
- *Compression failure*
- Variability of the repair material

- Improper use of repair materials
- Insufficient consolidation
- Incompatible *thermal expansion* between the repair material and the original slab
- *Feathering* of the repair material

This manual recommends practices that may help avoid these causes of failure.

1.4 Limitations

The cause and depth of spalling can limit the benefits of partial-depth spall repair. If partial-depth spall repair is being considered, cores should be taken at representative joints to determine whether partial-depth spall repair should be used. Spalling deeper than the top third of the slab, or spalling caused by misaligned dowel bars or *d-cracking,* should not be repaired with a partial-depth patch. In these cases, partial-depth spall repairs are likely to fail because of high shear stresses.

2.0 Need for Partial-Depth Spall Repair

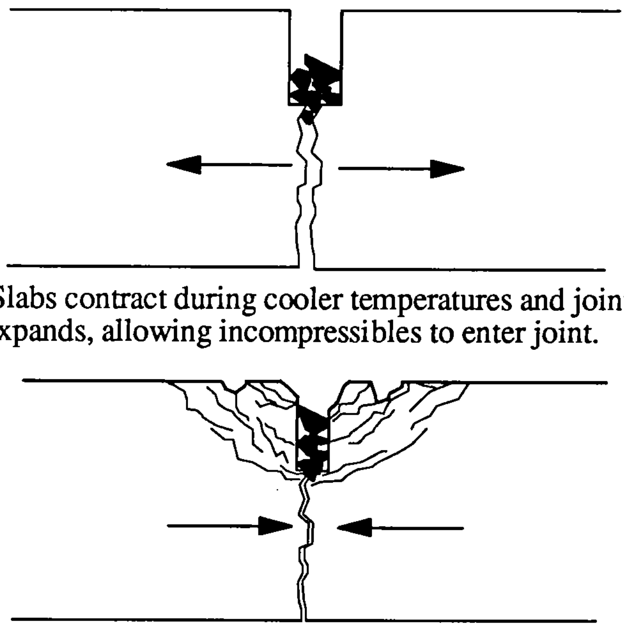
Incompressibles can become lodged in unsealed joints or cracks during cool weather when a jointed PCC pavement shrinks and the joints open. During warm weather, the pavement expands and joints close. Incompressibles in the joints will prevent the joints from closing and will produce high compressive stresses along the joint faces. This may cause spalling at both the top and bottom of the slabs. Figure 1 shows a partial-depth spall caused by incompressibles.

Partial-depth spall repairs may be used instead of full-depth repairs when deterioration is located primarily in the upper third of the slab and when existing *load transfer devices* are still working. Partial-depth repairs may be more cost-effective than full-depth repairs, such as when repairing shallow, small spalls along the entire length of a joint with a *full lane-width partial-depth patch.* Spalls caused by corroding metal *joint inserts* and high reinforcing steel may also be repaired with partial-depth patches.

Spalls caused by misaligned dowel bars or d-cracking should not be repaired with partial-depth patches. Partial-depth patches replace concrete only. They cannot accommodate the movement of joints and cracks, load-transfer devices, or reinforcing steel without undergoing high stress and damage.

2.1 Pavement Condition

Partial-depth spall repairs may be needed when a pavement is rehabilitated to restore structural integrity, improve ride, and extend the life of the pavement. Partial-depth spall repairs should not be used if the pavement must be rehabilitated by



a. Slabs contract during cooler temperatures and joint expands, allowing incompressibles to enter joint.

b. Slabs expand during warmer temperatures and joint contracts. Incompressibles in joint cause compressive stresses which result in cracking and spalling

Figure 1. Partial-depth spall caused by incompressibles

cracking and seating, breaking and seating, or *rubblization* before overlaying.

Partial-depth spall repairs may also be needed as part of a joint resealing project. Partial-depth repair of spalled joint areas creates a well-defined, uniform joint reservoir before resealing. Partial-depth spalls must be repaired when using a *preformed compression seal* to provide a uniform joint reservoir and to prevent the seal from working out of the joint.

2.2 Climatic Conditions

The wetter and colder the climate, the greater the need for timely partial-depth spall repair. However, spalling can occur in any climate, and proper partial-depth spall repair will help reduce further deterioration.

The damage caused by freezing and thawing cycles is a serious problem in jointed PCC pavements. In wet and freezing climates, the continued presence of water on and in the pavement and the use of deicing salts often makes the damage even worse.

Even in non-freezing climates, any moisture in the concrete can cause corrosion of reinforcing steel in the pavement. Corroding steel creates expansive forces that can lead to cracking, spalling, and *debonding* of the concrete around it. Reinforcing steel without enough concrete cover is even more likely to corrode. Timely partial-depth spall repair can protect high reinforcing steel that has not yet corroded and can prevent more serious spalling.

Spalling may also occur in dry and freezing climates. Incompressibles that are trapped in a joint when the adjacent slabs contract during freezing create high compressive stresses in the joint face when the slabs expand during thawing. Early repair of nonfunctioning joint sealant systems, along with any adjacent spalling, can protect the joint from further deterioration.

3.0 Planning and Design

Spall repair performance is partially a function of design-related parameters. Design-related causes of failure of partial-depth patches include the following:

- Not including all deteriorated concrete within the repair boundaries
- Not accounting for the climatic conditions likely to be present during the repair when selecting the repair material and the installation procedure
- Not selecting a repair material that has thermal compatibility with the pavement
- Not accounting for the climatic conditions that the repair material will experience throughout its lifetime
- Not accounting for the expected time of opening to traffic when selecting the repair material
- Not accounting for the type of aggregate that will be used when selecting the repair material
- Not selecting a *joint bond breaker* that is compatible with the selected joint sealant

3.1 Objectives in Selecting Materials and Procedures

The objectives for selecting the materials and procedures used in partial-depth spall repair depend on climatic conditions, urgency, and future rehabilitation schedules. In *adverse patching conditions*, when the spall presents a hazard to highway users, a temporary repair may be needed. In this case, the design should provide for adequate temporary patch life until a permanent repair can be made. Material properties and a repair technique that will accommodate the existing or expected adverse conditions should be selected.

Spalls that are repaired before a pavement overlay do not need patch edges as vertical and straight as they should otherwise be, and the repair material does not need to wear well. Furthermore, patches that are covered by an overlay will undergo slower temperature changes than patches that are not covered by an overlay. Therefore, thermal compatibility between the patch and pavement may be less important for these patches.

A partial-depth patch that will not be covered or destroyed in a future rehabilitation will be exposed to traffic and climate for a long time. In this case, it may be more cost-effective to choose a material and repair procedure that cost more initially, but that provide long-term performance.

Sometimes a spall must be repaired because it is hazardous to highway users, but the pavement (and the patch) will be destroyed during an upcoming rehabilitation. In this case, design considerations should reflect the expected short life of the patch. It may be more cost-effective to choose a low-cost combination of material and repair methods.

The highway agency must determine the most cost-effective material and repair method in light of the urgency of the partial-depth spall repair and the rehabilitation schedule for the pavement. Section 3.8 provides guidelines for doing so.

3.2 Assessing Existing Conditions

Before the design stage of partial-depth spall repair, the highway agency should assess the local climate and condition of the pavement. Factors to consider include the climatic conditions expected during construction and throughout the life of the patch; the degree, depth, and cause of spalling; the time available before the patch must be opened to traffic; and the need for other repairs, such as drainage, stabilization, etc.

The "4R" participant's notebook, *Techniques for Pavement Rehabilitation: Training Course*, is an excellent guide for assessing and performing many highway repairs.[6]

The highway agency can select an appropriate material and procedure combination based on the results of this assessment, equipment availability, maintenance crew or contractor experience, cost constraints, and performance demands.

3.3 Selecting a Repair Material

The highway agency must determine which materials are suitable for its particular environment and working conditions. Some materials have tight working tolerances, such as air temperatures and surface-wetting conditions during placement, mixing quantities and times, and maximum depths of placement. Material specifications must be carefully consulted during material selection.

Material cost, shelf life, physical properties, workability, and performance vary greatly among the different types of materials, and from brand to brand within each type. When comparing costs, the initial material cost plus the cost of installation in terms of time, equipment, and labor must be considered. Section 3.8 presents a worksheet to help calculate these costs. Table 1 lists properties and cost factors for some materials.[7, 8, 9] The cost factor is the ratio of the cost of the given material to the cost of a typical rapid-setting Type III PCC material.

Material cost varies with the amount of material purchased and the distance the material must be shipped. The cost factors listed in table 1 are for illustration only. They do not include the cost of shipping or discounts that may be realized

Table 1. Properties of some rapid-setting partial-depth spall repair materials

Product	Category	Working time	Installation temp. range[1]	Time-to-traffic (70°F)	Moisture conditions[2]		Cost factor[3]
					repair surface	aggregate	
Type III PCC	Cementitious (PCC)	20 min	32-110°F	4-6 hr	SSD to dry	1-3% to dry	1
Duracal	Cementitious (gypsum-based)	20 min	32-110°F	1.5 hr	SSD to dry	1-3% to dry	0.7[4]
Set-45	Cementitious (magnesium phosphate)	10 min	32-90°F	1.5 hr	dry	1-3% to dry	3.5[4]
Five Star HP	Cementitious (high alumina)	20 min	32-90°F	1.5 hr	SSD to dry	1-3% to dry	3
Pyrament 505	Hydraulic cement	30 min	40-110°F	2-3 hr	SSD to dry	1-3% to dry	2
SikaPronto 11	Polymer (modified methacrylate)	30 min	35-90°F	1.5 hr	SSD to dry[5]	dry	16
Penatron R/M-3003	Polymer (epoxy-urethane)	7-10 min	-10-150°F	30 min	dry	dry	17
MC-64	Polymer (epoxy)	10 min	40-90°F	2 hr	dry	dry	23
Percol FL	Polymer (polyurethane)	1 min	>0°F	10-20 min	dry	dry	9

Table 1. Properties of some rapid-setting partial-depth spall repair materials (continued)

Product	Category	Working time	Installation temp. range[1]	Time-to-traffic (70°F)	Moisture conditions[2]		Cost factor[3]
					repair surface	aggregate	
UPM High Perf. Cold Mix	Bituminous	na	32-100°F	immediately	SSD to dry	1-3% to dry	0.5-0.6
Spray-injection mix	Bituminous	na	-10-100°F	immediately	SSD to dry	1-3 % to dry	0.2-0.4[6]

1 The installation temperature range shown is the temperature range at which the material manufacturer claims it can be installed. However, patching is generally not recommended when the temperature is below 40°F or above90°F. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing. °C = (°F-32) × 5/9.

2 SSD = *saturated*, surface-dry; dry aggregate = oven-dried; 1-3% = 1-3% moisture allowed in the aggregate.

3 The cost factor is the ratio of the cost of the given material to the cost of a typical rapid-setting Type III PCC material. It includes the cost of bagged aggregate, *bonding agent* if required, and admixtures if required.

4 Does not include the cost of the bonding agent. Bonding agent recommended if used in shallow patches.

5 The manufacturer states a SSD pavement surface is acceptable; however, lab tests indicate bonding needs a dry surface.[(2)]

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

by buying large amounts. Cementitious materials may be purchased from local distributors. The newer materials may require shipping and may therefore cost more. Manufacturers will provide exact material and shipping costs upon request.

Highway agencies should select the most cost-effective material that meets the requirements of the project. Cost-effectiveness is a function of patch performance and life, as well as the characteristics of a given project, such as traffic and user cost. Section 3.8 provides guidelines for determining cost-effectiveness.

Table 2 shows some of the information in table 1 in a different format. When the expected installation temperature, time-to-traffic, and moisture conditions are known, table 2 can be used to identify materials that may be acceptable for a project. However, tables 1 and 2 show information on just a few rapid-setting materials. Additional factors that can restrict material selection are discussed in the following sections. Material manufacturers should be consulted for complete details on the correct use of their product.

3.3.1 Cementitious Concretes

Cementitious materials include PCC-based, *gypsum-based*, *magnesium phosphate*, and *high alumina concretes*. Regular PCC is the most common material used for spall repair. However, if the road must be opened to traffic relatively quickly, rapid-setting or *high early-strength materials* must be used.

Portland Cement Concrete

Typical PCC mixes combine Type I, II, or III portland cement with coarse aggregate. Type III portland cement, or

Table 2. Initial material selection criteria for some rapid-setting materials

Criteria	Materials[1]										
	III	Dur	St45	5HP	Pyr	SP11	Pen	MC64	PFL	UPM	Spray
Installation temperature[2]											
-10°F < T < 32°F							✓		✓	✓	✓
32°F ≤ T < 40°F[2]	✓	✓	✓	✓	✓		✓		✓	✓	✓
40°F < T ≤ 90°F	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
T> 90°F[2]	✓	✓					✓		✓	✓	✓
Time-to-traffic at 70°F											
5 min										✓	✓
30 min							✓		✓	✓	✓
2 hr		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
4 hr	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Aggregate moisture											
1-3% moisture allowed	✓	✓	✓	✓						✓	✓
Oven-dried[3]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Pavement surface moisture											
Saturated, surface-dry	✓	✓		✓	✓	✓[4]				✓	✓
Dry[5]	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

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

2 Patching is generally not recommended when the temperature is below 40°F or above 90°F. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing. °C = (°F - 32) × 5/9.

3 Water content should be adjusted as needed.

4 The manufacturer states a saturated, surface-dry pavement surface is acceptable; however, lab tests indicate bonding needs a dry surface.[2]

5 Wet surface before material placement if required by manufacturer.

Type I portland cement, with the addition of a set-accelerator, may be used when the concrete repair must be opened quickly to traffic. The main difference between Type I and Type III portland cement is that Type III is more finely ground than Type I. When cement is ground more finely, more cement surface area comes into contact with the water in the mix. This speeds up the *hydration rate*, which speeds up strength development and heat release during the first 7 days of curing. Type II portland cement, even though it is ground to the same fineness as Type I, gains strength too slowly to be used for rapid repair.

Type III portland cement, with or without *admixtures*, has been used for fast, permanent repairs longer and more widely than most other materials because of its relatively low cost, availability, compatibility with existing pavements, and ease of use. Rich mixtures (700 lb per yd^3 to 900 lb per yd^3 [420 kg per m^3 to 540 kg per m^3]) gain strength quickly in warm weather (4 to 12 hours). However, the rate of strength gain may be too slow to permit quick opening to traffic in cool weather. Insulating layers can be used to retain the *heat of hydration* and reduce curing time.

Gypsum-based Concrete

Gypsum-based (calcium sulfate) patching materials (e.g., Duracal, Rockite) gain strength rapidly and can be used in temperatures above freezing (up to 110°F, for example, in the case of Duracal). However, gypsum concrete does not appear to perform well when exposed to moisture or freezing weather.[10] Additionally, the presence of *free sulfates* in the typical gypsum mixture may promote steel corrosion in reinforced pavements.[11]

Magnesium Phosphate Concrete

Magnesium phosphate concretes (e.g., Set-45, Eucospeed MP, Propatch MP) set very quickly, and make high early-strength, impermeable patches that bond to clean and dry surfaces. However, these materials are extremely sensitive to water on the pavement, and even very small amounts of extra water in the mix severely decreases strength. They also cannot be used with limestone aggregates.[11] These limitations have led to variable field performance.[10, 12]

High Alumina Concrete

Calcium aluminate concretes (e.g., Five Star HP) gain strength fast, bond well (best to a dry surface), and shrink very little during curing. However, they may lose strength over time because of a *chemical conversion* that takes place, particularly at high curing temperatures.[3, 10, 11]

3.3.2 Polymer Concretes

Polymer concretes are a combination of *polymer resin*, aggregate, and a *set initiator*. The aggregate makes the polymer concrete more economical, provides thermal compatibility with the pavement, and provides a wearing surface. The polymer concretes described in this manual are *epoxy, methyl methacrylate,* and *polyurethane concretes.*

Epoxy Concrete

Epoxy concretes (e.g., MC-64, Burke 88/LPL, Mark 103 Carbo-Poxy) are impermeable and are excellent adhesives. They have a wide range of setting times, application temperatures, strengths, and bonding conditions. The epoxy concrete mix design must be thermally compatible with the pavement, otherwise the patch may fail. Deep epoxy repairs often must be placed in lifts to control heat development. Epoxy concrete should not be used to patch spalls caused by reinforcing steel corrosion, as the rate of deterioration of adjacent sound pavement may be accelerated.[13]

Methyl Methacrylate Concrete

Methyl methacrylate concretes and *high molecular weight methacrylate concretes* (e.g., SikaPronto 11, Degadur 510) are polymer-modified concretes that could also be classified as cementitious materials. They have relatively long working times, high *compressive strengths*, and good adhesion. Many methyl methacrylates are volatile and may pose a health hazard from prolonged exposure to the fumes.[8] As with all materials, material safety data sheets (MSDS) must be obtained from the manufacturer and followed to ensure the safe use of these materials.

Polyurethane Concrete

Polyurethane concretes (e.g., Percol FL, Penatron R/M-3003) generally consist of a two-part polyurethane *resin* mixed with aggregate. Polyurethanes generally set very quickly (90 sec). Some manufacturers claim their materials are moisture-tolerant; that is, they can be placed on a wet surface with no adverse effects. This type of material has been used for several years with variable results.[8, 14]

3.3.3 Bituminous Materials

Bituminous patches are used almost everywhere in all climates. They are often considered temporary, but are sometimes left in place for many years. They are fairly inexpensive, widely available, and easy to place with small crews. They usually need little, if any, cure time. The most effective bituminous materials are the hot mix asphalt concretes (HMAC). A few States have successfully used bituminous spray-injection mixes (e.g., AMZ, Rosco). Many *proprietary* bituminous cold mixes also perform well (e.g., UPM High Performance Cold Mix), although they may become sticky and hard to work with at the upper end of their placement temperature range.

3.3.4 Material Testing

Materials must be rigorously tested in a laboratory to determine if the product or mix design is suitable for a given region or condition. The suggested approval or acceptance tests for cementitious materials include:

- Compressive strength
- Modulus of elasticity
- Flexural strength
- Bond strength
- Freeze-thaw resistance
- Scaling resistance
- Surface abrasion resistance
- Thermal compatibility
- Coefficient of thermal expansion

The suggested tests for bituminous cold mixes include:

- Workability
- Stripping
- Drainage
- Cohesion

These laboratory tests are index tests and do not necessarily predict performance. Therefore, initial field testing should be conducted. Material safely data sheets should be examined, as well as storage requirements and shelf life.

3.4 Selecting Accessory Materials

Many materials besides the patching materials are used in the partial-depth spall repair process. Bonding agents, joint bond breakers, joint sealants, and curing compounds may also be required. This section provides guidance in selecting these accessory materials.

