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

Manual of Practice

Federal Highway Administration
U.S. Department of Transportation

Strategic Highway Research Program
National Research Council

FOREWORD

This manual (FHWA-RD-99-152) presents guidelines and recommendations to assist highway maintenance agencies and other related organizations in planning, constructing, and monitoring the performance of concrete pavement partial-depth spall repair projects. Included in the manual are discussions pertaining to when partial-depth spall repair operations are appropriate, the types of repair materials and construction methods that should be used, how each individual step in a spall repair operation should be performed, and how the performance and cost-effectiveness of spall repairs can be evaluated. This report will be of interest and benefit to various levels of agency maintenance personnel, from crew supervisors to the chief maintenance engineer.

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16. Abstract
The Strategic Highway Research Program (SHRP) H-106 maintenance experiment and the Federal Highway Administration (FHWA) *Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites* project studied the repair of partial-depth spalls in concrete pavements. Many different repair materials and methods were investigated between 1991 and 1998 through test sites installed at four locations in the United States. The findings of these combined studies have been merged with standard highway agency procedures to provide the most useful and up-to-date information on the practice of concrete partial-depth spall repair.

This Manual of Practice is an updated version of the 1993 SHRP Spall Repair Manual. It contains the latest information pertaining to the performance of repair materials and methods, the availability and relative costs of repair materials, and the proper ways of planning, designing, constructing, and monitoring the performance of partial-depth spall repair projects. It also provides an updated partial listing of material and equipment manufacturers.

This Manual is intended for field and office personnel within highway maintenance agencies and contracted maintenance firms. It contains valuable information for supervisors and foremen in charge of individual spall repair operations, engineers in charge of planning and overseeing many spall repair projects, and managers in charge of establishing repair policies and standards.

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Preface

This manual is intended for use by highway maintenance agencies and contracted maintenance firms in the field and in the office. It is a compendium of good practices for portland cement concrete (PCC) partial-depth spall repair operations, stemming from the Strategic Highway Research Program (SHRP) pavement maintenance studies and a follow-up study sponsored by the Federal Highway Administration (FHWA).

In SHRP 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 (Smith et al., 1991). The information and findings from that study were then used in the subsequent field experiments conducted under SHRP project H-106, *Innovative Materials Development and Testing*.

In project H-106, 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 through the end of 1992. The first version of this manual was prepared in October 1993 and was based on this work effort.

Following the conclusion of the SHRP in 1993, the FHWA sponsored a study to continue monitoring the performance of the experimental repairs and treatments, beginning in October 1993. Under the *Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites* project, the experimental repairs and treatments were evaluated annually through the end of 1997. The pertinent long-term performance and cost-effectiveness information generated by the continued monitoring of the experimental spall repairs has been included in this revised manual.

For the reader's convenience, potentially unfamiliar terms are italicized at their first occurrence in the manual and are defined in a glossary. Readers who want more information on topics included in this manual should refer to the reference list provided at the back. The final report for the H-106/*LTM* partial-depth spall repair study may be of particular interest to many readers (Wilson et al., 1999). It details the installation procedures, laboratory testing of the materials, and field performance of each spall repair type investigated.

Acknowledgments

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- Arizona Department of Transportation.
- Commonwealth of Pennsylvania Department of Transportation.
- South Carolina Department of Highways and Public Transportation.
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1.0 Introduction

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

1.1 Scope of Manual

This manual describes procedures and materials recommended for partial-depth *spall* repair in jointed PCC pavements. Only *rapid-setting materials* are discussed. The manual presents detailed guidelines on design, construction, and inspection. The information in this manual is based on the most recent research, obtained through reviews of literature and current practices, and the results of a large-scale, long-term (6.5 years) spall repair field study sponsored by the Strategic Highway Research Program (SHRP) and the Federal Highway Administration (FHWA) (Smith et al., 1991; Evans et al., 1993a; Wilson et al., 1999).

