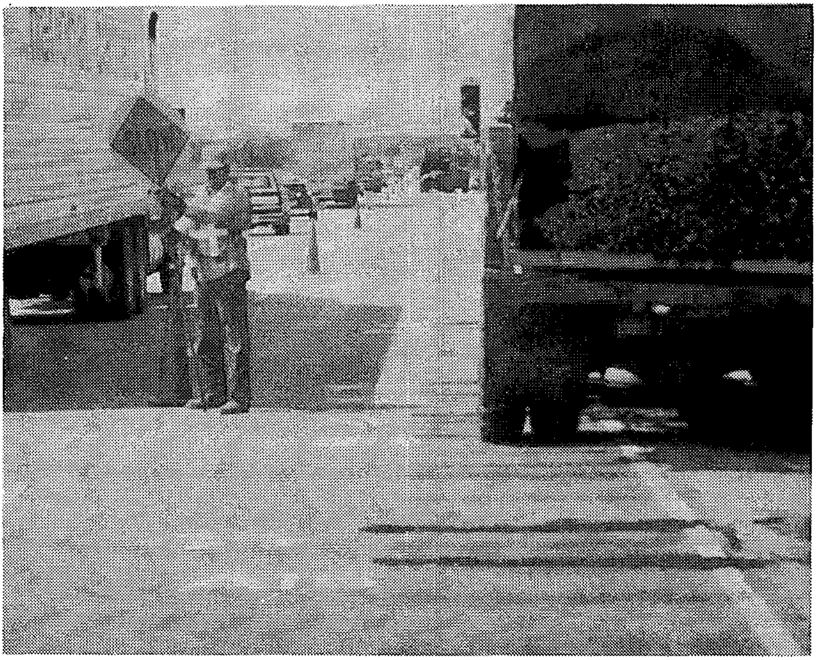
SHRP-H-348

Manuals of Practice



Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements

Kelly L. Smith, A. Russell Romine

Materials and Procedures for the Repair of Potholes in Asphalt-Surfaced Pavements

Thomas P. Wilson, A. Russell Romine

ERES Consultants, Inc., Savoy, Illinois

shrp

Strategic Highway Research Program

National Research Council

SHRP-H-348
ISBN 0-309-05607-1
Contract H-106
Product Code 3003

Program Manager: Don M. Harriott
Project Manager: Shashikant C. Shah
Program Area Secretary: Francine A. Burgess
Production Editor: Katharyn L. Bine

August 1993
Reprinted February 1994

key words:
asphalt concrete
cold mix
crack filling
crack sealing
patching
potholes
pavement maintenance
spray injection

Strategic Highway Research Program
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

.7M/NAP/294

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 asphalt concrete (AC) crack sealing and filling and pothole 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.

Acknowledgments

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

Special thanks are due the project management team at SHRP, and to the following highway agencies.

Manual for sealing and filling cracks:
- Texas Department of Transportation
- Kansas Department of Transportation
- Washington State Department of Transportation
- Iowa Department of Transportation
- Ministry of Transportation of Ontario.

Manual for pothole repair:
- Illinois Department of Transportation
- Vermont Agency of Transportation
- Ontario Ministry of Transportation
- City of Draper, Utah
- California Department of Transportation
- Oregon Department of Transportation
- Texas Department of Transportation
- New Mexico Highway and Transportation Department

The contributions of the following individuals are also acknowledged.

Manual for sealing and filling cracks: Michael Darter, Samuel Carpenter, David Peshkin, Mike Belangie, Henry Bankie, and Jim Chehovits.

Manual for pothole repair: Michael Darter, Samuel Carpenter, and David Peshkin.

Materials and Procedures for Sealing and Filling Cracks in Asphalt-Surfaced Pavements

Manual of Practice

shrp

Strategic Highway Research Program
National Research Council

Contents

List of Figures

List of Tables

1.0 Introduction

Cracking in asphalt concrete (AC)-surfaced pavements is a phenomenon that pavement design and maintenance engineers have had to contend with for years. It is one of two principal considerations (fatigue cracking and rutting) in the pavement design process, and it is the primary mode of deterioration in AC pavements. Cracks are inevitable, and neglect leads to accelerated cracking and/or potholing, further reducing pavement *serviceability.**

The problem of cracks is handled in many ways, ranging from pavement maintenance activities, such as surface treatments and crack filling, to full-scale pavement rehabilitation projects, like resurfacing. Maintenance departments bear most of the burden of dealing with cracks. Departments with sufficient funding are often responsible for adding a few more years of serviceable life to deteriorated pavements, through preventive or routine maintenance, or both.

Two of the more common options exercised by maintenance departments are crack sealing and crack filling. These operations have been conducted for many years, generally on a routine basis. However, only in the last two decades has their potential benefits as preventive maintenance tools been realized. With proper and timely application, crack sealing and filling can extend pavement life past the point where the cost-benefit of added pavement life exceeds the cost of conducting the operation.

* Italicized words are defined in the glossary.

1.1 Scope of Manual

This manual has been prepared to guide pavement maintenance personnel (i.e., engineers, supervisors, and crewpersons) in the selection, installation, and evaluation of materials and procedures used to treat (seal or fill) cracks in AC-surfaced pavements. The information contained herein is based on the most recent research, obtained through literature reviews and current practices, and on the results of an ongoing field study.[1,2]

This manual provides both general and specific information for carrying out each of four primary phases associated with a *crack treatment* program. These phases are as follows:

1. Determining the need for crack treatment
2. Planning and designing the crack treatment project
3. Construction
4. Evaluating and assessing the performance of the crack treatment

Crack treatment is far from being the long, involved process typical of a pavement construction or rehabilitation project. However, like these projects, it must be carefully planned and conducted to be successful. Table 1 illustrates the steps involved in the crack treatment process, as well as the factors that must be considered. Chapters 2 through 5 provide in-depth guidance for successfully completing each of the four phases listed above.

Table 1. Steps in a crack treatment program

Step	Description
1	Obtain and review construction and maintenance records. - Pavement age, design, repairs, etc.
2	Perform pavement/crack survey. - Record distress types, amounts, and severities.
3	Determine appropriate type of maintenance for cracked pavement based on density and condition of cracks. - High density of cracks with moderate to no edge deterioration ⇒ pavement surface treatment. - Moderate density of cracks with moderate to no edge deterioration ⇒ crack treatment. - Moderate density of cracks with high level of edge deterioration ⇒ crack repair.
4	For crack treatment, determine whether cracks should be sealed or filled. - Cracks typically show significant annual horizontal movement ⇒ crack sealing.[a] - Cracks typically show very little annual horizontal movement ⇒ crack filling.[a]
5	Select materials and procedures for crack treatment operation based on the following considerations: - Climate (dry-freeze, dry-nonfreeze, wet-freeze, wet-nonfreeze). - Traffic (high, medium, low). - Crack characteristics (width, deterioration). - Available equipment. - Available manpower. - Cost-effectiveness (anticipated treatment cost and performance).
6	Acquire materials and equipment.
7	Conduct and inspect crack treatment operation.
8	Periodically evaluate treatment performance.

[a] See sections 2.3 and 2.4.

2.0 Need for Crack Treatment

If a particular cracked pavement appears to be in need of some sort of maintenance, a relatively quick assessment can be made to ascertain the need and, more important, to help in determining the appropriate action. Such an assessment requires an evaluation of existing pavement conditions and a knowledge of future rehabilitation plans.

2.1 Pavement/Crack Evaluation

While maintenance engineers or supervisors are normally quite familiar with the roads they maintain, a quick review of construction, maintenance, and other records will provide important general information regarding the following:

- Pavement age
- Pavement and geometric design
- Pavement section boundaries
- Traffic
- Climate
- Type and extent of previous maintenance treatments
- Condition rating

After these records are reviewed, a shoulder survey should then be performed on a small representative sample of the pavement section, about 500 ft (153 m), to determine the amount, type, and condition or severity of cracks, as well as the condition or *effectiveness* of any previously applied crack treatments (see chapter 5). A sample survey form for recording pavement and crack information is provided in figure 1.

Pavement/Crack Survey Form

Location and Geometrics

Highway/road: | Milepost/station of section:
Number of lanes: | Length of section:
Lane widths: | Shoulder type and width:

Design, Construction, and Rehabilitation

Year of original construction:
Type and year of most recent rehabilitation:
Future rehabilitation planned:

Climate, Traffic, and Highway Classification

Average annual precipitation (in):
No. days below 32°F (0°C):
No. days above 100°F (38°C):
Functional classification:
Most recent 2-way ADT:

Pavement Cross-Section

Material = | Thickness =
Material = | Thickness =
Material = | Thickness =
Material = | Thickness =

Pavement Condition

Cracking Distress

Primary crack type/orientation:
- Density (lin ft/500-ft section): | Average width (in):
- Edge deterioration (%):
- Cupping? Lipping? Faulting? | Average depth/height (in):
- Previous treatment? Y N
  - Material type?
  - Effectiveness (%):

Other crack type/orientation:
- Density (lin ft/500-ft section): | Average width (in):
- Edge deterioration (%):
- Cupping? Lipping? Faulting? | Average depth/height (in):
- Previous treatment? Y N
  - Material type?
  - Effectiveness (%):

Other Significant Distresses

Type: | Density:
Type: | Density:
Type: | Density:

Figure 1. Pavement/crack survey form

Table 2. Guidelines for determining the type of maintenance to conduct

Crack Density	Average Level of Edge Deterioration (percent of crack length)		
	Low (0 to 25)	Moderate (26 to 50)	High (51 to 100)
Low	Nothing	Crack treatment??	Crack repair
Moderate	Crack treatment	Crack treatment	Crack repair
High	Surface treatment	Surface treatment	Rehabilitation

2.2 Determining the Type of Maintenance

The appropriate type of maintenance for cracked pavements often depends on the density and general condition of the cracks. If cracks are abundant (i.e., high in density) and do not exhibit a high degree of *edge deterioration*, they may best be treated through chip seals, slurry seals, or the like. If cracks are low to moderate in density and have typically progressed to a point of high edge deterioration, then *crack repair* strategies, such as partial-depth patching or spot patching, may be warranted. Finally, if cracks are moderate in density and show moderate to no deterioration at the edges, they may be treated effectively through sealing or filling operations. Table 2 summarizes these guidelines.

As table 2 indicates, crack density levels are described in general terms. This is because experienced personnel can usually make reasonable assessments of density. Figures 2 through 5 illustrate typical crack situations and potential remedies.

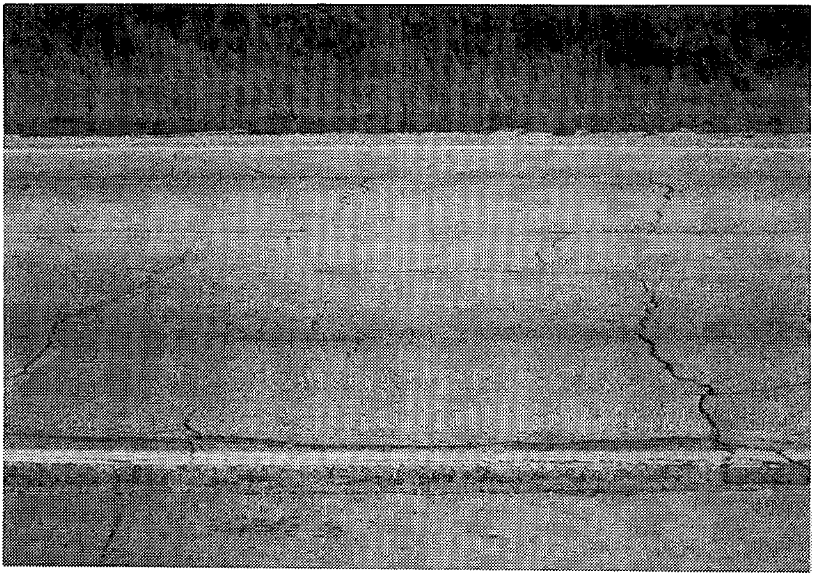


Figure 2. Pavement candidate for surface treatment: high-density cracking

Figure 3. Pavement candidate for crack repair

Figure 4. Pavement candidate for transverse crack sealing

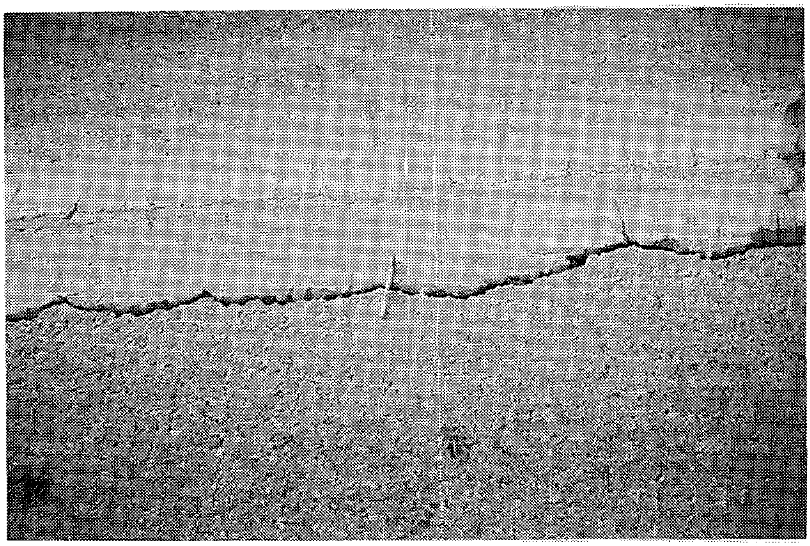


Figure 5. Pavement candidate for longitudinal crack filling

In general, a large number of cracks or severely deteriorated cracks indicate a pavement in an advanced state of decay. Crack sealing or filling in these circumstances is both uneconomical and technically unsound, as it does little to delay the need for more extensive corrective actions.

Most highway agencies have established policies that specify the type of maintenance to perform on cracked pavements and when to perform it. The policies are often based on an assessment of the overall pavement condition (extent of cracking) or specific crack characteristics (type and/or width).

2.2.1 Other Considerations

On occasion, cracks may be found to have other types of deficiencies. In particular, crack edges may exhibit vertical distresses, such as *cupping*, *lipping*, or *faulting*, and/or may undergo significant vertical deflections or movements under traffic loading. Such deficiencies can add significantly to overall pavement roughness and often worsen rapidly with time.

Normally, repair alternatives, such as patching and/or milling, are appropriate for correcting these deficiencies. However, if the amount of vertical deflection and the severity of the distress (cupping especially) are not too high, a temporary fix with crack treatment may be adequate.

2.3 Objectives of Sealing and Filling

Although little distinction has been made in the past between crack sealing and crack filling, the purposes and functions of each must be clearly understood so that the most cost-effective and long-lasting treatment is applied.

Crack Sealing—The placement of specialized materials either above or into *working* cracks using unique configurations to prevent the intrusion of water and *incompressibles* into the crack.

Crack Filling—The placement of materials into *nonworking* cracks to substantially reduce infiltration of water and to reinforce the adjacent pavement.

Working refers to horizontal and/or vertical crack movements greater than or equal to 0.1 in (2.5 mm); nonworking refers to movements less than 0.1 in (2.5 mm). It is assumed in this manual that where cracks are exhibiting significant vertical deflections, the appropriate repair strategy(s) will be sought. Hence, for cracks with limited vertical movement, horizontal movement becomes the critical factor in determining the need for, and planning for, a crack treatment operation.

As the above definitions indicate, the objectives of crack sealing are significantly more difficult to accomplish than those of crack filling. Sealing requires considerably more forethought, greater costs, and the use of specially formulated materials and more sophisticated equipment.

2.4 Determining Whether to Seal or Fill

Frequently, the first type of cracks to appear in a pavement are *transverse* cracks. However, several different types of cracks may appear at one time. In these cases, one treatment, using a material appropriate for the most demanding crack type, is desirable.

The amount of annual horizontal movement of the targeted crack type is the principal basis for determining whether to seal or fill. Normally, working cracks with limited edge deterioration should be sealed, while nonworking cracks with moderate to no edge deterioration should be filled.

Whether a crack is working or nonworking can generally be determined by its type. Working cracks are usually transverse in orientation; however, some *longitudinal* and diagonal cracks may meet the 0.1-in (2.5-mm) movement criterion. Materials placed in working cracks must adhere to the crack sidewalls and flex as the crack opens and closes. Rubber-modified materials designed for low-stress elongation, especially at low temperatures, are preferred for treating these cracks.

Nonworking cracks typically include diagonal cracks, most longitudinal cracks, and some block cracks. Because of the relatively close spacing or free edges between nonworking cracks, little movement occurs. Minimal movement permits the use of less expensive, less specialized crack-filler materials. Experienced personnel can usually determine if the targeted crack type is working or nonworking. Table 3 provides recommended criteria for determining which cracks to seal and which to fill.

2.4.1 When to Seal and When to Fill

Crack sealing is a preventive maintenance activity. Ideally, it is conducted shortly after working cracks have developed to an adequate extent and at a time of year when temperatures are moderately cool (45 to 65°F [7 to 18°C]), such as in the spring or fall. When newly developed cracks are sealed, deteriorated crack segments (i.e., *secondary cracks*, *spalls*), which adversely affect seal performance, are minimized. Typically, transverse thermal cracks in AC

Table 3. Recommended criteria for determining whether to seal or fill

Crack Characteristics	Crack Treatment Activity	
	Crack Sealing	Crack Filling
Width, in[a]	0.2 to 0.75	0.2 to 1.0
Edge Deterioration (i.e., spalls, secondary cracks)	Minimal to none ($\leq$ 25 percent of crack length)	Moderate to none ($\leq$ 50 percent of crack length)
Annual Horizontal Movement, in	$\geq$ 0.1	< 0.1
Type of Crack	Transverse thermal cracks Transverse reflective cracks Longitudinal reflective cracks Longitudinal cold-joint cracks	Longitudinal reflective cracks Longitudinal cold-joint cracks Longitudinal edge cracks Distantly spaced block cracks

[a] 1 in = 25.4 mm

flexible pavements appear 2 to 7 years after construction, while transverse reflective cracks in AC overlayed concrete pavements materialize 1 to 3 years after resurfacing.

Sealing cracks in moderately cool temperatures is beneficial from two standpoints. First, cracks are partly opened so that a sufficient amount of material can be placed in the crack if cutting is not performed. Second, the width of the *crack channel*, whether cut or uncut, is nearly at the middle of its working range. This is important to the performance of the sealant material because it will not have to undergo excessive extension or contraction.

Most crack-filling operations can be conducted year-round. However, they often take place during cool or moderately cool weather (35 to 55°F [2 to 13°C]). At these temperatures, cracks are most or all the way open, and more material can be applied.

Crack-filling operations can be preventive or routine in nature, depending on the highway agency's approach to treating the cracks. Like sealing operations, preventive crack-filling maintenance should be conducted shortly after nonworking cracks have developed adequately. Depending on the type of cracks to be filled, this may be between 4 and 8 years after construction or resurfacing. Durable filler materials should be used to reduce the number of repeat applications. By filling cracks shortly after they are fully developed, further growth as a result of the collection of debris and/or stripping of the asphalt is delayed.

Historically, most crack filling was done on a routine basis with inappropriate materials that provided less than desirable performance. This approach to crack filling is rarely cost-effective because treatment performance is generally poor and maintenance costs are high. In addition, the safety of the workers and traveling public is compromised since the filling operation must be conducted frequently.

3.0 Planning and Design

3.1 Primary Considerations

The following factors should be addressed when planning crack-sealing or crack-filling operations:

1. Climatic conditions
   a. At time of installation
   b. General
2. Highway classification
3. Traffic level and percent trucks
4. Crack characteristics and density
5. Materials
6. Material placement configurations
7. Procedures and equipment
8. Safety

The planning process centers on selecting an appropriate material and placement configuration, and determining the procedures and equipment to use based on the existing and future roadway conditions.

The site-specific climatic conditions during treatment operations can occasionally influence which procedures or materials should be used. For instance, in areas where moisture or cold temperatures present scheduling problems, the use of a heat lance may help expedite operations.

Overall climatic conditions must also be considered in deciding which materials and procedures to use. Hot climates necessitate the use of materials that will not significantly soften and track at high temperatures. Very cold climates, on the other hand, will generally require materials that retain good flexibility at low temperatures.

Highway classification and traffic characteristics are important from two standpoints. First, highway geometrics and traffic levels may be such that overall safety during installation is greatly compromised. Applying longer lasting treatments reduces the number of subsequent applications. Fewer applications mean less time on the roadway and increases safety.

Second, if a material is to be placed in an *overband* configuration, consideration must be given to the amount of traffic expected over the material and whether or not snowplows, particularly direct-contact plows, are used. The most durable, yet flexible, material would be desirable on roads where traffic levels are medium or high (average daily traffic [ADT] > 5,000 vehicles/day) and/or snowplows are operated.

Crack characteristics, such as width, movement, and edge deterioration, will also influence which materials and procedures should be used. Some of these characteristics, along with crack density, are needed for estimating the amount of material required for the project.

3.2 Selecting a Sealant or Filler Material

There are many different crack treatment material products on the market today, each with distinct characteristics. The products essentially comprise three material families and are often grouped by material type, according to their composition and manufactured process. The principal material families and types are as follows:

- Cold-applied *thermoplastic* materials
  - Liquid asphalt (emulsion, cutback)
  - Polymer-modified liquid asphalt

- Hot-applied thermoplastic materials
  - Asphalt cement
  - Mineral-filled asphalt cement
  - Fiberized asphalt
  - Asphalt rubber
  - Rubberized asphalt
  - Low-modulus rubberized asphalt
- Chemically cured *thermosetting* materials
  - Self-leveling silicone

Asphalt cement and liquid asphalt possess little, if any, flexibility and are very temperature susceptible. Hence, they are limited to use as fillers for nonworking cracks. Similarly, since additives such as mineral fillers and fibers provide minimal elasticity to asphalt and do not significantly affect temperature susceptibility, mineral-filled and fiberized asphalts are most appropriate in crack-filling operations.

The addition of rubber polymer to liquid or heated asphalt generally improves field performance because it imparts flexibility to the asphalt. The degree of flexibility basically depends on the type and nature of the asphalt, the percentage of vulcanized rubber used, and how the rubber is incorporated into the asphalt (i.e., mixed or melted in). Other polymers are often incorporated into asphalt, either exclusively or along with rubber, to increase resilience. The following is the general increasing trend in performance characteristics of polymer-modified asphalts:

Polymer-Modified Liquid Asphalt → Asphalt Rubber → Rubberized Asphalt → Low-Modulus Rubberized Asphalt

Chemically cured thermosetting materials are one- or two-component materials that cure by chemical reaction from a liquid state to a solid state. This type of material has been used in asphalt concrete pavement only in recent years. Self-leveling silicone is a one-component, cold-applied sealant that requires no tooling since it is self-leveling.

Table 4 provides general information about each material type, including examples of products, applicable specifications, and cost ranges. It should be noted that asphalt cutback is not listed in this table. This material is used rarely today because it presents environmental hazards; it will not be discussed in this manual.