3.4.1 Bonding Agents

Different bonding agents require varying cure periods. Therefore, the bonding agent should be selected after the repair material has been chosen and the time-to-traffic has been determined. Not all patching materials need a bonding agent. The manufacturer's recommendation should always be followed. Epoxy bonding agents should be used with Type III PCC materials, as they provide a curing time of 6 hours or less.

3.4.2 Joint Bond Breakers

Joint bond breakers (polyurethane, polystyrene, or polyethylene strips, and fiberboards) prevent patches installed at a joint from bonding to the adjacent slab. Joint bond breakers must be nonabsorbent, closed cell, chemically inert, compressible with good *compression recovery*, and compatible with the joint sealant. Bond breakers used with hot-poured sealants must be heat resistant for the installation temperature of the sealant. Section 4.5 describes how to install joint bond breakers.

Joint bond breakers that have been scored at an appropriate depth before placement, as shown in figure 2, are recommended, as they save time and labor. Once the scored bond breaker has been placed in the clean joint, and the patch has been installed and has cured or set, the top strip is removed. This provides a clean surface and a pre-formed joint reservoir that is ready for the installation of the joint sealant. Fiberboard is more rigid than other types of bond breakers. It should be used at the lane-shoulder joint where more support is needed.

For information on selecting dimensions for the joint reservoir (the width of the joint bond breaker, and the depth of scoring) consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice.*[15]

3.4.3 Curing Materials

Water loss during curing causes the patch volume to decrease. This can lead to *shrinkage cracks* and poor bond. Therefore, curing methods that reduce water loss should be used. The recommended moist curing methods are:

- Water curing
  - continuous water spraying
  - saturated coverings (burlap, sand, or straw)

- Sealed curing
  - plastic sheeting
  - curing compounds

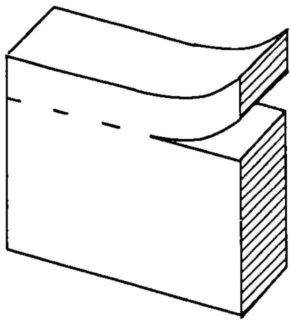


Figure 2. Scored joint bond breaker

Water curing supplies additional water and prevents moisture loss. Continuous water spraying works well only when water and labor are plentiful and runoff is not a problem. Furthermore, vigorous spraying can erode the patch. Saturated coverings need periodic wetting, but may provide insulation in winter if topped with a dry layer. Potable water that is clean and free of oil, salt, and other contaminants must be used when water curing.

Sealed curing does not add water to the patch, but does prevent moisture loss when uniformly and adequately applied. Pigmented, liquid, membrane-forming curing compounds are popular because their *opaque* color shows if they have been adequately applied, they can reflect or absorb sunlight, and they do not blow away. They also do not require rewetting or large amounts of water on the construction site.

Curing compounds can interfere with bonding between the overlay and the patch. However, unless the patch is large, such as a full lane-width patch, the effect on bonding should not be that great. A large patch can be cleaned before overlaying if the curing compound has not already worn off. Curing compounds should not be used in the fall, if the patch will soon be exposed to de-icing salts. Curing compounds should be white in color in hot weather, and gray or black in cold weather.

3.4.4 Joint Sealants

An appropriate joint sealant must be installed to ensure the performance of the partial-depth patch. The sealant must prevent water and incompressibles from entering the joint. If the pavement will not be overlaid and the remaining life of the pavement is expected to be long, silicones and high quality hot-poured rubberized or polymerized asphalt sealants are generally recommended. If the pavement will be overlaid, the joints should still be filled, but lower quality materials may be acceptable. For information on selecting a joint sealant consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice.*[15]

3.5 Selecting Dimensions of the Repair Area

Partial-depth patches should be limited in depth to the top third of the slab and should never come in contact with dowel bars. **If dowel bars are reached, a *full-depth spall repair* must be used.** Partial-depth patches must be at least 2 in (51 mm) deep for weight and volume stability. They should extend 2 in to 6 in (51 mm to 152 mm) in each possible direction beyond the spalled area, and be at least 4 in (102 mm) wide and 10 in (254 mm) long. Table 3 shows the minimum dimensions for patches in various locations. Figures 3 and 4 show the minimum dimensions of partial depth patches located at one joint; figures 5 and 6, at two joints.

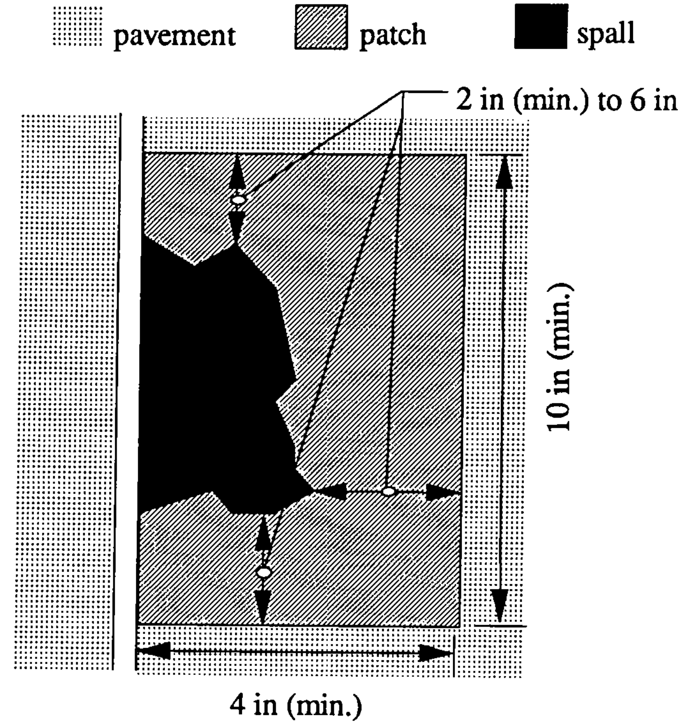
Table 3. Minimum dimensions of repair area for spalls at various locations

Location of spalling	Minimum dimensions of repair area		
	Depth[1] (in)	Length[1] (in)	Width[1] (in)
at one joint	2	10 **or** length of spalled area + 4 **whichever is greater**	4 **or** width of spalled area + 2 **whichever is greater**
at two joints	2	8 **or** length of spalled area + 2 **whichever is greater**	4 **or** width of spalled area + 2 **whichever is greater**
away from joints	2	10 **or** length of spalled area + 4 **whichever is greater**	5.5 **or** width of spalled area + 4 **whichever is greater**

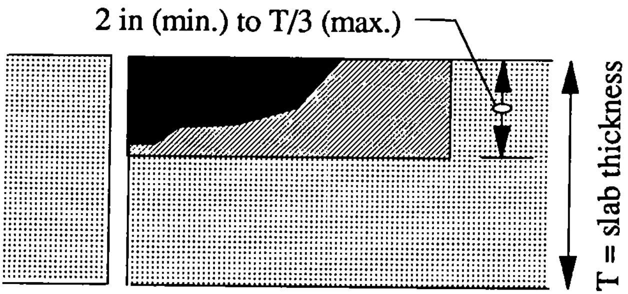
[1] 1 in = 25.4 mm.

Areas less than 6 in (152 mm) long or 1.5 in (38 mm) wide are normally not patched, but are filled with a sealant. Patches less than 1 ft (305 mm) from each other should be repaired with one patch, as shown in figures 4 and 6. When several small spalls exist at one joint, it usually costs less to patch the entire joint length than to repair individual spalls.

In the early stages of spalling, there are often weak areas in the slab that cannot be seen. The extent of deterioration should be determined by sounding–striking the concrete with a solid steel rod, chain, or ball peen hammer and listening to the sound produced. A clear ringing sound indicates sound concrete, while a dull sound indicates weak concrete. All weak concrete must be located and included within the patch boundaries.



Plan View



Profile View

Figure 3. Dimensions of patch at one joint.
1 in = 25.4 mm

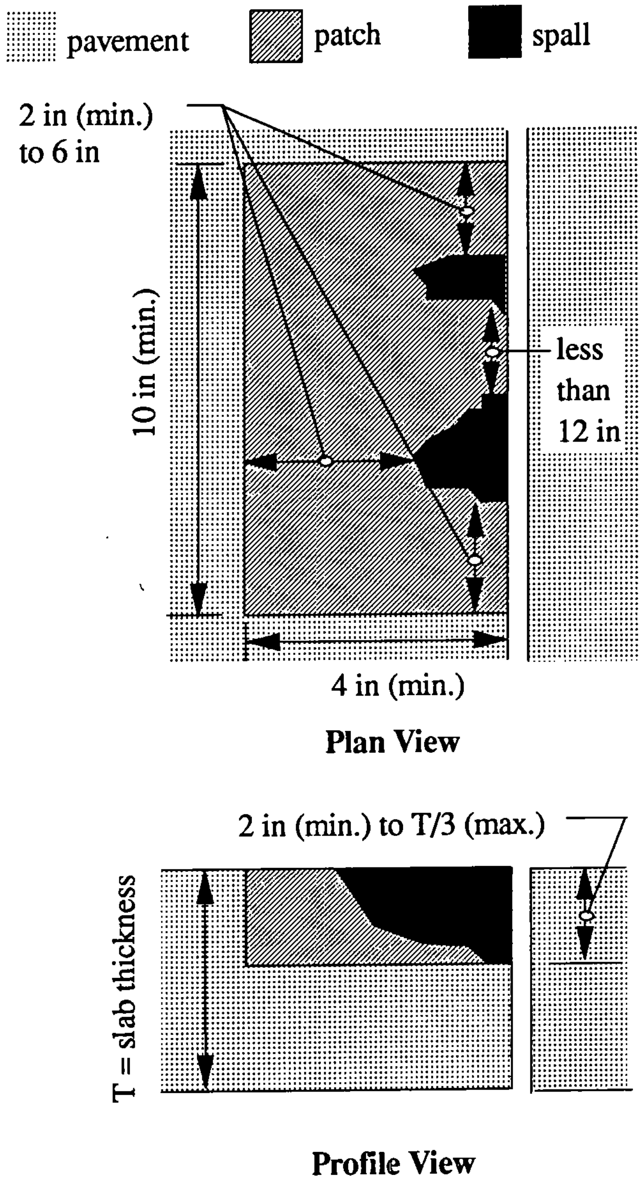


Figure 4. Dimensions of patch at one joint for spalls less than 12 in apart. 1 in = 25.4 mm

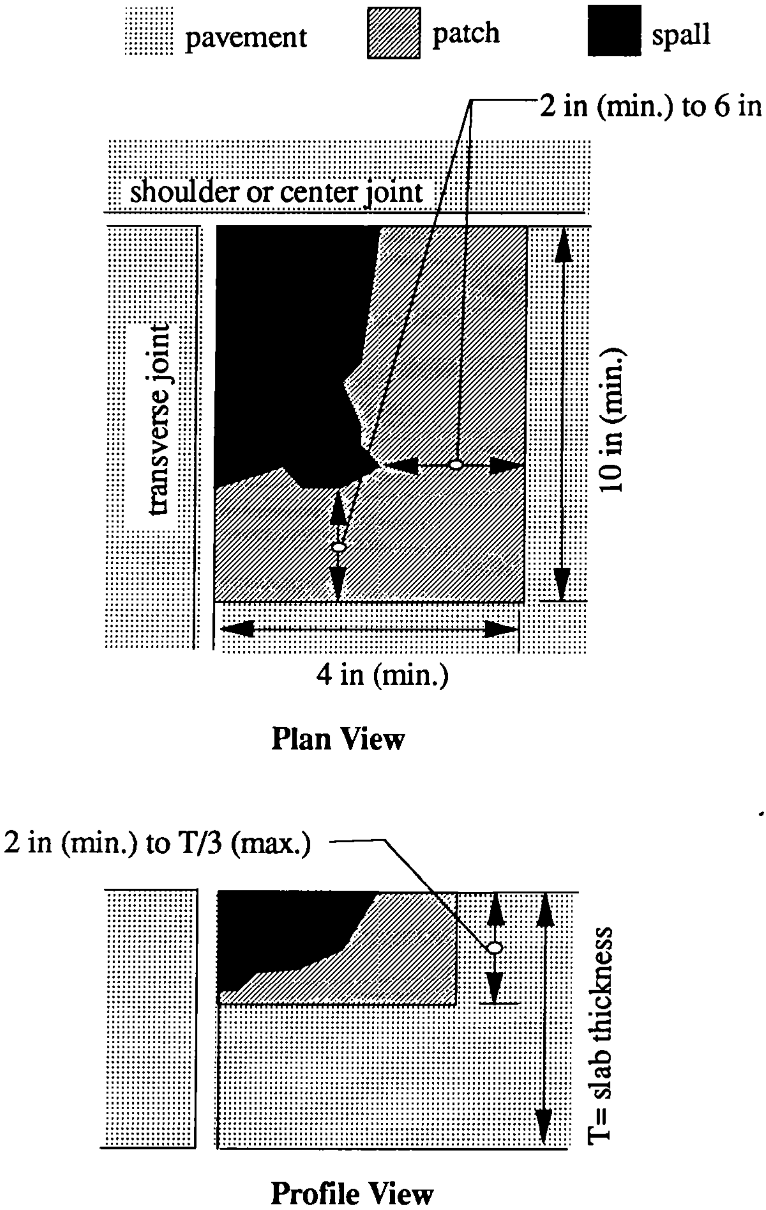


Figure 5. Dimensions of patch at two joints.
1 in = 25.4 mm

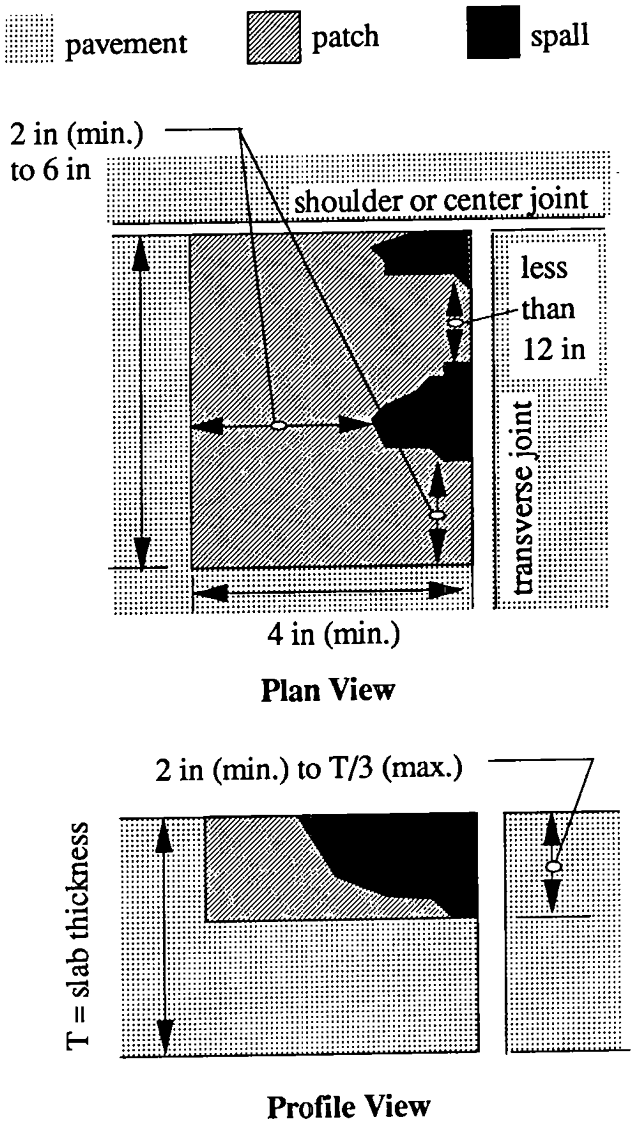


Figure 6. Dimensions of patch at two joints for spalls less than 12 in apart. 1 in = 25.4 mm

3.6 Selecting Patch Preparation Procedures

The patch preparation procedures discussed in this manual include the saw-and-patch procedure, the chip-and-patch procedure, the mill-and-patch procedure, the waterblast-and-patch procedure, and the clean-and-patch procedure. The only difference between these patch preparation procedures is the method used to remove the deteriorated concrete. Sandblasting and airblasting are highly recommended for all preparation procedures, though they may be impractical under adverse conditions.

When selecting a procedure, the highway agency should consider equipment availability and cost, the availability of a crew trained in the procedure, the available construction time, and the cost-effectiveness of the procedure. Section 3.8 provides guidelines for determining cost-effectiveness.

3.6.1 Saw and Patch

The first step in the saw-and-patch procedure is sawing the patch boundaries with a diamond blade saw. The deteriorated concrete in the center of the patch is then removed using a light jackhammer with a maximum weight of 15 lb (6.8 kg); a jackhammer with a maximum weight of 30 lb (13.6 kg) may be allowed if damage to sound pavement is avoided. Finally, the deteriorated concrete near the patch borders is removed using a light jackhammer with a maximum weight of 15 lb (6.8 kg) and hand tools. The work should progress from the inside of the patch toward the edges, and the chisel point should be directed toward the inside of the patch.

The advantages of the saw-and-patch procedure include the following:

- The saw leaves vertical edge faces.
- The forces experienced by the pavement during chipping are isolated within the sawed boundaries.
- Very little spalling of the remaining pavement occurs.
- Removing the deteriorated concrete within the sawed boundaries is usually easier and faster when the boundaries are sawed than when they are not sawed.
- Most crews are familiar with the method.

The disadvantages of the saw-and-patch procedure include the following:

- More workers are required than in the other procedures.
- Since water is used when sawing, the repair area is saturated for some time, possibly delaying the repair.
- Saw overcuts weaken the repair area and must be cleaned and sealed.
- The saw may encroach into the open lane of traffic.
- The polished, vertical patch boundary faces may lead to poor bonding.

If the patching material is moisture-sensitive and will not bond to a wet surface, placement must be delayed. This can be avoided by sawing joints and boundaries 1 to 2 days before removing and replacing the material. (Sawed edges do not spall when traffic is allowed onto repair areas that have been cut 1 to 2 days in advance.) However, if more unsound concrete is later found beyond the sawed boundaries, the saw must be brought back to saw new boundaries, possibly causing further delay. Also, the saw may encroach into the open lane of traffic if the spall is near the open lane, creating a hazardous situation.

Saw overcuts occur because the boundaries must be overcut 2 in to 3 in (51 mm to 76 mm) in each direction to obtain the needed depth of cut. These overcuts create weak areas that may deteriorate unless cleaned and sealed.