1.2 Purpose of Partial-Depth Spall Repair

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

[*] Italicized words are defined in the glossary.

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

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

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

1.3 Partial-Depth Patch Performance

Studies have shown that when partial-depth patches are properly installed with good quality control, 80 to 100 percent of the repairs perform well after 3 to 10 years of service (Snyder et al., 1989; McGhee, 1977; Webster et al., 1978). In the SHRP/FHWA-sponsored study, several types of partial-depth patches were observed to have failure rates less than 20 percent after more than 5 years of service (Wilson et al., 1999).

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

- Improper selection of repair materials.
- Lack of bond between the patch and the pavement.

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

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

1.4 Limitations

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

2.0 Need for Partial-Depth Spall Repair

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

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

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

2.1 Pavement Condition

Partial-depth spall repairs may be needed when a pavement is rehabilitated to restore structural integrity, improve ride, and

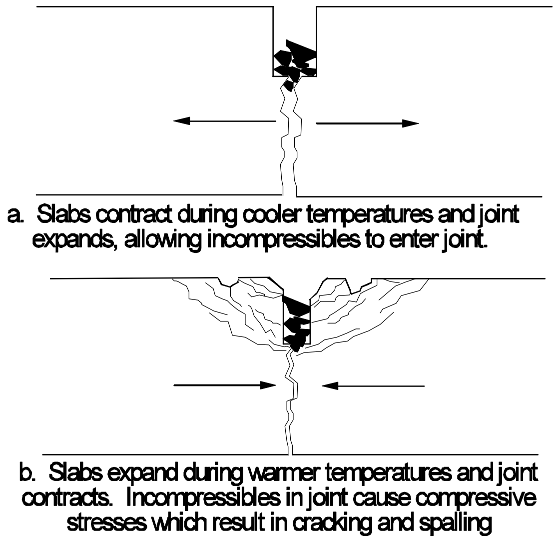

Figure 1. Partial-depth spall caused by incompressibles.

extend the life of the pavement. Partial-depth spall repairs should not be used if the pavement must be rehabilitated by *cracking and seating, breaking and seating,* or *rubblization* before overlaying.

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

2.2 Climatic Conditions

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

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

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

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

3.0 Planning and Design

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

- Exclusion of some deteriorated concrete from the repair boundaries.
- Incompatibilities between the climatic conditions during repair placement and the materials or procedures used.
- Thermal incompatibility between the repair material and the pavement.
- Climatic conditions during the life of the repairs that are beyond the capabilities of the repair material.
- Inadequate cure time prior to opening repairs to traffic.
- Incompatibility between the *joint bond breaker* and the joint sealant material.

3.1 Objectives in Selecting Materials and Procedures

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

Spalls that are repaired before a pavement overlay do not need patch edges as vertical and straight as they should otherwise be, and the repair material does not need to wear well.

Furthermore, patches that are covered by an overlay will undergo slower temperature changes than patches that are not covered by an overlay. Therefore, thermal compatibility between the patch and pavement may be less important for these patches.

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

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

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

3.2 Assessing Existing Conditions

Before the design stage of partial-depth spall repair, the highway agency should assess the local climate and condition of the pavement. Factors to consider include the climatic conditions expected during construction and throughout the life of the patch; the degree, depth, and cause of spalling; the time available before the patch must be opened to traffic; and the need for other repairs, such as drainage, stabilization, etc. The National Highway Institute (NHI) 4R Manual (*Techniques for*

Pavement Rehabilitation) is an excellent guide for assessing and performing many highway repairs (ERES, 1993).

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

3.3 Selecting a Repair Material

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

Material cost, shelf life, physical properties, workability, and performance vary greatly among the different types of materials, and from brand to brand within each type. When comparing costs, the initial material cost plus the cost of installation in terms of time, equipment, and labor must be considered. Section 3.8 presents a worksheet to help calculate these costs. Table 1 lists properties and approximate cost factors for some materials (Evans et al., 1991; Krauss, 1985; Tempe et al., 1984). The cost factor is the ratio of the cost of the given material to the cost of a typical rapid-setting Type III PCC material.