The first step in selecting a material is to identify the key properties that a material must possess to be efficiently placed and perform successfully in the conditions provided for the time desired. Several of the more desirable properties include the following:

- Short preparation time
- Quick and easy to place (good workability)
- Short cure time
- *Adhesiveness*
- *Cohesiveness*
- Resistance to softening and flow
- *Flexibility*
- *Elasticity*
- Resistance to aging and weathering
- *Abrasion* resistance

Table 5 illustrates the material types that possess most of the above properties. As can be seen, the rubberlike properties associated with the materials on the right make them good choices for sealing working cracks, whereas the preparation and installation attributes of emulsion and asphalt cement make them desirable for crack filling.

Table 4. Summary of AC crack treatment materials

Material Type	Example Product(s)	Applicable Specification(s)	Recommended Application	Cost Range, $/lb[a]
Asphalt Emulsion	CRS-2, CMS-2, HFMS-1	ASTM[b] D977 & AASHTO[c] M140, ASTM D2397 & AASHTO M208	Filling	0.08 to 0.15
Polymer-Modified Emulsion	Elf CRS-2P, Hy-Grade Kold Flo	ASTM D977 & AASHTO M140, ASTM D2397 & AASHTO M208	Filling (possibly sealing)	0.40 to 0.55
Asphalt Cement	AC-10, AC-20	ASTM D3381, AASHTO M20, AASHTO M226	Filling	0.08 to 0.15
Mineral-Filled Asphalt Cement	-	Various state specs	Filling	0.15 to 0.25
Fiberized Asphalt	Hercules Fiber Pave® + AC, Kapejo BoniFibers® + AC	Manufacturer's recommended specs	Filling	0.15 to 0.25
Asphalt Rubber	Koch 9000, Crafco AR2	Various state specs, ASTM D 5078	Sealing (possibly filling)	0.20 to 0.30
Rubberized Asphalt	Meadows #164, Koch 9001, Crafco RoadSaver® (RS) 211	ASTM D1190 & AASHTO M173 & Fed SS-S-164	Sealing	0.25 to 0.40
	Meadows Hi-Spec,® Koch 9005, Crafco RS 221	ASTM D3405 & AASHTO M301 & Fed SS-S-1401	Sealing	0.30 to 0.50
Low-Modulus Rubberized Asphalt	Meadows XLM, Koch 9030, Crafco RS 231	Various state-modified ASTM D 3405 specs	Sealing	0.35 to 0.65
Silicone	Dow Corning® 890-SL	Manufacturer's recommended specs	Sealing	2.30 to 2.50

[a] Based on 1991 and 1992 costs; 1 lb = 0.454 kg

[b] ASTM - American Society for Testing and Materials

[c] AASHTO - The American Association of State Highway and Transportation Officials

Table 5. Properties associated with various material types

Property	Material Type[a]							
	Asphalt Emulsion	Polymer-Modified Emulsion	Asphalt Cement	Fiberized Asphalt	Asphalt Rubber	Rubberized Asphalt	Low-Modulus Rubberized Asphalt	Self-Leveling Silicone
Short Preparation	✓	✓						✓✓
Quick & Easy to Place	✓	✓	✓✓	✓✓	✓✓	✓✓	✓✓	
Short Cure Time			✓✓	✓✓	✓✓	✓✓	✓✓	✓
Adhesiveness	✓✓	✓	✓✓	✓	✓	✓	✓	✓
Cohesiveness					✓	✓	✓✓	✓
Resistance to Softening and Flow (cured state)		✓			✓	✓	✓✓	✓✓
Flexibility		✓			✓	✓	✓✓	✓✓
Elasticity		✓			✓	✓	✓	✓✓
Resistance to Aging and Weathering						✓	✓	✓✓
Resistance to Tracking and Abrasion					✓	✓✓	✓	

[a] ✓ Applicable; ✓✓ Very Applicable

Table 5 shows which type(s) of material will best meet the demands of the project. For instance, if the material to be used must be moderately flexible, resistant to tracking and abrasion, and rapidly installable, then a rubberized asphalt should be considered. If the project requires a material that is adhesive, resistant to abrasion, rapidly installable, and quick to cure, then asphalt rubber or rubberized asphalt should be considered.

Actual field performance should always be considered when determining which material to use. Assuming adequate placement, filler materials placed in nonworking cracks generally last between 1 and 4 years, while sealant materials placed in working cracks last between 2 and 6 years. It is recommended that maintenance planners keep abreast of information about the local performance of specific materials.

In order to obtain the maximum benefit from each maintenance dollar spent, all costs associated with installing a material must be added and compared with the service life of the material. This is referred to as a cost-effectiveness analysis. Again, table 4 provides general information on material purchasing costs. Cost-effectiveness analysis is discussed in greater detail in section 3.6.

3.2.1 Laboratory Testing

Laboratory testing of the selected sealant or filler material is highly recommended. Testing ensures that the material obtained exhibits the properties for which it was selected.

The testing process begins with material sampling. As a general rule, a minimum sample of 5 to 10 lb (2.2 to 4.5 kg) should be taken from each batch, or lot, of material shipped. These samples should then be submitted for testing at an agency-approved testing laboratory prior to placement.

Laboratory testing should be conducted in full accordance with the test methods specified for the material. Variations in testing parameters, such as rates, temperatures, and specimen sizes, can significantly affect test results.

If the material does not meet all applicable specifications, it should be rejected. On the other hand, good performance does not guarantee material compliance with specifications. **Proper installation is a must, no matter how good the material!**

For illustrations of commonly used test criteria for the major sealant material types, refer to appendix A.

3.3 Selecting a Placement Configuration

Sealant and filler materials can be placed in cracks in numerous configurations; the most common are shown in figure 6. These placement configurations are grouped into four categories:[3]

1. Flush-fill
2. Reservoir
3. Overband
4. Combination (reservoir and overband)

In the flush-fill configuration, material is simply dispensed into the existing, uncut crack, and excess material is struck off. Configuration A in figure 6 illustrates the flush-fill configuration.

In a reservoir configuration, material is placed only within the confines of a cut crack (i.e., *crack reservoir*). The material is placed either flush with or slightly below the pavement surface. Configurations D, F, H, J, and K in figure 6 are reservoir-type configurations.

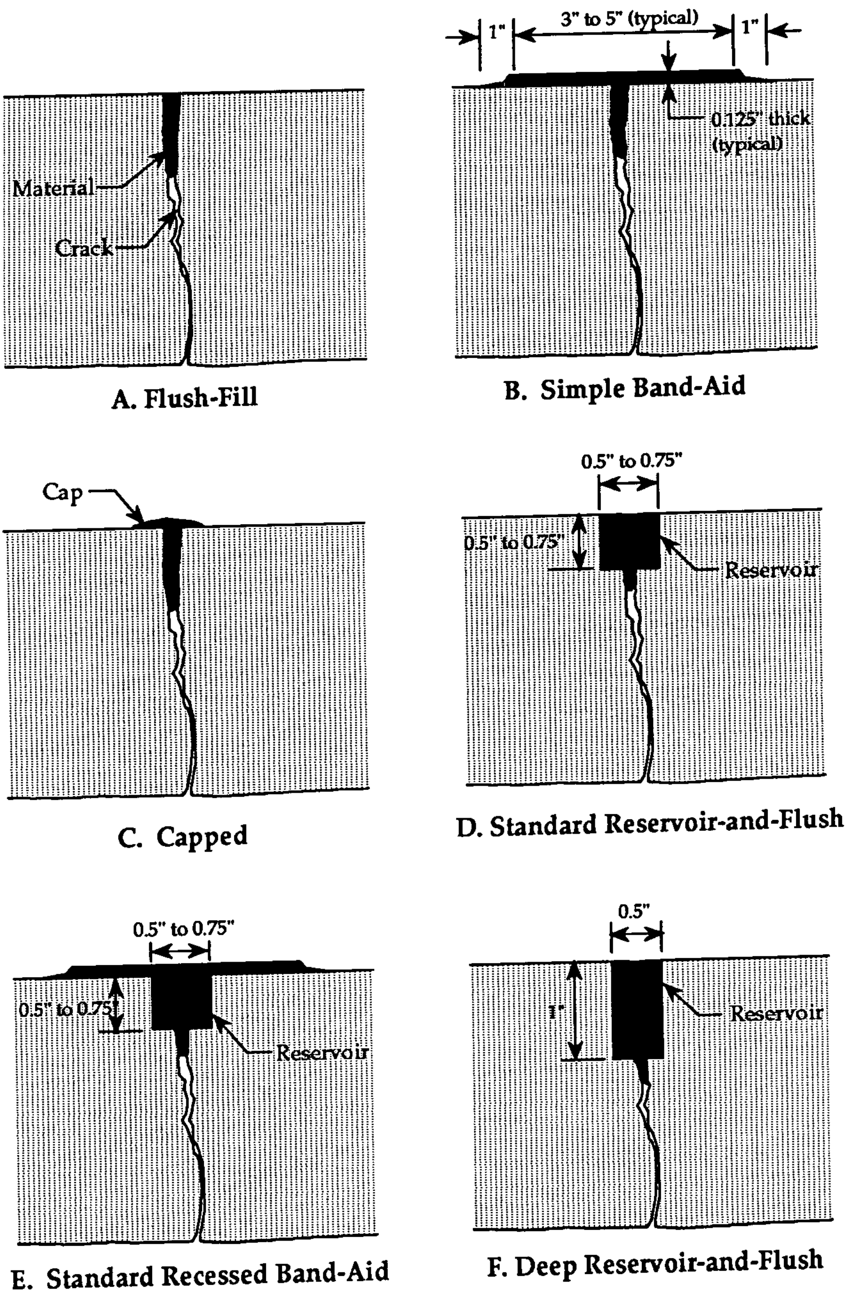


Figure 6. Material placement configurations

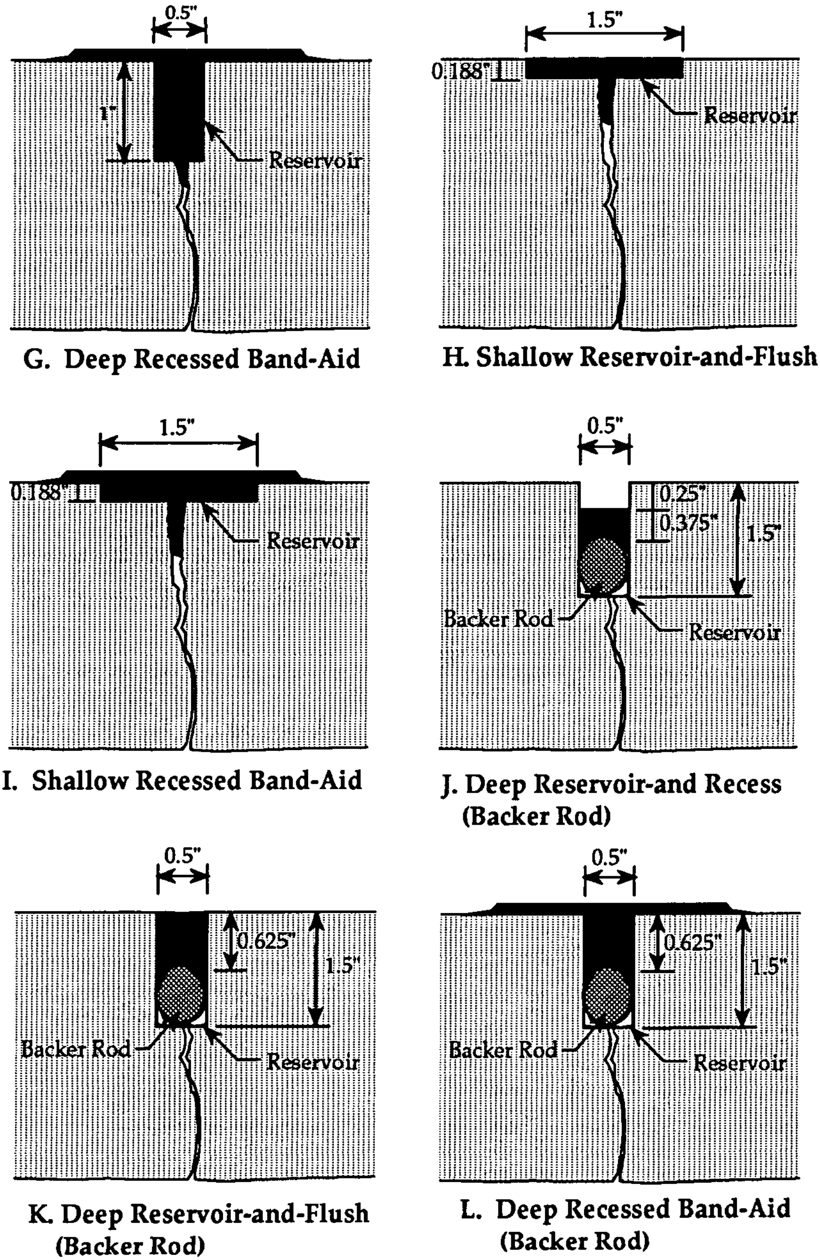


Figure 6. Material placement configurations (cont.)

In an overband configuration, the material is placed into and over an <u>uncut</u> crack. If the material over the crack is shaped into a band using a squeegee, then the simple *band-aid* configuration is formed (configuration B). If the material over the crack is left unshaped, then the *capped* configuration is created (configuration C).

A combination configuration consists of a material placed into and over a <u>cut</u> crack. A squeegee is used to shape the material into a band that is centered over the crack reservoir. Configurations E, G, I, and L in figure 6 are combination-type configurations.

Individual configurations are based on four controlling variables.

1. Type of application
   a. Direct—Material applied directly to crack channel
   b. Bond-breaker—Backer material placed at bottom of crack reservoir prior to material installation in order to prevent three-sided adhesion (i.e., bonding by material to crack reservoir bottom and sidewalls)
2. Type of crack channel
   a. Uncut
   b. Cut—Router or saw used to create uniform crack reservoir
3. Strike-off or finishing characteristics
   a. Recessed
   b. Flush
   c. Capped
   d. Band-aid
4. Dimensions of crack reservoir and/or overband

Nearly all sealing and filling operations have the material applied directly to the crack channel (configurations A through I). Occasionally, however, a bond-breaker material, such as a polyethylene foam backer rod, is placed at the reservoir bottom of a working crack prior to sealant application (configurations J, K, and L). The backer rod prevents sealant material from running down into the crack during application and also from forming a three-sided bond with the reservoir perimeter. As a result, the sealant's potential performance is enhanced.

Sealant shape, particularly for reservoir configurations, also influences performance. It is the primary design consideration and is often dealt with in terms of shape factor. The shape factor is defined as the ratio between the width and depth of the sealant.[4] In direct applications, shape factor is controlled solely by the crack-cutting operation (i.e., cutting width and depth). In backer rod applications, shape factor is controlled by both the cutting operation and the depth to which the backer rod is placed.

Current recommendations for both direct and bond-breaker applications are that rubber-modified asphalt sealants be given a shape factor of 1 and silicone sealants a shape factor of 2. Generally, seals with smaller shape factors risk adhesion loss, while those with larger shape factors have increased resistance to adhesion loss.

Bond-breaker application should be considered only when the following two factors apply.

1. The costs of installing backer rod are anticipated to be lower than the cost-benefits of improved performance.
2. Working cracks are relatively straight (as with joint reflection cracks) and are accompanied by very little edge deterioration.

Most hot-applied, rubber-modified sealants are recommended for direct application; the increased cost of using backer rod with these materials is not justified. Silicone is perhaps the only material recommended for placement with backer rod.

A meandering crack is often difficult to follow accurately with cutting equipment. Portions of the crack may occasionally be missed, resulting in two adjacent channels. This presents the dilemma of whether to seal both the cut and uncut crack segments or cut the missed crack segment too and seal both reservoirs. A similar dilemma arises with secondary cracks along the primary crack.

Routers and saws are usually equipped with controls for varying the depth of cut, and the width setting can normally be adjusted manually. Backer rod can be placed in deep reservoirs (1.0 to 1.5 in [25 to 38 mm]) to a depth that allows for the desired shape factor. This depth normally varies between 0.5 and 0.75 in (12.7 and 19.1 mm). The backer rod should be about 25 percent wider than the width of the crack reservoir for it to maintain its vertical position and provide proper shape for the material.

The decision of whether or not to overband a sealant or filler material depends primarily on the material being used. Some materials, such as silicone and emulsion, simply must not come in contact with traffic. Also, some materials wear away more easily under traffic than others.

If overbanding of hot-applied, rubber-modified asphalt is desired, it also must be decided if the material will be shaped into a band-aid or left as a capped configuration. The latter process generally requires one less laborer, but possibly at the sacrifice of treatment effectiveness. This is because shaping with a squeegee or dish attachment helps in establishing a "hot bond" for the entire band. In capped configurations, the material may continue to flow and level out after being applied. Bonds occurring as a result of this self-leveling are likely to be weaker because the material will have decreased in temperature.

The dimensions of the band-aid are typically 3 to 5 in (76 to 127 mm) wide and 0.125 to 0.188 in (3.2 to 4.8 mm) thick. The simple band-aid configuration (configuration B) evolved out of a desire to make application quick and easy by eliminating crack-cutting operations. The recessed band-aid configuration was devised to improve the performance of reservoir-type configurations through the addition of the band as a wearing surface.

Selecting a placement configuration is an involved process. Table 6 offers a few basic considerations to aid the planner.

3.4 Selecting Procedures and Equipment

Crack treatment consists of at least two and up to five steps, depending on the type of treatment (sealing or filling), treatment policy, and available equipment. These steps are:

1. Crack cutting (i.e., routing or sawing)
2. Crack cleaning and drying
3. Material preparation and application
4. Material finishing/shaping
5. Blotting

Steps 1, 4, and 5 above are considered optional. Crack cutting is rarely done in filling operations but frequently done in sealing operations. In regions with significant annual temperature variations, typical of many northern states, crack cutting is often performed in order to achieve material shape factors that can provide added flexibility for withstanding high crack movements.

Table 6. Placement configuration considerations

Consideration	Applicability
Type and Extent of Operation	Most filling operations and some sealing operations omit crack-cutting operation. Many northern states find crack cutting necessary and/or desirable.
Traffic	Overband configurations experience wear and subsequent high tensile stresses directly above the crack edges, leading to internal rupture.
Crack Characteristics	Overband configurations are more appropriate for cracks with a considerable amount of edge deterioration (> 10% of crack length), because the overband simultaneously fills and covers the deteriorated segments in the same pass.
Material Type	Materials such as emulsion, asphalt cement, and silicone must not be exposed to traffic because of serious tracking or abrasion problems.
Desired Performance	For long-term sealant performance, flush or reservoir configurations and recessed band-aid configurations should be considered.
Aesthetics	Overband and combination configurations detract from the appearance of the pavement.
Cost	Omission of crack-cutting operation reduces equipment and labor costs. Combination configurations cost more than reservoir configurations because they use significantly more material.

Most crack treatment programs use squeegees to finish or shape the material at the surface; capped and recess configurations require no finishing.

Finally, blotting, in which a temporary covering such as toilet paper, sand, or limestone dust is placed directly on top of the material, may be necessary to prevent tracking. Asphalt emulsions and hot-applied materials placed in overband configurations and prematurely subjected to traffic are prime candidates for blotting.

Many types and brands of equipment are available for crack treatment operations. Table 7 lists the types of equipment commonly used, examples of equipment manufacturers, and general recommendations concerning each piece of equipment. Table 8 provides additional information about the manpower requirements and typical production rates associated with each procedure.

3.4.1 Crack Cutting

Crack cutting is done with routers or saws, as illustrated in figures 7 and 8. However, because crack cutting can inflict additional damage on the pavement and is often the slowest activity in sealing operations, it is desirable to use a high-production machine that follows cracks well and produces minimal spalls or fractures.

The vertical-spindle router is perhaps the least damaging and most maneuverable cutting machine; however, its production rate is quite low. Rotary-impact routers are much more productive than vertical-spindle routers but, depending on the type of cutting bit used, can cause considerably more damage. Carbide router-bits are highly recommended over steel router-bits.

Table 7. Crack treatment equipment characteristics and recommendations

Operation	Type of Equipment	Example Equipment	Recommendations[a]
Crack Cutting	Vertical-spindle router	Berry	Use only with sharp, carbide or diamond router-bits
	Rotary-impact router	Crafco, Tennant	Use only with sharp, carbide router-bits
	Random-crack saw	Cimline, Target	Use only on fairly straight cracks Diamond-blade saw—8-in maximum diameter
Crack Cleaning and Drying	Blowers (backpack and power-driven)	Toro, Maintenance Inc.	**Not Recommended**—Insufficient blast velocity (200 to 330 ft/s)
	Air compressor	Ingersoll-Rand, Worthington, Joy	Equipped with oil and moisture filters Pressure—90 lb/in^2 minimum Flow—150 ft^3/min minimum Velocity—3250 ft/s minimum
	Hot air lance	Linear Dynamics, Seal-All, Cimline, L/A	Velocity—2000 ft/s minimum Temp—2500°F minimum No direct flame on pavement Highly Recommended Velocity—3000 ft/s minimum Temp—3000°F minimum
	Sandblaster	Clemco, Ingersoll-Rand, P.K. Lindsay	Acceptable air compressor (minimum 90 lb/in^2 pressure and 150 ft^3/min) Minimum 1-in inside diameter lines and 0.25-in diameter nozzle
	Wirebrush	Crafco, Berry	Do not use with worn brushes Not recommended for cleaning previously treated cracks as there is a tendency to smear material

Table 7. Crack treatment equipment characteristics and recommendations (cont.)