3.6.2 Chip and Patch

The chip-and-patch procedure is the same as the saw-and-patch procedure, except the patch boundaries are not sawed. The deteriorated concrete in the center of the patch is removed using a light jackhammer with a maximum weight of 15 lb (6.8 kg); however, a jackhammer with a maximum weight of 30 lb (13.6 kg) may be allowed if damage to sound pavement is avoided. The deteriorated concrete near the patch borders is then removed using a light jackhammer with a maximum weight of 15 lb (6.8 kg) and hand tools. The work should progress from the inside of the patch toward the edges, and the chisel point should be directed toward the inside of the patch.

The advantages of the chip-and-patch procedure include the following:

- The rough vertical edge produced promotes bonding.
- There are no saw overcuts.
- It has fewer steps than the saw-and-patch method.
- Spalling is controlled by using light hammers at the edges.
- It may be quicker than the saw-and-patch method.

The chip-and-patch procedure may be faster because it has fewer steps: the patch boundaries are not sawed, and there are no saw overcuts to be cleaned and sealed. Once joint sawing is completed (see section 4.2.2), the saw is not needed again, even if more unsound concrete is later found beyond the boundaries.

The disadvantages of the chip-and-patch procedure include the following:

- Sound concrete may be damaged by heavy hammers.
- Jackhammers can cause feathered patch edges.
- Vertical sides are difficult to achieve.

The transmission of destructive forces may be reduced by using a heavy hammer only at the center of the repair area and a light hammer around the edges. If the selected repair material should not be feathered (e.g., some cementitious materials), a minimum 1-in (25-mm) vertical face on all sides must be specified; that is, the top portion of the patch boundaries must be vertical for at least 1 in (25 mm).

3.6.3 Mill and Patch

Some States have successfully used carbide-tipped milling machines for spall repair.[16] Standard milling machines with 12-in to 18-in (305-mm to 457-mm) wide cutting heads have proven efficient and economical, particularly when used for large areas (e.g., for full lane-width repairs). The milling operation leaves a rounded cavity that may be made vertical by hammering or sawing. The milling machine should have a drum diameter of 3 ft (0.9 m) or less and make a 12-in (305-mm) wide cut or narrower.

The advantages of the mill-and-patch procedure include the following:

- It is efficient and economical when repairing large areas.
- It leaves a rough, irregular surface that promotes bonding.

The disadvantages of the mill-and-patch procedure include the following:

- If the spall is less than 1 ft^2 (0.09 m^2), the patch may be larger than needed, because the smallest milling head currently available provides a 1 ft^2 (0.09 m^2) cut.
- The milling operation may cause spalling on the adjacent pavement edges.
- The milling machine makes a hole with two rounded edges (perpendicular to the direction of milling) that

should be made vertical by chiseling if they are perpendicular to the direction of traffic.

Some milling machines seem better suited for milling asphalt and than for milling concrete. More powerful equipment may increase concrete milling efficiency and reduce spalling of the adjacent pavement.

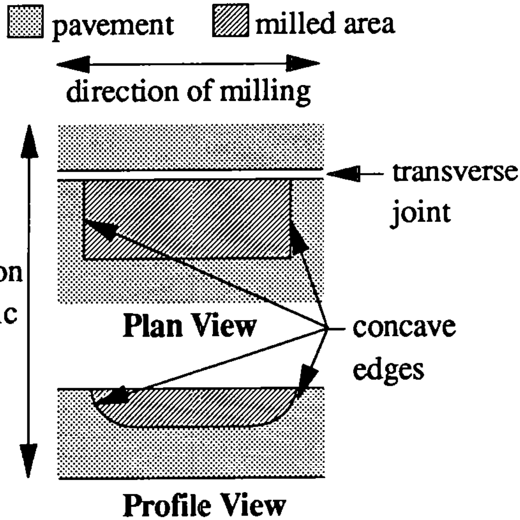
The orientation of the rounded edges should be parallel to the direction of traffic whenever possible, as shown in figure 7. However, due to traffic in the adjacent lane, the equipment may not always be able to maneuver into such an orientation. The larger the repair areas and the further they are from the adjacent lane of traffic, the higher the efficiency of the milling operation. The efficiency of milling is also affected by the number of milling teeth that must be replaced per day.

Milling machines are readily available in many regions of the United States. However, a suitable machine at a reasonable cost may not be available at a specific project site.

3.6.4 Waterblast and Patch

The waterblast-and-patch procedure uses a high-pressure water jet to remove the deteriorated concrete. Several States are testing this method for repairing pavements. The waterblasting machine should be capable of producing a stream of water at 15,000 psi to 30,000 psi (100,000 kPa to 200,000 kPa) and should be controlled by a mobile robot. The waterblasting equipment must be capable of removing deteriorated concrete at an acceptable production rate, be under continuous automatic control, and have filtering and pumping units operating with a remote-controlled robotic device. The noise level must be less than 90 decibels at a distance of 50 ft (15 m) from either the power pack unit or the remote robot.

a.



b.

Figure 7. a. Recommended orientation of milled patch,
b. Milled patch with rounded edges

The advantages of waterblasting include the following:

- It requires fewer workers than the other procedures.
- Once an experienced operator adjusts the *operating parameters*, only weak concrete is removed.
- The patch surfaces produced are vertical, rough, and irregular, and enhance bonding.
- No hauling is required.

The disadvantages of waterblasting include the following:

- The finished surfaces are saturated. Placement must be delayed until the area dries unless the repair material is not moisture-sensitive.
- The fine *slurry laitance* remaining after the procedure requires careful attention during cleaning.
- A shield must be built around the repair area to protect traffic if the patch is next to a lane carrying traffic.
- It can be difficult to control the depth of removal.
- Equipment rental is expensive.
- It can be difficult to obtain a good production rate; performance of waterblasting equipment has been variable, and waterblasting had to be abandoned in several recent projects.

Some manufacturers expect a concrete removal rate of 60 ft^2 (5.6 m^2) per hour from their waterblasting equipment. But problems with equipment or very tough aggregate (such as granite) can quickly drop the production rate to as low as 7 ft^2 to 15 ft^2 (0.7 m^2 to 1.4 m^2) per hour. The waterblasting equipment must function properly, and the operator must be very skilled to achieve high production rates.

3.6.5 Clean and Patch

Adverse patching conditions consist of an air temperature below 40°F (4°C) and a repair area that is saturated with surface moisture. Under these conditions, highway agencies often use the clean-and-patch procedure to perform emergency repairs. Deteriorated and loose concrete is removed with hand tools and swept away using stiff brooms. Occasionally, a light jackhammer may be used if the spalled area is large or if the cracked concrete is held tightly in place. The clean-and-patch procedure should be used only if a spall is hazardous to highway users and the climate is so adverse that no other procedure can be used.

3.7 Estimating Material, Equipment, and Labor

Estimates of the amount of materials needed will depend on the size and number of spalls, as well as the type of repair material selected. Many repair materials have a range within which they may be extended with aggregate (e.g., Type III PCC, Duracal, Set-45, Five Star HP, Pyrament 505). Other materials require that the aggregate be placed in the repair hole before the material itself is applied (e.g., Percol FL, Penatron R/M-3003). Volume yields of these two types of materials will depend on the size and amount of the aggregate used to extend the material. Extending a material with aggregate (up to the manufacturer's approved limit) will make the mix more thermally compatible with the existing pavement and reduce its overall cost. The total volume needed to fill all the patches should be estimated, and material manufacturers should be consulted to determine the necessary amount of materials.

Once a repair material has been chosen, the manufacturer's material specifications should be consulted for equipment requirements. Table 4 shows the equipment typically used

Table 4. Typical equipment used for the five patch preparation procedures

Equipment	Preparation Procedure[1]				
	S	C	M	W	A
Sounding equipment: rod, chain, or ball peen hammer	✓	✓	✓	✓	✓[2]
Double-bladed concrete saw for joint sawing	✓	✓	✓	✓	
Single-bladed concrete saw for sawing patch boundaries	✓				
15-lb (6.8-kg) jackhammer with air compressor	✓	✓	✓[3]		✓[4]
30-lb (13.6-kg) jackhammer with air compressor	✓[5]	✓[5]			
Stiff brooms for debris removal	✓	✓	✓	✓	✓
Hand tools (pick axe, etc.)	✓	✓			✓
Truck for hauling removed material	✓	✓	✓		✓
Waterblasting machine				✓	
Milling machine			✓		
Sandblasting equipment with directional nozzle, sand, air compressor	✓	✓	✓	✓	✓[2]
Airblasting equipment with oil and water filtering capability, air compressor	✓	✓	✓	✓	✓[2]

[1] S = saw and patch, C = chip and patch, M = mill and patch, W = waterblast and patch, and A = adverse-condition clean and patch.

[2] Sounding, sandblasting, and airblasting may not be practical under adverse conditions.

[3] To remove rounded edges.

[4] Jackhammering may be used for large areas, or when the deteriorated concrete cannot be removed using hand tools.

[5] 15-lb (6.8-kg) jackhammers are preferred. 30-lb (13.7-kg) hammers should **never** be used at patch boundaries.

for the five spall preparation procedures that are discussed in this manual. Table 5 shows the mixing and placement equipment and supplies typically used with some rapid-setting spall repair materials. Table 6 shows the personnel typically used with the five spall preparation procedures. Table 7 shows the personnel typically used for the mixing and placement of some rapid-setting partial-depth spall repair materials.

In certain cases (e.g., the pre-placement of the aggregate with Percol FL or Penatron R/M-3003, and the insertion of the joint bond breaker), one person can be used for two activities that do not occur at the same time. A supervisor may be needed to oversee the crews and their operations. Additional personnel may be needed for inspection and traffic control.

3.8 Overall Cost-Effectiveness

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

3.8.1 Cost-Effectiveness Worksheet

This section presents a worksheet that helps calculate the cost of a partial-depth spall repair operation. The worksheet asks the user to enter values and perform calculations in a step-by-step fashion. When worksheets have been completed for

Table 5. Typical mixing and placement equipment and supplies

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

[1] III = Type III PCC, Dur = Duracal, St45 = Set-45, 5HP = Five Star HP, M64 = MC-64, SP11 = SikaPronto 11, Pen = Penatron R/M-3003, Pyr = Pyrament 505, PFL = Percol FL, UPM = UPM High Performance Cold Mix, Spray = Spray-injection Mix. 1 in = 25.4 mm.

[2] Mixer should have twice the volume of the amount of material to be mixed.

[3] Capable of 400-600 rpm.

[4] May be used in hot (> 85°F [29°C]), windy (>25 mph [40 kph]) weather.

Table 6. Typical personnel used for spall repair procedures

Procedure	Typical personnel	Total
Joint sawing	1 person operating saw 1 person directing saw	2
Saw and patch	1 person operating saw 1 person directing saw 2 persons operating jackhammers 2 persons cleaning repair hole 1 person removing debris	7
Chip and patch	2 persons operating jackhammers 2 persons cleaning repair hole 1 person removing debris	5
Mill and patch	1 person operating milling machine 1 person directing milling machine 2 persons operating jackhammers 2 persons cleaning repair hole 1 person removing debris	7
Waterblast and patch	1 person operating waterblaster 1 person operating water truck 1 person cleaning repair hole	3
Clean and patch	1 person using hand tools (or jackhammer if necessary) 1 person cleaning repair hole	2
Inserting joint bond breaker	1 person installing bond breaker (otherwise available for other activities)	1

Table 7. Typical personnel used for mixing and placing

Material	Typical personnel	Total
Type III PCC	2 persons mixing and applying epoxy 1 person proportioning and mixing Type III mix 2 persons placing, compacting, and finishing	5
Duracal	1 person proportioning and mixing Duracal 2 persons placing, compacting and finishing	3
Five Star HP	1 person proportioning and mixing Five Star HP 2 persons placing, compacting, and finishing 1 person spraying curing water	4
Set-45	1 person proportioning and mixing Set-45 2 persons placing, compacting and finishing	3
Pyrament 505	1 person proportioning and mixing Pyrament 505 2 persons placing, compacting, and finishing	3
Sika Pronto 11	2 persons mixing and applying SikaPronto 19 1 person proportioning and mixing SikaPronto 11 2 persons placing, compacting, and finishing	5
MC-64	4 persons mixing MC-64 2 persons placing and finishing	6
Percol FL	1 person placing rock into prepared hole 1 person driving truck with pumps and tanks 1 person applying Percol FL 1 person applying broadcast aggregate	4
Penatron R/M-3003	1 person placing rock into prepared hole 2 persons mixing Penatron R/M-3003 3 persons placing and finishing	6
UPM High Perf. Cold Mix	2 persons shoveling and placing mix 1 person operating vibratory roller or plate	3
Spray-Injection Mix	1 person driving truck 1 person operating binder/aggregate sprayer	2

different combinations of materials and procedures, they can be compared to determine which combination is the most cost-effective.

The cost-effectiveness worksheet is shown in figure 8. Explanations for the variables included in the worksheet follow.

Project Size or Seasonal Partial-Depth Patching Needs

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

(B_1) **Average Finished Patch Length**–The expected average length of the finished patches, in inches. This value could be based either on data from the previous season or on a field survey where several patches throughout the project are sounded to determine the dimensions of deteriorated area. This value is helpful in estimating the amount of repair materials needed in the project (e.g., bonding agent, curing compound, joint bond breaker, etc.)

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[5] In weather below 45°F (7°C).
[6] As needed; sufficient for demand.
[7] Air-driven, automatic, ration-metering pump.
[8] Capable of delivering chip-size aggregate and asphalt emulsion (e.g., AMZ, Rosco).

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

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

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

Material 1 = _____________			
Material 1 Purchase Cost	______	\$/__	(D_1)
Expected Material 1 Needs	______	____	(E_1)
Material 1 Shipping Cost	______	\$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	______	\$	(G_1)
Material 2 = _____________			
Material 2 Purchase Cost	______	\$/__	(D_2)
Expected Material 2 Needs	______	____	(E_2)
Material 2 Shipping Cost	______	\$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	______	\$	(G_2)
Material 3 = _____________			
Material 3 Purchase Cost	______	\$/__	(D_3)
Expected Material 3 Needs	______	____	(E_3)
Material 3 Shipping Cost	______	\$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	______	\$	(G_3)
Material 4 = _____________			
Material 4 Purchase Cost	______	\$/__	(D_4)
Expected Material 4 Needs	______	____	(E_4)
Material 4 Shipping Cost	______	\$	(F_4)
Total Material 4 Cost $[(D_4 \times E_4) + F_4]$	______	\$	(G_4)

Figure 8. Cost-effectiveness worksheet

LABOR COSTS

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

EQUIPMENT COSTS

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

Figure 8. Cost-effectiveness worksheet (continued)

SUMMARY COSTS

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

[1] Until patch survival rates have been determined, agency experience should be applied. See Appendix B for calculation examples.

Figure 8. Cost-effectiveness worksheet (continued)

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

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

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

Material Cost Variables

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

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

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

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

Labor and Equipment Costs Worksheet Variables

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

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

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

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

(L) **Supervisor Daily Wage**–The wage paid to the supervisor who oversees the repair operation, in dollars per day.

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

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

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

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

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

(R) **Consolidation/Compaction Equipment**–The cost associated with the equipment used to *consolidate* or *compact* the patches, in dollars per day.

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

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

Summary Costs

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

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

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

(X) **User Costs**–The costs to the highway user per day due to the delay associated with the repair operation, in dollars per day. This value is fairly difficult to calculate; the agency may rely on its experience.

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

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

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

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

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

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

3.8.2 Determining Cost-Effectiveness Inputs

The cost-effectiveness analysis requires an evaluation of the maintenance crew, their past efficiency, their current salary levels, and the availability of equipment. The costs of materials, shipping, and rental equipment may be obtained from manufacturers and dealers such as those listed in Appendix E. It is difficult to obtain accurate user costs and partial-depth patch survival rate for a given material and procedure. Pavement condition, material quality, climatic conditions, and crew ability all factor into these values. Guidelines for calculating patch survival rates are given in Chapter 5; examples of patch survival rate calculation are included in Appendix B.

4.0 Construction

The most frequent construction-related causes of partial-depth patch failure include the following:

- Failure to square the hole
- Failure to remove all deteriorated material
- Inadequate cleaning
- Lack of bond
- Failure to re-establish the joint (compression failure)
- Variability of the repair material
- Insufficient consolidation

This chapter provides guidelines for each step in the construction process to help eliminate these causes of failure. The topics covered include: traffic control, safety precautions, materials testing, joint preparation, patch preparation, mixing the repair materials, placing the repair materials, consolidating and compacting, screeding and finishing, curing, joint sealing, cleaning up, opening to traffic, and inspection of the construction process.

4.1 Traffic Control

Whenever any partial-depth patching operation is performed, it is very important to provide adequate traffic control. This ensures a safe working environment for the maintenance crew and safe travel for vehicles in the construction area. Traffic control operations should cause the least possible amount of disturbance in the flow of traffic. While the actual traffic control requirements for each construction site will vary, every maintenance agency has the responsibility of ensuring that all necessary steps are taken to maintain safety.

4.2 Safety Precautions

Many rapid-setting materials require special safety precautions, both to protect the maintenance workers using them and to protect the environment. **It is extremely important that highway agencies follow all instructions regarding worker protection and repair material disposal. These instructions are available from the manufacturer in the form of material safety data sheets.**

In addition, the agency should follow safety instructions for worker protection and material disposal for any other **accessory** material or substance used (e.g., solvents, bonding agents, joint bond breakers, admixtures, curing compounds, etc.), as well as for all equipment that is used in the partial-depth spall repair process.

Some common-sense safety precautions for using materials and equipment in the partial-depth spall repair process are included in Appendix C.

4.3 Material Testing

Material testing during the construction phase of a partial-depth spall repair project involves daily quality control. A program of testing samples of the repair mix for slump, air, compressive strength, or flexural strength should be conducted, as appropriate, for each type of cementitious repair material. Testing of bituminous and flexible polymer repair materials must be done before their use in the field. Appendix A outlines suggested pre-construction material testing specifications.

4.4 Initial Joint Preparation

The most frequent cause of failure of partial-depth spall repairs is high compressive stress. Nonflexible partial-depth patches placed directly against transverse joints and cracks will be crushed by the compressive forces created when there is not enough room for thermal expansion of the slabs. Patches may also fail if, during placement, the repair material is allowed to flow into the joint or crack opening below the bottom of the patch. When cured, the material will prevent the crack or joint from working and will keep the slabs from moving. These failures must be prevented by using proper joint preparation methods.