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

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

Product	Material Category	Working Time, minutes	Installation Temp. Range[a]	Time-to-Traffic (21EC), hours	Moisture Conditions[b]		Material Cost Factor[c]
					Repair Surface	Aggregate	
Type III PCC	Cementitious (PCC)	20	0 to 43EC	4 to 6	SSD to dry	1-3% to dry	1
Duracal	Cementitious (gypsum-based)	20	0 to 43EC	1.5	SSD to dry	1-3% to dry	0.7[d]
Set-45	Cementitious (magnesium phosphate)	10	0 to 32EC	1.5	dry	1-3% to dry	3.5[d]
Five Star HP	Cementitious (high alumina)	20	0 to 32EC	1.5	SSD to dry	1-3% to dry	3
Pyrament 505	Hydraulic cement	30	0 to 43EC	2 to 3	SSD to dry	1-3% to dry	2

[a] The installation temperature range shown is the temperature range at which the material manufacturer claims it can be installed. However, patching is generally not recommended when the temperature is below 4ºC or above 32ºC. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing.

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

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

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

[e] The manufacturer states that an SSD pavement surface is acceptable; however, lab tests indicate that bonding needs a dry surface (Evans et al., 1993a).

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

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

Product	Material Category	Working Time, minutes	Installation Temp. Range[a]	Time-to-Traffic (21EC), hours	Moisture Conditions[b]		Material Cost Factor[c]
					Repair Surface	Aggregate	
SikaPronto 11	Polymer (modified methacrylate)	30	2 to 32EC	1.5	SSD to dry[e]	dry	16
Penatron R/M 3003	Polymer (epoxy-urethane)	7 to 10	-23 to 66EC	0.5	dry	dry	17
MC-64	Polymer (epoxy)	10	4 to 32EC	2	dry	dry	23
Percol FL	Polymer (urethane)	1	> -18EC	0.15 to 0.30	dry	dry	9
UPM High Perf. Cold Mix	Bituminous	Not applicable	0 to 38EC	immediately	SSD to dry	1-3% to dry	0.5 to 0.6
Spray-injection mix	Bituminous	Not applicable	-23 to 38EC	immediately	SSD to dry	1-3% to dry	0.2 to 0.4[f]

[a] The installation temperature range shown is the temperature range at which the material manufacturer claims it can be installed. However, patching is generally not recommended when the temperature is below 4°C or above 32°C. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing.

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

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

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

[e] The manufacturer states that an SSD pavement surface is acceptable; however, lab tests indicate that bonding needs a dry surface (Evans et al., 1993a).

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

purchased from local distributors. Other materials may require shipping and may therefore cost more. Manufacturers will provide exact material and shipping costs upon request.

Highway agencies should select the most cost-effective material that meets the requirements of the project. Cost-effectiveness is a function of patch performance and life, as well as the characteristics of a given project, such as traffic and user costs (see section 3.8). Results from the recently concluded SHRP H-106 spall repair study indicate good long-term (>5 years) performance capabilities among most of the cementitious and polymeric repair materials (Wilson et al., 1999). However, the much lower material costs associated with these materials often resulted in the lowest total life-cycle costs. In addition, although bituminous cold-mix materials (including spray-injection mixes) were shown to perform for much shorter durations (2 to 4 years), their low installation costs occasionally made them as cost-effective as the cementitious materials.