Operation	Type of Equipment	Example Equipment	Recommendations
Material Installation	Pour-pots	Maintenance Inc.	Not recommended for production operations
	Asphalt distributor	Western, Rosco, LeeBoy	Not suitable for fiber- or rubber-modified asphalt materials
	Melter-applicator	Crafco, Cimline, Aeroil, Berry, Western Industries, Ghausse, Stepps, Bearcat	Direct-heat kettles not suitable for fiber- or rubber-modified asphalt materials Indirect-heat kettles should be equipped with: * Double-boiler, mechanical agitator with separate automatic temperature controls for oil and melting chamber * Sealant heating range to 450°F * Full-sweep agitator * Accurately calibrated material and heating oil temperature gauges
	Backer rod installation tools	Control Tool, O.J.S. Machines, Sealing Contractors	Maintains proper recess Does not damage backer rod
	Silicone pump and applicator	Pyles-Graco Inc, Aro Corp, Semco	Flow Rate—0.4 gal/min minimum Hose lined with teflon; all seals and packing made with teflon
Material Finishing	Squeegee	Crafco, janitorial supply stores	Heavy-duty, industrial U- or V-shaped

[a] 1 in = 25.4 mm; 1 ft = 0.305 m; 1 lb/in^2 = 6.895 kPa; °C = 5/9*(°F - 32); 1 gal/min = 0.063 L/s

Table 8. Typical manpower requirements and production rates for crack treatment operations

Operation	Equipment	Manpower		Approximate Productivity, ft/min[a]
		Equipment	Driver	
Crack Cutting	Routing (vertical-spindle router)	1	—	1.5 to 2.5
	Routing (rotary-impact router)	1	—	12 to 15
	Sawing (diamond-blade crack saw)	1 to 2	—	4 to 7
Crack Cleaning and Drying	Airblasting (blowers)	1	—	12 to 18
	Airblasting (compressed air)	1	1	10 to 15
	Hot airblasting (hot compressed-air lance)	1	1	5 to 10
	Sandblasting (sandblaster)	2 to 3	1	3 to 4 (2 passes)
	Wirebrushing (wirebrush)	1	—	9 to 12
Material Installation	Drums and pour-pots	2 to 3	1	5 to 10
	Asphalt distributor with wand and hose	2	1	15 to 25
	Melter-applicator	2	1	15 to 25
	Backer rod	2	—	9 to 15
	Silicone pump and applicator	2	1	6 to 12
Material Finishing	U- or V-shaped squeegee	1	—	25 to 35
Material Blotting	Sand	1 to 2	0 to 1	12 to 18
	Toilet paper	1	—	30 to 45

[a] 1 ft = 0.305 m

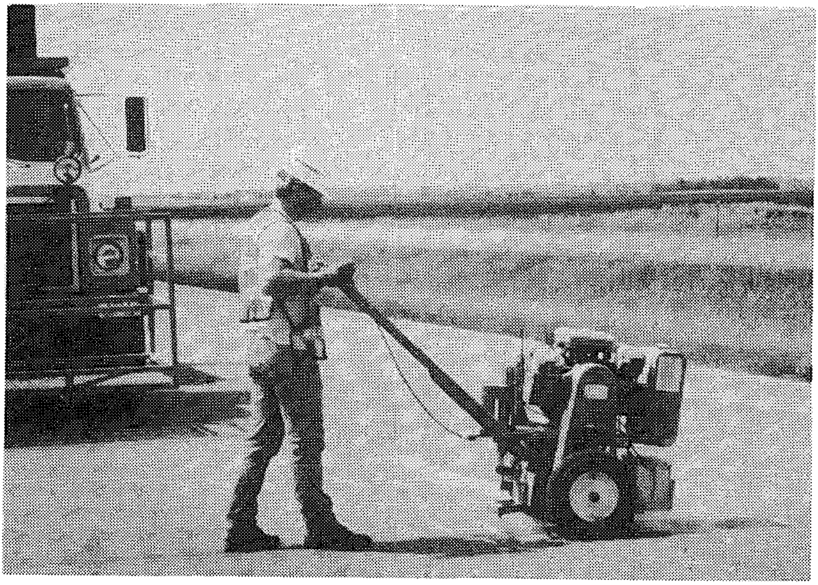


Figure 7. Rotary-impact router

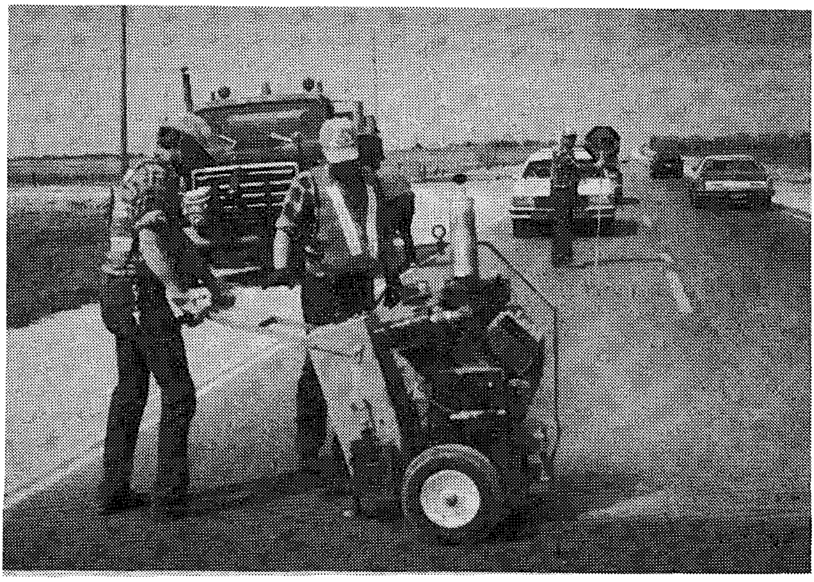


Figure 8. Diamond-blade crack saw

A random-crack saw with 6- to 8-in (152- to 203-mm) diameter diamond blades can follow meandering cracks moderately well. While its cutting rate is not nearly as high as the rotary-impact router, it provides a more rectangular reservoir with smoother walls and a higher percentage of aggregate surface area.

3.4.2 Crack Cleaning and Drying

Crack preparation procedures are the techniques used to clean and/or dry crack channels to attain the best conditions possible for the material to be placed. It is perhaps the most important aspect of sealing and filling operations because a high percentage of *treatment failures* are adhesion failures that result from dirty and/or moist crack channels.

The four primary procedures used in preparing crack channels are as follows:

1. Airblasting
2. Hot airblasting
3. Sandblasting
4. Wirebrushing

Airblasting

Airblasting is done with one of two types of equipment:

- Portable backpack or power-driven blowers
- High-pressure air compressors with hoses and wands

Backpack and power-driven blowers are generally used to clean pavement surfaces prior to sealcoating. However, they have also been used to clean cracks. These blowers deliver high volumes of air but at low pressures. As a result, blast velocity is generally limited to between 250 and 350 ft/s

(76 and 107 m/s). Although blowers require only one laborer and provide better mobility, the high-pressure (>100 lb/in^2 [690 kPa]) capabilities of compressed-air units make them more desirable than blowers for crack cleaning.

High-pressure airblasting (figure 9) is fairly effective in removing dust, debris, and some loosened AC fragments. However, it is not nearly as effective in removing laitance or in drying the crack channel.

Compressed-air units should have a minimum blast pressure of 100 lb/in^2 (690 kPa) and a blast flow of 150 ft^3/min (0.07 m^3/s). In addition, compressed-air units equipped with oil- and moisture-filtering systems are highly recommended, as the introduction of oil or moisture to the crack channel can seriously inhibit bonding of the sealant to the sidewall.

Hot Airblasting

Hot airblasting is performed with a hot compressed-air (HCA) lance, or heat lance, connected to a compressed-air unit, as shown in figure 10. This form of crack preparation is quite effective at removing dirt, debris, and laitance. Moreover, the extreme heat it delivers to a crack provides two unique benefits. First, crack moisture is quickly dissipated, thereby improving the potential for bonding of the sealant or filler material. Second, assuming the material installation operation follows closely behind the hot airblasting operation, the heated crack surface can enhance the bonding of hot-applied sealant or filler materials.

There are a number of HCA lance models available on the market today, each with its own heat and blast capacities and operational control features (push-button ignition, wheels, balancing straps, etc.). Minimum requirements for these units are a 2500°F (1370°C) heat capacity and a 2000 ft/s (610 m/s) blast velocity. Heat lances with high heat and

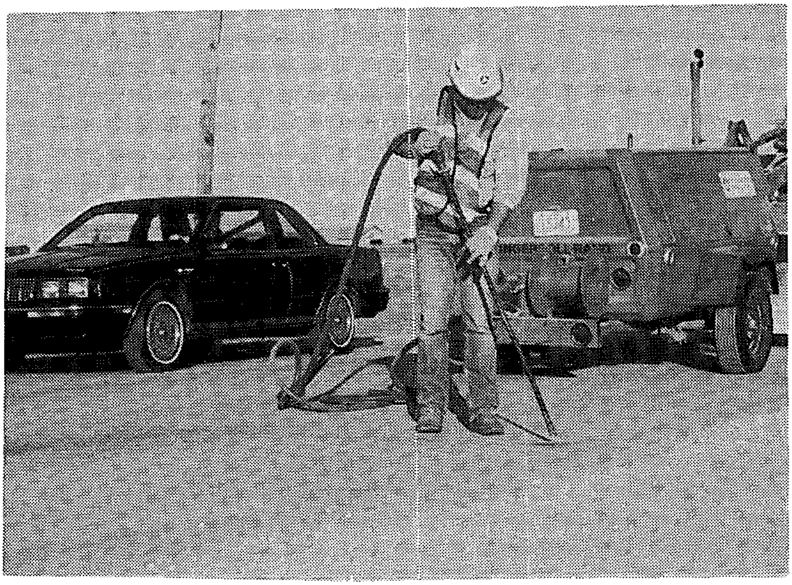


Figure 9. High-pressure airblasting using compressed air

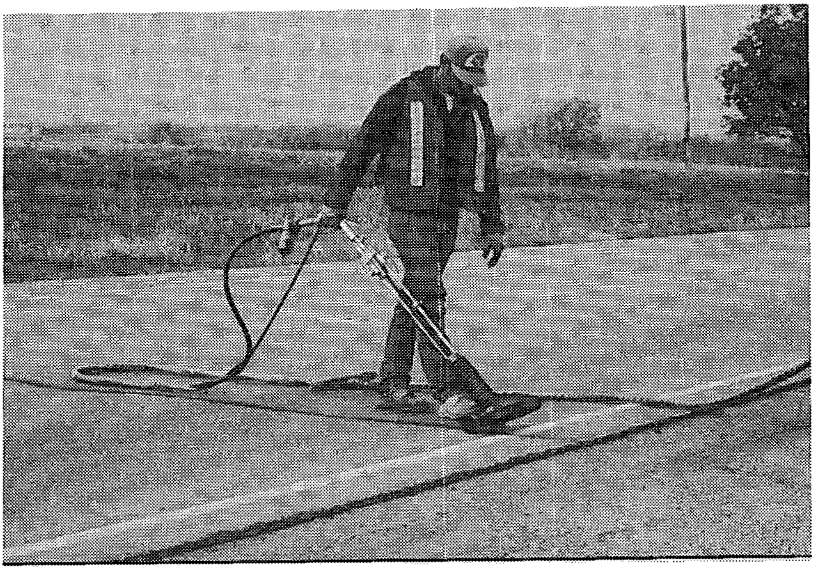


Figure 10. Hot airblasting using HCA (heat) lance

blast velocity (3000°F [1650°C] and 3000 ft/s [915 m/s]) are preferred for production operations. However, caution must be exercised with these units to avoid burning the asphalt concrete. Finally, direct-flame torches should never be used, and air compressors used in hot airblasting operations should be equipped with oil- and moisture-filter systems.

Sandblasting

Sandblasting is a labor-intensive operation that is quite effective at removing debris, laitance, and loosened AC fragments from the sidewalls of sawn cracks. The procedure, depicted in figure 11, leaves a clean, textured surface that is ideal for bonding.

Sandblasting equipment consists of a compressed-air unit, a sandblast machine, hoses, and a wand with a venturi-type nozzle. A second air compressor is often necessary for follow-up cleaning after the sandblasting operation.

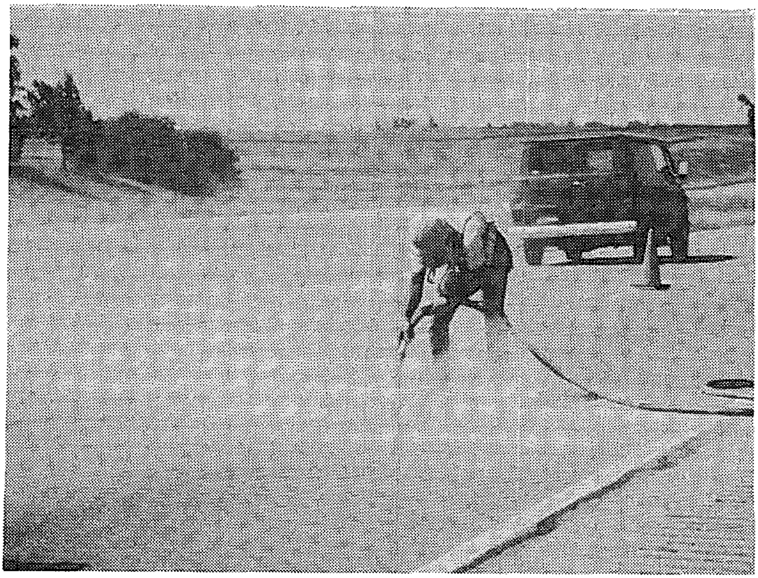


Figure 11. Sandblasting operation

The compressed-air supply is the most critical part of a sandblasting operation. At least 90 lb/in^2 (620 kPa) of pressure and 150 ft^3/min (0.07 m^3/s) of oil- and moisture-free air volume should be provided. Large air supply and sandblast hoses should also be used to reduce friction losses and resulting pressure drops. A minimum of 1-in (25-mm) inside diameter lines and a 0.25-in (6.4-mm) diameter nozzle orifice size are recommended.

Wirebrushing

Occasionally, sawn or routed cracks are cleaned using mechanical, power-driven wirebrushes in conjunction with some form of compressed air. Depending on the brush and bristle characteristics, this combination is quite effective at removing debris lodged in the crack reservoir, but not as effective at removing laitance and loosened AC fragments from the crack sidewalls.

Wirebrushes are available commercially, with and without built-in airblowers. Some agencies have had success modifying pavement saws by removing the sawblades and attaching wirebrush fittings to the rotor of the machine.

3.4.3 Material Preparation and Application

Bond-Breaker Installation

The simplest and easiest tool for placing backer rod is one equipped with two roller wheels and an adjustable central insertion wheel, as illustrated in figure 12. This type of tool generally accommodates a threaded broom handle and comes with insertion wheels of various widths.

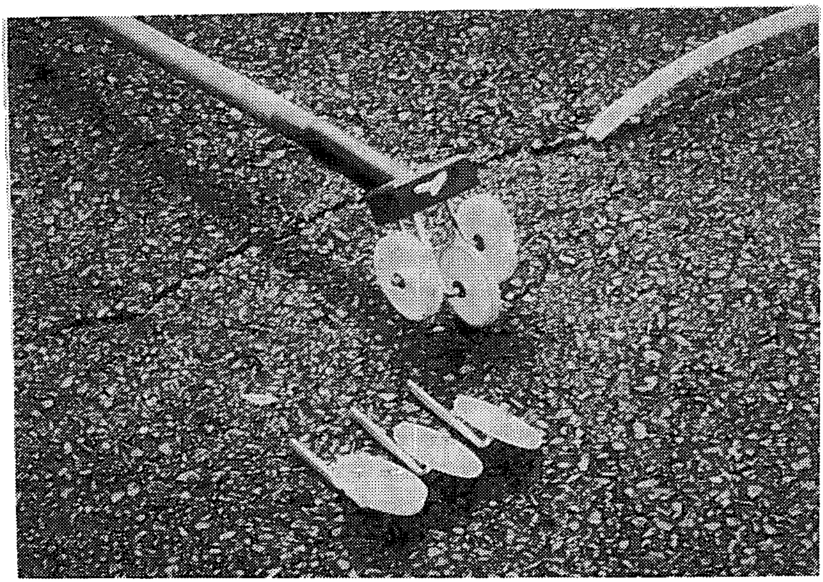


Figure 12. Backer-rod installation tool

Cold-Applied Thermoplastic Materials

Emulsion materials can be prepared and applied in various ways. They can be loaded into distributors for partially heated application or kept in drums for unheated application. Distributors are often equipped with pressure or gravity hoses for wand application. Hand-held or wheeled pour-pots may be used to apply heated or unheated emulsion in the cracks.

Deciding which method to use for preparing and installing emulsion depends primarily on the availability of equipment. However, the need for partial-heating and the size of the job must also be considered.

Material heating for hot-applied thermoplastics is usually done with an asphalt distributor or an asphalt kettle/melter, similar to that shown in figure 13. Unmodified asphalt materials, such as asphalt cement, are usually heated and placed using distributors or direct-heat kettles. These units typically burn propane gas for heat, and the heat is applied directly to the melting vat containing the asphalt material. The direct-heat system is not recommended for heating modified asphalt materials because it can cause uneven heating or overheating of the asphalt, particularly when no agitation devices are available.

Rubber- and fiber-modified asphalt materials <u>must</u> be heated and mixed in indirect-heat, agitator-type kettles. These machines burn either propane or diesel fuel, and the resulting heat is applied to a transfer oil, which surrounds a double-

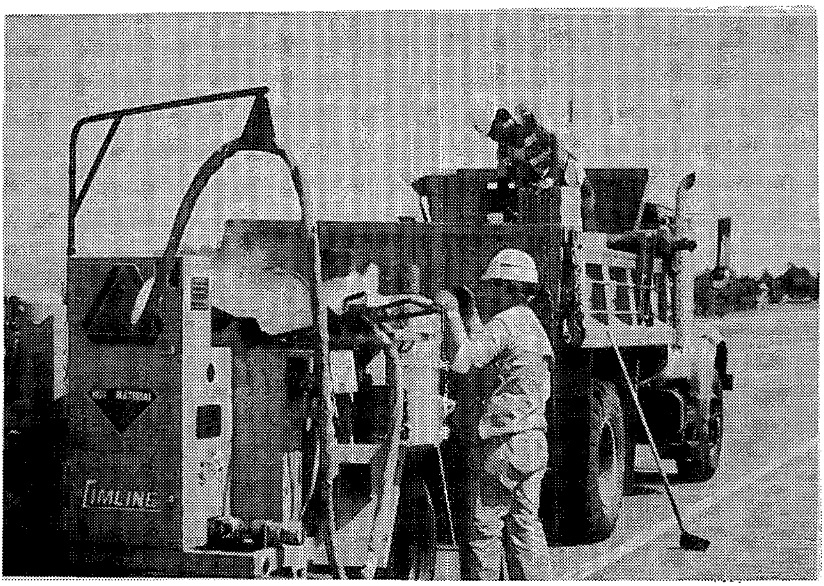


Figure 13. Asphalt kettle with pressure applicator

jacketed melting vat containing the treatment material. This indirect method of heating is safer and provides a more controlled and uniform way to heat the material. Agitation devices are usually standard equipment on these units.

As with other crack treatment equipment, several types and sizes of asphalt kettles are available and in use. Some items that should be considered when determining which kettle to use include the following:

- Type of material
- Size of job
- Constraints on preparation time
- Air temperature during preparation
- Safety

Rubber-modified asphalt sealants can be adequately heated and applied by most indirect-heat kettles equipped with pressure applicators. However, because of their thick consistency, fiberized asphalt materials often require the use of kettles with heavy-duty application pumps, large hoses, and full-sweep agitation equipment. A 20-hp (14.9-kW) engine is generally recommended for fiberized applications along with a 2-in (51-mm) recirculating pump and discharge line.

For small jobs, a small-capacity kettle (100 gal [378 L] maximum) is desirable. Since it is generally recommended that kettles be filled to at least one-third of their capacity to avoid overheating the material and allow effective operation, large-capacity kettles would not be appropriate because more material would be heated than necessary.

Unless the kettle operator begins work several hours prior to normal starting time, material heating time can substantially cut into operational time. This is particularly true in cold weather and when using large kettles. Depending on the amount of material prepared, large kettles (400 gal [1515 L] plus) may take as long as 3 hours to bring a material to application temperature. Small kettles (50 to 100 gal [190 to 380 L]) usually take between 60 and 75 min.

In general, kettles should allow the operator to regulate material temperatures up through 425°F (218°C). Accurate thermostats should monitor both the material and heating oil temperatures, and these thermostats should control the operation of the burners. The kettle should allow recirculation of materials back into the vat during idle periods. Insulated applicator hoses and wands are recommended, and hoses should meet or exceed the kettle manufacturer's specifications.

Cold-Applied Thermosetting Materials

Silicone pumps must be capable of directly attaching to the original material container, typically a 5- or 55-gal (19- or 208-L) drum. Pumps and applicators should provide sealant to the crack at a rate that does not limit the operator; 0.4 gal/min (0.025 L/s) is recommended as a minimum flow rate. Teflon-lined application hoses and seals are also recommended because they are able to prevent silicone from curing in the pump or hose.

3.4.4 Material Finishing/Shaping

Material finishing can be accomplished in two ways. First, various sizes of dish-shaped attachments are available that can be connected to the end of the application wand for one-step application and finishing. Second, industrial rubber squeegees, like the one shown in figure 14, can be used behind the material applicator to provide the desired shape.

Figure 14. Industrial squeegee molded into a "U" shape

The one-step method requires one less worker but often does not provide as much control in finishing as the squeegee method, especially for overband configurations.

3.4.5 Material Blotting

The equipment necessary for blotting depends on the type of blotter material to be used. Sand generally requires a truck or trailer on which it can be stored and shovels for spreading.

Toilet paper can often be loaded on the same truck with the prepackaged sealant blocks. Rolls of toilet paper can then be placed on a modified paint roller (equipped with a long handle) for easy application.

3.5 Estimating Material Requirements

Although maintenance agencies frequently purchase a year's supply of one or two materials, reliable estimates of material necessary for a particular project can be very useful in attempting to use the right material in each situation. The worksheet in figure 15 should help the crack treatment planner compute how much material to acquire for a project. An example calculation is provided in appendix B.

3.6 Cost-Effectiveness Analysis

While performance is important, cost-effectiveness is often the preferred method of determining which materials and procedures to use. Obviously, a treatment that costs $5/ft ($16.40/m) in-place and performs adequately for 5 years is more desirable than a treatment that costs $10/ft ($32.80/m) in-place and performs for the same amount of time. However, this philosophy has limits. For instance, it would be impractical to treat a particular pavement with asphalt cement every other month even if this was the most cost-effective solution.

The worksheet in figure 16 should assist the planner in computing treatment cost-effectiveness. An example of how to compute cost-effectiveness with this worksheet is provided in appendix C.

Determining Material Quantity Requirements

A. Length of section to be treated	______ ft
B. Length of sample segment inspected	______ ft
C. Amount (length) of targeted crack in sample segment inspected	______ lin ft
D. Amount (length) of targeted crack in section [D = C × (A/B)]	______ lin ft
E. Average estimated width of targeted crack	______ in
F. Type of material configuration planned	______
G. Cross-sectional area of planned configuration	______ in^2
H. Total volume in ft^3 of targeted crack to be treated [H = (G/144) × D]	______ ft^3
I. Total volume in gal of targeted crack to be treated [I = H × 7.48 gal/ft^3)	______ gal
J. Unit weight of planned treatment material in lb/gal	______ lb/gal
K. Theoretical amount of material needed in lb [K = J × I]	______ lb
L. Total amount of material recommended with ___ percent wastage [L = 1.___ × K]	______ lb

Figure 15. Worksheet for determining material quantity requirements

Treatment Cost-Effectiveness

A. Cost of purchasing and shipping material in \$/lb	\$ ________ /lb
B. Application rate in lb/lin ft (including wastage)	________ lb/lin ft
C. Placement cost (labor and equipment) in \$/day	\$ ________ /day
D. Production rate in lin ft of crack per day	________ lin ft/day
E. User delay cost in \$/day	\$ ________ /day
F. Total installation cost in \$/lin ft $F = (A \times B) + (C/D) + (E/D)$	\$ ________ /lin ft
G. Interest rate	________ %
H. Estimated service life of treatment in years (time to 50% failure)	________ years
I. Average annual cost in \$/lin ft $I = F \times \left[\frac{G \times (1 + G)^H}{(1 + G)^H - 1} \right]$	\$ ________ /lin ft

Figure 16. Cost-effectiveness computation worksheet

4.0 Construction

Once the most appropriate material and placement procedure are selected, proper field application must be carried out.