4.4.1 Removing Old Sealant

If a nonflexible patching material is used, the old sealant in the adjacent joint and 3 in to 4 in (76 mm to 102 mm) beyond the patch must be removed for placement of a joint bond breaker. If a flexible polymer material is used, the old sealant should still be removed, and the area adjacent to the patch should be cleaned thoroughly. Bituminous materials do not need any special cleaning.

Most spall repair materials are nonflexible. However, some materials (e.g., some polymers, cold mixes, spray-injection mixes) are flexible and do not need a joint sealant or a joint bond breaker. The material manufacturer should be consulted to determine if joint sealant or bond breakers are necessary.

4.4.2 Joint Sawing

When a joint bond breaker is needed, the existing transverse and longitudinal joints next to the repair should be resawn using a double-bladed concrete saw. The depth of the cut should be at least 1 in (25 mm) deeper than the depth of the repair. The saw cut should extend 2 in to 3 in (51 in to 76 mm) beyond the repair area in each direction. This sawing is usually done before removing the deteriorated concrete, and must be done before cleaning the repair area. Figure 9 shows the proper dimensions of the saw cut. Water-wash equipment should be used to remove all sawing slurry from the repair area before it dries.

Joint sawing may not be needed if flexible materials, such as Percol FL and Penatron R/M-3003, are used. Joint sawing is not used either in the clean-and-patch procedure because of adverse conditions or when UPM High Performance Cold Mix and spray-injection mix (e.g., AMZ, Rosco) are used.

Repairs can be constructed without transverse joint bond breakers by sawing the transverse joint to full depth as soon as the patch has gained sufficient strength. However, if the joint closes before sawing, the patch will fracture. This operation is not recommended because timing is critical.

4.4.3 Sawing Out Joint Inserts

Spalls caused by metal or plastic joint inserts usually start at the bottom fin of the insert, about 2.5 in (64 mm) below the surface. When repairing this type of spall, the joint insert should be sawed out along the entire length of the joint to prevent further deterioration. The joint can then be repaired and resealed. This is normally done using a double-bladed concrete saw, before removing the deteriorated concrete.

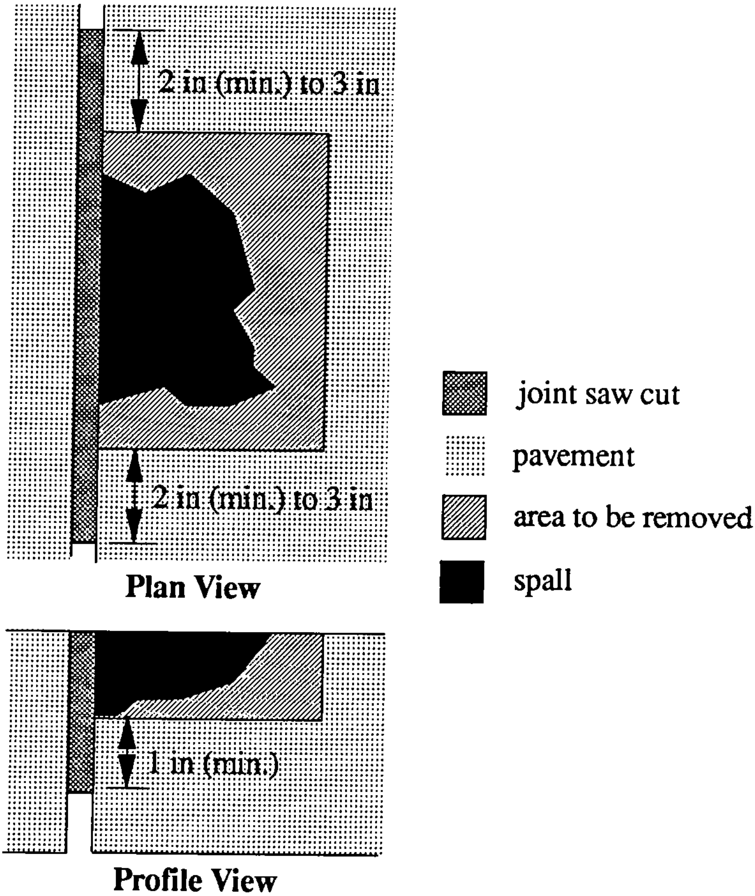


Figure 9. Dimensions of joint saw cut

4.5 Removing the Deteriorated Concrete

Partial-depth removal of the deteriorated concrete may be done using several methods. The most frequently used method, the saw-and-patch procedure, uses a wheel saw to cut the patch boundaries, and jackhammers to remove the concrete inside the boundaries. Small hand-held saws are occasionally used, but wheel saws are more common. Other methods include chiseling without sawing the patch boundaries, cold milling, waterblasting, and using hand tools (under adverse conditions).

4.5.1 Saw and Patch

In the saw-and-patch procedure, a single-bladed concrete saw is used to cut the boundaries of the patch and to make removing the deteriorated concrete easier, as shown in figure 10. The saw cut should be 1 in to 2 in (25 mm to 51 mm) deep and usually extends 2 in to 3 in (51 mm to 76 mm) beyond the patch boundaries, to obtain that depth for the entire length and width of the patch. The cut boundary should have straight, vertical faces and square corners. Vertical boundaries reduce the spalling associated with thin or feathered concrete along the repair perimeter. The recommended dimensions of the repair boundaries are shown in figures 3 through 6. For large areas of repair, the area to be removed may be sawed in a shallow criss-cross or waffle pattern to facilitate concrete removal, as shown in figure 11. Water-wash equipment should be used to remove sawing slurry from the repair area before it dries.

After sawing, jack hammers are used to remove the unsound concrete. Initially hammers weighing less than 15 lb (6.8 kg) are used, but hammers weighing up to a maximum of 30 lb (13.6 kg) may be allowed. Removal should begin near the center of the spall and proceed toward (but not to) the patch boundary. Care must be taken not to fracture the sound concrete below the repair or to overcut the repair boundaries.

Removal near the repair boundaries must be completed with 10-lb to 15-lb (4.6-kg to 6.8-kg) hammers fitted with *spade*

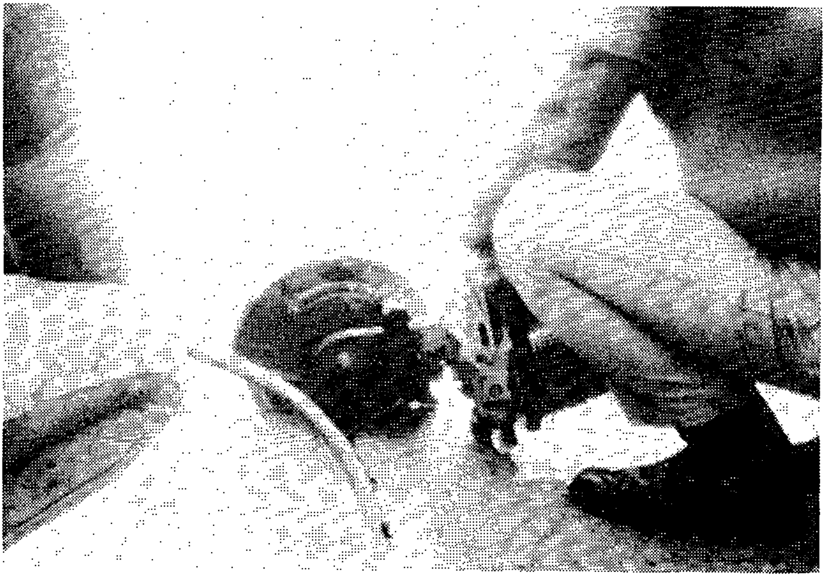


Figure 10. Sawing patch boundaries with a small hand-held saw

bits, as *gouge bits* can damage sound concrete. Spade bits are shown in figure 12. Jackhammers and mechanical chipping tools should be operated at an angle less than 45 degrees from the vertical as shown in figure 13.

Finally, the repair area must be tested again for soundness after removing the deteriorated concrete as shown in figure 14. Any additional unsound concrete must be removed by continued chipping. A full-depth repair must be used if the deterioration is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are reached.

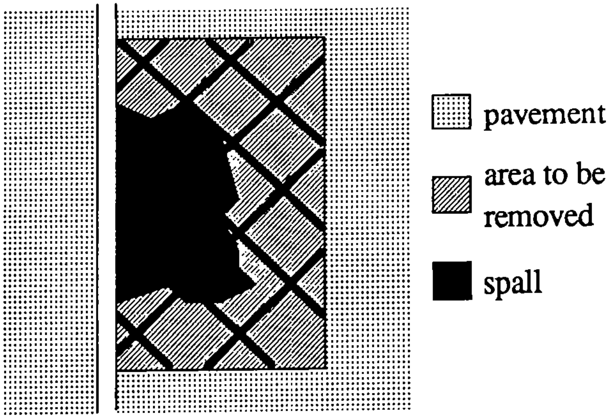


Figure 11. Sawing pattern for large repair areas

4.5.2 Chip and Patch

The chip-and-patch procedure is the same as the saw-and-patch procedure, except that the patch boundaries are not sawed. Cutting boundaries with jackhammers may result in *scalloped* boundaries. Therefore, a 1-in vertical edge must be specified when using a repair material that does not perform well when feathered. A scalloped edge and a 1-in (25-mm) vertical edge are shown in figure 15.

Finally, the repair area must be tested again for soundness, as shown in figure 14. Any additional unsound concrete must be removed by continued chipping. A full-depth repair must be used if the deterioration is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are reached.

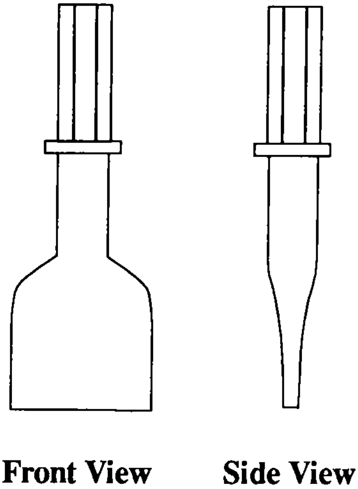


Figure 12. Spade bits

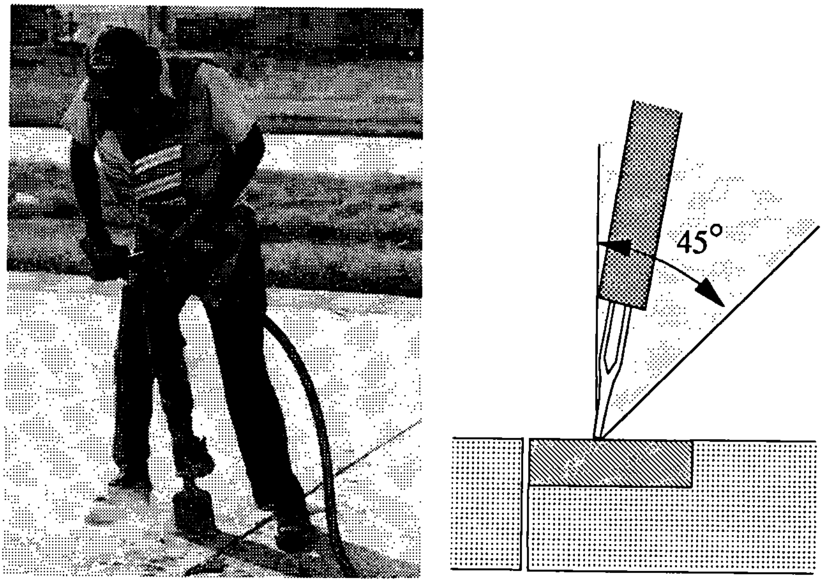


Figure 13. Using a jackhammer

Figure 14. Sounding repair area with a steel rod

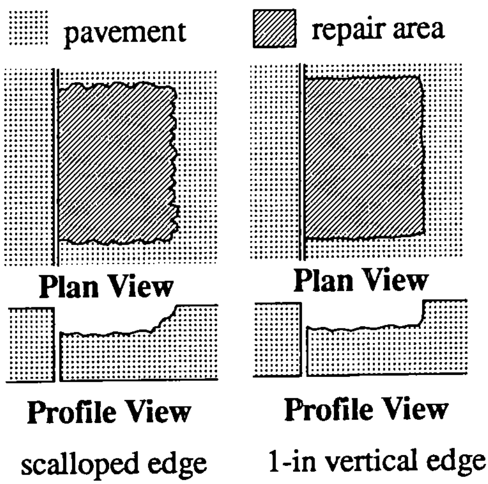


Figure 15. Scalloped edge and 1-in vertical edge

4.5.3 Mill and Patch

In the mill-and-patch procedure, all unsound concrete within the marked area is removed to a minimum depth of 2 in (51 mm) using a carbide-tipped milling machine. The small amount of material that remains at the patch corners must be removed by light jackhammering or sawing. Whenever possible, the milling machine should be oriented such that the rounded edges of the hole it produces are parallel to the direction of traffic. The proper orientation of the rounded edges of the milled patch is shown in figure 7. If this orientation is not possible, the rounded edges should be made vertical using a light jackhammer.

Finally, the repair area must be tested again for soundness, as shown in figure 14. Any additional unsound concrete must be removed by continued milling. A full-depth repair must be used if the deterioration is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are reached.

4.5.4 Waterblast and Patch

The first step in the waterblast-and-patch procedure is to build a shield around the repair area if there is any traffic passing in the next lane, as shown in figure 16. Two trial areas, one of sound concrete and one of deteriorated concrete, are then used to determine the appropriate waterblasting operating parameters. These parameters include speed, pressure, and the number of overlapping passes. Using trial and error in the test areas, the waterblaster must be programmed to remove all unsound concrete without removing sound concrete unnecessarily.

Once properly calibrated, the operating parameters should not be changed while waterblasting the rest of the spalls, unless

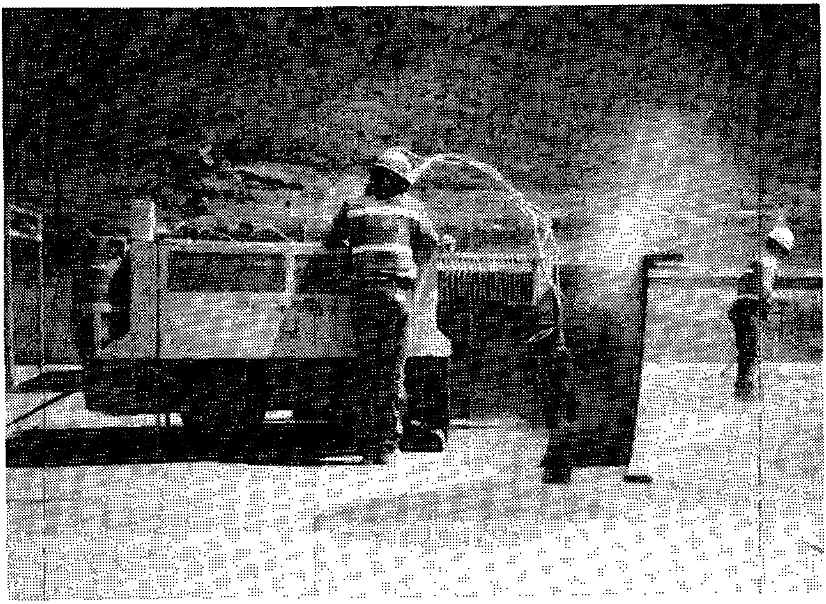


Figure 16. Protective shield around waterblasting operation

the concrete changes (for example, a harder aggregate has been used in one section of the highway). If the concrete does change, the waterblasting machine must be recalibrated using two new trial areas in the section of the highway with the different concrete.

All unsound concrete within a marked spalled area should be removed to a minimum depth of 2 in (51 mm) with neat vertical faces. Then the repair area must be tested again for soundness, as shown in figure 14. Any additional unsound concrete must be removed by continued waterblasting. A full-depth repair must be used if the deterioration is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are reached.

The debris and slurry that result from the waterblasting operation must be removed using a low-pressure water stream before the slurry dries and hardens on the surface of the hole. If this is not done, the repair area may have to be refaced. Once dried, sandblasting may or may not be able to remove the dried slurry residue. Some moisture-sensitive materials may require the repair area be completely dry before placing the material.

4.5.5 Clean and Patch

Under adverse conditions, handpicks and shovels should be used to remove loose material. A light jackhammer may sometimes be used for larger areas.

4.6 Cleaning the Repair Area

After all unsound concrete has been removed, the surface of the repair area must be cleaned. Sandblasting, airblasting, and sweeping normally provide a clean, rough surface for the development of a good bond between the patch and the pavement. High-pressure water may also be used to remove dirt, dust, and other contaminants, but sandblasting usually produces better results.

4.6.1 Sandblasting

Sandblasting, shown in figure 17, is highly recommended for cleaning the surface. It removes dirt, oil, thin layers of unsound concrete, and laitance. Sandblasting equipment consists of a compressed air unit, a sand dispenser, hoses, and a wand with a venturi-type nozzle. The compressed air must be free of oil and water, since a contaminated surface will prevent bonding. The air quality can be checked by placing a cloth over the air compressor nozzle and visually

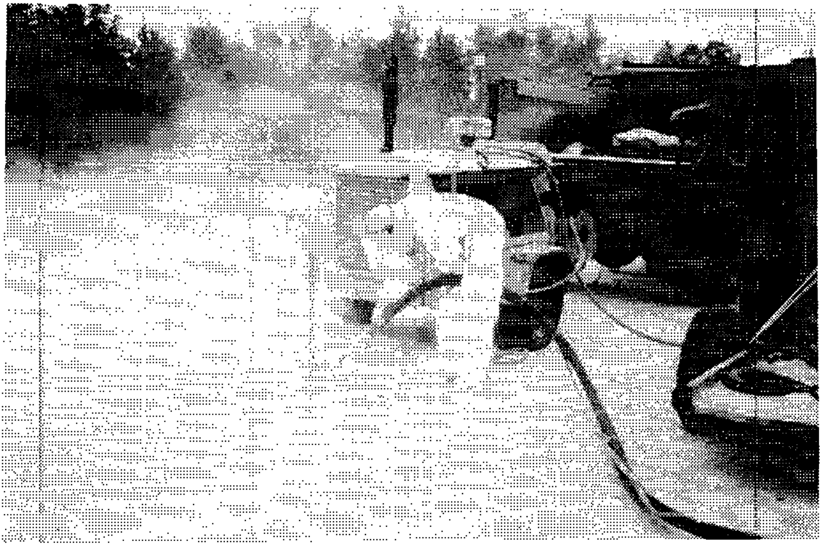


Figure 17. Sandblasting

inspecting for oil. Sandblasting is generally not used under adverse conditions.