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

3.3.1 Cementitious Concretes

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

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

Criteria	Materials[a]										
	III	Dur	Set45	5HP	Pyr	SP11	Pen	MC64	PFL	UPM	Spray
Installation temperature[b]											
-23°C < T < 0°C							T		T	T	T
0°C # T < 4°C[b]	T	T	T	T	T		T		T	T	T
4°C < T # 32°C	T	T	T	T	T	T	T	T	T	T	T
T> 32°C[b]	T	T					T		T	T	T
Time-to-traffic at 21°C											
5 min										T	T
30 min							T		T	T	T
2 hr		T	T	T	T	T	T	T	T	T	T
4 hr	T	T	T	T	T	T	T	T	T	T	T
Aggregate moisture											
1-3% moisture allowed	T	T	T	T						T	T
Oven-dried[c]	T	T	T	T	T	T	T	T	T	T	T
Pavement surface moisture											
Saturated, surface-dry	T	T		T	T	T[d]				T	T
Dry[e]	T	T	T	T	T	T	T	T	T	T	T

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

[b] Patching is generally not recommended when the temperature is below 4°C or above 32°C. At cold or hot temperatures, special precautions may be needed, such as the use of warmed or iced water during mixing, or insulating blankets during curing.

[c] Water content should be adjusted as needed.

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

[e] Wet surface before material placement if required by manufacturer.

Portland Cement Concrete

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

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

Gypsum-Based Concrete

Gypsum-based (calcium sulfate) patching materials (e.g., Duracal, Rockite) gain strength rapidly and can be used in temperatures above freezing (up to 43°C, for example, in the case of Duracal). However, gypsum concrete does not appear to perform well when exposed to moisture or freezing weather (Stingley, 1977). In addition, the presence of *free sulfates* in the typical gypsum mixture may promote steel corrosion in reinforced pavements (Smith et al., 1991).

Magnesium Phosphate Concrete

Magnesium phosphate concretes (e.g., Set-45, Eucospeed MP, Propatch MP) set very quickly, and make high early-strength, impermeable patches that bond to clean and dry surfaces. However, these materials are extremely sensitive to water on the pavement, and even very small amounts of extra water in the mix severely decreases strength. They also cannot be used with limestone aggregates (Smith et al., 1991). These limitations have led to variable field performance (Stingley, 1977; Tyson, 1977).

High Alumina Concrete

Calcium aluminate concretes (e.g., Five Star HP) gain strength fast, bond well (adhere best to a dry surface), and shrink very little during curing. However, they may lose strength over time because of a *chemical conversion* that takes place, particularly at high curing temperatures (Snyder et al., 1989; Stingley, 1977; Smith et al., 1991).

3.3.2 Polymer Concretes

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

Epoxy Concrete

Epoxy concretes (e.g., MC-64, Burke 88/LPL, Mark 103 Carbo-Poxy) are impermeable and are excellent adhesives. They have a wide range of setting times, application temperatures, strengths, and bonding conditions. The epoxy concrete mix design must be thermally compatible with the pavement, otherwise the patch may fail. Deep epoxy repairs often must be placed in lifts to control heat development. Epoxy concrete should not be used to patch spalls caused by reinforcing steel corrosion, as the rate of deterioration of adjacent sound pavement may be accelerated (Furr, 1984).

Methyl Methacrylate Concrete

Methyl methacrylate concretes and *high molecular weight methacrylate concretes* (e.g., SikaPronto 11, Degadur 510) are polymer-modified concretes that could also be classified as cementitious materials. They have relatively long working times, high *compressive strengths*, and good adhesion. Many methyl methacrylates are volatile and may pose a health hazard from prolonged exposure to the fumes (Krauss, 1985). As with all materials, material safety data sheets (MSDS's) must be obtained from the manufacturer and followed to ensure the safe use of these materials.

Polyurethane Concrete

Polyurethane concretes (e.g., Percol FL, Penatron R/M-3003) generally consist of a two-part polyurethane *resin* mixed with aggregate. Polyurethanes generally set very quickly (90 sec). Some manufacturers claim their materials are moisture-tolerant; that is, they can be placed on a wet surface with no adverse effects. This type of material has been used for several years with variable results (Krauss, 1985; Mueller, 1988).