The best method for achieving proper application is to ensure that the objective of each step in the crack treatment operation is met. Toward this end, crews should be fully aware of what they are expected to do, and of the importance of what they will be doing. Likewise, supervisors/inspectors must know what to expect as a result of each operation.

This chapter presents the fundamental objective of each operational step and provides general guidance on how the operations should be performed to best meet the objectives. Operational checklists have been prepared to help both crews and supervisors/inspectors monitor work quality. These checklists are provided in appendix D.

4.1 Traffic Control

A vital part of crack treatment operations is traffic control. Whether it's provided as a moving operation or a stationary work zone, good traffic control is necessary to provide a safe working environment for the installation crew, and a safe, minimally disruptive path for traffic.

The appropriate traffic control setups are usually stipulated by department policies. However, a quick survey of the roadway to be treated can help identify special precautions and the need for additional safety equipment during the installation. Flag persons are often needed on operations that encroach into adjacent lanes, particularly on moderately and highly trafficked highways. Such operations often include crack cutting, crack cleaning, and squeegeeing.

4.2 Safety

Another aspect of safety is worker protection from material and equipment hazards. Mandated highway safety attire, such as vests and hard hats, should always be worn by crews and foremen during operations. In addition, crews should be made aware of all safety precautions associated with the particular materials and equipment with which they are working. A more detailed explanation of material and equipment safety is provided in appendix E.

4.3 Crack Cutting

Objective: To create a uniform, rectangular reservoir, centered as closely as possible over a particular crack, while inflicting as little damage as possible to the surrounding pavement.

If crack cutting is to be performed, saw blades or router-bits must be checked for sharpness and sized or spaced to produce the desired cutting width. Most cutting equipment have mechanical or electric-actuator cutting-depth controls and depth gauges for quick depth resetting. The desired cutting depth and corresponding gauge setting should be established prior to formal cutting of cracks.

Regardless of the type of cutting equipment used, every effort should be made to accurately follow the crack while cutting. Even though production may be considerably compromised on meandering cracks, missed crack segments, such as those shown in figure 17, can be minimized, and high performance potential can be maintained. Centering the cut over the crack as much as possible provides added leeway when cutting.

Figure 17. Crack segment missed by cutting equipment

If a secondary crack is encountered along a primary crack, such as that shown in figure 18, a decision must be made as to whether or not to cut it. Two closely spaced channel cuts can significantly weaken the integrity of the AC along that particular segment. A general rule is to cut only secondary cracks spaced farther than 12 in (305 mm) from a primary crack. Secondary cracks closer than 12 in (305 mm) should be cleaned and sealed only.

4.4 Crack Cleaning and Drying

Objective: To provide a clean, dry crack channel, free of loosened AC fragments, in which the crack treatment material and any accessory materials can be placed.

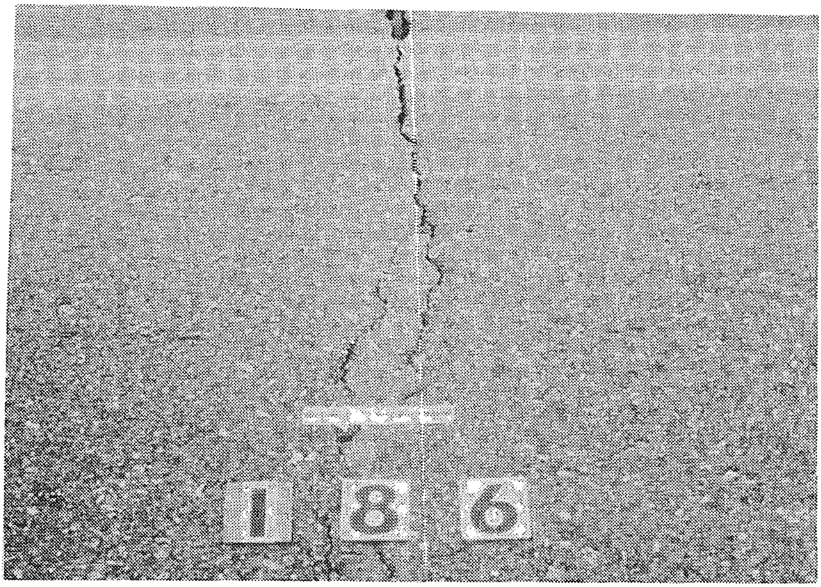


Figure 18. Primary crack accompanied by secondary crack

Crack-cleaning operators are likely to encounter some loosened AC fragments while cleaning, particularly if cracks are cut. Operators should remove these fragments because they will be detrimental to sealant or filler performance. If the cleaning equipment is unable to remove these fragments, they should be removed manually with hand tools.

Finally, the cutting operator should periodically inspect newly created reservoirs for shape and size. Cold temperatures, coarse AC mixes, or dull cutting elements can lead to spalled crack edges and/or highly distorted rectangular channels. These have an adverse effect on material performance.

4.4.1 High-Pressure Airblasting

Because high-pressure airblasting provides no heat and very little drying, it should performed only when the pavement and crack channels are completely dry and when ambient temperatures are above 40°F (4°C) and rising. Furthermore, since many modern air compressors introduce water and oil into the air supply, compressors should be equipped with moisture and oil filters that effectively remove these contaminants.

High-pressure airblasting equipment must be able to provide a continuous, high-volume, high-pressure airstream using clean, dry air. Recommended operational criteria are 90 lb/in^2 (620 kPa) pressure and 150 ft^3/min (4.3 m^3/min) flow.

Operators should make at least two passes of high-pressure airblasting along each crack or crack segment. The first pass dislodges loose and partially loose dirt and debris from the crack channel. The wand should be held no less than 2 in (51 mm) away from the crack. The second pass completely removes all the dislodged crack particles from the roadway and shoulder. In this pass, the wand can be held further away from the pavement surface to make use of a larger blast area.

High-pressure airblasting should be conducted just ahead of the sealing or filling operation. The greater the time interval between these two operations, the more likely dust and debris will resettle in the crack channel.

4.4.2 Hot Airblasting

Unlike high-pressure airblasting, hot airblasting can be used in both ideal and partly adverse conditions for cleaning, drying, and warming cracks. Its most practical applications are: drying damp cracks resulting from overnight dew or a short sprinkle and warming pavement cracks below 50°F (10°C) to promote bonding with hot-applied materials. However, a heat lance should not be used as part of a crack treatment operation being conducted during rainshowers or in saturated pavement conditions.

Heat lances should provide a continuous stream of hot, high-pressure air with no flame at the exit nozzle. As stated earlier, units with high heat and blast capabilities (3000°F [1650°C] and 3000 ft/s [915 m/s]) are recommended but must be used with extreme caution so that the asphalt concrete is not burned.

Like high-pressure airblasting, hot airblasting should be conducted in two steps. The first pass, made along the crack in a steady fashion, should clean and heat, but not burn, the crack sidewalls (and surrounding pavement if material is to be overbanded). The heat lance should be held approximately 2.0 inches (51 mm) above the crack channel. Proper heating is manifested by a slightly darkened color; burning is apparent by a black color and a very gritty texture. The second pass completely removes all the dislodged crack particles from the roadway and shoulder.

Hot airblasting should be conducted immediately ahead of the sealing or filling operation. This will not only limit the amount of dust and debris blown into the cleaned crack channel, but it will also maximize crack warmth and minimize the potential for the formulation of moisture condensation in the crack channel. The less time between the two operations, the greater the bonding potential of the sealant or filler material.

4.4.3 Sandblasting

Sandblasting operations should be done in dry weather and should be followed up by airblasting to remove abrasive sand from the crack reservoir and roadway. The sandblasting equipment must be capable of removing dirt, debris, and sawing residue with a correctly metered mixture of air and abrasive sand.

A minimum of 100 lb/in^2 (690 kPa) and 150 ft^3/min (4.3 m^3/min) of oil and moisture-free air should be supplied to the sandblaster, such that a minimum nozzle pressure of 90 lb/in^2 (620 kPa) is maintained. In addition, 1-in (25-mm) inside diameter hoses and a 0.25-in (6.4-mm) diameter nozzle orifice are recommended.

One pass of the sandblaster should be made along each side of the crack reservoir. The flow of air and sand should be directed toward the surfaces (generally crack sidewalls), which will form bonds with the sealant material. In general, the wand should be kept 4 to 6 in (102 to 152 mm) from the crack channel to provide optimal cleaning without damaging the integrity of the crack reservoir. An adjustable guide, such as that shown in figure 19, can be attached quickly to the nozzle to consistently provide the desired results and reduce operator fatigue.

4.4.4 Wirebrushing

Power-driven, mechanical wirebrushes should be used only for cleaning dry crack channels that have very little laitance. They must be able to closely follow the crack and should be supplemented with some form of airblasting. In addition, brush attachments should contain bristles flexible enough to allow penetration into the crack channel, yet rigid enough to remove dirt and debris.

Figure 19. Sandblasting wand with wooden guide attached

As with saws and routers, most mechanical wirebrushes have actuator-type depth-control switches. The absence of depth gauges, however, requires careful setting for each new crack to be cleaned.

4.5 Material Preparation and Application

Objective: To install any accessory materials into the crack channel, prepare the crack treatment material for recommended application, and place the proper amount of material into and/or over the crack channel to be treated.

The material installation operation must follow closely behind the crack cleaning and drying operation in order to ensure the cleanest possible crack channel.

4.5.1 Installing Backer Rod

If bond-breaker sealant application is specified, backer rod may be installed only after the crack reservoir and pavement surface have been adequately cleaned. The recommended method of installing backer rod is as follows:

1. Adjust the insertion disk on the backer rod installation tool to the appropriate depth for placement. The depth should be slightly greater than the required depth of backer rod because the rod compresses slightly when installed.
2. Reel out a sufficient amount of backer rod from the spool to cover the length of the crack.
3. Insert the end of the rod into one end of the crack reservoir.
4. Tuck the rod loosely into the reservoir at various points along the crack, leaving a little slack in the rod between points. Stretching and twisting of the backer rod should be avoided.
5. Starting from the end, push the rod into the reservoir to the required depth using the installation tool. It will be necessary during this time to periodically take out any slack in the rod that might have developed or already existed.
6. Roll over the rod a second time with the installation tool to ensure proper depth.
7. Cut the rod to the proper length making sure no gaps exist between segments of backer rod.
8. If segments of the crack reservoir are wider than the rod, it will be necessary either to place additional pieces of rod or install larger diameter backer rod in those sections.

4.5.2 Material Preparation

Every crack treatment material requires some form of preparation, whether it's loading the material into the applicator, heating it to the appropriate temperature, or mixing it for proper consistency and uniform heating. While this manual presents some basic guidelines for the preparation and installation of materials, the specific recommendations provided by the manufacturer of the material to be placed should be followed closely. Such recommendations generally pertain to items such as minimum placement temperature, material heating temperatures, prolonged heating, and allowable pavement temperature and moisture conditions.

The best placement conditions for most materials are dry pavement and an air temperature that is at least 40°F (4°C) and rising. However, the use of a heat lance will usually permit many hot-applied materials to be placed in cold or damp conditions, as discussed earlier. Some emulsion materials can be placed in temperatures below 40°F (4°C), but the threat of rain generally precludes their placement because they are susceptible to being washed away by water.

Two temperatures are important to monitor while preparing hot-applied materials:

- **Recommended application temperature**—The temperature of the material at the nozzle that is recommended for optimum performance.

- **Safe heating temperature**—The maximum temperature that a material can be heated to before experiencing a breakdown in its formulation.

Recommended application temperatures for hot-applied asphalt materials generally range from 370 to 390°F

(188 to 200°C). Notable exceptions to this are some fiberized asphalt materials that must be applied at temperatures in the range of 280 to 320°F (138 to 160°C). Emulsions may be applied at ambient temperature or may be partially heated to between 125 and 150°F (52 to 66°C).

Prior to heating a material, kettle operators should know what its safe heating temperature is and what the effects of overheating or extended heating are. Safe heating temperatures for hot-applied materials are typically 20 to 30°F (11 to 17°C) higher than recommended application temperatures. The effects of overheating or extended heating depend on the specific material. Some materials exhibit a thickened, gel-like consistency, while others thin out or soften considerably. In either case, the material should be discarded, and new material should be prepared.

Other preparation-related concerns for hot-applied materials include prolonged heating and reheating as a result of work delays. Most hot-applied materials have prolonged heating periods between 6 and 12 hours, and they may be reheated once. In both instances, more material should be added, if available, to extend application life.

Substantial carbon buildup should be cleaned off the melting vat walls before an asphalt kettle is used. In addition, all temperature gauges on the unit should be calibrated to display exact temperatures. An ASTM 11F or equivalent thermometer should be available for verifying material temperatures in the kettle and measuring material temperatures at the nozzle.

A few guidelines for initial heating of hot-applied materials follow:

1. Heating should begin so that the material is ready by the time normal work operations begin.

2. Heating oil temperature should be kept no more than 50 to 75°F (28 to 42°C) above the safe heating temperature of the material, depending on the material manufacturer's recommendation.
3. Material temperatures must remain below the recommended pouring temperature.
4. The agitator should be started as soon as possible.

An emulsion material applied cold from the original container may need to be mixed if asphalt particles have settled during storage. Simple stirring at the bottom of the container will bring the material to a uniform consistency.

4.5.3 Material Application

Hot-pour application should commence once the material has reached the recommended application temperature and the first few cracks have been prepared. From this point, the focus is on three items:

1. Consistently maintaining the material at or near the recommended application temperature without overheating.
2. Maintaining a sufficient supply of heated material in the kettle.
3. Properly dispensing the right amount of material into the crack channels.

The kettle operator must be fully aware of the recommended application temperature and the safe heating temperature of the material being installed. These temperatures are generally marked on the material containers for quick and easy reference.

Maintaining a consistent material temperature can be rather difficult, especially in cold weather. Underheated material may produce a poor bond and/or freeze the application line, causing a work delay. Overheating, on the other hand, will lead to either poor treatment performance or a suspended operation.

Guidelines for maintaining hot-applied material in a sufficient quantity and at the proper temperature during application are as follows:

1. Check the temperature of the material at the nozzle and in the melting vat.
2. Adjust the heating controls to reach the recommended application temperature (or as near to as possible without exceeding the safe heating temperature).
3. Regularly check the sealant temperatures and adjust as necessary.
4. Watch for carbon buildup on the sidewalls of the heating chamber and visually inspect material for changes in consistency.
5. Periodically check the level of material in the melting vat. Add material as needed.

The application procedure for all crack treatment materials is basically the same, regardless of what application device is used. Pressure applicators are almost always used; however, pour-pots are occasionally used for applying cold-applied emulsion materials. In all cases, a relatively free-flowing material must be poured into, and possibly over, the crack channel.

General guidelines for material application include the following:

1. Apply the material with the nozzle in the crack channel, so that the channel is filled from the bottom up and air is not trapped beneath the material.

2. Apply the material in a continuous motion, making sure to fill the channel to the proper level for recessed configurations or provide a sufficient amount of material for flush, capped, or overbanded configurations.
3. Reapply material to crack segments where material has sunk into the crack or an insufficient amount was furnished in the previous pass.
4. Recirculate material through the wand into the melting vat during idle periods.

4.5.4 Asphalt Kettle Cleanout

At the end of each day's work, the applicator system lines on the asphalt kettle must be purged of hot-pour material. In addition, if nonreheatable materials are being used, material left in the melting vat must be removed. In any case, the amount of material in the melting vat should be closely monitored so that as little material as possible remains when work is finished for the day.

When using reheatable materials, the applicator lines can be purged of material using either reverse flow or air cleanout procedures. Thorough cleaning can be accomplished using reverse flow procedures followed by solvent flushing procedures.

When using nonreheatable materials, as much material as possible should be placed in cracks at the project site. Any leftover material will have to be discharged into containers for subsequent disposal. Solvent may then be added and circulated through the system to flush it of any excess material.

If flushing solvents are used in cleanout, the kettle operator must ensure that they do not contaminate the sealant or filler material. Step-by-step instructions on how to clean kettles and applicator lines are generally found in the kettle manufacturer's operation manual.

4.6 Material Finishing/Shaping

Objective: To shape or mold the previously applied material to the desired configuration.

Prior to installation, the finishing tool should be tested to ensure that the desired configuration is achieved. If a dish attachment is to be used on the applicator wand, it should be the proper size and aligned to facilitate application.

Squeegees should be properly molded into a "U" or "V" shape so that the material can be concentrated over the crack. If strike-off is to be flush, the rubber insert should be flat. If a band-aid configuration is required, the rubber insert should be cut to the desired dimensions. The depth of the cut should be a little larger than the desired thickness of the band because some thickness will be lost as a result of the squeegee being pushed forward and slightly downward.

A few recommendations for finishing are as follows:

1. Operate the squeegee closely behind the wand. If the material is runny enough to sink into the crack or flows from the mold provided by the squeegee, maintain a little distance to allow for reapplication and/or material cooling.
2. Concentrate on centering the application dish or band-aid squeegee over the crack channel.
3. Keep the squeegee free from material buildup by regularly scraping it on the pavement. It may be necessary periodically to remove built-up material with a propane torch.

4.7 Material Blotting

Objective: To apply a sufficient amount of blotter material to protect the uncured crack treatment material from tracking.

When rubber-modified asphalt materials must be blotted to prevent tracking, toilet paper, talcum powder, and limestone dust are often used. These blotters should be applied immediately after finishing so that they can stick to the material and serve as temporary covers. Care must be taken not to overapply dust and powder materials.

Sand is used primarily as a blotter for many emulsion materials and occasionally asphalt cement. It should be applied in a thin layer and should fully cover the exposed treatment material.

5.0 Evaluating Treatment Performance

Monitoring the performance of crack treatments is good practice, and it can be done rather quickly (1 or 2 hours) with fair accuracy. At least one inspection should be made each year to chart the rate of failure and plan for subsequent maintenance. A mid-winter evaluation is highly recommended as it will show treatment effectiveness during a time of near maximum pavement contraction and near maximum crack opening.

As in the initial pavement/crack survey, a small representative sample of the pavement section, about 500 ft (153 m), should be selected for the evaluation. The sealant or filler material in each crack within the sample section should then be visually examined to determine how well the material is performing its function of keeping out water.

Items signifying treatment failures include the following:

- Full-depth adhesion loss
- Full-depth cohesion loss
- Complete pull-out of material
- Spalls or secondary cracks extending below treatment material to crack
- Potholes

A good estimate of the percentage of treatment failure can be calculated by measuring and summing the lengths of failed segments and dividing this figure by the total length of treated cracks inspected.

$$\text{Percent Failure} = 100 \times (\text{Failed Length}/\text{Total Length})$$

Treatment effectiveness can then be determined by subtracting the percentage of treatment failure from 100 percent.

Percent Effectiveness = 100 − Percent Failure

After a few inspections, a graph of effectiveness versus time can be constructed, such as the one in figure 20. A minimum allowable effectiveness level (often 50 percent) will help indicate when future maintenance should be performed.

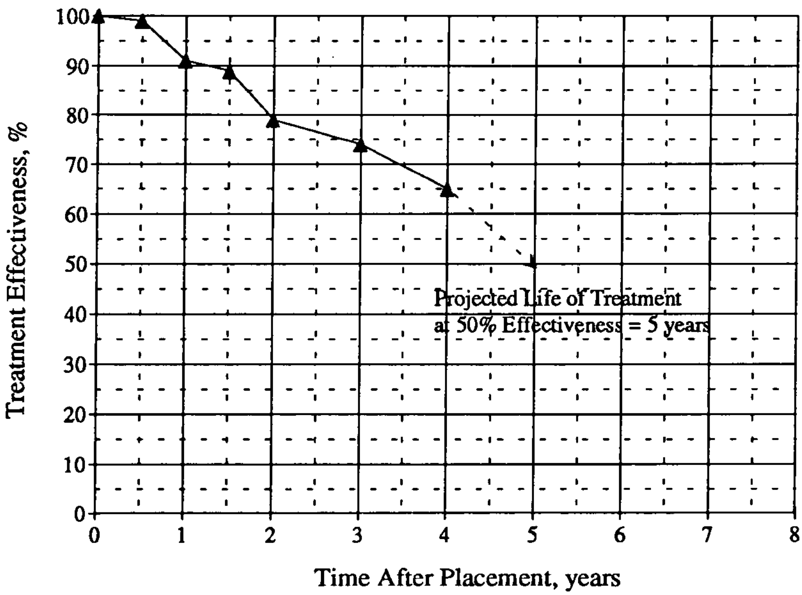


Figure 20. Example graph of treatment effectiveness versus time

Appendix A

Material Testing Specifications

This appendix presents testing specifications for the primary material types used for sealing cracks. These criteria are based on specifications prepared by national agencies, such as ASTM and AASHTO, state highway agencies, and material manufacturers.

Table A-1. Asphalt rubber specifications

Test[a]	ASTM D 5078 Test Criteria
Cone Penetration (77°F, dmm)	70 max
Cone Penetration (39.2°F, dmm)	15 min
Resilience (77°F, % recovery)	30 min
Softening Point (°F)	150 min
Asphalt Compatibility	Pass

[a] 1 dmm = 0.1 mm; °C = 5/9(°F - 32)

Table A-2. Self-leveling silicone specifications

Test[a]	Test Method	Manufacturer's Suggested Test Criteria
Extrusion Rate (gm/min)	Mil S 8802[b]	275 to 550
Specific Gravity	ASTM D 1475	1.26 to 1.34
Skin-Over Time (min)	Manufacturer	60 max
Tack-Free Time (hr)	ASTM C 679	3 to 5
Nonvolatile content (%)	Manufacturer	96 min
Elongation (%)	ASTM D 412 (Die C)	1400 min
Modulus (lb/in^2)	ASTM D 3583	7 max (@ 50%) 8 max (@ 100%) 9 max (@ 150%)
Tensile Adhesion (% Elongation)	ASTM D 3583	600 min

[a] 1 gm/min = 0.0353 oz/min; 1 lb/in^2 = 6.895 kPa
[b] Dow Corning Corporation

Table A-3. Rubberized asphalt specifications

Test[a]	Test Criteria						
	Previous Standard			Current 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 max	90 max	90 max	90 max	90 max	90 max	110 to 150
Flow (140°F, mm)	5 max	5 max	5 max	3 max	3 max	3 max	3 max
Resilience (77°F, % recovery)				60 min	60 min	60 min	60 min
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.)							Pass 3 cycles
Asphalt Compatibility				Pass	Pass	Pass	Pass
Cone Penetration (0°F, dmm)							40 min
Storage Stability						Pass after 2 years	

[a] 1 dmm = 0.1 mm; °C = 5/9(°F - 32); 1 mm = 0.0394 in

Appendix B

Determining Material Quantity Requirements

The following is an example of how to calculate the amount of sealant or filler material needed for a project.