4.6.2 Airblasting

After sandblasting, high-pressure airblasting should be used to remove any remaining dust, debris, and loosened concrete fragments. Debris must be blown out and away from the patch so that wind or passing traffic cannot carry it back into the patch. The cleanliness of the repair area must be checked using a black glove or cloth. If the glove or cloth picks up material (dust, asphalt, slurry) when rubbed across the prepared surface, the surface should be cleaned again or poor bonding will result. If there is a delay between cleaning and patch placement, the surface may have to be cleaned again. Airblasting is generally not used with the clean-and-patch procedure under adverse conditions.

Either trailer-mounted air compressors or portable back-pack blowers may be used. Back-pack blowers need only one laborer and are very mobile. However, trailer-mounted air compressors are recommended because they provide a higher pressure (greater than 100 psi [670 kPa]). The compressed air unit should have oil and moisture filters; otherwise, it may blow oil or moisture into the repair area and prevent the patch from bonding. When patching with a spray-injection machine (e.g., AMZ, Rosco), the hole may be cleaned with its blower.

4.6.3 Sweeping

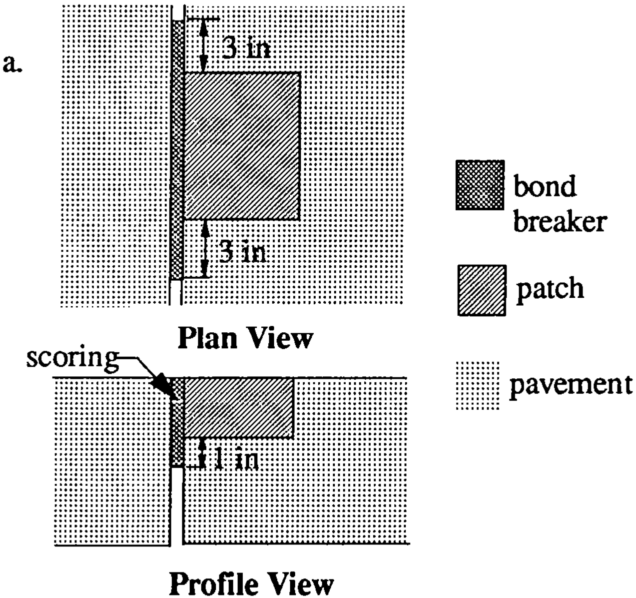
Sweeping is most commonly used to clean the repair area when patching under adverse conditions. Under better conditions, sandblasting and airblasting should be used.

4.7 Final Joint Preparation

If a nonflexible repair material is used, a compressible joint bond breaker must be installed as the last step of joint preparation. The type of joint (i.e., transverse, centerline, or lane-shoulder) will determine the type of bond breaker to use. Some flexible materials may not need a bond breaker.

Polystyrene or polyethylene joint bond breakers are placed flush with the pavement surface, between the new (nonflexible) concrete and the adjacent slab to reduce the risk of compression-related failure. They also protect the patch from damage caused by deflection under traffic.

The bond breaker should have a scored top strip as shown in figure 2. It should extend 1 in (25 mm) below and 3 in (76 mm) beyond the repair boundaries, as shown in figures 18 a.



b.

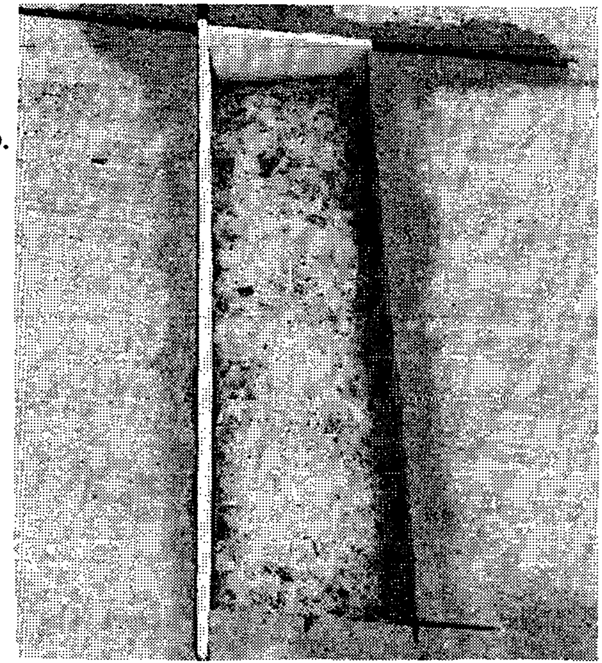


**Figure 18. a. Correct dimensions of joint bond breaker placement at one joint.
b. Incorrectly installed bond breaker at two joints. 1 in = 25.4 mm.**

and 19. The extension will prevent the repair material from flowing into the joint during placement. The bond breaker should be slightly wider than the joint so that it is slightly compressed when installed. The scored top strip must later be torn off and the resulting joint reservoir filled with an appropriate joint sealant.

Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for more information on selecting appropriate dimensions for the joint reservoir and joint bond breaker, and for appropriate joint sealing materials and methods.[15]

4.7.1 Preparing Transverse Joints

A straight joint line should be maintained during bond breaker placement at transverse joints. This may be difficult with back-to-back patches. Bond breakers of different heights may be installed in patches of different depths. Alternatively, the bond breaker may be stacked to the needed depth, which may be difficult. *Latex caulking* may be used to seal any gaps between layers of bond breaker or between the bond breaker and the joint opening, as illustrated in figure 19. This will prevent the repair material from flowing into the joint or a crack opening below the bottom of the patch.

4.7.2 Preparing Centerline Joints

Partial-depth patches placed at the centerline joint often spall because of curling stresses. To prevent this, a polyethylene strip (or other thin bond-breaker material) must be placed along the centerline joint to prevent the patch from contacting the adjacent lane, as described in section 4.7.1.

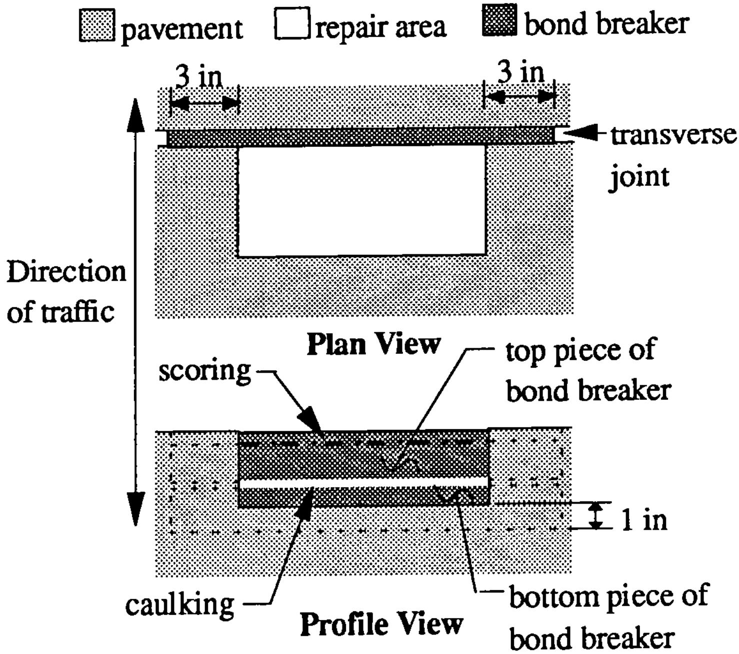


Figure 19. Joint bond breaker that has been stacked and caulked

4.7.3 Preparing Lane-Shoulder Joints

The joint must be formed using a piece of fiberboard if the repair is at the lane-shoulder joint. Fiberboard is stiffer than a polyethylene or polystyrene joint bond breaker, and it provides the support needed at the lane-shoulder joint when placing the repair material. Like more flexible bond breakers, fiberboard will prevent the repair material from flowing into the shoulder during material placement. If the repair material flows into the lane-shoulder joint, it will restrict longitudinal movement of the slab and damage the repair. Fiberboard must be placed to the same dimensions as the more flexible bond breaker, as shown in figure 18.

4.7.4 Using Flexible Repair Materials

Some proprietary flexible repair materials, such as MC-64, Percol FL, and Penetron R/M-3003, and some bituminous materials, such as UPM High Performance Cold Mix and spray-injection mix (e.g. AMZ, Rosco), may have enough compressibility to allow joints to move without needing a joint bond breaker. The manufacturer should be consulted for the appropriate joint treatment when using a flexible spall repair material.

4.8 Pre-Placement Inspection of the Repair Area

After cleaning, the repair area should be inspected to determine if there is any more unsound concrete. If there is, it should be removed, and the repair area should be cleaned again. Sandblasting should never be used to remove unsound material.

If the repair area is sound, it should then be inspected for clean, dry, freshly exposed concrete. Any dust remaining on the pavement surface around the repair area should be removed by sweeping, especially on windy days or when traffic passes alongside the repair. If there is a delay between cleaning and placing the material, the repair area must be inspected again at the time of placement, and must be cleaned again by airblowing if dirt has blown into it.

4.9 Mixing the Bonding Agent

Some partial-depth patching materials require epoxy or proprietary bonding agents. Epoxy bonding agents should be mixed carefully according to the manufacturer's instructions.

An electric drill with a Jiffy mixer may be used to mix the two epoxy components for the required time.

Some spall repair materials, such as SikaPronto 11, specify a proprietary bonding agent. The manufacturer's mixing instructions should be followed exactly to ensure good patch performance.

4.10 Mixing the Repair Material

The volume of material required for a partial-depth repair is usually small (0.5 ft^3 to 2.0 ft^3 [0.014 m^3 to 0.057 m^3]). Ready-mix trucks and other large equipment cannot efficiently produce small quantities. Small drum or paddle-type mixers with capacities of 6 ft^3 to 8 ft^3 (0.17 m^3 to 0.23 m^3) and Jiffy mixers are often used. Based on trial batches, repair materials may be weighed and bagged in advance to make the batching process easier. Prebagged cement may also be used; aggregate may be weighed using a precalibrated volume method (i.e., a bucket can be marked by volume for the appropriate weight). Continuous-feed mixers are also widely used.

Mixing times and water content must be carefully observed for prepackaged rapid-setting materials. Mixing for a longer time than needed for good blending reduces the already short time available for placing and finishing rapid-setting materials. Additional water may significantly reduce the strength of the patch.

4.10.1 Cementitious Concretes

Rapid-setting cementitious materials used in partial-depth spall repair, such as Type III PCC, gypsum-based concrete (e.g., Duracal), magnesium phosphate concrete (e.g., Set-45), and high alumina concrete (e.g., Five Star HP), generally are mixed with small drum or mortar mixers, as shown in figure 20.

The proportions of water, aggregate, and cement depend on the type of material selected. A rapid-setting Type III PCC mix generally includes an air-entraining agent, an accelerating agent, and a superplasticizer. In addition to the cement itself, rapid-setting cementitious materials need clean water and a manufacturer-specified gradation of aggregate. Some proprietary materials (e.g., Duracal) also need sand. Most cementitious materials require that the water be added to the running mixer, followed by the aggregate, and then the cement. Warm water may be needed at air temperatures below 55°F (13°C), while icewater may be needed at higher temperatures. The manufacturer's recommendations for proportions, mixing sequence, and mixing times for each component should be followed exactly.

4.10.2 Polymer Concretes

Polymer concretes, such as epoxies (e.g., MC-64), methyl methacrylates (e.g., SikaPronto 11), and polyurethanes (e.g., Percol FL, Penatron R/M-3003), are generally mixed with a Jiffy mixer or a mortar mixer, as specified by the material manufacturer.

The materials usually consist of two or more premeasured liquid components, or a liquid component and cementitious components. The different components are generally mixed separately and then in combination. Mortar mixers are used for mixing large batches of liquid components and for mixing cementitious components with aggregate. Jiffy mixers are used for mixing small batches of liquid components, as shown in figure 21. Liquid mixtures are either mixed with or

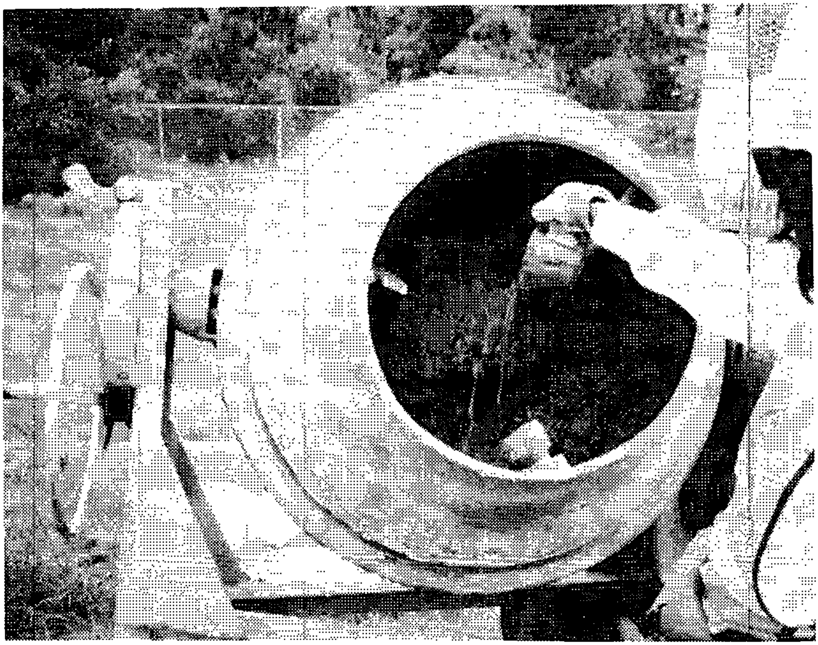


Figure 20. Adding carefully measured components to a drum mixer

poured over a specified gradation of oven-dried aggregate. The manufacturer's recommendations for mixing sequence, component amounts, and mixing times should be followed exactly.

4.10.3 Bituminous Materials

Bituminous cold mixes (e.g., UPM High Performance Cold Mix) are generally mixed at a local plant using the manufacturer's mix design. They may also come premixed in drums, buckets, or bags. When patching spalls with a spray-injection machine (e.g., AMZ, Rosco), the machine mixes asphalt emulsion heated to approximately 135°F (57°C)

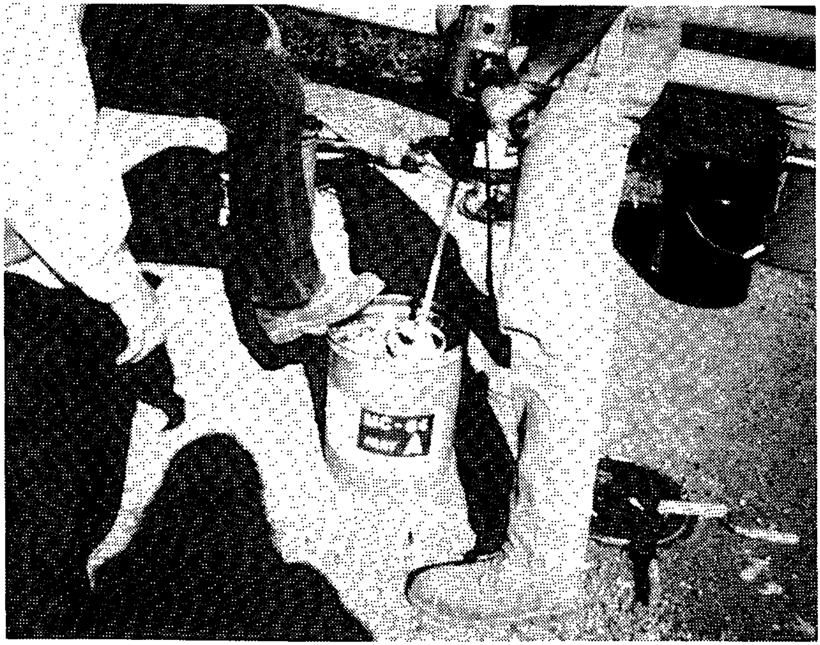


Figure 21. Using a Jiffy mixer

and aggregate. An experienced operator should carefully control the volume of each component. The asphalt and aggregate are sprayed out under pressure. Care should be taken not to overfill or to spill material outside of the repair area.

4.11 Applying the Bonding Agent

A bonding agent should be applied after cleaning the repair area and just before placing PCC repair materials. The manufacturer's directions must be closely followed when using epoxies or other manufactured grouts. The bottom and sides of the repair area must be thoroughly coated by brushing the grout or epoxy onto the concrete as shown in figure 22. Spraying may be appropriate for large repair

Figure 22. Applying bonding agent

areas. Excess bonding agent should not be allowed to collect in pockets. The placement of the bonding agent should be timed so that it is tacky when the repair material is placed.

4.12 Placing the Repair Material

For materials that will be consolidated or compacted, the placement procedure begins by slightly overfilling the repair hole to allow for the reduction in volume. Materials that contain aggregate **must** be placed with a shovel. *Segregation* will occur if these materials are dumped from a bucket or wheelbarrow.

4.12.1 Cementitious Concretes

PCC and most of the rapid-setting proprietary patching materials should not be placed when the air or pavement temperature is below 40°F (4°C). Insulating covers and longer cure times may be needed at temperatures below 55°F (13°C). The repair area must be sprayed with water to enhance bonding before placing many cementitious materials (e.g., Duracal, Five Star HP, Pyrament 505). Vibration may be needed during placement to improve workability.

4.12.2 Polymer Concretes

Some polymer concretes may be installed under adverse conditions of low temperatures and wet *substrates* with reasonable success.[10] However, these materials perform better when installed under more favorable conditions.

Due to their high heat of hydration, some polymer concretes, such as epoxies (e.g., MC-64), and methyl methacrylates (e.g., SikaPronto 11), are placed in lifts no more than 1.5 to 2 in (38 to 51 mm) deep. The time between lifts should be that recommended by the manufacturer. These materials have also been placed in one lift during partial-depth spall repair with no adverse effects.

When placing polyurethane concretes, such as Percol FL and Penatron R/M-3003, the repair area is first filled to grade with washed, oven-dried, and crushed stone of the type and gradation specified by the manufacturer. The polymer is then poured (as in the case of Penatron R/M-3003) or pumped (as in the case of Percol FL) directly over and through the preplaced aggregate until all the aggregate is encased in the concrete and the material is flush with the pavement surface, as shown in figure 23. If specified by the manufacturer,

Figure 23. Pumping polymer into a patch that was prefilled with aggregate

aggregate may then be broadcast over the top of the repair as a friction layer.

4.12.3 Bituminous Materials

Some bituminous mixes may be installed under adverse conditions of low temperatures and wet substrates with reasonable success.[10] However, these materials perform better when installed under more favorable conditions.