3.3.3 Bituminous Materials

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

3.3.4 Material Testing

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

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

The suggested tests for bituminous cold mixes include:

- Workability.
- Stripping.
- Drainage.
- Cohesion.

These laboratory tests are index tests and do not necessarily predict performance. Therefore, initial field testing should be conducted. MSDS's should be examined, as well as storage requirements and shelf life.

3.4 Selecting Accessory Materials

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

3.4.1 Bonding Agents

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

3.4.2 Joint Bond Breakers

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

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

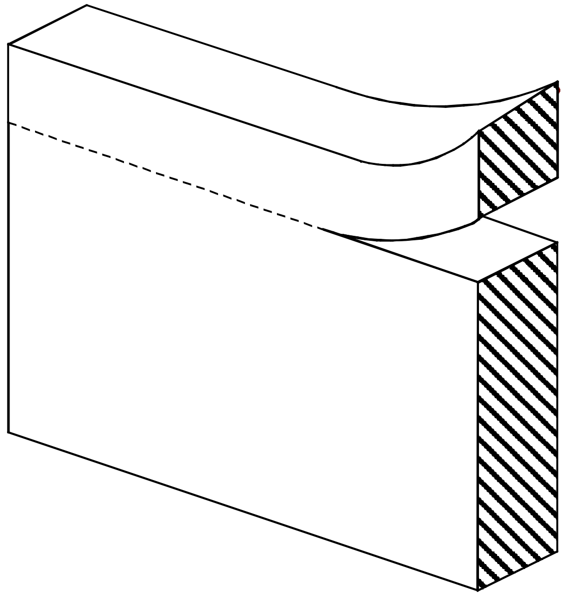

Figure 2. Scored joint bond breaker.

is more rigid than other types of bond breakers. It should be used at the lane-shoulder joint where more support is needed.

For information on selecting dimensions for the joint reservoir (the width of the joint bond breaker, and the depth of scoring), consult *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* (Evans and Romine, 1993b).

3.4.3 Curing Materials

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

- Water curing.
  - continuous water spraying.
  - saturated coverings (burlap, sand, or straw).
- Sealed curing.
  - plastic sheeting.
  - curing compounds.

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

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

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

3.4.4 Joint Sealants

An appropriate joint sealant must be installed to ensure the performance of the partial-depth patch. The sealant must prevent water and incompressibles from entering the joint. If the pavement will not be overlaid and the remaining life of the pavement is expected to be long, silicones and high-quality hot-poured rubberized or polymerized asphalt sealants are generally recommended. If the pavement will be overlaid, the joints should still be filled, but lower quality materials may be acceptable. For information on selecting a joint sealant, consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* (Evans and Romine, 1993b).

3.5 Selecting Dimensions of the Repair Area

Partial-depth patches should be limited in depth to the top third of the slab and should never come in contact with dowel bars. **If dowel bars are reached, a *full-depth spall repair* must be used.** Partial-depth patches must be at least 50 mm deep for weight and volume stability. They should extend 50 mm to 150 mm in each possible direction beyond the spalled area, and be at least 100 mm wide and 250 mm long. Table 3 shows the minimum dimensions for patches in various locations. Figures 3 and 4 show the minimum dimensions of partial depth patches located at one joint; figures 5 and 6, at two joints.

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

Location of Spalling	Minimum Dimensions of Repair Area		
	Depth (mm)	Length (mm)	Width (mm)
At One Joint	50	250 **or** length of spalled area + 100 **whichever is greater**	100 **or** width of spalled area + 50 **whichever is greater**
At Two Joints	50	200 **or** length of spalled area + 50 **whichever is greater**	100 **or** width of spalled area + 50 **whichever is greater**
Away From Joints	50	250 **or** length of spalled area + 100 **whichever is greater**	140 **or** width of spalled area + 100 **whichever is greater**

Areas less than 150 mm long or 40 mm wide are normally not patched, but are filled with a sealant. Patches less than 300 mm from each other should be repaired with one patch, as shown in figures 4 and 6. When several small spalls exist at one joint, it usually costs less to patch the entire joint length than to repair individual spalls.