A pavement/crack survey reveals the following information about a particular pavement section:

Project length: 8 mi or 42,240 ft
Length of sample segment: 500 ft
Length of targeted crack in segment: 200 ft
Average width of targeted crack: 0.25 in

A rubberized asphalt product with a unit weight of 9.8 lb/gal will be placed in the shallow reservoir-and-flush configuration (configuration H, p. 23). A 15 percent waste factor is assumed.

Calculation of the amount of material required is shown in figure B-1.

A. Length of section to be treated	42,240 ft
B. Length of sample segment inspected	500 ft
C. Amount (length) of targeted crack in sample segment inspected	200 lin ft
D. Amount (length) of targeted crack in section [D = C × (A/B)]	200 × (42240/500) = 16896 lin ft
E. Average estimated width of targeted crack	0.25 in
F. Type of material configuration planned	Shallow Reservoir-and-Flush
G. Cross-sectional area of planned configuration	0.188 × 1.5 = 0.282 in^2
H. Total volume in ft^3 of design crack to be treated [H = (G/144) × D]	(0.282/144) × 16,896 = 33.1 ft^3
I. Total volume in gal of design crack to be treated [I = H × 7.48 gal/ft^3)	33.1 × 7.48 = 248 gal
J. Unit weight of planned treatment material in lb/gal	9.8 lb/gal
K. Theoretical amount of material needed in lb [K = J × I]	248 × 9.8 = 2,430 lb
L. Total amount of material recommended with 15 percent overage [L = 1.15 × K]	1.15 × 2,430 = 2,795 lb

Figure B-1. Solution to material requirements problem

Appendix C

Sample Cost-Effectiveness Calculations

The following is an example illustration of how material cost-effectiveness can be computed using the worksheet provided in figure 16. In the exercise, two different treatment options are being considered by a maintenance agency for an AC transverse crack-sealing project.

Option #1
Rubberized asphalt, unit weight = 9.5 lb/gal (or 71.1 lb/ft^3)
Standard recessed band-aid configuration (config E, p. 22)
Material and shipping cost: $ 0.65/lb
Estimated production rate: 3,000 lin ft of crack per day
Estimated service life: 3 years

Option #2
Low-Modulus rubberized asphalt, unit weight = 8.9 lb/gal (or 66.6 lb/ft^3)
Shallow recessed band-aid configuration (config I, p. 23)
Material and shipping cost: $ 0.86/lb
Estimated production rate: 2,500 lin ft of crack per day
Estimated service life: 5 years

The following assumptions are made for both options:

- Same wastage factors (15 percent)
- 10 laborers, each @ $120/day
- 1 supervisor @ $200/day
- Equipment costs = $500/day
- User delay cost = $2000/day

Application rates are computed on the following page and the actual cost-effectiveness analysis is illustrated in figure C-1.

Option #1

Cross-sectional area of reservoir $= (0.5 \text{ in} \times 0.5 \text{ in}) + (4 \text{ in} \times 0.125 \text{ in})$
$= 0.75 \text{ in}^2 \ (0.00521 \text{ ft}^2)$

Volume of reservoir (1 lin ft of crack) $= 1 \text{ ft} \times 0.00521 \text{ ft}^2$
$= 0.00521 \text{ ft}^3$

Gross application rate (no waste) $= 71.1 \text{ lb/ft}^3 \times 0.00521 \text{ ft}^3$
$= 0.37$ lb/lin ft of crack

Net application rate (15% waste) $= 1.15 \times 0.37$ lb/lin ft
$= 0.43$ lb/lin ft of crack

Option #2

Cross-sectional area of reservoir $= (1.5 \text{ in} \times 0.188 \text{ in}) + (4 \text{ in} \times 0.125 \text{ in})$
$= 0.782 \text{ in}^2 \ (0.00543 \text{ ft}^2)$

Volume of reservoir (1 lin ft of crack) $= 1 \text{ ft} \times 0.00543 \text{ ft}^2$
$= 0.00543 \text{ ft}^3$

Gross application rate (no waste) $= 66.6 \text{ lb/ft}^3 \times 0.00543 \text{ ft}^3$
$= 0.36$ lb/lin ft of crack

Net application rate (15% waste) $= 1.15 \times 0.36$ lb/lin ft
$= 0.41$ lb/lin of crack

Placement Cost (both options)

Labor cost = (10 lab x \$120/lab) + (1 sup x \$200/sup)
= \$1400/day

Equipment cost = \$500/day

Placement cost = \$1400/day + \$500/day
= \$1900/day

Treatment Cost-Effectiveness

		Option #1		Option #2
A. Cost of purchasing and shipping material		$ 0.65/lb		$ 0.86/lb
B. Net application rate		0.43 lb/lin ft		0.41 lb/lin ft
C. Placement cost (labor and equipment)		$ 2250/day		$ 1900/day
D. Production rate		3000 lin ft/day		2500 lin ft/day
E. User delay cost		$ 2000/day		$ 2000/day
F. Total installation cost F = (A × B) + (C/D) + (E/D)	(0.65 × 0.43) + (1900/3000) + (2000/3000)	= $ 1.58/lin ft	(0.86 × 0.41) + (1900/2500) + (2000/2500)	= $ 1.91/lin ft
G. Interest rate		5.0 percent		5.0 %
H. Estimated service life (time to 50%)		3 years		5 years
I. Average annual cost $I = \frac{F \times \{[G \times (1 + G)^H]}{(1 + G)^H - 1}$	$\frac{1.58 \times [0.05 \times (1 + 0.05)^3]}{[(1 + 0.05)^3 - 1]}$	= $ 0.58/lin ft	$\frac{1.91 \times [0.05 \times (1 + 0.05)^5]}{[(1 + 0.05)^5 - 1]}$	= $ 0.44/lin ft

Figure C-1. Example of cost-effectiveness analysis

Based on the calculations made in figure C-1, option #2, with an average annual cost of $0.44/lin ft, is more cost-effective than option #1, with an average annual cost of $0.58/lin ft.

Appendix D

Inspection Checklists for Construction

This appendix contains inspection checklists for the various operational steps in a sealing or filling operation. These checklists were developed for use by inspectors or supervisors to maximize workmanship in the field, giving crack treatment the best chance possible to perform well.

D.1 Crack-Cutting

☐ 1. Cutting tips or blades are sufficiently sharp to minimize spalling and cracking?

☐ 2. Operator is wearing appropriate safety attire?

☐ 3. All guards and safety mechanisms on equipment are functioning properly?

☐ 4. Cutting equipment follows cracks so that the percentage of missed cracks is minimized (less than 5 percent missed crack)?

☐ 5. AC surface is not so cold as to inhibit cutting operations and cause excessive spalling or cracking?

☐ 6. AC surface mixture is not so coarse as to inhibit cutting operations and cause excessive spalling or cracking?

☐ 7. Crack reservoir dimensions satisfactory and uniform, especially for bond-breaker sealant application so that appropriate backer rod depth can be achieved?

D.2 Crack Cleaning and Drying

☐ 1. Oil and moisture filters on air compressor functioning properly? Periodic check for oil and moisture made by placing white towel over nozzle during operation?

☐ 2. Operator is wearing appropriate safety attire?

☐ 3. Dirt and debris are adequately blown from crack channel <u>and</u> surrounding pavement area to well off edge of roadway?

☐ 4. At least one pass on each side of crack channel is made with cleaning equipment?

☐ 5. When cleaning and drying with hot compressed air, intended bonding surfaces are partially darkened but not burned?

☐ 6. Cleaning operation is maintained just ahead of sealing or filling operation to retain crack cleanliness?

☐ 7. Hot-airblasting operation is conducted immediately ahead of hot-applied sealant or filler installation so that the potential for moisture condensation is minimized and crack surface warmth is maximized (5 min or 150 ft [46 m] maximum)?

☐ 8. Check periodically for crack cleanliness by running finger along crack sidewalls and examining for dirt, dust, or oxidized asphalt grit?

☐ 9. Check periodically for crack moisture visually and by feeling crack sidewalls?

☐ 10. Consistently check cracks for loosened fragments, and remove by hand those that will come free?

☐ 11. Blasting operations (sand or air) always proceeding away from and are directed away from passing traffic?

☐ 12. Airblasting and hot-airblasting nozzles are held no more than 2 in (51 mm) away from crack channel during first pass?

☐ 13. Sandblasting nozzle is directed against crack sidewalls and maintained 4 to 6 in (102 to 152 mm) away?

D.3 Material Preparation and Installation

D.3.1 Backer Rod Installation

☐ 1. Backer rod placed to specified depth?

☐ 2. Wide crack segments filled with additional backer rod or larger sized backer rod?

☐ 3. Backer rod sufficiently compressed in reservoir so that the weight of uncured sealant does not force it down into the reservoir.

☐ 4. Surface of backer rod not damaged, twisted, or excessively stretched during installation?

D.3.2 Sealant or Filler Preparation and Installation

☐ 1. A double-boiler, agitator-type kettle with oil heat transfer is used for hot-applied, rubber-modified asphalt materials?

☐ 2. Kettle with full-sweep agitation and 2-in (51-mm) recirculating pump used for fiberized asphalt applications?

- ☐ 3. Operator is wearing appropriate safety attire?
- ☐ 4. Melting vat kept at least one-third full of material to reduce chance of burning material or introducing air into pumping system (surges of material extruded)?
- ☐ 5. Systematic check of material temperature in vat by both kettle temperature gauge and thermometer probe?
- ☐ 6. Recirculate material during idle periods?
- ☐ 7. Pump functions efficiently (loss of power causing surges of material extrusion)?
- ☐ 8. Crack channel filled with material from bottom up?
- ☐ 9. Crack channel filled with material to specified level in recessed configurations?
- ☐ 10. Sufficient amount of material is dispensed to form design configuration, but not so much as to oversupply squeegee?
- ☐ 11. Material is reapplied to crack segments that initially received too little material or experienced settling of material?
- ☐ 12. Material installation operation follows immediately behind cleaning and drying operation in order to retain crack cleanliness and, if hot airblasting, minimize the potential for moisture condensation in the crack and maximize crack warmth?
- ☐ 13. Bubbling due to moisture in crack channel after installation of hot-applied materials?

☐ 14. Spilled material is removed from the pavement surface?

☐ 15. Melter vat and application equipment thoroughly cleaned of contaminant materials?

D.4 Material Finishing/Shaping

☐ 1. Squeegee size and shape appropriate for planned material placement configuration?

☐ 2. Rubber inserts on squeegee cut to desired dimension for creating overband (periodically checking for cut-out wear)?

☐ 3. Material buildup on squeegee being removed with propane torch?

☐ 4. Squeegee operated immediately after material application or delaying strike-off to allow overly runny material to cool in order to prevent slumping of band?

☐ 5. Band-aid squeegee consistently centered over crack?

☐ 6. Hot-applied material is cooling sufficiently to prevent tracking given the type of traffic control setup and ambient conditions?

☐ 7. Checking for bond by peeling "cooled" hot-applied sealant from crack channel (check for moisture and dirt)?

☐ 8. Bubbling due to moisture in crack channel after installation of hot-applied materials?

D.5 Material Blotting

☐ 1. Sufficient amount of sand applied to fully cover emulsion material?

☐ 2. Toilet paper, dust, or powder applied so as to fully cover hot-applied, rubber-modified asphalts?

Appendix E

Material and Equipment Safety Precautions

E.1 Materials

To protect their health and well-being, maintenance workers who handle the various treatment materials should review material safety data sheets (MSDS). These sheets provide important information about health, fire, and reactivity hazards.

Some common-sense precautions for preventing harmful contact or ingestion of materials includes wearing the following protective clothing and equipment:

- Long-sleeved shirts
- Long pants
- Gloves
- Steel-toed boots
- Eye protection

E.2 Equipment

Safety precautions should also be taken for those operating equipment used in sealing or filling operations. In general, this includes the following:

- Routers and saws—Eye and hearing protection, protective clothing, steel-toed boots

- Air compressors—Eye and hearing protection, protective clothing

- HCA/heat lances—Eye and hearing protection and fire-retardant clothing including boots and leggings that cover lower legs

- Sandblasters—Air-fed protective helmet, air supply purifier, and protective clothing

- Distributors and asphalt kettles—Eye protection, protective clothing

Appendix F

Partial List of Material and Equipment Sources

This appendix includes a partial listing of crack treatment material and equipment manufacturers. Addresses and phone numbers are provided for major manufacturers who can provide the user with information regarding products, installation practices, and safety procedures.

This list is intended to serve as a starting point for the user pursuing information about materials and equipment. It is not an endorsement for the manufacturers included and is not intended to carry negative connotations for manufacturers not included.

F.1 Materials

F.1.1 Manufacturers of Cold-Applied Thermoplastics

Hy-Grade Corporation
3993 East 93rd Street
Cleveland, OH 44105
(216) 341-7711
(800) 341-7751

Witco Corporation
Golden Bear Division
P.O. Box 456
Chandler, AZ 85244-0161
(602) 963-2267

F.1.2 Manufacturers of Hot-Applied Thermoplastics

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

Crafco Inc.
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

F.1.3 Manufacturers of Self-Leveling Silicone

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

F.2 Equipment

F.2.1 Manufacturers of Cutting Equipment

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

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

F.2.2 Manufacturers of Heat Lances

L/A Manufacturing Inc.
1000 Mary Laidley Drive
Covington, KY 41017
(606) 356-1222

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

F.2.3 Manufacturers of Asphalt Kettles

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

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

White Asphalt Equipment
Midwest Tank and
Manufacturing Co.
2075 South Belmont Ave
Indianapolis, IN 46221
(317) 632-9326

Bearcat Manufacturing
P.O. Box 2059
Wickenburg, AZ 85358
(602) 684-7851

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

F.2.4 Manufacturers of Silicone Pumps

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

Glossary

Abrasion—The wearing away of treatment material by tire friction or snowplow scraping.

Adhesiveness—The ability of a material to remain bonded to crack sidewalls and/or pavement surface.

Band-aid—An overband configuration where material is shaped/finished to desired dimensions.

Capped—An overband configuration where material is not shaped/finished. The material is allowed to level over the crack channel by itself.

Cohesiveness—The ability of a material to resist internal rupture.

Cost-effectiveness—The degree to which a treatment is both useful and economical.

Crack channel—The crack cavity as defined by either the original (uncut) crack or cut crack.

Crack repair—Maintenance in which badly deteriorated cracks are repaired through patching operations.

Crack reservoir—A uniform crack channel resulting from cutting operations. Generally rectangular in shape.

Crack treatment—Maintenance in which cracks are directly treated through sealing or filling operations.

Cupping—A depression in the pavement profile along crack edges caused by damaged or weakened sublayers.

Edge deterioration—Secondary cracks and spalls that occur within a few inches of the edges of a primary crack.

Effectiveness—See ***Treatment effectiveness***

Elasticity—The ability of a material to recover from deformation and resist intrusion of foreign materials.

Faulting—A difference in elevation between opposing sides of a crack caused by weak or moisture-sensitive foundation material.

Flexibility—The ability of a material to extend to accommodate crack movement.

Incompressible—Material, such as sand, stone, and dirt, that resists the compression of a closing crack channel.

Lipping—An upheaval in the pavement profile along crack edges. Lipping may be the result of bulging in underlying PCC base or the infiltration and buildup of material in the crack.

Longitudinal—Parallel to the centerline of the pavement or laydown direction.[5]

Nonworking (cracks)—Cracks that experience relatively little horizontal and/or vertical movement as a result of temperature change or traffic loading. As a general rule, movement less than 0.1 in (2.5 mm).

Overband—A type of finish in which material is allowed to completely cover crack channel by extending onto pavement surface. Overbands consist of band-aid and capped configurations.

Secondary crack—A crack extending parallel to and/or radially from a primary crack. A form of edge deterioration.

Serviceability—The ability, at time of observation, of a pavement to serve traffic that use the facility.[6]

Spall—A chipped segment of asphalt concrete occurring along a primary crack edge. A form of edge deterioration.

Thermoplastic (material)—A material that becomes soft when heated and hard when cooled.

Thermosetting (material)—A material that hardens permanently when heated.

Transverse—Perpendicular to the pavement centerline or direction of laydown.[5]

Treatment failure—The degree to which a treatment is not performing its function.

Treatment effectiveness—The degree to which a treatment is performing its function.

Working (cracks)—Cracks that experience considerable horizontal and/or vertical movement as a result of temperature change or traffic loading. In general, movement greater than or equal to 0.1 in (2.5 mm).

References

1. Smith, K.L., et al. *Innovative Materials and Equipment for Pavement Surface Repairs–Final Report.* Volumes I and II. Report no. SHRP-M/UFR-91-504. SHRP, National Reserch Council, Washington DC: 1991.

2. Evans, L.D., et al. *Innovative Materials Development and Testing–Final Report.* Volumes I-V. SHRP, National Reserch Council, Washington DC. Forthcoming.

3. Cook, J.P., F.E. Weisgerber, and I.A. Minkarah. "Development of a Rational Approach to the Evaluation of Pavement Joint and Crack Sealing Materials–Final Report." University of Cincinnati: 1991.

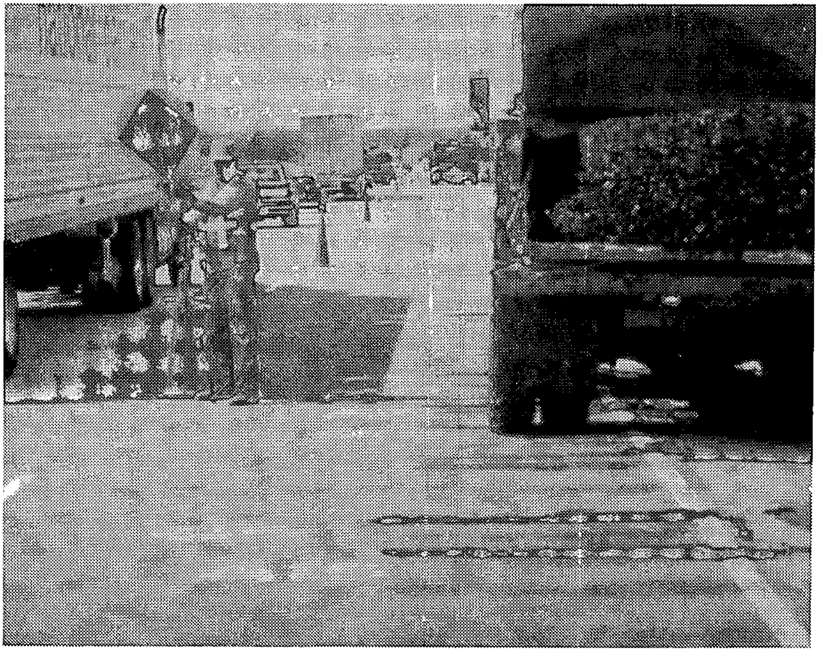
4. Peterson, D.E. *NCHRP Synthesis of Highway Practice No. 98: Resealing Joints and Cracks in Rigid and Flexible Pavements.* TRB, National Research Council, Washington DC, December 1982.

5. *Distress Identification Manual for the Long-Term Pavement Performance Project.* Report no. SHRP-P-338. SHRP, National Research Council, Washington DC: 1993.

6. *AASHTO Guide for Design of Pavement Structures.* American Association of State Highway and Transportation Officials, Washington DC: 1986.

Materials and Procedures for the Repair of Potholes in Asphalt-Surfaced Pavements

Manual of Practice



Strategic Highway Research Program
National Research Council

Contents

List of Figures

List of Tables

1.0 Introduction

As asphalt pavements age and deteriorate, the need for corrective measures to restore safety and rideability increases. Funding for rehabilitation and overlay of these pavements is not likely to keep up with the demand, requiring more agencies to use the most cost-effective methods when patching distressed areas. The patches will also be expected to survive longer and carry more traffic loadings.

1.1 Scope of Manual

This manual describes materials and procedures for the repair of *potholes** in asphalt surfaced pavements. The materials and procedures discussed are for cold-mix, stockpiled materials and for *spray injection* patching devices. The information in this manual is based on the most recent research, and has been obtained through reviews of literature and current practice, and the results of an ongoing study. This study investigated the performance of various cold-mix patching materials and procedures, as well as spray-injection patches.[2] The use of hot mix asphalt concrete, while recognized as a preferred alternative for patching operations, is not covered in this manual.

The patching operations described in this manual can be done during any type of weather. With the exception of the spray-injection procedure, they require the use of cold-mix patching materials. The spray-injection procedure requires a device that can place virgin aggregate and heated emulsion into a pothole simultaneously; even so, this procedure can be carried out in most weather conditions.

* Italicized words are defined in the glossary.

1.2 Pothole Repair

Any agency responsible for asphalt-surfaced pavements (either full-depth or composite) eventually performs *pothole patching*. Potholes occur on pavements subjected to a broad spectrum of traffic levels, from two-lane rural routes to multilane interstate highways. Pothole patching can be performed during weather conditions ranging from clear spring days to harsh winter storms, with temperatures anywhere from 100 °F (38 °C) to 0 °F (-18 °C).

Pothole patching is generally performed either as an emergency repair under harsh conditions, or as routine maintenance, scheduled for warmer and drier periods.

Even though the moisture and traffic conditions patches experience vary, the materials and methods for placing quality repairs are fairly similar. This manual describes patching techniques that have been used successfully under actual field conditions across the United States and Canada.

2.0 Need for Pothole Repair

The decision to patch potholes is influenced by many factors:

- The level of traffic
- The time until scheduled rehabilitation or overlay
- The availability of personnel, equipment, and materials
- The tolerance of the travelling public

In most cases, the public likes all potholes to be promptly repaired, and forms a negative opinion of the highway agency when this fails to happen.

Potholes are generally caused by moisture, freeze-thaw action, traffic, poor underlying support, or some combination of these factors. Pothole repair is necessary in those situations where potholes compromise safety and pavement rideability.

Pothole repair operations can usually be divided into two distinct periods. The first period is winter repairs, when temperatures are low, base material is frozen, and additional moisture and freeze-thaw cycles are expected before the spring thaw. The second period is spring repairs, when base material is wet and soft, and few additional freeze-thaw conditions are expected.

Regardless of the climatic conditions, when deciding whether a pothole should be patched, the potential safety and rideability problems that could result from the unrepaired distress should always be considered. A highway agency must repair potentially hazardous potholes as soon as it becomes aware of them.

3.0 Planning and Design

For any pothole repair operation, two main elements of quality patching are material selection and repair procedures. For every combination of these two factors, the cost-effectiveness of the overall patching operation will be affected by material, labor, and equipment costs. For each agency, different combinations of materials and procedures will produce optimum cost-effectiveness. The following sections discuss each of these items.

3.1 Materials

Most agencies have three types of cold mixes available to them. The first of these is cold mix produced by a local asphalt plant, using the available aggregate and binder, usually without an opportunity to consider compatibility or expected performance.