Bituminous cold mixes, such as UPM High Performance Cold Mix, must be placed by shovel. When patching using a spray-injection machine (e.g., AMZ, Rosco), a coating of emulsified asphalt should be sprayed into the hole and onto the edges of the pavement around the repair. A mixture of emulsified asphalt and aggregate should then be sprayed directly into the hole. The repair should be filled slightly above level with the pavement surface, and a coating of chip stone should be sprayed onto the patch to prevent tracking.

4.13 Consolidating and Compacting

Cementitious repair materials must be consolidated by vibration during placement to release trapped air from the fresh mix. Failure to do so may result in poor durability, spalling, and rapid deterioration. Voids between the repair material and pavement can cause total debonding and loss of repair material. Percol FL, MC-64, Penatron R/M-3003, bituminous cold mixes (e.g., UPM High Performance Cold Mix, and spray-injection [e.g., AMZ, Rosco]) do not need vibration.

Three common methods of consolidation are:

- Using internal vibrators with small heads (less than 1 in [25 mm] in diameter)
- Using *vibrating screeds*
- Rodding or tamping and cutting with a trowel or other hand tools

The internal vibrator, shown in figure 24, and the vibrating screed give the best results. However, partial-depth patches are usually too small to use a vibrating screed. Internal pencil vibrators are recommended. Very small repairs may be consolidated using hand tools. Cutting with a trowel seems to give better results than rodding or tamping. The tools used should be small enough to work easily in the repair area.

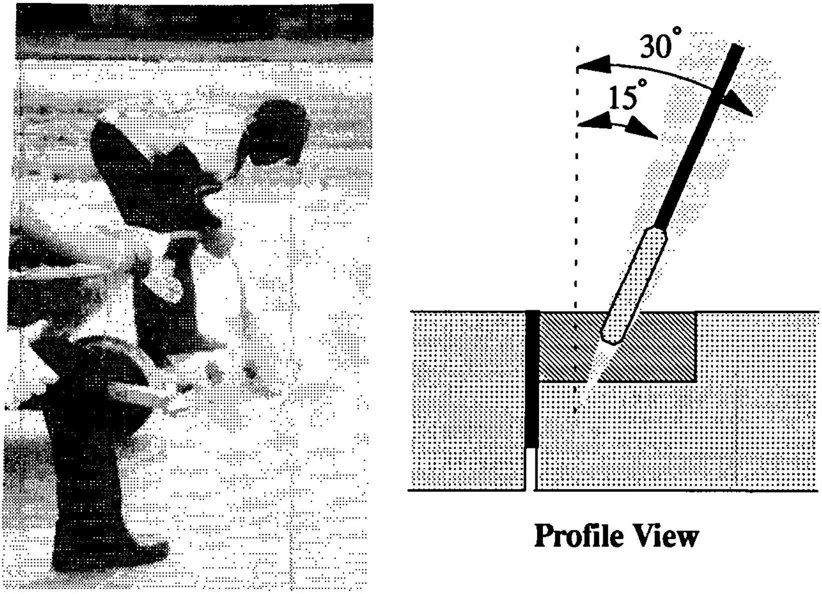


Figure 24. Using an internal vibrator

The vibrator should be held at 15 degrees to 30 degrees from the vertical, as shown in figure 24, and should be moved through the patch until the entire repair has been vibrated. It should be lifted up and down, but not moved horizontally in the patch. The vibrator should not be used to relocate material within the repair as this may cause segregation. The mix is adequately consolidated when it stops settling, air bubbles no longer emerge, and a smooth layer of mortar appears at the surface.

Bituminous patching materials, such as UPM High Performance Cold Mix, are generally compacted using a vibratory roller or plate until level with the pavement. The patches should be compacted with three to eight passes. The roller or plate must not bridge the patch.

4.14 Screeding and Finishing

The surface of the patch should be troweled flush with the pavement surface. Vibration may be needed to make the work finishable if the mix is too stiff. Partial-depth repairs are usually small enough that a stiff board resting on the adjacent pavement can be used as a screed. The material should be worked toward the edges of the patch to establish contact and enhance bonding to the pavement, as shown in figure 25. At least two passes should be made to ensure a smooth surface.

The repair surface must be hand-troweled to remove any remaining minor irregularities, as shown in figure 26. The edge of a repair located next to a transverse joint should be tooled to provide a good reservoir for joint sealing. Extra mortar from troweling can be used to fill any saw overcuts at the patch corners. Extra epoxy may also be used, or the saw overcuts may be filled with joint sealant during the joint sealing process.

Partial-depth repairs typically cover only a small portion of the pavement surface and have little effect on *skid resistance.* However, the finished surface of the repair should match that of the pavement as closely as possible.

4.15 Curing

Curing is as important for partial-depth repairs as it is for full-depth repairs. Since partial-depth repairs often have large surface areas in relation to their volumes, moisture can be lost quickly. Improper curing can result in shrinkage cracks that may cause the repair to fail prematurely.

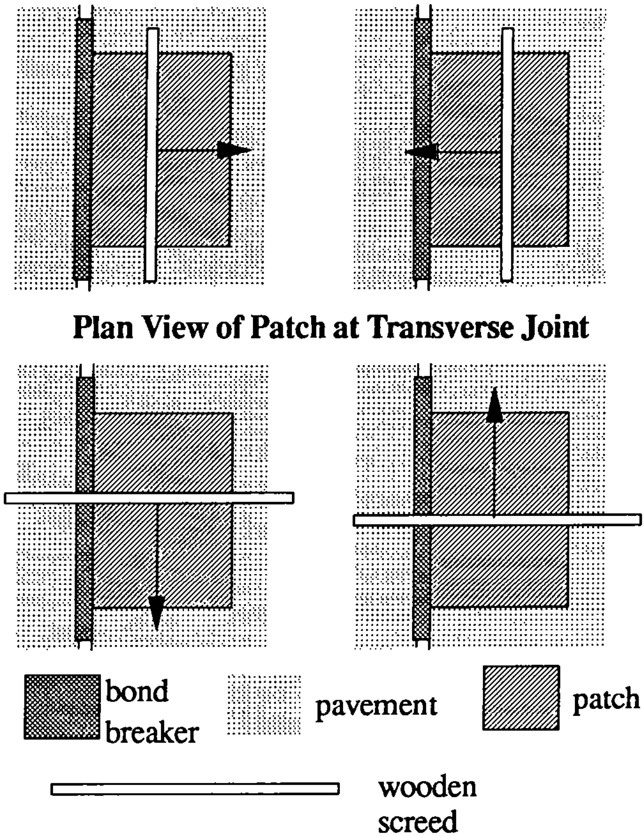


Figure 25. Screeding the patch

4.15.1 PCC Patching Materials

The most effective curing method when patching with PCC materials in hot weather is to apply a white-pigmented curing compound as soon as water has evaporated from the repair surface. The compound will reflect radiant heat while allowing the heat of hydration to escape and will provide protection for several days. Moist burlap and polyethylene sheeting can also be used, but must be removed when the roadway is opened to traffic. In cold weather, insulating

Figure 26. Finishing the patch

blankets or tarps can be used to provide more rapid curing and to allow an earlier opening to traffic. The required curing time should be stated in the project plans and specifications.

4.15.2 Proprietary Patching Materials

Some proprietary materials may require some form of moist curing after the mix has stiffened (e.g., Five Star HP). Others require the application of a curing compound (e.g., Pyrament 505). Some proprietary repair materials may be air-cured (e.g., SikaPronto 11). Epoxy and proprietary repair materials should be cured as recommended by their manufacturers.

4.16 Joint Sealing

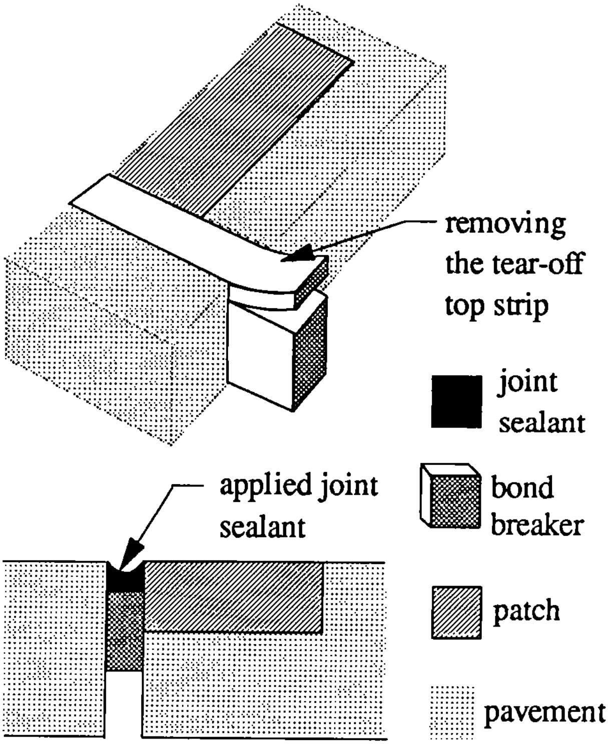
The final step in partial-depth spall repair is restoring the joints. When the recommended scored bond breaker has been used, the tear-off top strip should be removed, as shown in figure 27, and the selected sealant applied (see section 3.4.4). If a scored bond breaker has not been used, joint restoration is accomplished by resawing the joint to a new *shape factor*, sandblasting and airblasting both faces of the joint, inserting a closed-cell backer rod, and applying the sealer. A minimum 1-week cure time should be allowed before joint sealing. Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for more information on proper joint sealing practices.[15]

4.17 Cleanup Requirements

The material manufacturer's instructions should be consulted for information on cleaning equipment that has been used to mix, place, and finish their material. The cleaning solvent for most cementitious materials is simply potable water. Some proprietary materials may require a special solvent; table 5 shows which of several rapid-setting repair materials require a special cleaning solvent. Equipment must be cleaned immediately after use so it will not contaminate the next material it contacts.

4.18 Opening to Traffic

Compressive strength requirements for paving concrete are generally specified at 3,000 psi (20,700 kPa) at 28 days. The repair concrete should develop an equal or greater strength by the time it receives traffic loadings. However, to minimize



Profile View

Figure 27. Removing the tear-off top strip of a joint bond breaker

lane closures, traffic loadings may be allowed on a patched area when the repair concrete has attained the minimum strength needed to assure its structural integrity. The compressive strength required for the opening of partial-depth patches to traffic may be lowered because of their *lateral confinement* and shallow depth.

The specifications of rapid-setting proprietary mixes should be checked for recommended opening times. Cylinders or beams can be tested for strength to determine what opening time will allow the repair material to develop enough strength. The time to opening to traffic at 70°F (21°C) for several rapid-setting partial-depth spall repair materials is shown in table 1.

4.19 Inspection

Quality control and inspection of the entire construction process is crucial to the success of the repair. Field experience has shown that each step in the partial-depth spall repair process requires careful supervision and inspection. An inspector must continually observe the various operations to ensure that proper procedures are being followed. Appendix D contains detailed checklists for each step of the inspection process.

5.0 Evaluating Partial-Depth Patch Performance

It is good practice to monitor the performance of partial-depth patches. By doing so, patch performance factors can be determined and used in comparing cost-effectiveness of different material-procedure patch treatments. One method for calculating a performance factor is described in this chapter.

5.1 Data Required

To determine the effectiveness of a given patch type (material-procedure combination), a field survey must be conducted periodically. The highway agency must count the number of patches from the initial patching operation that have failed, as well as the number of patches lost to rehabilitation (e.g., overlay or slab replacement) since the time of installation. The time of the field survey must also be recorded. Table 8 shows a typical collection of patch performance data.

Figure 28 shows several plots of patch survival over time. In all three cases, the percent of patches remaining after 10 years is 80 percent. However, patch type B would have the highest patch survival rate when compared with patch types A and C, because it performed better longer than the other two patch types (and therefore has a larger area under its survival curve).

Table 8. Sample patch performance data

Time of survey (years) (T_t)	Patches in-place (R_{ip})	Cumm. patches failed (R_f)[1]	Cumm. patches lost to rehab. (R_l)[2]	Percent patches surviving (P_s)[3]
0	200	0	0	100
1	194	6	0	97
2	186	12	2	94
3	180	16	4	92
4	175	20	5	90
6	153	38	9	80

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

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

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

5.2 Calculations

The patch survival rate is the area under the patch survival curve. The worksheet presented in table 9 can be used to calculate the area for any available patch survival data. It allows the systematic calculation of the area under the patch

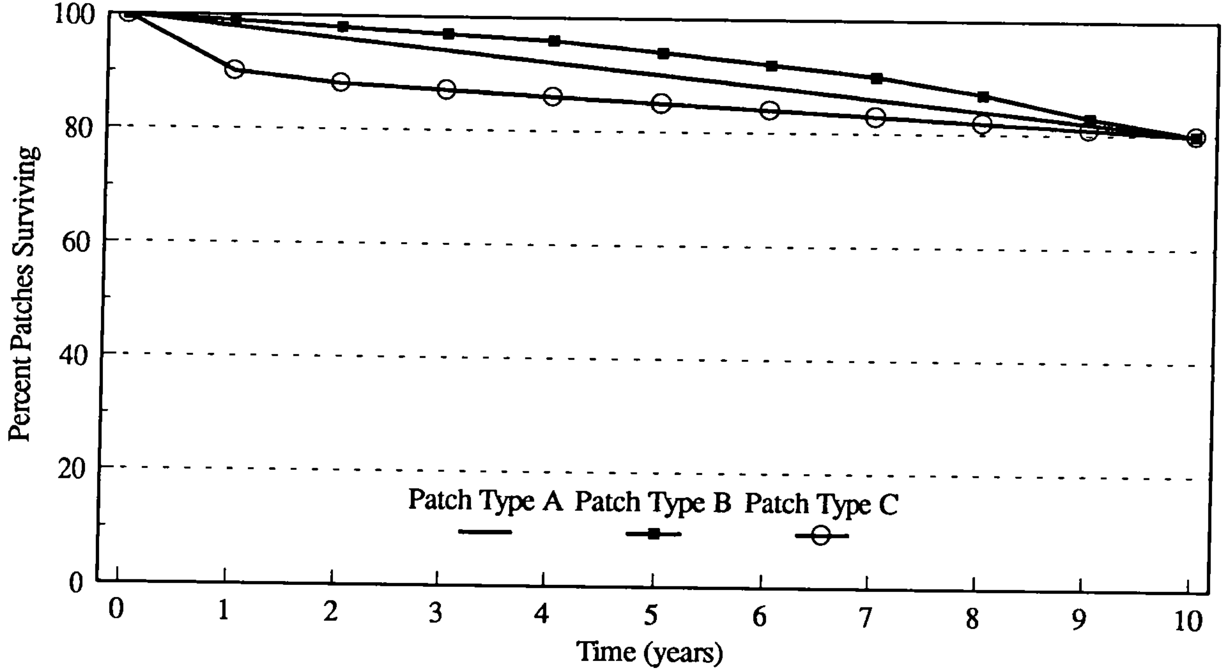


Figure 28. Patch survival curves

Table 9. Worksheet for calculating patch survival rate

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

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

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

[2] $I_{(t)} = T_{(t+1)} - T_{(t)}$

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

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

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

$= (548 / 600) \times 100$

$= 91.3\%$

survival curve between each time of observation, as well as the final calculation of a performance rating by which patch types can be compared. As an example, the data from table 8 have been used to calculate a patch survival rate, using the worksheet in table 9.

The average percent of patches surviving, P_{avg}, is calculated by averaging the two percent values that straddle the line being calculated, as shown in the shaded region of the worksheet in table 9. Each time interval, I_t, is calculated by subtracting the earlier time, T_t, from the later time, T_{t+1}, again for the two lines straddling the line being calculated.

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

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

Appendix A

Material Testing Specifications

The following specifications for partial-depth spall repair materials are given as a guideline only and should be modified to reflect the conditions and requirements of a particular climatic region or roadway classification.

A.1 Rapid-Setting Cementitious Concretes

The cementitious rapid-setting patching materials and some non-flexible rapid-setting polymer materials (e.g., SikaPronto 11) shall meet the following suggested guidelines for acceptance as approved materials.

Initial set time, minimum	15 min
Compressive strength ASTM C 39, 3 hours	1000 psi
Compressive strength ASTM C 39, 24 hours	3000 psi
Bond strength of epoxy-resin systems ASTM C 882	200 psi
Bond strength of concrete overlay and patching materials, California test	200 psi
Flexural strength ASTM C 78	450 psi
Freeze-thaw resistance ASTM C 666, Procedure A (150 cycles)	15 grams
Scaling resistance ASTM C 672 (100 cycles)	5
Surface abrasion resistance California Test T550	25 grams
Thermal compatibility ASTM C 884	pass

A.2 Rapid-Setting Flexible Polymer Concretes

The flexible polymer materials shall meet the following suggested guidelines for acceptance as approved materials.

Initial set time, minimum	15 min
Bond strength of epoxy-resin systems ASTM C 882	200 psi
Bond strength of concrete overlay and patching materials, California test	200 psi
Freeze-thaw resistance ASTM C 666, Procedure A (150 cycles)	15 g
Scaling resistance ASTM C 672 (100 cycles)	5
Surface abrasion resistance California Test T550	25 g
Thermal compatibility ASTM C 884	pass

A.33 Bituminous Materials

Bituminous patching materials shall meet the agency's suggested guidelines for acceptance as approved materials. Tests for workability, stripping, drainage, and cohesion are highly recommended. Additional tests suggested by other agencies and proprietary material manufacturers may also be used. Consult Appendix A of *Materials and Procedures for the Repair of Potholes in Asphalt Pavements–Manual of Practice* for more information on compatibility and acceptance tests for bituminous cold mix materials.[17]

Appendix B

Sample Cost-Effectiveness Calculations

This appendix contains sample worksheets for cost-effectiveness calculations. Different material and procedure combinations illustrate the financial differences between patching operations.

When using the examples in the following sections, it is important to remember that crew size and productivity differ greatly among agencies. These examples are fictitious and their only purpose is to show how the worksheets are used when completing them with the information relevant to a particular agency.

Table B-1 is a blank worksheet that may be used to summarize the patch performance data on a particular patch type. Table B-2 is a blank worksheet that may be used to calculate the patch survival rate, which is used in the cost-effectiveness worksheet. Chapter 5 explains the use of both of these worksheets.

Each example considers the placement of 200 partial-depth patches with an average finished patch length of 18 in (457.2 mm), width of 9 in (228.6 mm), and depth of 2 in (50.8 mm). Therefore, for all examples the expected total volume of the finished patches is 1.39 yd^3 (1.06 m^3). The average daily wage for the maintenance worker is assumed to be $120 in each example. Other data vary from example to example.

Calculation of the amount of materials needed, such as a patching material, bonding agent, joint bond breaker, or curing compound, is not demonstrated. The examples assume that agencies are already familiar with these calculations based on the number, length, width, and depth of the patches, and a typical waste factor for each material.