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

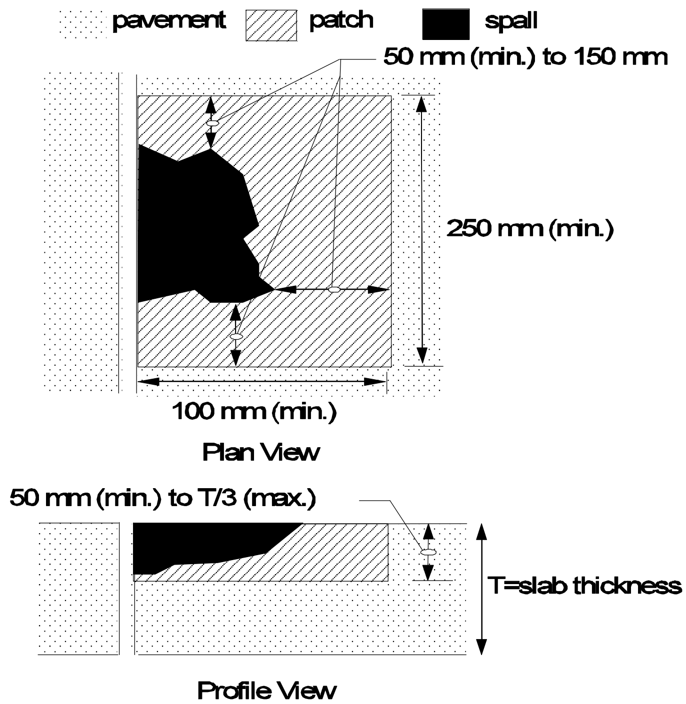

Figure 3. Dimensions of patch at one joint.

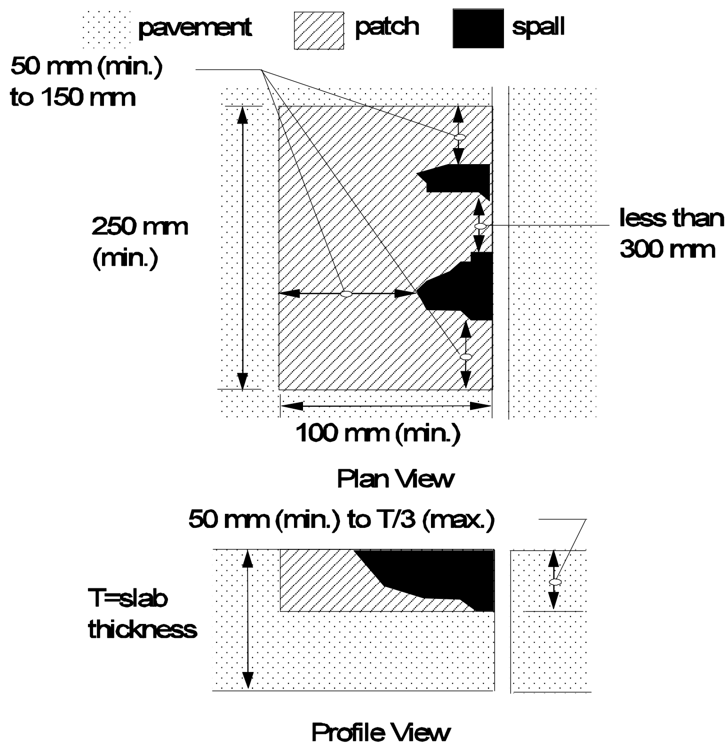

Figure 4. Dimensions of patch at one joint for spall
less than 300 mm apart.