The second type is cold mix produced according to specifications set by the agency that will use the mix. The specifications normally include the type of aggregate and asphalt that are acceptable, as well as acceptance criteria for the agency to purchase the material. Testing the aggregate and asphalt for compatibility is usually performed before specifying acceptable sources. The use of spray-injection devices by agency employees would fall into this category, since the agency must check the asphalt-aggregate compatibility before placing patches.

The third type is proprietary cold mix. A local asphalt plant generally produces this material using specially formulated binders. These binders are produced by companies that test the local aggregate, design the mixes, and monitor production to ensure the quality of the product. These materials (like other cold mixes) can be produced in bulk and stockpiled or they can be packaged into buckets or bags to make the material easier to handle in the field. Spray-injection patching performed by a contractor would fall into this third category, since the aggregate and binder are supplied by and should be tested by a patching contractor.

For each of these materials, and agency must address different concerns when verifying the quality of materials used for patching. When using cold mixes that are produced according to agency specifications, the compatibility of the binder and aggregate needs to be checked. When using proprietary materials that are already mixed, some acceptance testing must to be done before purchasing the material. Acceptance testing of spray injection materials is more difficult than for a stockpiled cold mix due to the nature of the finished product. Examples of both compatibility and acceptance testing procedures are provided below.

3.1.1 Compatibility testing

The first step in producing a quality cold-mix material is to test the compatibility of the binder and aggregate. While the majority of asphalt-aggregate combinations will produce satisfactory results, there are combinations that produce cold mixes that do not perform well. Being able to identify potential mix problems prior to large-scale production can be very beneficial.

In addition to determining compatibility, target asphalt contents also need to be determined. Appendix A summarizes a testing plan for material compatibility and for estimating the optimum asphalt content. This testing plan is recommended when an agency is considering using a previously untried combination of asphalt and aggregate.

Most agencies use cold mixes consisting of asphalt-aggregate combinations that have been used successfully. The following section describes a testing plan to ensure the quality of the cold-mix material before use under actual roadway conditions.

3.1.2 Acceptance testing

When a previously used cold mix or proprietary material is being considered for use, acceptance testing is recommended to ensure the quality of the current batches. The acceptance test procedure is presented in appendix A. While the acceptance procedure does not guarantee a successful patching material, it is designed to identify materials likely to perform poorly in the field.

3.2 Repair Techniques

Many maintenance agencies use the *throw-and-go* method for repairing potholes. While not considered the best way to patch potholes, it is the most commonly used method because of its high rate of production. The procedure, as described in this manual, is more accurately termed "*throw-and-roll,*" and should be considered a superior alternative to the traditional throw-and-go.

An installation technique used by many agencies is the *semi-permanent* repair procedure. This procedure represents an increased level of effort for patching potholes. This increased effort increases the performance of the patches by improving the underlying and surrounding support provided for the patches; it also raises the cost of the patching operation.

Agencies also use spray-injection devices for repairing potholes. This technique has higher equipment costs than the other procedures, but also has a high rate of productivity and lower material costs.

3.2.1 Throw-and-roll

The throw-and-roll method consists of the following steps:

- Place the material into a pothole (which may or may not be filled with water or debris), as shown in figure 1.
- Compact the patch using truck tires, as shown in figure 2.
- Verify that the compacted patch has some crown (between 0.125 in and 0.25 in [3.2 mm and 6.4 mm]).
- Move on to the next pothole.
- Open the repair to traffic as soon as maintenance workers and equipment are clear.

One difference between this method and the traditional throw-and-go method is that some effort is made to compact the patches. Compaction provides a tighter patch for traffic than simply leaving loose material. The extra time to compact the patches (generally 1 to 2 additional minutes per patch) will not significantly affect productivity. This is especially true if the areas to be patched are separated by long distances and most of the time is spent traveling between potholes.

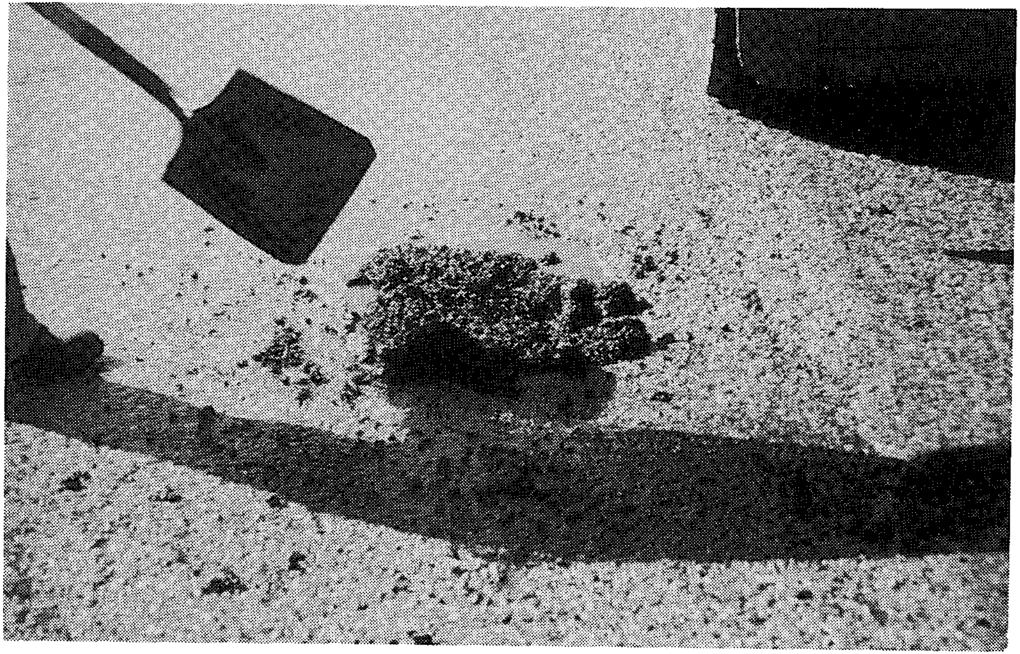


Figure 1. Throw-and-roll procedure—material placement

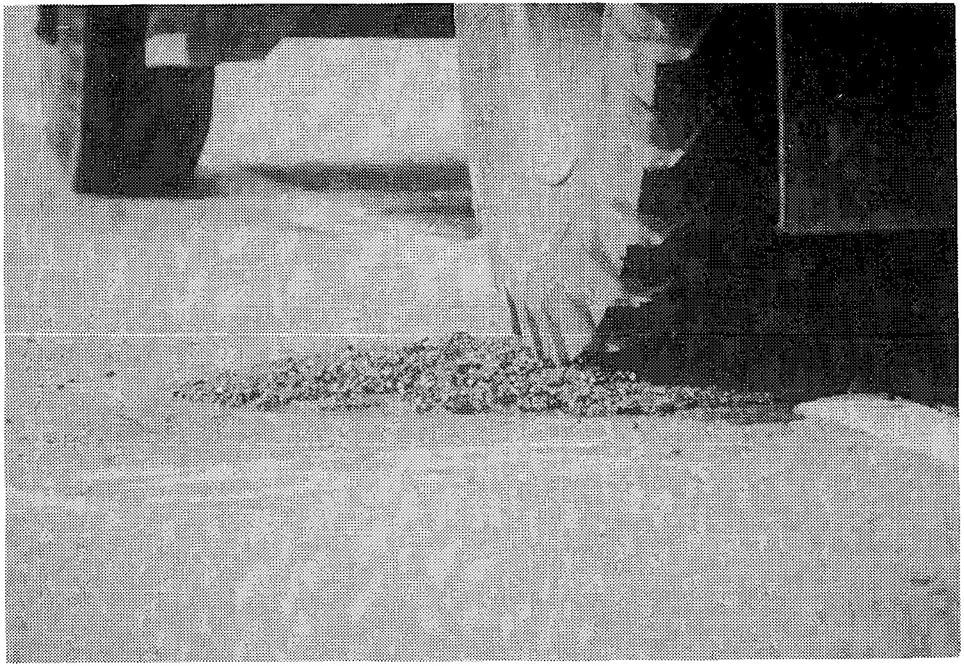


Figure 2. Throw-and-roll procedure–compaction of patch

3.2.2 Semi-permanent

The semi-permanent repair method is considered one of the best for repairing potholes, short of full-depth removal and replacement. This procedure includes the following steps:

- Remove water and debris from the pothole.
- Square up the sides of the patch area until vertical sides exist in reasonably sound pavement, as shown in figures 3 and 4.
- Place the mix.
- Compact with a device smaller than the patch area (single-drum vibratory rollers and vibratory plate compactors work best), see figures 5 and 6.
- Open the repair to traffic as soon as maintenance workers and equipment are clear.

This repair procedure provides a sound area for patches to be compacted against, and results in very tightly compacted patches. However, it requires more workers and equipment and has a lower productivity rate than either the throw-and-roll or the spray-injection procedure.

3.2.3 Spray Injection

The spray-injection procedure consists of the following steps:

- Blow water and debris from the pothole.
- Spray a tack coat of binder on the sides and bottom of the pothole.
- Blow asphalt and aggregate into the pothole.
- Cover the patched area with a layer of aggregate.
- Open the repair to traffic as soon as maintenance workers and equipment are clear.

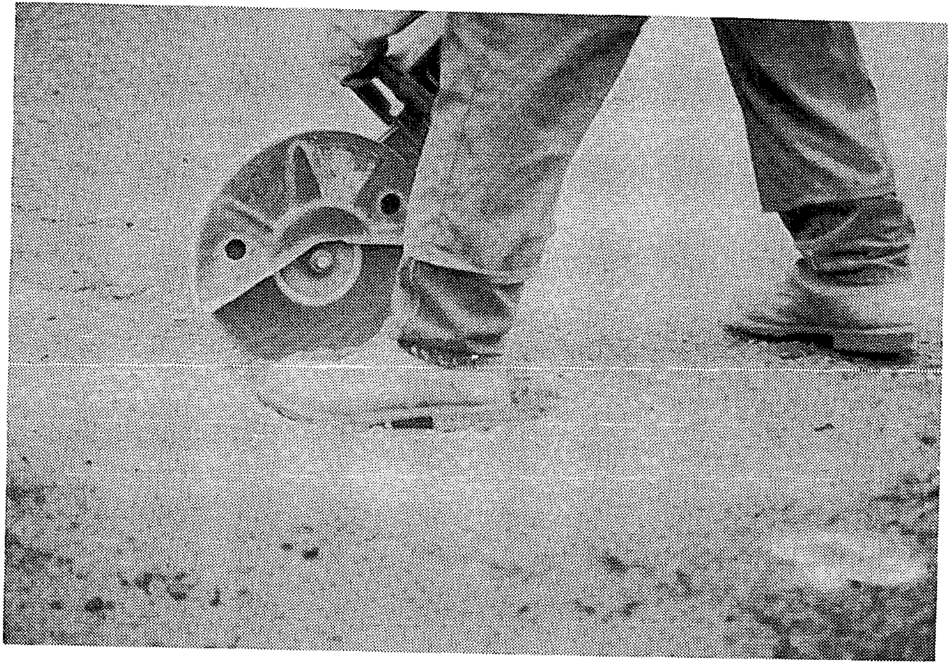


Figure 3. Semi-permanent procedure–straightening edges using hand-held pavement saw

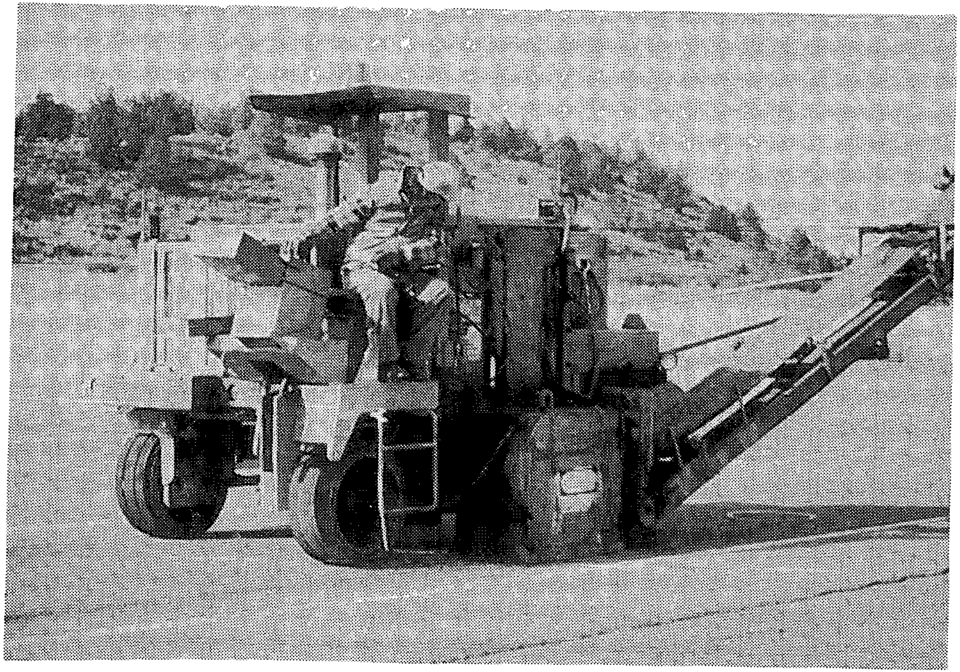


Figure 4. Semi-permanent procedure–straightening edges using cold milling machine

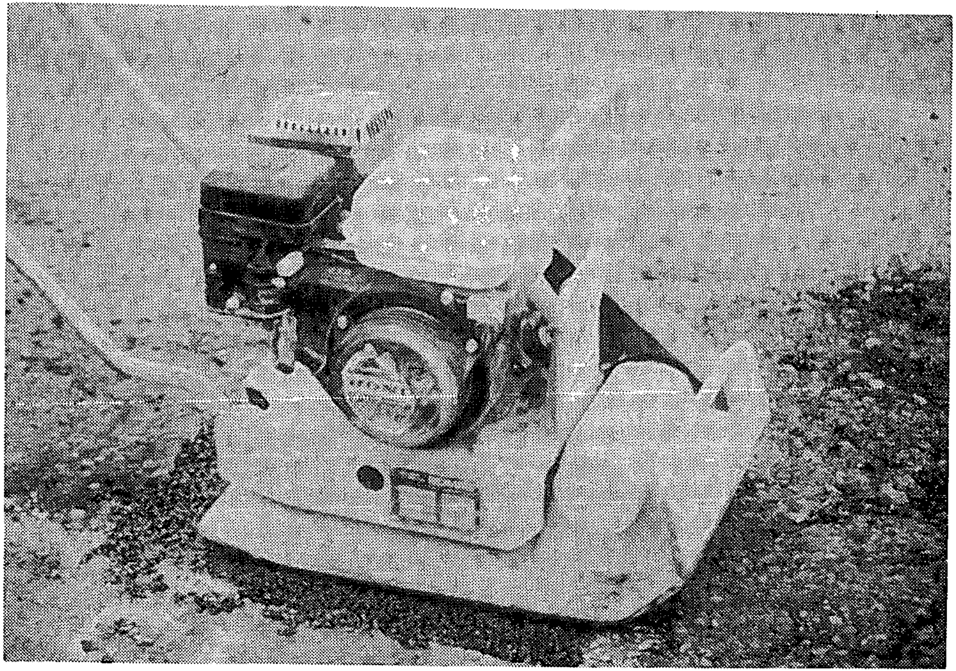


Figure 5. Semi-permanent procedure–compaction using vibratory plate compactor

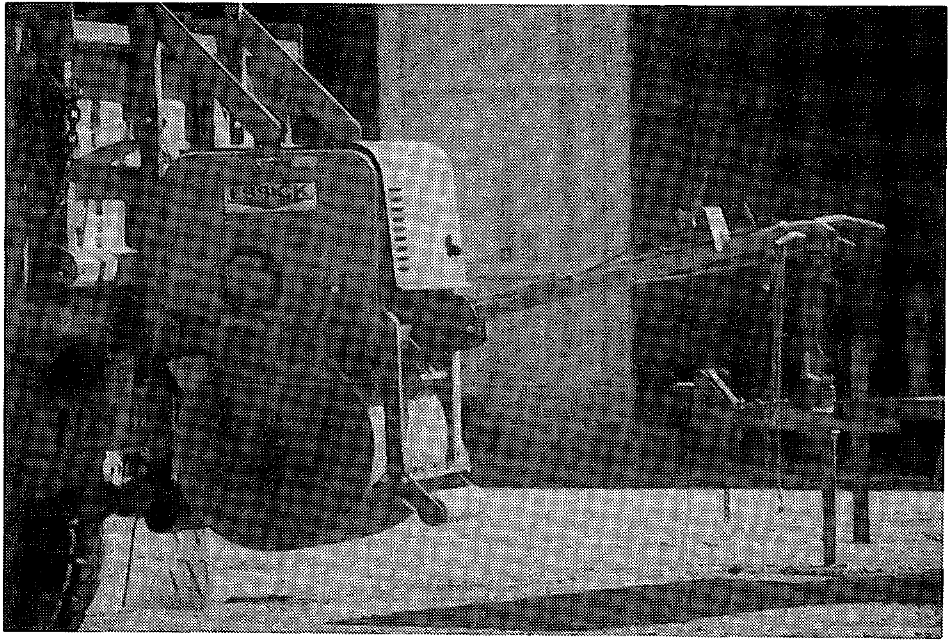


Figure 6. Semi-permanent procedure–single-drum vibratory roller used for compaction

This procedure requires no compaction after the cover aggregate has been placed. Figures 7 and 8 illustrate the two main types of spray injection devices available. The first is a trailer unit towed behind a truck carrying the aggregate. The second is a unit with aggregate, heated binder tank, and delivery systems all contained in a single vehicle.

3.3 Patching Costs

The three main costs for pothole patching for most agencies are: material, labor, and equipment. There may also be some user-delay costs associated with pothole-patching operations, and the associated lane-closure time. The following sections discuss the costs of these aspects of the patching operation.

3.3.1 Materials

The cost most commonly associated with pothole patching is the cost of purchasing material. This is usually one of the least significant contributors to the overall cost of a patching operation. However, the material used for patching does impact the cost of the overall operation when there are differences in performance. More expensive materials that are placed with less effort and last longer can reduce the cost of the initial patching effort, as well as the amount of repatching needed. This reduces the labor and equipment costs for the overall operation.

Figure 7. Spray injection device–truck and trailer unit

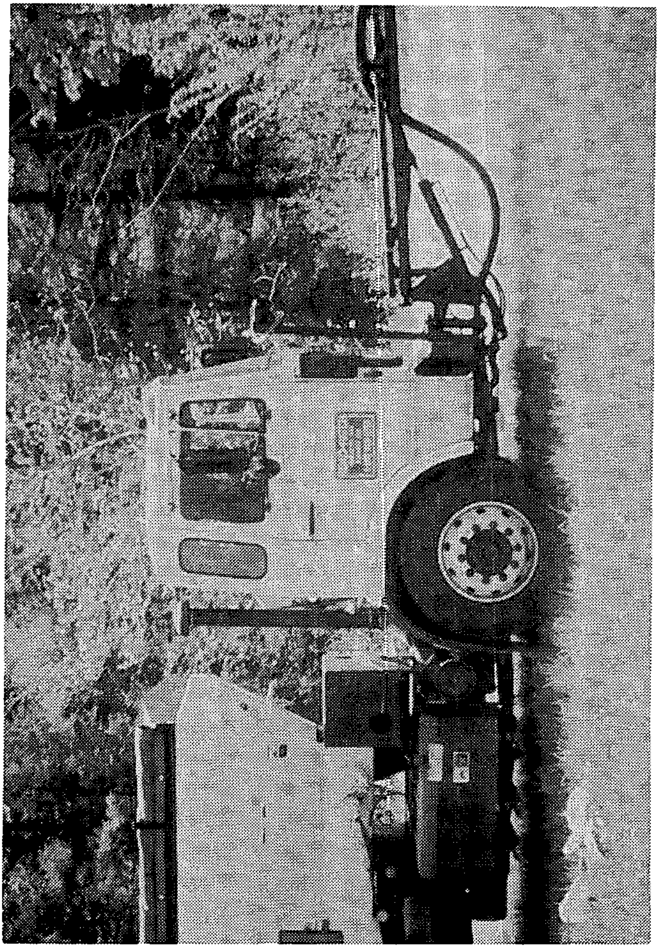


Figure 8. Spray injection device–self contained unit

3.3.2 Labor

For the throw-and-roll technique, the labor cost can be as little as two workers who do the actual patching, plus traffic control costs. One of the two workers drives the truck and compacts the patches, and the other shovels the material from the truck into the pothole. In some instances, the driver of the vehicle is able to shovel material when patching large areas. This generally improves the productivity of the overall operation.

The semi-permanent patching operation has proven most efficient when four workers are used, plus the appropriate traffic control. Basically, two workers clear out debris and square up the edges, while the other two follow behind, placing material and compacting the patches. This procedure can be accomplished using more or fewer workers, although the experience of many agencies has found four to be the optimum.

The cost of traffic control can be handled in several different ways, depending upon the site of the patching operation and the needs of the particular agency. Labor costs for traffic control should be included when necessary.

The single-unit spray-injection device requires a single operator. Two operators are recommended when using the trailer-unit equipment (one to operate the vehicle and one to place the material). In both cases, traffic control is required.

3.3.3 Equipment

For the throw-and-roll and semi-permanent procedures, shovels, rakes, or other hand tools are needed for placing the material. For the throw-and-roll method, the only major equipment costs are for the truck carrying the material and the traffic control vehicles and signs.

For the semi-permanent repair procedure, the necessary equipment varies from agency to agency. A basic list follows:

- Material truck (with hand tools)
- Equipment truck
- Compaction device (vibratory plate and single-drum vibratory roller are generally both the most inexpensive and the most maneuverable)
- Air compressor
- Edge straightening device (jack hammer, pavement saw, cold milling machine)
- Traffic control vehicles and signs

The only equipment needed for spray injection is the spray-injection device and the traffic control trucks and signs.

3.4 Overall Cost-Effectiveness

In order to evaluate its current patching operation, an agency must calculate the cost-effectiveness of the overall operation.

Figure 9 shows a worksheet that can be used to calculate the cost of a patching operation. This form can be used either for a current operation or for a proposed patching operation, using different materials or procedures.

3.4.1 Cost-effectiveness worksheet

The worksheet shown in figure 9 requires the user to enter information for each material-procedure combination to be evaluated. Explanations of the inputs are given below.