Table B-1. Blank patch performance data worksheet

Time of survey (years) (T_t)	Patches in-place (R_{ip})	Cumm. patches failed (R_f)[1]	Cumm. patches lost to rehab. (R_l)[2]	Percent patches surviving (P_s)[3]
0[4]		0	0	100

1 R_f = the number of patches that have failed since the time of installation.
2 R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.
3 $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$
4 Installation.

Table B-2. Blank worksheet for calculating patch survival rate

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

[1] $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$
[2] $I_{(t)} = T_{(t+1)} - T_{(t)}$
[3] $A_{part(t)} = P_{avg(t)} \times I_{(t)}$
[4] $A_{tot(t)} = I_{(t)} \times 100$

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

B.1 Example 1

Example 1 considers the placement of 200 material "A" patches using the saw-and-patch procedure. Material, labor, and equipment costs can be directly entered on the cost-effectiveness worksheet. However, the average daily productivity, the estimated number of days for the patching operation, and the partial-depth patch survival rate require a few advance calculations.

In calculating the average daily productivity and estimated number of days for patching, the examples assume that the last patch will be placed at the latest possible time and that preparation will stop when there is enough time to place the last patch. Therefore the patch preparation rate will control the number of patches that can be placed per day. The example also assumes that a crew of seven places seven patches per hour, and that the average patch volume is 0.187 ft^3 (0.005 m^3).

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

The patch survival rate is calculated using tables B-3 and B-4. Assume that in a previous project, 200 partial-depth patches made with material "A" had been placed using the saw-and-patch procedure. If these 200 patches experienced a 30 percent failure rate over the 10 years following their installation, the patch survival rate would be 85 percent, as shown in table B-4. Figure B-1 shows the completed cost-effectiveness worksheet for this example.

Table B-3. Example 1 patch performance data

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

1 R_f = the number of patches that have failed since the time of installation.
2 R_l = the number of patches that have been lost to rehabilitation, such as overlay or slab replacement, since the time of installation.
3 $P_s = \{R_{ip} / (R_f + R_{ip})\} \times 100$

Table B-4. Example 1 patch survival rate calculation

No. of Observ. (t)	Time (years) (T_t)	Percent Survived (P_s)	Avg. % Survived ($P_{avg(t)}$)[1]	No. of Time Interval (t)	Time Interval (years) (I_t)[2]	Partial Area ($A_{part(t)}$)[3]	Total Possible Area ($A_{tot(t)}$)[4]
1	0	100					
			85	1	10	850	1000
2	10	70					
			Sum Total			**850**	**1000**

1 $P_{avg(t)} = (P_{s(t)} + P_{s(t+1)}) / 2$
2 $I_{(t)} = T_{(t+1)} - T_{(t)}$
3 $A_{part(t)} = P_{avg(t)} \times I_{(t)}$
4 $A_{tot(t)} = I_{(t)} \times 100$

Patch Survival Rate $= (\Sigma A_{part(t)} / \Sigma A_{tot(t)}) \times 100$
$= (850 / 1000) \times 1000 = 85\%$

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

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

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

Material 1 = Patching Material "A"			
Material 1 Purchase Cost	132	$\$/yd^3$	(D_1)
Expected Material 1 Needs	1.60	yd^3	(E_1)
Material 1 Shipping Cost	0	$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	211	$	(G_1)
Material 2 = Bonding Agent			
Material 2 Purchase Cost	45	$/gal	(D_2)
Expected Material 2 Needs	15	gal	(E_2)
Material 2 Shipping Cost	0	$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	675	$	(G_2)
Material 3 = Joint Bond Breaker			
Material 3 Purchase Cost	0.328	$/ft	(D_3)
Expected Material 3 Needs	500	ft	(E_3)
Material 3 Shipping Cost	0	$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	164	$	(G_3)
Material 4 = Curing Compound			
Material 4 Purchase Cost	10	$/gal	(D_4)
Expected Material 4 Needs	2	gal	(E_4)
Material 4 Shipping Cost	0	$	(F_4)
Total Material 4 Cost $[(D_4 \times E_4) + F_4]$	20	$	(G_4)

Figure B-1. Example 1 cost-effectiveness worksheet

LABOR COSTS			
	amount	units	
Number in Repair Crew	9		(H)
Average Daily Wage per Person	120	$/day	(I)
Number in Traffic Control Crew	2		(J)
Average Daily Wage per Person	120	$/day	(K)
Supervisor Daily Wage	200	$/day	(L)
EQUIPMENT COSTS			
Material Truck	20	$/day	(M)
Traffic Control Trucks and Signs	150	$/day	(N)
Patch Preparation Equipment			
(e.g., concrete saw, jackhammer,	225	$/day	(O_1)
milling machine, waterblaster)	60	$/day	(O_2)
Cleaning Equipment	350	$/day	(P_1)
(e.g., sandblaster, airblaster)	0	$/day	(P_2)
Mixing Equipment	35	$/day	(Q_1)
(e.g., mortar mixer, Jiffy mixer)	0	$/day	(Q_2)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	20	$/day	(R)
Extra Equipment Truck	0	$/day	(S)
Miscellaneous Equipment	0	$/day	(T_1)
(e.g., spray-injection machine, joint sealing equipment, etc.)	0	$/day	(T_2)

Figure B-1. Example 1 cost-effectiveness worksheet (continued)

SUMMARY COSTS

	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	1070	\$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1520	\$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) + (P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) + R + S + (T_1 + T_2 + ...)]$	860	\$/day	(W)
User Costs	1000	\$/day	(X)
Average Daily Productivity	28	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	8	days	(Z)
Total Labor and Equipment Cost $[(V + W) \times Z]$	19,040	\$	(AA)
Total Patching Operation Cost $[U + AA + (X \times Z)]$	28,110	\$	(BB)
Partial-depth Patch Survival Rate[1] (Duration may vary)	85	%	(CC)
Effective Patching Cost $[BB \times (2 - \{CC \div 100\})]$	32,327	\$	(DD)

[1] Until patch survival rates have been determined, agency experience should be applied. See chapter 5 for calculation examples.

Figure B-1. Example 1 cost-effectiveness worksheet (continued)

B.2 Example 2

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

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

The patch survival rate is calculated using tables B-5 and B-6. This example assumes that the agency is familiar with a previous project in which 200 partial-depth patches made with material "B" were placed using the chip-and-patch procedure. In this fictitious project, 25 patches failed during the five years following installation, and 55 more patches failed during the next five years. Table B-6 shows that this pattern of failure results in a patch survival rate of 84 percent. Figure B-2 shows the completed cost-effectiveness worksheet for this example.

Table B-5. Example 2 patch performance data

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

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

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

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

Table B-6. Example 2 patch survival rate calculation

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

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

2 $I_{(t)} = T_{(t+1)} - T_{(t)}$

3 $A_{part(t)} = P_{avg(t)} \times I_{(t)}$

4 $A_{tot(t)} = I_{(t)} \times 100$

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

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

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

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

Material 1 = Material B			
Material 1 Purchase Cost	214	$/yd^3	(D_1)
Expected Material 1 Needs	1.60	yd^3	(E_1)
Material 1 Shipping Cost	0	$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	342	$	(G_1)
Material 2 = Joint Bond Breaker			
Material 2 Purchase Cost	0.348	$/f	(D_2)
Expected Material 2 Needs	500	ft	(E_2)
Material 2 Shipping Cost	0	$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	174	$	(G_2)
Material 3 = ________________			
Material 3 Purchase Cost	0	$/___	(D_3)
Expected Material 3 Needs	0	_____	(E_3)
Material 3 Shipping Cost	0	$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	0	$	(G_3)
Material 4 = ________________			
Material 4 Purchase Cost	0	$/___	(D_4)
Expected Material 4 Needs	0	_____	(E_4)
Material 4 Shipping Cost	0	$	(F_4)
Total Material 4 Cost $[(D_4 \times E_4) + F_4]$	0	$	(G_4)

Figure B-2. Example 2 cost-effectiveness worksheet

LABOR COSTS

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

EQUIPMENT COSTS

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

Figure B-2. Example 2 cost-effectiveness worksheet (continued)

SUMMARY COSTS	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	516	\$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1280	\$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) +$ $(P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) +$ $R + S + (T_1 + T_2 + ...)]$	860	\$/day	(W)
User Costs	1000	\$/day	(X)
Average Daily Productivity	28	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	8	days	(Z)
Total Labor and Equipment Cost $[(V + W) \times Z]$	17,120	\$	(AA)
Total Patching Operation Cost $[U + AA + (X \times Z)]$	25,636	\$	(BB)
Partial-depth Patch Survival Rate[1] (Duration may vary)	84	%	(CC)
Effective Patching Cost $[BB \times (2 - \{CC \div 100\})]$	29,738	\$	(DD)

[1] Until patch survival rates have been determined, agency experience should be applied. See chapter 5 for calculation examples.

Figure B-2. Example 2 cost-effectiveness worksheet (continued)

Appendix C

Material and Equipment Safety Precautions

This appendix contains some common-sense safety precautions for using materials and equipment in the partial-depth spall repair process. These precautions are not a complete list, nor will they apply to all materials and equipment. **It is essential that the highway agency obtain, review, and follow safety data sheets for all materials and all equipment.** The agency should develop a safety training program that will properly instruct highway workers in the safe use of all materials and equipment involved in partial-depth spall repair.

C.1 Materials

Some common-sense precautions for the safe use of many rapid-setting materials, admixtures, bonding agents, curing compounds, and solvents include the following:

- To avoid skin contact during mixing, placing, and cleaning
    - Wear long-sleeved shirts.
    - Wear long pants.
    - Wear gloves.
    - Wear steel-toed boots.

- To avoid ingestion during mixing, placing, and cleaning
    - Wear eye protection.
    - Wash hands (even if gloves have been worn) before handling anything that will go into the mouth (e.g., lunch containers, silverware, food, drinks, tobacco, gum, etc.).
    - Wash hands before touching the face, eyes, nose, mouth, or any other part of the body .

- Avoid inhaling fumes and vapors (use respirators if required).
- Use in well-ventilated areas.

- To avoid creating additional toxic vapors or fumes never combine any substances unless following the specific instructions of the manufacturers of those substances. This includes combination by mixing, by cleaning, by adjacent placement, by contamination, etc.

C.2 Equipment

Some common-sense precautions for the safe use of typical partial-depth spall repair equipment include the following:

- Wear eye protection, gloves, long-sleeved shirts, long pants, and steel-toed boots during sawing, jackhammering, sandblasting, airblasting, milling, waterblasting, spray injection, and any other operation that could injure the skin, eyes, limbs, etc.

- Use ear protection during sawing, jackhammering, sandblasting, airblasting, milling, waterblasting, spray injection, and any other operation that is loud and could permanently damage the hearing.

Appendix D

Inspection Checklists for Construction

This appendix is intended for inspectors of the partial-depth spall repair process. It contains discussions of planning, equipment, and procedures crucial to successfully completing a partial-depth spall repair project. Checklists pertaining to each step of the process–including planning, equipment, material mixing, patch preparation, material installation, and safety precautions–are provided.

D.1 Plans and Specifications

Plans must be prepared and distributed to the inspector and the supervisor of the installation crew. The plans must contain the following information:

- ☐ 1. Project layout (including stationing, slab lengths, location of spalls to be repaired, etc.)
- ☐ 2. Original pavement material type
- ☐ 3. Location and type of any pre-patching repairs required
- ☐ 4. Required patch dimensions
- ☐ 5. Required joint reservoir dimensions

Specifications may be based either on adherence to designated procedures or on achieving a quality end-product. They may also combine the two. **Procedure-based specifications** must contain the following information:

- ☐ 1. Delivery and storage requirements
- ☐ 2. Equipment requirements
- ☐ 3. Material requirements
- ☐ 4. Material mixing procedure requirements
- ☐ 5. Patch preparation procedure requirements
- ☐ 6. Installation procedure requirements
- ☐ 7. Weather condition limitations

- ☐ 8. Traffic control requirements
- ☐ 9. Material disposal requirements.
- ☐ 10. Safety requirements

End-result specifications must contain the following information:

- ☐ 1. Delivery and storage requirements
- ☐ 2. Required results of mixing procedures and acceptance-rejection criteria
- ☐ 3 Required results of each preparation procedure and acceptance-rejection criteria
- ☐ 4. Required results of the installation process and acceptance-rejection criteria
- ☐ 5. Weather condition limitations
- ☐ 6. Traffic control requirements
- ☐ 7. Material disposal requirements
- ☐ 8. Safety requirements

Most projects combine procedure-based and end-result specifications. The following inspection process is based on their combination.

D.2 Equipment

All equipment must be inspected and approved before the project begins, as well as during mixing, patch preparation, patch installation, and sealant installation. A list of proposed equipment should be submitted before installation for approval. During the pre-installation inspection, the inspector should check all equipment, ensuring that each piece meets the project specifications. Suitability of equipment for mixing and placing a particular repair material can be confirmed by contacting the material manufacturer.

The condition and effectiveness of each piece of equipment should be checked at the beginning of each day of patch preparation, mixing, and installation.

D.3 Material Quality

The inspector must confirm that the patching materials, joint bond breaker, bonding agent, curing compound, and so on are from the agency's "approved list" or are from a certified plant, and that samples of the materials have been submitted to the agency's laboratory for testing. The material manufacturer's recommendations for storage and shelf life should also be checked. Materials that are not stored properly or that are old may not meet quality standards.

D.4 Field Installation

After all required slab stabilization and other prepatching rehabilitation have been completed and approved, the partial-depth spall repair process can begin. Inspector(s) and supervisor(s) should meet before work begins to discuss the following subjects:

- ☐ 1. Exact locations and dimensions of all spalls to be patched. (The boundaries should be clearly marked.)
- ☐ 2. Traffic control requirements and lane closure time limitations
- ☐ 3. Methods for preparing and cleaning repair areas, for mixing and placing the repair materials, and for reinstalling a joint sealant system
- ☐ 4. Recommended accessory materials and instructions for their use
- ☐ 5. Material properties and working tolerances
  - ☐ Working times
  - ☐ Time to traffic at the anticipated mixing and placement temperatures
  - ☐ Moisture conditions allowable during placement
  - ☐ Temperatures allowable during mixing and placement
- ☐ 6. Mixing times, components, proportions, and sequences

☐ 7. Criteria for approval of all cleaning and installation equipment and processes
☐ 8. Criteria for final approval of the repair work
☐ 9. Any localized variations from the specified methods
☐ 10. Procedures in the event of hot, cold, and/or wet weather
☐ 11. Material disposal requirements
☐ 12. Safety requirements for all equipment and procedures and material safety data sheets

D.5 Preparing the Repair Area

Patch preparation includes removing deteriorated concrete and old sealant in the adjacent joint, final cleaning, installing the joint bond breaker, and applying the bonding agent. The following inspection checklist can be used to ensure that spall preparation is completed properly. Not all of these patch preparation procedures are used at one time.

☐ 1. **Sounding:**
- ☐ A solid steel rod, chain, or ballpeen hammer is used to sound the spalled area before and after the deteriorated concrete is removed.
- ☐ All deteriorated concrete is removed using the specified method until all parts of the repair area yield a clear ringing sound when they are sounded.

☐ 2. **Sawing:**
- ☐ The concrete saw is establishing straight, vertical patch boundaries to the required depth, where specified.
- ☐ The concrete saw is removing the required amount of concrete and sealant in any adjacent joint.
- ☐ The concrete saw is uniformly cutting to the proper width and depth. (Depth and width can be checked quickly using a metal template.)

- ☐ 3. The **water-wash** equipment is removing all sawing and/or waterblasting slurry from the repair area before it dries.
- ☐ 4. **Jackhammering:**
  - ☐ Jackhammers of the specified weight are removing all deteriorated concrete to the specified depth, without fracturing the sound concrete below the repair or undercutting or spalling any sawed boundaries.
  - ☐ Chiseling is begun in the center of the repair area and proceeds outward.
  - ☐ Only light jackhammers are used near the patch boundaries.
  - ☐ If patch boundaries have not been sawed, the hammering is producing rough, vertical edges (not scalloped edges into which the repair material will have to be feathered).
  - ☐ Spade bits (not gouge bits) are being used.
  - ☐ Jackhammers are being operated at an angle less than 45 degrees from the vertical.
- ☐ 5. **Milling:**
  - ☐ The carbide-tipped milling machine is removing all deteriorated concrete to the specified minimum depth.
  - ☐ Any material that remains at the patch corners is removed by light jackhammering or sawing.
  - ☐ Whenever possible, the milling machine is oriented such that the rounded edges of the milling hole are parallel to the direction of traffic.
    - ☐ If this is not possible, the rounded edges are chipped into straight, vertical edges.
  - ☐ Edge spalling is minimized.
- ☐ 6. **Waterblasting:**
  - ☐ A protective shield has been built around the repair area before waterblasting if traffic is passing in the next lane.
  - ☐ The waterblasting equipment has been calibrated to remove the specified depth of concrete

- ☐ Operation parameters are not changed throughout the remainder of the project unless the concrete changes (e.g., the aggregate hardness differs from one pavement section to another).
- ☐ The waterblasting equipment is removing all deteriorated concrete to the required depth, and is producing neat, vertical faces at the patch boundaries.
- ☐ Waterwashing equipment is used to wash the waterblasting slurry from the repair area before it dries.

☐ 7. A **full-depth repair** is used if at any point in the patch preparation process, the deteriorated area of concrete is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are encountered.

☐ 8. **Hand tools and shovels** are being used to remove all loose material, when preparing the patch under adverse conditions.

☐ 9. **Sandblasting:**

- ☐ The sandblasting equipment is uniformly cleaning the faces of the repair area. This typically requires that the nozzle be held 1 in to 2 in (25 mm to 51 mm) from the pavement and that several passes be made.
- ☐ No old sealant, oil, or dried sawing and/or waterblasting slurry remains in the repair area.
- ☐ The sandblasting equipment does not introduce oil or moisture to the repair area.
- ☐ After sandblasting, the entire surface area of the patch hole contains freshly exposed concrete.

☐ 10. **Airblasting:**

- ☐ The airblasting equipment is removing all dirt, dust, old sealant, and sand from the dry repair area.
- ☐ The airblaster does not introduce oil or moisture to the repair area.
- ☐ After airblasting, the repair area is clean and dry.