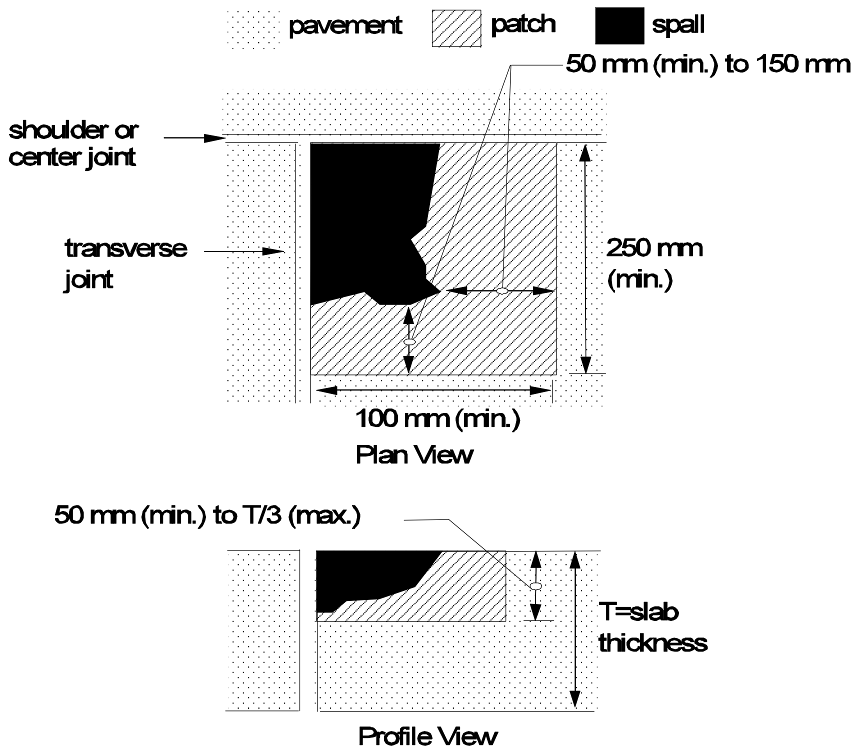

Figure 5. Dimensions of patch at two joints.

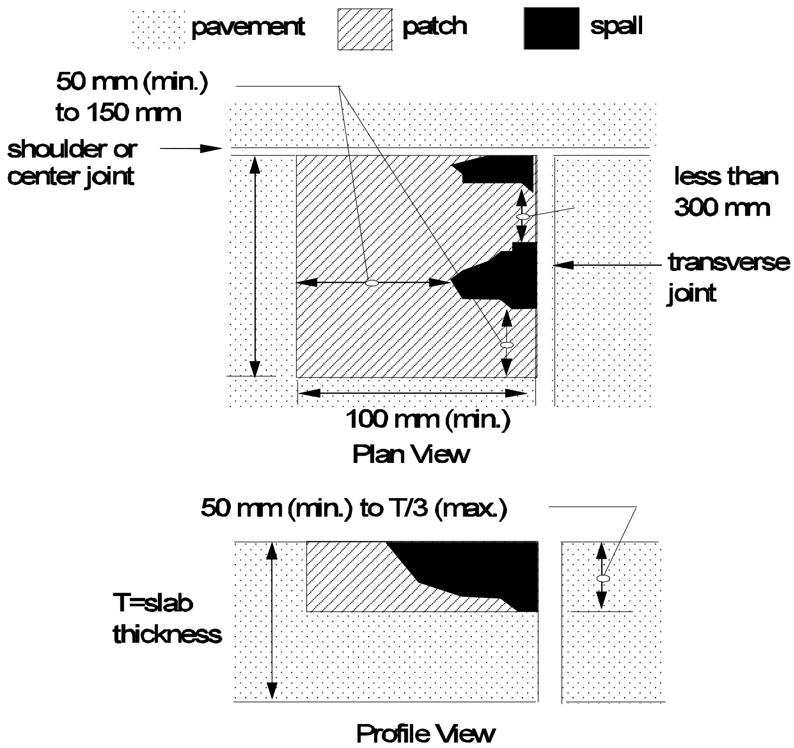

Figure 6. Dimensions of patch at two joints for spalls less than 300 mm apart.