MATERIAL COSTS

Material Purchase Cost	____________	$/ton (A)
Material Shipping Cost	____________	$/ton (B)
Anticipated Material Needs	____________	tons (C)

LABOR COSTS

Number in Patching Crew	____________	(D)
Average Daily Wage per Person	____________	$/day (E)
Number in Traffic Control Crew	____________	(F)
Average Daily Wage per Person	____________	$/day (G)
Supervisor Daily Wage	____________	$/day (H)

EQUIPMENT COSTS

Material Truck	____________	$/day (I)
Traffic Control Truck and Signs	____________	$/day (J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	____________	$/day (K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	____________	$/day (L)
Extra Equipment Truck	____________	$/day (M)
Specialty Equipment (i.e. Spray injection device)	____________	$/day (N)

USER COSTS

User Delay Costs	____________	$/day (O)

Figure 9. Worksheet for patching costs

Total Material Cost [(A+B)×C]	____________	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	____________	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	____________	$/day	(R)
Average Daily Productivity	__________	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	____________	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	____________	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	____________	$	(V)
Total Patching Operation Cost with User Costs (P+U)	____________	$	(W)
Total Patching Operation Cost without User Costs (P+V)	____________	$	(X)
Patch Survival Rate (Duration may vary)	____________	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	____________	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	____________	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	____________	$/ft³	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	____________	$/ft³	(CC)

Figure 9. Worksheet for patching costs (continued)

(A) **Material Purchase Cost**–The cost of purchasing or producing the material, not including shipping costs. The amount entered should be in dollars per ton.

(B) **Material Shipping Cost**–The cost of shipping the material from the site of production to the location of the stockpile. The amount entered should be in dollars per ton.

(C) **Anticipated Material Needs**–The amount of patching material needed for one year of pothole patching. The amount entered should be in tons.

(D) **Number in Patching Crew**–The number of workers who will be performing the patching operation. This number does not include traffic control personnel.

(E) **Average Daily Wage per Person**–The average wages paid to the members of the patching crew. Multiplying this figure by (D) results in the total labor costs for the patching crew. The amount entered should be in dollars per day.

(F) **Number in Traffic Control Crew**–The number of workers required to set up and maintain the traffic control operation. When the patching crew sets up traffic control before patching, the number of traffic control workers is zero, so that workers are not counted twice.

(G) **Average Daily Wage per Person**–The average wages paid to the members of the traffic control crew. Multiplying this figure by (F) results in the total labor costs for the traffic control crew. The amount entered should be in dollars per day.

(H) **Supervisor Daily Wage**–The wage paid to a supervisor or foreman who oversees the patching operation. If the supervisor is not exclusively involved in patching operations for the entire time, a fraction of the daily wage should be entered to estimate the time spent with the patching operation. The amount entered should be in dollars per day.

(I) **Material Truck**–The operating charges associated with the truck carrying the material. Only trucks transporting patching material should be included. The amount entered should be in dollars per day.

(J) **Traffic Control Truck and Signs**–The cost associated with all traffic control trucks and devices, including arrow boards, attenuators, etc. If vehicles are used to both set up traffic control and for other activities during the day, a fraction of the daily cost should be used to estimate the time spent in establishing traffic control. The amount entered should be in dollars per day.

(K) **Preparation Equipment**–The cost associated with any equipment used to prepare the pothole before placing the patching material. If the throw-and-roll or spray-injection methods are used, this value is zero. The amount entered should be in dollars per day.

(L) **Compaction Equipment**–The cost associated with any extra equipment used to compact the patches. If the material truck is used for compaction, this value is zero. The amount entered should be in dollars per day.

(M) **Extra Equipment Truck**–The cost associated with any extra truck used to transport preparation or compaction equipment to the site. The amount entered should be in dollars per day.

(N) **Specialty Equipment**–The cost associated with any special equipment used for the patching operation (e.g., spray-injection devices). The amount entered should be in dollars per day.

(O) **User Delay Cost**–The cost to the users of the roadway of the delay caused by the patching operation. The amount should be entered in dollars per day.

(S) **Average Daily Productivity**–The rate at which the patching crew can place the patching material. This amount should be for the crew size specified above. The amount entered should be in tons per day.

(W) **Patch Survival Rate**–An estimate of the percent of patches that will survive for one year. The value should be entered as a percentage.

3.4.2 Determination of Cost-effectiveness Inputs

A supervisor of foreman familiar with the crew and the available equipment can provide most of the information required to complete the cost-effectiveness worksheet.

The most difficult value to obtain accurately is the "patch survival rate." The pavement condition, material quality, climatic influence, crew ability, and past repair performance will all factor into this value. Chapter 5 presents one method for estimating the patch survival rate.

Appendix B contains examples of the cost-effectiveness calculation for several different types of patching operations.

4.0 Construction

Pothole-patching operations are usually performed when potholes have developed at various locations throughout a maintenance area. Most patching operations simply try to repair the distress and restore rideability as quickly as possible. This chapter contains recommendations for improving the overall quality of the patches.

These recommendations are divided into winter and spring patching alternatives, and include preparation, placement, and compaction alternatives. Suggestions for traffic control and safety are also included. The person most familiar with local conditions and the requirements for a safe traffic control situation should always make the final decisions concerning the safety of both the patching crew and the passing vehicles.

4.1 Traffic Control

Whenever any pothole-patching operation is performed, adequate traffic control must be provided. This ensures a safe working environment for the maintenance crew and safe travel lanes for vehicles. Traffic control operations should disturb the flow of traffic as little as possible.

While the actual traffic control requirements for each agency will vary, **every maintenance agency has the responsibility of providing a work area that is as safe as possible for both workers and drivers and of ensuring that all necessary steps are always taken to maintain safety.**

4.2 Safety

Safety concerns are not limited to traffic control. There are also safety concerns when using the repair materials and equipment. Material safety data sheets are available for the majority of cold-mix materials which are available. Special recommendations for handling and storing of all cold-mix materials should be followed closely.

Operators of jack hammers and other compressed-air equipment should exercise caution with the equipment as should operators of spray-injection devices. In particular, the aggregate from spray injection-devices can rebound with great force, and eye protection is highly recommended. Vehicle operators must exercise caution when moving in reverse, especially if other workers are in the area.

Everyone on the job should know where the potential hazards are located and should take care to avoid any possibly dangerous situations.

4.3 Winter Patching

Winter patching operations generally take place during periods of snow melt, when maintenance crews do not have to plow or apply abrasives or salt. Warmer weather not only provides time to patch, it also creates conditions conducive to the development of potholes. Warmer temperatures cause thawing and softening of frozen base materials, reducing underlying pavement support.

Since winter patching occurs while more winter conditions are expected, more stress is placed on the patching materials as they cycle between very cold and warm conditions.

4.3.1 Materials

Aggregates used for winter patching conditions should be high-quality, crushed aggregate with few fines. Binders should be emulsified asphalts with at least an anti-stripping additive. The mixture should be workable at low temperatures, to allow both easier handling by the workers and easier compaction in the hole. It is highly likely that water will be in the pothole, so an anti-stripping additive is crucial.

4.3.2 Selecting a procedure

Patching potholes under winter conditions does not usually allow time for using the semi-permanent procedure. Increasing the time required to patch the potholes decreases the productivity of the operation and increases the amount of time that the crew is exposed to traffic.

With a high-quality material, the throw-and-roll procedure provides a cost-effective means of patching under winter conditions. It is extremely important that a high-quality material be used, and that it be compacted by the truck. Leaving the patch to be compacted under traffic will result in premature patch failures.

4.3.3 Other Considerations

Patches placed under winter conditions have a shorter life expectancy than patches placed in the spring. This document presents information that can extend the life of winter patches from several days to several months. The goal of winter patching is to restore rideability and safety as quickly as possible (not to repair the distress permanently).

4.4 Spring Patching

Spring patching differs from the winter operation in that the climatic conditions will not stress the patches to the same degree. Because freeze-thaw cycling is finished, most of the conditions which soften the underlying support will have passed. Better climatic conditions increase the life expectancy for patches placed in the spring.

4.4.1 Materials

The choice of materials for spring patching should be based on a calculation of their cost-effectiveness. However, even when the cost-effectiveness calculation may indicate the superiority of one material over another, the experience of the local maintenance crew should be considered.

Also, any material acceptable for winter patching is generally acceptable for spring patching. However, the effects of having been stockpiled over the winter and the differences in workability over wide temperature ranges should be considered. Materials that are workable at very low temperatures tend to be very sticky and hard to use at higher temperatures.

High-quality, crushed aggregate, again with few fines, and an emulsified asphalt should be used for spring patching. Anti-stripping additives are still advised. The mixtures can set more slowly than winter materials, since higher temperatures allow more rapid evaporation.

4.4.2 Selecting a procedure

Spring patching can be done by spray injection, or by either the throw-and-roll or semi-permanent procedures. Cost-effectiveness and the availability of equipment and workers should be the most important criteria. Because the semi-permanent procedure requires more equipment and workers, that procedure may be impractical.

The throw-and-roll procedure should be considered a viable alternative for placing spring patches. Results from a recent study indicate that patches placed with this method can provide satisfactory results when high-quality materials are used.

4.4.3 Other considerations

Patches placed during the spring are expected to last longer than patches placed under winter conditions. Observations in a recent field test indicated that patches in place after the initial setting period (2 to 4 weeks) were likely to remain in place until the surrounding pavement begins to deteriorate. The goal of spring patching operations should be to place patches which last as long as the surrounding pavement. Patches surviving more than one year reduce the cost of the overall operation by reducing the amount of labor, equipment, and material needed in subsequent years, However, cost-effectiveness calculations should still be based on survival for one year.

5.0 Evaluating Repair Performance

When two or more patch types have been installed for the purpose of comparison, some method is needed to rank the patch types from best to worst. One method for calculating a performance factor is described here.

5.1 Data Required

To determine the effectiveness of a given patch type, the highway agency must monitor the repairs for at least one year. Monitoring repairs simply consists of checking for the presence of repairs and noting the survival or failure of each one. The time elapsed from installation to monitoring is also noted. Table 1 contains a typical collection of patch performance data.

Figure 10 illustrates several plots of patch survival over time. In all three cases, the percentage of patches remaining at the end of monitoring is the same. However, material B would have the highest patch survival rating when compared with materials A and C.

5.2 Calculations

The patch survival rate is defined as the area under the patch survival curves over time. To calculate the area, table 2 can be used for any available patch survival data. As an example, the data from table 1 have been used to calculate a patch survival rate.

Table 1. Sample patch performance data

Time (weeks) (T_T)	In-place Repairs (R_{IP})	Failed Repairs (R_F)	Repairs Lost to Overlay (R_L)	Percent Surviving (P_{SURV})
0 (Inst.)	30	0	0	100
4	28	2	0	93
10	26	2	2	93
16	24	3	3	89
30	20	7	3	74
40	19	8	3	70
52	15	10	5	60

$P_{SURV} = \{R_{IP} / (R_F + R_{IP})\} \times 100$

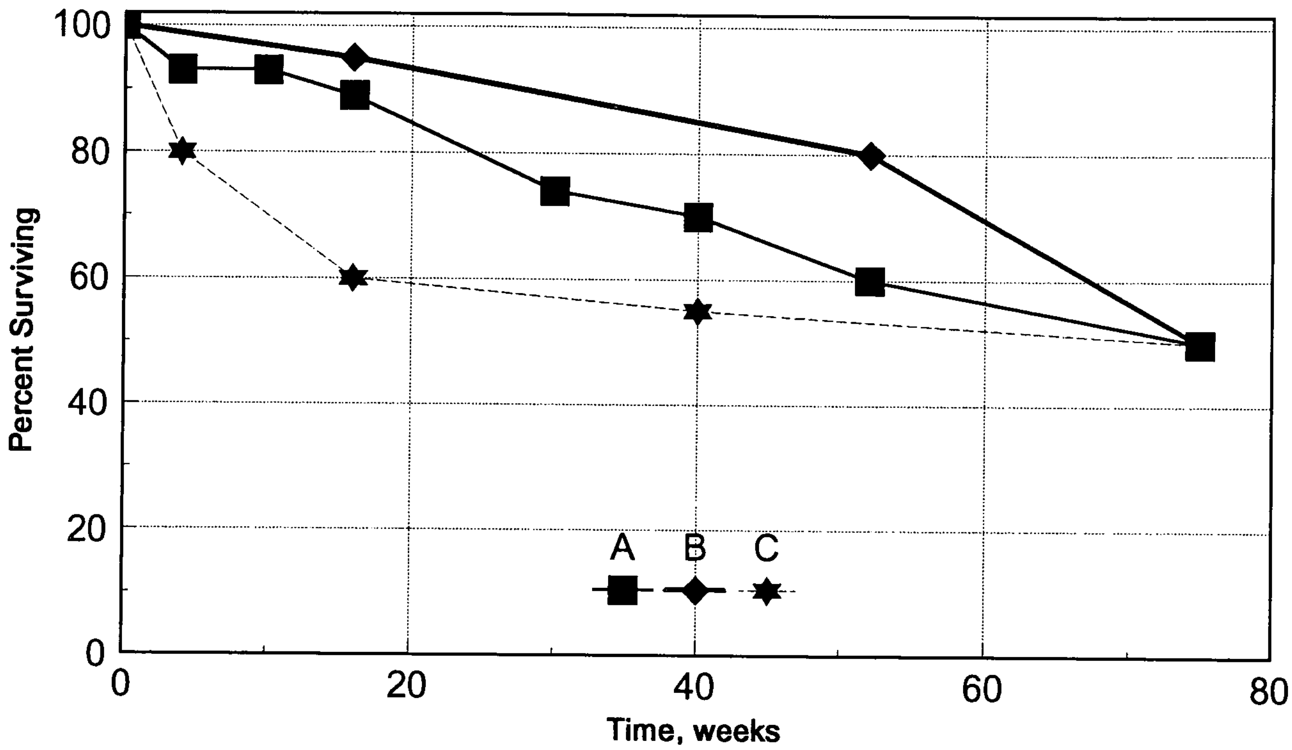


Figure 10. Example of patch survival curves

Table 2. Worksheet for calculating patch survival rate

Observ. No. (i)	Time (weeks) (T)	Percent Surviving (P_{SURV})	Average Percent Surviving (P_{AVG})	Time Interval (T_T)	Partial Area (A_{PART})	Total Possible Area (A_{TOT})
0	0	100				
1	4	93	96.5	4	386	400
2	10	93	93	6	558	600
3	16	89	91	6	546	600
4	30	74	81.5	14	1141	1400
5	40	70	72	10	720	1000
6	52	60	65	12	780	1200
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
				Total	4131	5200

Patch Survival Rate
$(\Sigma A_{PART})/(\Sigma A_{TOT}) \times 100$

79.4

$P_{AVG} = (P_{SURV(i)} + P_{SURV(i+1)})/2$
$T_T = T_{(i+1)} - T_{(i)}$
$A_{PART} = P_{AVG} \times T_T$
$A_{TOT} = T_T \times 100$

Each average percent surviving (P_{AVG}) is calculated by averaging the two percent surviving values that straddle the line being calculated, as shown in the two shaded portions of Table 2. Each time interval (T_T) is calculated by subtracting the smaller time ($T_{(i)}$) from the larger time ($T_{(i+1)}$) for the two lines straddling the line being calculated.

Each partial area (A_{PART}) is calculated by multiplying the P_{AVG} and T_T values for that line. Each total possible area (A_{TOT}) is simply the time interval (T_T) multiplied by 100. The total possible area (A_{TOT}) represents the best possible performance that can be expected for a patch type (that is, 100 percent survival for the interval observed).

Appendix A

Material Testing

An agency involved in pothole patching conducts materials testing that generally falls into one of two categories:

- Compatibility testing for new combinations of asphalt and aggregate to be used in producing cold-mix materials
- Acceptance testing for new cold-mix materials produced by proprietary sources

This appendix suggests testing methods for each of these categories. The testing methods are based on previous studies.[3, 4, 5]

These testing methods are intended to provide information concerning combinations of materials or cold-mix materials with which an agency has no prior experience. Testing may not be necessary when agencies are using cold-mix materials that have been successfully used in the past and that do not need confirmation of quality. However, testing these materials could provide reference values to compare with other cold mixes.

A.1 Compatibility Testing Procedure

When combining asphaltic cement and aggregate to produce cold-mix patching materials, there are several criteria for success:

- The asphalt should coat the aggregate well and remain coated, even after being stockpiled and subjected to various climatic conditions.
- The stockpiled material should remain workable and be easy to handle with shovels. (The outside crust of the stockpile may harden as the asphalt cement hardens, but this skin should prevent the inner material from hardening, so that when a loader breaks through the outer skin, the material is workable again.)
- The material should remain in the holes where it is placed.

The following testing plan presents of a series of simple laboratory tests to determine the ability of a particular asphalt-aggregate combination to meet all the requirements listed above. These tests can also identify a range of optimum asphalt content for materials determined to be compatible. The compatibility-testing procedure involves three tests, for coating, stripping, and drainage.

A.1.1 Coating test

1. Obtain samples of asphalt binder (emulsion or cutback) and aggregate proposed for production of cold mix. The aggregate should fall within the same gradation as the material that will be used for full-scale production. Aggregate samples should be approximately 2,000 g (4.4 lbs) in weight.
2. Dry aggregate samples at approximately 60 °C (140 °F). Stir the samples to prevent formation of lumps.
3. Mix dried aggregate and binder in proportion so that the residual asphalt content would be 4.0 percent. Enter the weights of both aggregate and the asphalt binder in columns C and D of table A-1. Continue mixing until the binder is dispersed throughout the mixture.
4. Spread mixture onto absorbent paper to dry. If desired, place the mixture can be placed in an oven at 96 °C (205 °F) to speed the drying process.
5. Continue to mix and dry batches of aggregate and binder at the residual asphalt contents listed in column A of table A-1. If mixture becomes soupy at any asphalt content, do not mix batches with any higher asphalt content.
6. When the mixtures are dry, estimate the percentage of aggregate covered with asphalt for each mixture. Enter the coating values for each mixture in column E of table A-1.
7. Enter the lowest asphalt content at which the coating value is at least 90 percent on line F below table A-1. The technician performing the test should judge whether the coating is acceptable.

Table A-1. Data table for coating test

Emulsion residual factor from specification testing:
________(R)

(A) Residual Asphalt Content %	(B) Emulsion Content % (A/R)	(C) Aggregate Weight gm	(D) Emulsion Weight gm (C × B)	(E) Percent Coating %
4.0				
4.5				
5.0				
5.5				
6.0				
6.5				
7.0				
7.5				
8.0				

1 lb = 454 g

Minimum asphalt content value for 90 percent coating:
________(F)

A.1.2 Stripping test

1. Prepare five aggregate samples of approximately 1,100 g (2.4 lbs). Heat the samples to 60 °C (140 °F). Part of each sample will be used in the drainability test that follows.
2. Beginning with minimum value from the coating test (F), mix the aggregate and asphalt samples, recording the actual weights of aggregate and binder used in columns G and I of table A-2. Increase the asphalt content in 0.5 percent increments for the remaining samples to be mixed. Do not increase asphalt content if mix becomes soupy during mixing.
3. Verify that the percent coated is greater than 90 percent for each of the samples that is mixed.
4. Remove approximately 100 g (3.5 oz) of mixture and allow to cool to room temperature. Set aside the remaining 1,000 g (2.2 lbs) from each sample for the drainability test.
5. Place the 100 g (3.5 oz) sample of the mixture into a 1-liter (1-quart) jar filled with distilled water. Place jar into an oven at 60 °C (140 °F) for 16 to 18 hours.
6. After heating, shake the jar vigorously for approximately 5 seconds, and then pour off the water. Spread the mixture on absorbent paper.
7. Estimate the coating of the mix as was done in the coating test. Record the percentage of aggregate coated in columns K and L of table A-2. Record on line M the minimum asphalt content at which the coating is greater than 90 percent. The technician performing the test should judge whether the coating is acceptable.

Table A-2. Data table for stripping test

Emulsion residual factor: _______ (R)

Minimum asphalt content from coating test: _______(F)

(G) Aggregate Weight, g	(H) Desired Emulsion Weight, g	(I) Actual Emulsion Weight, g	(J) Actual Asphalt Content % (I/G)×100×R	Percent Coated	
				(K) Initial	(L) Final
	G×[F/(100×R)]				
	G×[(F+0.5)/(100×R)]				
	G×[(F+1.0)/(100×R)]				
	G×[(F+1.5)/(100×R)]				
	G×[(F+2.0)/(100×R)]				
	G×[(F+2.5)/(100×R)]				
	G×[(F+3.0)/(100×R)]				

1 lb = 454 g

Minimum asphalt content for stripping test: _______(M)

A.1.3 Drainage Test

1. Record the weights of several 25 cm (10-in) diameter disposable aluminum pie pans in row N of table A-3.
2. Place the 1,000 g (2.2 lb) sample from stripping test into an aluminum pie pan, and enter the weight of the sample with the pie pan and the sample alone in rows O and P of table A-3.
3. Place mixtures (on the pie pans) into a 60 °C (140 °F) oven for 24 hours.
4. After heating, remove the mixture from the pie pan by simply turning the pan over and tapping the bottom until all aggregate particles are off pan.
5. Enter the weight of the pie pan with asphalt residue in row Q of table A-3.
6. Determine the highest asphalt content with a drainability of less than 4 percent of the original weight of asphalt, as calculated in row T, and record it on line U beneath table A-3.

Table A-3. Data table for drainage test

Minimum asphalt content from coating test: ______(F)

Emulsion residual factor: ______(R)

Desired Asphalt Content, %	F	F+0.5	F+1.0	F+1.5	F+2.0	F+2.5
(J) Actual Asphalt Content, %						
(N) Pie Pan Weight, g						
(O) Pie Pan and Sample Weight, g						
(P) Sample Weight, g						
(Q) Pie Pan and Asphalt Weight, g						
(S) Asphalt Weight, g (Q-N)						
(T) Percentage Drained, [S/(P×J)]×100						

1 lb = 454 g

Maximum asphalt content with drainage less than 4 percent: _______(U)

When the three tests have been completed, the values of the asphalt contents determined by coating and stripping (F and M) will represent lower boundaries for the true optimum asphalt content and the asphalt content determined by the drainage test (U) will represent an upper boundary. As these tests are being performed, the compatibility of the asphalt and aggregate combination will become apparent. If the asphalt content for acceptable drainability is below that for stripping and coating, the combination is unlikely to perform well in the field.

These testing procedures are intended to give a rough idea of the optimum asphalt content and to identify those combinations of asphalt binder and aggregate that would perform poorly in the field in terms of coating, stripping, and drainability. However, even reasonable values for the different tests do not guarantee that the material will perform satisfactorily in actual patching applications.

A.2 Acceptance Testing Procedure

For materials the agency will purchase in pre-mixed form, tests should ensure that the material will not perform poorly in the field. The two tests suggested for acceptance attempt to quantify two important characteristics of cold mixes; workability and cohesion. As with the compatibility-testing procedure, these tests do not guarantee success for the materials tested; rather, they indicate the potential for poor performance in the proposed materials.