- ☐ 11. **Compressed air** is removing all old sealant, sand, dirt, and dust from the pavement surface so that it cannot reenter the repair area, especially on windy days or when traffic passes next to the cleaned repair areas.
- ☐ 13. **Recleaning:**
  - ☐ The repair area is **re-checked for cleanliness** just before material placement.
  - ☐ Cleaned repair areas that have been recontaminated by rain, dew, dirt or oil, are cleaned again in a manner that restores the original cleanliness. This may require sandblasting and airblasting, or merely airblasting.
  - ☐ Cleaned repair areas that are left overnight are, at a minimum, airblasted again.
- ☐ 14. **The repair area** is allowed to dry if a moisture-sensitive repair material will be used. (Water on the surface of the repair area during material installation may severely reduce the ability of the material to bond to the surface, depending on the material type. Watch for heavy dew that may collect in the repair area and remain after the surface is dry.)
- ☐ 15. **Scored bond breaker:**
  - ☐ A strip of scored bond breaker is placed at the joint-patch interface 1 in (25 mm) deeper than the repair, and extends at least 2 in to 3 in (51 mm to 76 mm) beyond the repair boundaries.
  - ☐ The bond breaker is either of the appropriate height or is stacked and latex-caulked when necessary so that there are no gaps through which the repair material can flow.
  - ☐ A true, straight joint line is maintained when installing the bond breaker.
- ☐ 16. **Bonding agent:**
  - ☐ The bonding agent sprayer or brush is applying a thin layer of bonding agent uniformly over the repair area.

- ☐ The bonding agent is still tacky when the repair material is placed.

☐ 17. **Safety:**
- ☐ All required **operator safety equipment** is in use.
- ☐ All required safety precautions are followed.

D.6 Installing the Patch

Patch installation includes mixing, placing, and finishing the patching material. The following inspection checklist can ensure that patch installation is completed properly.

D.6.1 Mixing

During the mixing of the repair materials, the following items should be regularly checked to ensure that they meet the requirements. Not all rapid-setting partial-depth spall repair materials require mixing.

☐ 1. All **mixing equipment** is clean before use. Some material manufacturer's may recommend pre-wetting the mixer so no water is lost when mixing the first batch.

☐ 2. The **water** used for mixing is clean.

☐ 3. The mixing operation results in a **consistently-mixed** material.

☐ 4. The **material** is not over- or undermixed.

☐ 5. Any **spilled material** is removed from the pavement surface.

☐ 6. The **mixing temperature** is as recommended. Warm water or ice water is used to raise or lower the mix temperature as needed.

☐ 7. **Mixing time, mix components, mix proportions, and mix sequences** are carefully followed.

☐ 8. The mixing equipment is **cleaned with the solvent specified by the material manufacturer** immediately after use.

☐ 9. The mixing of the bonding agent and repair material is scheduled such that the **bonding agent** is tacky when the repair material is placed.
☐ 10. Disposal of all **wasted materials and solvents** follows the manufacturer's specifications and State ordinances.
☐ 11. All required **operator safety equipment** is in use.
☐ 12. All required **safety precautions** are followed.

Material that has begun to set during mixing, or material that is too wet, should not be placed. It should be discarded, and the mixing process begun again; a *retarding agent* may need to be added. The mixing time or amount of water may also need to be adjusted.

D.6.2 Placement

During placement, the following items should be regularly checked to ensure that they meet the requirements. Not all steps will be required for all materials.

☐ 1. The repair material is placed in a **clean repair hole**, under the **specified moisture conditions**, using the **specified placement methods.**
☐ 2. The **bonding agent** thoroughly coats the bottom and sides of the repair area, but does not collect in any pockets.
☐ 3. The **material** is placed when the bonding agent is still tacky.
☐ 4. The repair hole is **slightly overfilled** with the repair material for those materials that require consolidation or compaction.
☐ 5. A **shovel** is used (**not** a wheelbarrow or a bucket) to place repair materials that contain aggregate, so that segregation does not occur.
☐ 6. The repair **material** is not placed below or above its permissible placement temperature range.
☐ 7. **Deep repairs** are placed in lifts to control heat development, when specified.

☐ 8. A pencil **vibrator or hand tools** are used to release trapped air from the mix.
☐ 9. The **vibrator** is held at 15 to 30 degrees from the vertical, and is moved through the concrete by lifting it up and down to vibrate the entire area until the mix stops settling, air bubbles no longer emerge, and a smooth layer of mortar appears at the surface.
☐ 10. A bituminous cold mix patch is compacted to release trapped air using a **vibratory roller or plate** until it is level with the pavement.
☐ 11. Disposal of all **wasted materials and solvents** follows the manufacturer's specifications and State ordinances.
☐ 12. **Field testing** is conducted as appropriate for the patching materials, such as testing beams or cylinders for strength and quality control.
☐ 13. All required **operator safety equipment** is in use.
☐ 14. All required **safety precautions** are followed.

D.6.3 Material Finishing and Curing

During finishing, the following items should be regularly checked to ensure that they meet the requirements. Not all steps will be required by all materials.

☐ 1. The repair material is **troweled** level with the pavement before finishing.
☐ 2. The repair material is **screeded** with a stiff board, using at least two passes.
☐ 3. The repair material is **worked toward** the patch edges to enhance bonding with the existing slab.
☐ 4. The **saw cuts** are filled with excess mortar or epoxy, or are filled with joint sealant during the joint resealing process.
☐ 5. The patch surface is **finished** to match the surface of the surrounding pavement.
☐ 6. Appropriate **curing methods** are used so that shrinkage cracks do not develop.

- ☐ **Curing agents** are applied uniformly to the patch.
- ☐ The **water** used for curing is clean.
- ☐ **Insulating covers and longer cure times** are used at cooler temperatures, as specified by the material manufacturer.

☐ 7. Disposal of **wasted repair material, curing compound, and cleaning solvents** follows the manufacturer's specifications and State ordinances.

☐ 8. **Traffic** is not allowed on the pavement until the material has developed the strength necessary to carry traffic without being damaged.

☐ 9. All required **operator safety equipment** is in use.

☐ 10. All required **safety precautions** are followed.

D.6.4 Joint Resealing

Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for information regarding the inspection of the joint resealing process.[15] In addition to the inspection criteria listed in that manual, when using a scored bond breaker, the following criteria should be met:

☐ 1. **Joint resealing or filling** is conducted after a minimum curing time of one week.

☐ 2. Immediately before joint resealing or filling, the **top strip** is torn off of the scored bond breaker, leaving a uniform, clean, dry reservoir.

☐ 3. Before resealing or filling the joints, **low-pressure air cleaning** is used if dust or dirt has blown into the joints after removal of the tear-away top strip.

D.7 Final Inspection

During installation and before approval, the partial-depth patches should be individually inspected, ensuring that the patch meets the highway agency's criteria, and noting the presence and severity of any distresses. The final inspection should include the following:

- ☐ 1. The patch is **bonded** firmly to the existing pavement and has not separated from the sidewalls.
- ☐ 2. The patch is **level** with the surface of the existing pavement.
- ☐ 3. The patch contains **no cracks** (other than fine hairline shrinkage cracks) or bubbles.
- ☐ 4. All material that has spilled on the pavement has been **removed**.
- ☐ 5. **No debris** has been left on the pavement.

Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements-Manual of Practice* for information regarding final inspection of the joint sealant system.[15]

Appendix E

Partial List of Material and Equipment Sources

This appendix contains a partial listing of material and equipment manufacturers. Addresses and phone numbers are provided for manufacturers and/or suppliers who can provide the inquirer with information regarding products, installation practices, safety procedures, costs, and local suppliers.

Material safety data sheets, where applicable, should be available from all manufacturers. Information regarding the safe use of all materials and equipment should be carefully followed to ensure worker safety and the safety of the traveling public.

Inclusion of a particular material, piece of equipment, or supplier in this list does not serve as an endorsement of that material, equipment, or supplier. Likewise, omission from this list is not intended to carry negative connotations for the materials, pieces of equipment, and suppliers omitted.

E.1 Partial-Depth Patching Materials

E.1.1 Manufacturers of Cementitious Concretes

Euclid Chemical Company
19218 Redwood Road
Cleveland, OH 44110-2799
(216) 531-9222

Five Star Highway Products, Inc.
425 Stillson Road
Fairfield, CT 06430
(203) 336-7900

Fosroc, Inc.
55 Skyline Drive
Planview, NY 11802
(516) 935-9100

Hartline Products Company, Inc.
2186 Noble Road
Cleveland, OH 44112
(216) 451-6573

L&M Construction Chemicals, Inc.
14851 Calhoun Road
Omaha, NE 68152
(402) 453-6600

Master Builders
23700 Chagrin Boulevard
Cleveland, OH 44122
(800) 227-3350

United States Gypsum Company
Industrial Gypsum Division
125 South Franklin Avenue
Chicago, IL 60606-4678
(312) 606-4000

E.1.2 Manufacturers of Polymer Concretes

Accelerated Systems Technology Corporation
140 Chaparral Court
Suite 100
Anaheim, CA 92808
(714) 263-9074

HC Epoxy Company, Inc.
862 East 19th Street
Tucson, AZ 85719
(602) 624-7929

Percol Polymerics, Inc.
17435 Newhope Street
Fountain Valley, CA 92708-4220
(714) 979-5555

Pyrament/Lone Star Industries, Inc.
340 North Sam Houston Parkway, East
Houston, TX 77060
(800) 633-6121

Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
(201) 933-8800

The Burke Company
P.O. Box 5818
San Mateo, CA 94402
(415) 349-7600
(800) 423-9140

Thoro System Products
Department PWM
7800 N.W. 38th Street
Miami, FL 33166

E.1.3 Manufacturers of Bituminous Materials

Unique Paving Materials Corportation
3993 East 93rd Street
Cleveland, OH 44105-4096
(800) 441-4881

E.1.4 Manufacturers of Bonding Agents

Master Builders
23700 Chagrin Boulevard
Cleveland, OH 44122
and
3637 Weston Road
Toronto, ONT M9L 1W1
CANADA
(800) 227-3350

The Burke Company
6433 East 30th Street
Indianapolis, IN 46219
(317) 543-4475

E.2 Partial-Depth Patching Equipment

E.2.1 Manufacturers of Sawing Equipment

Cimline, Inc.
3025 Harbor Lane
Suite 130
Plymouth, MN 55447
(800) 328-3874

Target Products Division
4320 Clary Boulevard
Kansas City, MO 64130
(816) 923-5040

Vermeer Manufacturing Company
Route 2
P.O. Box 200
Pella, IA 50219
(515) 628-3141

E.2.2 Manufacturers of Spray-Injection Equipment

Zimmerman Equipment Corporation
1000 South Thompson Lane
Nashville, TN 37211
(615) 833-5705

Wildcat Manufacturing Company, Inc.
Highway 81
P.O. Box 1100
Freeman, SD 57029
(605) 925-4512

ONE MAN, Inc.
7301 Jefferson, N.E.
Suite A-113
Albuquerque, NM 87109
(505) 898-1900

E.2.3 Manufacturers of Waterblasting Equipment

FLOW Services
23500 64th Street
Kent, WA 98032
(800) 446-3569, Ext. 900

E.2.4 Manufacturers of Milling Equipment

Cedarapids, Inc.
916 16th Street, N.E.
Cedar Rapids, IA 52402
(319) 363-3511

Vermeer Manufacturing Company
Route 2
P.O. Box 200
Pella, IA 50219
(515) 628-3141

E.2.5 Manufacturers of Jackhammers

Atlas Copco Berema, Inc.
161 Lower Westfield Road
Holyoke, MA 01040
(800) 284-2373
(413) 536-0600

E.2.6 Manufacturers of Compacting Equipment

Stone Construction Equipment, Inc.
Corporate Offices/Northern Manufacturing Plant
32 East Main Street
P.O. Box 150
Honeoye, NY 14471-0150
(800) 888-9926

Glossary

Admixture–A substance added to a mixture during mixing.

Adverse patching conditions–Climatic conditions in which the air temperature is below 40°F (4°C) and the repair area is saturated with surface moisture.

Bonding agent–A substance that promotes good bonding between the pavement surface and a repair material placed on the surface.

Breaking and seating–The breaking and compaction of a continuously-reinforced concrete pavement, reducing the amount of reflective cracking in the overlay.

Calcium aluminate concrete–A high alumina (Al_2O_3) cementitious concrete.

Chemical conversion–A chemical process that results in a change in the nature, structure, or properties of a substance.

Compact–To release trapped air and reduce volume using compression.

Compression failure–The crushing of a repair due to the expansion of the surrounding pavement during freeze-thaw cycles.

Compression recovery–The property of being able to regain original shape and volume after being compressed.

Compressive strength–The maximum compressive stress a material can withstand before failure.

Compressive stress–A stress that causes an elastic body to shorten in the direction of the applied force and that causes an inelastic body to rupture.

Consolidate–To release trapped air from fresh concrete mix by using vibration.

Cracking and seating–The breaking and compacting of a plain concrete pavement, reducing the amount of reflective cracking in the overlay.

D-cracking–Durability cracking; a pattern of cracks running parallel and close to a joint or linear crack caused by freeze-thaw expansion of large, nondurable aggregate.

Debonding–The partial or complete loss of bond between two materials, such as between a patch and a slab.

Diamond grinding–A surface restoration in which patterns are cut into hardened concrete with closely spaced diamond saw blades to correct surface distresses.

Epoxy concrete–A polymer concrete containing epoxy resin, a flexible, thermosetting resin made by polymerization of an epoxy compound.

Feathering–The thin placement of patching materials because of curved or angled patch edges that do not allow adequate depth of placement.

Free sulfate–A chemical group containing sulfur and oxygen ($-SO_4$) that is free to react chemically with other chemical groups.

Full-depth spall repair–The removal of an area of deteriorated concrete the entire depth of a pavement slab, and its replacement with a repair material along with the restoration of load transfer devices.

Full lane-width patch–A patch that extends the entire width of a lane.

Gouge bit–A curved chisel tip used in jackhammering that is not recommended for partial-depth spall repair.

Gypsum-based concrete–A cementitious concrete that contains gypsum, a common sulfite mineral.

Heat of hydration–The heat given off when molecular water is incorporated into a complex molecule with molecules such as those found in cementitious mixes.

High alumina concrete–A cementitious concrete that contains a higher amount of alumina, the native form of aluminum oxide, than regular concrete.

High early-strength materials–Patching materials that gain high strength levels early in their curing period.

High molecular weight methacrylate concrete–A cementitious concrete containing high molecular weight methacrylate, an acrylic resin or plastic made from a derivative of methacrylic acid ($C_4H_6O_2$).

Hydration rate–The rate at which molecular water is incorporated into a complex molecule with molecules such as those found in cementitious mixes.

Incompressible–A material that resists compression, such as stones, sand, or dirt, in a crack or joint reservoir that is closing.

Joint bond breaker–A strip of polyurethane, polyethylene, or fiberboard that is placed in a joint to prevent a patch placed at that joint from bonding to the adjacent slab.

Joint insert–A metal or plastic strip inserted into fresh concr ete to form a weakened plane and induce cracking at a desired location.

Joint sealant system–All components that function to seal joints, including the sealant material, surrounding concrete, and the sealant-concrete interface.

Laitance–A residue left on a surface, such as the dried residue left on pavement after a wet-sawing operation.

Lateral confinement–Being held in place from the sides.

Latex caulking–The filling and water sealing of a space with a latex material.

Load transfer devices–Devices such as dowel bars that transfer the traffic load from one slab across a joint to the adjacent slab and that reduce the relative deflection across that joint.

Magnesium phosphate concrete–A cementitious concrete that contains magnesium phosphate, a metallic element (Mg) bound to a phosphate group ($-PO_4$).

Methyl methacrylate concrete–Cementitious concrete containing methyl methacrylate ($C_5H_8O_2$), a volatile, flammable liquid that readily polymerizes.

Opaque–Not transparent to rays of light.

Operating parameters–Equipment settings, such as speed, pressure, and number of overlapping passes.

Partial-depth spall–An area of deteriorated concrete that is limited to the top third of a concrete pavement slab.

Polymer–A chemical compound or mixture of compounds formed by polymerization and consisting of repeating structural units; a substance made of giant molecules formed by the union of simple molecules.

Polymer resin–A resin that is a polymer; see polymer and resin.

Polyurethane concrete–A concrete consisting of aggregate mixed with a two-part polyurethane resin, a resin of repeating structural units of urethane ($C_3H_7NO_2$).

Preformed compression seal–A preformed seal, generally made from neoprene, that can be compressed and inserted into concrete joints for sealing purposes.

Proprietary–Something that is used, produced, or marketed under exclusive legal right of the inventor or maker.

Radiant heat–Heat that radiates from the sun.

Rapid-setting materials–In the context of this manual, patching materials that set within 30 minutes of mixing.

Resin–Any of a class of solid or semisolid organic products of natural or synthetic origin with no definite melting point, generally of high molecular weight. Most resins are polymers.

Retarding agent–A substance added to a cementitious material mixture that initially slows down the rate of hydration, allowing a longer period of workability.

Rubblization–The breaking of a concrete pavement into pieces smaller than 12 in (304.8 mm) in diameter and its compaction, reducing the amount of reflective cracking in the overlay.

Saturated–Full of moisture; having voids filled with water.

Scalloped–Having a series of curves in its edges.

Segregation–The separation of cement and aggregate.

Set initiator–An admixture that triggers the setting of a material.

Shape factor–The ratio of the width to depth of a sealant.

Shrinkage cracks–Fine hairline cracks that develop as a result of water loss and volume reduction during curing.

Skid resistance–The resistance of a pavement to tires sliding over its surface; generally a function of the macro- and micro-texture of the pavement surface.

Slab jacking–The lifting of a slab at a low point to restore it to its original elevation and rideability.

Slurry–The mixture of water, concrete dust, old sealant, and dirt that results from resawing a joint in concrete pavement.

Spade bit–A flat, spade-shaped chisel tip used in jackhammering that is recommended for partial-depth spall repair.

Spalling–The cracking, breaking, or chipping away of concrete fragments in a pavement.

Spall–A small broken or chipped segment of concrete normally occurring along a joint or crack.

Substrate–A base layer, such as the repair surface, upon which a material is applied or placed.

Thermal compatibility–Compatibility between the thermal properties of two materials, such as similar amounts of thermal expansion resulting from a given temperature increase in the two materials.

Thermal expansion–The increase in volume of materials due to an increase in temperature.

Undersealing–Filling voids beneath a concrete pavement using a pressurized slurry or hot asphalt material.

Vibrating screed–A leveling device drawn over freshly poured concrete that is vibrated to allow consolidation of the material.

Waterblasting machine–A machine controlled by a mobile robot that produces a high-pressure water jet capable of removing deteriorated concrete.

Weight and volume stability–Structural strength due to sufficient patch weight and volume.

References

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