A.2.1 Workability Test

This test requires a workability box, a pocket penetrometer (normally used for soil testing) and a penetrometer adapter. Figure A-1 illustrates the necessary equipment

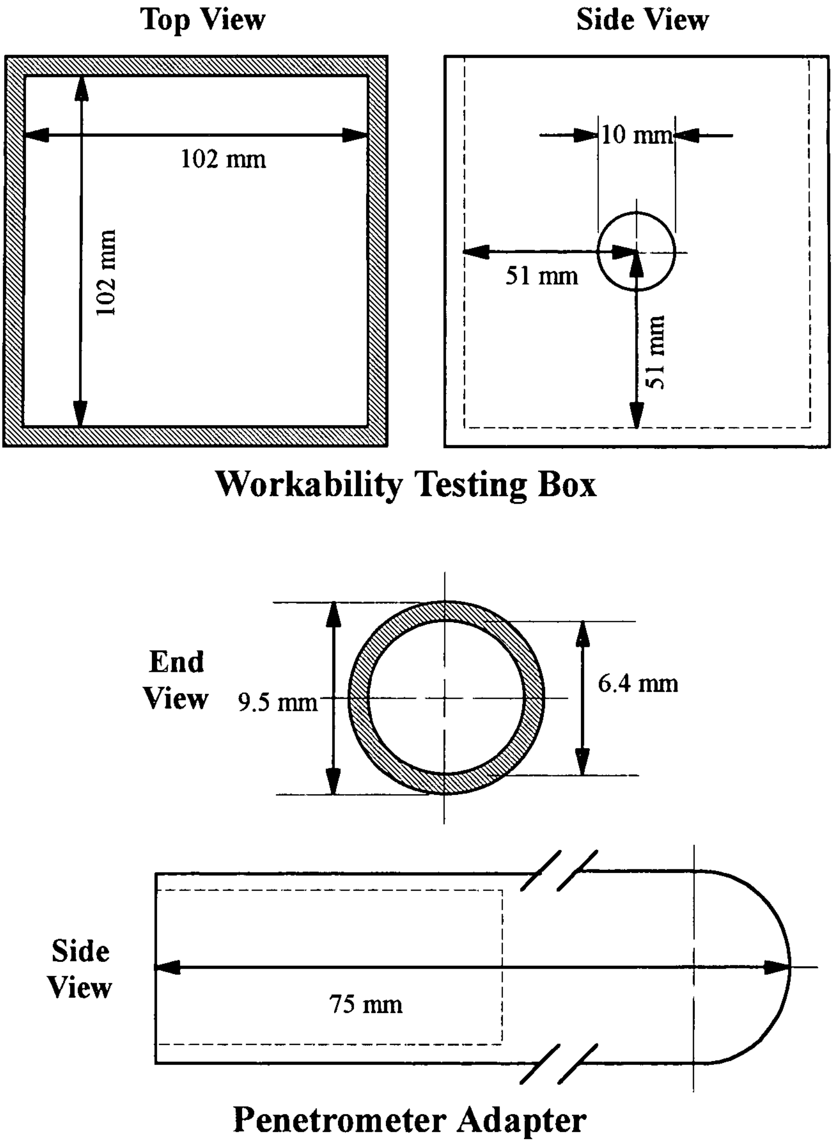


Figure A-1. Workability testing box and penetrometer adapter (1 in = 25.4 mm)

The workability box should measure 102 mm (4 in) on all sides and should have a 10 mm (0.375-in) hole in one side. The Soiltest CL 700-A is one acceptable penetrometer; it has a scale of 0 to 4.5 tons per ft^2, with a 6.4 mm (0.25-in) diameter end. The penetrometer adapter will increase the diameter of the penetrometer to 9.5 mm (0.375 in).

1. Prepare three samples of cold mix of approximately 2,500 g (5.5 lbs) and cool the samples to 4 °C (40 °F).
2. Place the cooled mixture into the workability box. Drop the mixture loosely into the box, making no effort to pack the material into the box.
3. Push the penetrometer with adapter through the holes in both sides of the box. Record the maximum resistance as the workability measurement.
4. Repeat steps 2 and 3 for all three samples. Calculate the average workability measurements for all samples.

An average workability reading between 3 and 4 would be considered marginal, while a value over 4 should be rejected. Values under 3 are acceptable.

A.2.2 Cohesion Test

1. Cool several 1,200 g (2.6 lbs) samples of cold mix to a temperature of 4 °C (40 °F).
2. Place the cold mix into a standard Marshall mold, 63.5 mm (2.5 in) high, with a diameter of 102 mm (4 in). Compact the sample using 5 blows of a standard Marshall hammer (4.5 kg [10 lb]) to each side, from a drop height of 457 mm [18 in].
3. Extrude the sample, and record the weight of the compacted sample.
4. Place the compacted sample along the bottom edge of a 12-in (305 mm) diameter sieve while both the sieve

and the sample are standing on end, as shown in figure A-2.

5. Place the cover on the sieve while it is still on end. Roll the sieve with the sample inside back and forth 20 times, taking approximately 1 second for each of the 20 passes.
6. Lay the sieve (with the sample still inside) against the edge of a table, allowing room for sample pieces to fall through the sieve openings. Leave the sieve in this position for 10 seconds.
7. Flip the sieve and lid over so that the sample in the sieve falls onto the lid. Weigh the material retained.
8. Determine the average percentage retained by dividing the weight retained by the original weight. A minimum retention value of 60 percent is recommended for this test.

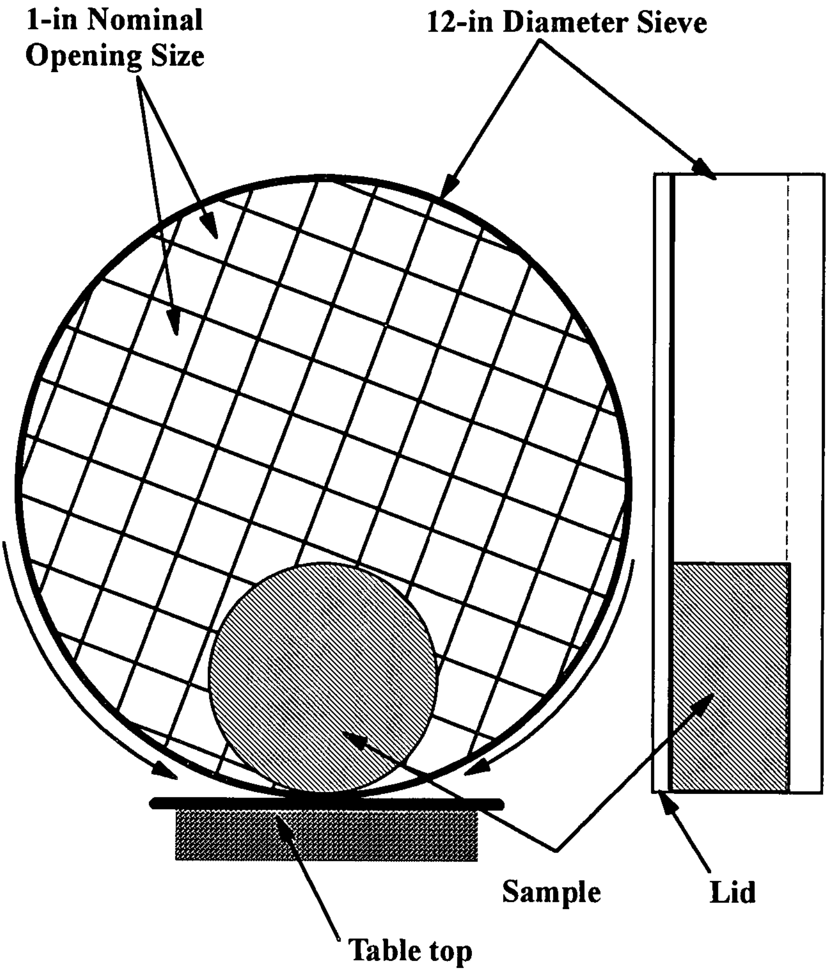


Figure A-2. Rolling Sieve cohesion test
(1 in = 25.4 mm)

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. The examples demonstrate how to use the worksheet for calculating the cost-effectiveness of several different pothole-patching operations (figures B-1 through B-5). These examples illustrate the differences in materials, procedures, equipment, and location when performing pothole patching operations. Values for the variables are given below.

Example 1

Material	Local cold mix
Method	Throw-and-roll
Cost	$20.00 per ton
Patching Crew Size	2 laborers
Traffic Control Crew	2 laborers
Daily Wage	$100 per day per laborer
Equipment Cost	$20 per day (material truck)
	$25 per day (traffic control)
Productivity	4 tons per day
Patch Survival Rate	25 percent (after 12 months)
User Delay Costs	$1,000 per day

Example 2

Material	UPM High Performance Cold Mix
Method	Throw-and-roll
Cost	$85.00 per ton
Patching Crew Size	2 laborers
Traffic Control Crew	2 laborers
Daily Wage	$100 per day per laborer
Equipment Cost	$20 per day (material truck) $25 per day (traffic control)
Productivity	4 tons per day
Patch Survival Rate	90 percent (after 12 months)
User Delay Costs	$1,000 per day

Example 3

Material	Local cold mix
Method	Semi-permanent
Cost	$20.00 per ton
Patching Crew Size	4 laborers 1 supervisor
Traffic Control Crew	2 laborers
Daily Wage	$100 per day per laborer $120 per day per supervisor
Equipment Cost	$20 per day (material truck) $25 per day (traffic control) $10 per day (preparation) $5 per day (compaction) $10 per day (equipment truck)
Productivity	1.5 tons per day
Patch Survival Rate	80 percent
User Delay Costs	$1,000 per day

Example 4

Material	Spray injection
Method	Spray injection
Cost	$0.00 per ton
Patching Crew Size	0 laborers
Traffic Control Crew	2 laborers
Daily Wage	$100 per day per laborer
Equipment	$750 per day (spray injection device, crew and material)
Productivity	4 tons per day
Patch Survival Rate	90 percent (after 12 months)
User Delay Costs	$1,000 per day

Example 5

Material	Local cold mix
Method	Throw-and-roll
Cost	$20.00 per ton
Patching Crew Size	2 laborers
Traffic Control Crew	2 laborers
Daily Wage	$100 per day per laborer
Equipment Cost	$20 per day (material truck) $25 per day (traffic control)
Productivity	4 tons per day
Patch Survival Rate	25 percent (after 12 months)
User Delay Costs	$10,000 per day

MATERIAL COSTS			
Material Purchase Cost	20.00	$/ton	(A)
Material Shipping Cost	0.00	$/ton	(B)
Anticipated Material Needs	200	tons	(C)
LABOR COSTS			
Number in Patching Crew	2		(D)
Average Daily Wage per Person	100.00	$/day	(E)
Number in Traffic Control Crew	2		(F)
Average Daily Wage per Person	100.00	$/day	(G)
Supervisor Daily Wage	0.00	$/day	(H)
EQUIPMENT COSTS			
Material Truck	20.00	$/day	(I)
Traffic Control Truck and Signs	25.00	$/day	(J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	0.00	$/day	(K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	0.00	$/day	(L)
Extra Equipment Truck	0.00	$/day	(M)
Specialty Equipment (i.e. Spray injection device)	0.00	$/day	(N)
USER COSTS			
User Delay Costs	1,000.00	$/day	(O)

Figure B-1. Cost worksheet for example 1

Total Material Cost [(A+B)×C]	4,000.00	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	400.00	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	45.00	$/day	(R)
Average Daily Productivity	4	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	50	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	72,250.00	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	22,250.00	$	(V)
Total Patching Operation Cost with User Costs (P+U)	76,250.00	$	(W)
Total Patching Operation Cost without User Costs (P+V)	26,250.00	$	(X)
Patch Survival Rate (Duration may vary)	25	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	133,440.00	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	45,940.00	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	41.70	$/ft³	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	14.36	$/ft³	(CC)

Figure B-1. Cost worksheet for example 1 (continued)

MATERIAL COSTS			
Material Purchase Cost	70.00	$/ton	(A)
Material Shipping Cost	15.00	$/ton	(B)
Anticipated Material Needs	200	tons	(C)
LABOR COSTS			
Number in Patching Crew	2		(D)
Average Daily Wage per Person	100.00	$/day	(E)
Number in Traffic Control Crew	2		(F)
Average Daily Wage per Person	100.00	$/day	(G)
Supervisor Daily Wage	0.00	$/day	(H)
EQUIPMENT COSTS			
Material Truck	20.00	$/day	(I)
Traffic Control Truck and Signs	25.00	$/day	(J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	0.00	$/day	(K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	0.00	$/day	(L)
Extra Equipment Truck	0.00	$/day	(M)
Specialty Equipment (i.e. Spray injection device)	0.00	$/day	(N)
USER COSTS			
User Delay Costs	1,000.00	$/day	(O)

Figure B-2. Cost worksheet for example 2

Total Material Cost [(A+B)×C]	17,000.00	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	400.00	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	45.00	$/day	(R)
Average Daily Productivity	4	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	50	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	72,250.00	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	22,250.00	$	(V)
Total Patching Operation Cost with User Costs (P+U)	89,250.00	$	(W)
Total Patching Operation Cost without User Costs (P+V)	39,250.00	$	(X)
Patch Survival Rate (Duration may vary)	90	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	98,180.00	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	43,180.00	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	30.68	$/ft^3	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	13.49	$/ft^3	(CC)

Figure B-2. Cost worksheet for example 2 (continued)

MATERIAL COSTS			
Material Purchase Cost	20.00	$/ton	(A)
Material Shipping Cost	0.00	$/ton	(B)
Anticipated Material Needs	75	tons	(C)
LABOR COSTS			
Number in Patching Crew	4		(D)
Average Daily Wage per Person	100.00	$/day	(E)
Number in Traffic Control Crew	2		(F)
Average Daily Wage per Person	100.00	$/day	(G)
Supervisor Daily Wage	120.00	$/day	(H)
EQUIPMENT COSTS			
Material Truck	20.00	$/day	(I)
Traffic Control Truck and Signs	25.00	$/day	(J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	10.00	$/day	(K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	5.00	$/day	(L)
Extra Equipment Truck	20.00	$/day	(M)
Specialty Equipment (i.e. Spray injection device)	0.00	$/day	(N)
USER COSTS			
User Delay Costs	1,000.00	$/day	(O)

Figure B-3. Cost worksheet for example 3

Total Material Cost [(A+B)×C]	1,500.00	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	720.00	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	80.00	$/day	(R)
Average Daily Productivity	1.5	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	50	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	90,000.00	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	40,000.00	$	(V)
Total Patching Operation Cost with User Costs (P+U)	91,500.00	$	(W)
Total Patching Operation Cost without User Costs (P+V)	41,500.00	$	(X)
Patch Survival Rate (Duration may vary)	80	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	109,800.00	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	49,800.00	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	91.50	$/ft^3	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	41.50	$/ft^3	(CC)

Figure B-3. Cost worksheet for example 3 (continued)

MATERIAL COSTS			
Material Purchase Cost	0.00	$/ton	(A)
Material Shipping Cost	0.00	$/ton	(B)
Anticipated Material Needs	200	tons	(C)
LABOR COSTS			
Number in Patching Crew	0		(D)
Average Daily Wage per Person	0.00	$/day	(E)
Number in Traffic Control Crew	2		(F)
Average Daily Wage per Person	100.00	$/day	(G)
Supervisor Daily Wage	0.00	$/day	(H)
EQUIPMENT COSTS			
Material Truck	0.00	$/day	(I)
Traffic Control Truck and Signs	25.00	$/day	(J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	0.00	$/day	(K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	0.00	$/day	(L)
Extra Equipment Truck	0.00	$/day	(M)
Specialty Equipment (i.e. Spray injection device)	750.00	$/day	(N)
USER COSTS			
User Delay Costs	1,000.00	$/day	(O)

Figure B-4. Cost worksheet for example 4

Total Material Cost [(A+B)×C]	0.00	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	200.00	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	775.00	$/day	(R)
Average Daily Productivity	4	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	50	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	88,750.00	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	38,750.00	$	(V)
Total Patching Operation Cost with User Costs (P+U)	88,750.00	$	(W)
Total Patching Operation Cost without User Costs (P+V)	38,750.00	$	(X)
Patch Survival Rate (Duration may vary)	90	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	97,620.00	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	42,620.00	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	30.51	$/ft^3	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	13.32	$/ft^3	(CC)

Figure B-4. Cost worksheet for example 4 (continued)

MATERIAL COSTS			
Material Purchase Cost	20.00	$/ton	(A)
Material Shipping Cost	0.00	$/ton	(B)
Anticipated Material Needs	200	tons	(C)
LABOR COSTS			
Number in Patching Crew	2		(D)
Average Daily Wage per Person	100.00	$/day	(E)
Number in Traffic Control Crew	2		(F)
Average Daily Wage per Person	100.00	$/day	(G)
Supervisor Daily Wage	0.00	$/day	(H)
EQUIPMENT COSTS			
Material Truck	20.00	$/day	(I)
Traffic Control Truck and Signs	25.00	$/day	(J)
Preparation Equipment (i.e. Compressor, Jack Hammer, Pavement Saw, etc.)	0.00	$/day	(K)
Compaction Equipment (i.e. Vibratory Plate, Single-Drum, etc.)	0.00	$/day	(L)
Extra Equipment Truck	0.00	$/day	(M)
Specialty Equipment (i.e. Spray injection device)	0.00	$/day	(N)
USER COSTS			
User Delay Costs	10,000.00	$/day	(O)

Figure B-5. Cost worksheet for example 5

Total Material Cost [(A+B)×C]	4,000.00	$	(P)
Total Daily Labor Cost [(D×E)+(F×G)+H]	400.00	$/day	(Q)
Total Equipment Cost (I+J+K+L+M+N)	45.00	$/day	(R)
Average Daily Productivity	4	tons/day	(S)
Estimated days for Initial Patching Operation (C÷S)	50	days	(T)
Total User, Labor, and Equipment Cost [(O+Q+R)×T]	522,250.00	$	(U)
Total Labor and Equipment Cost [(Q+R)×T]	22,250.00	$	(V)
Total Patching Operation Cost with User Costs (P+U)	526,250.00	$	(W)
Total Patching Operation Cost without User Costs (P+V)	26,250.00	$	(X)
Patch Survival Rate (Duration may vary)	25	%	(Y)
Effective Patching Operation Cost with User Costs [W×{2-(Y÷100)}]	913,940.00	$	(Z)
Effective Patching Operation Cost without User Costs [X×{2-(Y÷100)}]	45,940.00	$	(AA)
Cost per Original Pothole Volume with User Costs [Z×(0.0625÷C)]	285.61	$/ft^3	(BB)
Cost per Original Pothole Volume without User Costs [AA×(0.0625÷C)]	14.36	$/ft^3	(CC)

Figure B-5. Cost worksheet for example 5 (continued)

Appendix C

Partial List of Material and Equipment Sources

This appendix contains a directory of manufacturers and representatives who can explain how an agency would obtain any of the materials used in the SHRP H-106 project. Addresses and phone numbers are given for national representatives of the different proprietary materials and spray-injection devices. Information on obtaining specifications for other materials is also provided.

All manufacturers should provide material safety data sheets where applicable. All highway agencies should follow instructions regarding the safe use of all materials, to ensure the safety of their workers and 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, piece of equipment, or supplier. Likewise, omission from this list is not intended to carry negative connotations for those materials, pieces of equipment, and suppliers. In cases in which some discrepancy exists as to which patch type will perform better for a particular agency, side-by-side testing of all available patch types is encouraged.

C.1 Patching Materials

UPM High Performance Cold Mix
Sylvax Corporation
83 South Bedford Road
Mount Kisco, New York 10549
(516) 753 2525

QPR 2000
US Pro-Tech
7471 Tyler Boulevard
Mentor, Ohio 44060
(800) 263 7511

Perma-Patch
National Paving and Contracting Company
4200 Menlo Drive
Baltimore, Maryland 21215
(410) 764 7117

HFMS-2 (modified with Styrelf)
Elf Asphalt
Tulsa, Oklahoma
(918) 438 6450

PennDOT 485 and PennDOT 486
IA Construction
P. O. Box 366
Punxsutawney, Pennsylvania 15767
(814) 938 7650

C.2 Patching Equipment

Durapatcher Spray Injection
Duraco Industries
P. O. Box 6127
Jackson, Mississippi 39288-6127
(601) 932 2100

Roadpatcher Spray Injection
Wildcat Manufacturing
P. O. Box 523
Freeman, South Dakota 57029
(605) 925 4512

Asphalite 200 Spray Injection
Rosco Manufacturing Company
1001 S.W. 1st Street
Madison, South Dakota 57042
(605) 256 6942

C.3 Patching Services

RoadPatch Services, Inc.
P. O. Box 191
Mountainhome, Pennsylvania 18342
(800) 468 1108

Glossary

Pothole–Localized distress in an asphalt-surfaced pavement resulting from the breakup of the asphalt surface and possibly the asphalt base course. Pieces of asphalt pavement created by the action of climate and traffic on the weakened pavement are then removed under the action of traffic, leaving a pothole.

Pothole patching–The repair of severe, localized distress in asphalt-surfaced pavements. This maintenance activity is generally done by agency responsible for the roadway, and is intended to be a temporary repair at best. Pothole patching is not intended to be a permanent repair. Full-depth reconstruction of the distressed areas is necessary for a permanent repair in most instances.

Semi-permanent–Repair technique for potholes in asphalt-surfaced pavements that includes removing water and debris from the pothole before placing repair material. Once the pothole has been cleaned, the edges of the distress are straightened using a pavement saw, jack hammer, milling machine, or similar equipment. After the edges have been straightened and are in sound pavement, the cold mix is placed. The patch is compacted using a single-drum vibratory roller or a vibratory-plate compactor.

Spray injection–Repair technique for potholes in asphalt-surfaced pavements and spalls in PCC-surfaced pavements that uses a spray-injection device. Spray-injection devices are capable of spraying heated emulsion, virgin aggregate, or both into a distress location.

Throw-and-go—Repair technique for cold-mix patching materials in which material is shoveled into the pothole, with no prior preparation of the pothole, until it is filled; compaction of the patch is left to passing traffic, while the maintenance crew moves on to the next distress location.

Throw-and-roll—Repair technique for cold-mix patching materials in which material is shoveled into the pothole, with no prior preparation of the pothole, until it is filled; the material truck tires are used to compact the patch before the crew moves on to the next distress location.

References

1. Smith, K.L., et al. *Innovative Materials and Equipment for Pavement Surface Repairs–Final Report.* Volumes I and II. Report no. SHRP-M/UFR-91-504. SHRP, National Reserch Council, Washington DC: 1991.

2. Evans, L.D., et al. *Materials and Procedures for Pavement Repairs–Final Report.* SHRP, National Reserch Council, Washington DC. Forthcoming.

3. Anderson, D.A., et al. *More Effective Cold, Wet-Weather Patching Materials for Asphalt Pavements.* Report no. FHWA-RD-88-001. Federal Highway Administration, U.S. Department of Transportation, Washington DC: 1988.

4. Tam, K.K. and D.F. Lynch. "New Methods for Testing Workability and Cohesion of Cold Patching Material. Bituminous Section, Engineering Materials Office, Ontario Ministry of Transportation: December 1987.

5. Carpenter, S.H., and T.P. Wilson. "Evaluations of Improved Cold Mix Binders–Field Operations Plan." Contract no. DTFH61-90-00021. Federal Highway Administration, U.S. Department of Transportation, Washington, DC: October 1991.