3.6 Selecting Patch Preparation Procedures

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

When selecting a procedure, the highway agency should consider equipment availability and cost, the availability of a crew trained in the procedure, the available construction time, and the performance and cost-effectiveness (section 3.8) of the procedure. Results from the recently concluded SHRP H-106 spall repair study indicate no significant differences in the performance capabilities of the saw-and-patch, chip-and-patch, mill-and-patch, and waterblast-and-patch methods (Wilson et al., 1999). However, the lower installation costs associated with the chip-and-patch procedure make it the more attractive approach from an overall cost-effectiveness standpoint.

3.6.1 Saw and Patch

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

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

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

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

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

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

Also, the saw may encroach into the open lane of traffic if the spall is near the open lane, creating a hazardous situation.

Saw overcuts occur because the boundaries must be overcut 50 mm to 75 mm in each direction to obtain the needed depth of cut. These overcuts create weak areas that may deteriorate unless cleaned and sealed.

3.6.2 Chip and Patch

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

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

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

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

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

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

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

3.6.3 Mill and Patch

Some States have successfully used carbide-tipped milling machines for spall repair (Zoller et al., 1989). Standard milling machines with 305-mm- to 457-mm-wide cutting heads have proven efficient and economical, particularly when used for large areas (e.g., for full lane-width repairs). The milling operation leaves a rounded cavity that may be made vertical by hammering or sawing. The milling machine should have a drum diameter of 0.9 m or less and make a 305-mm-wide cut or narrower.

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

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

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

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

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

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

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

3.6.4 Waterblast and Patch

The waterblast-and-patch procedure uses a high-pressure water jet to remove the deteriorated concrete. Several States are testing this method for repairing pavements. The waterblasting

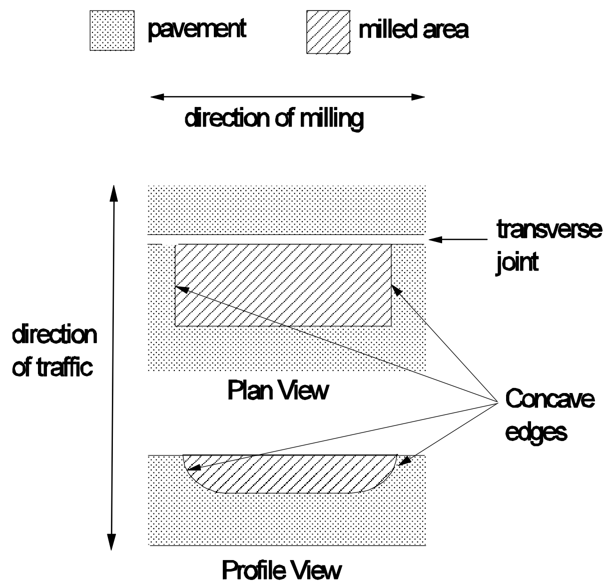

Figure 7a. Recommended orientation of milled patch.

Figure 7b. Milled patch with rounded edges.

machine should be capable of producing a stream of water at 100,000 kPa to 200,000 kPa and should be controlled by a mobile robot. The waterblasting equipment must be capable of removing deteriorated concrete at an acceptable production rate, be under continuous automatic control, and have filtering and pumping units operating with a remote-controlled robotic device. The noise level must be less than 90 decibels at a distance of 15 m from either the power pack unit or the remote robot.

The advantages of waterblasting include the following:

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

The disadvantages of waterblasting include the following:

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

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

3.6.5 Clean and Patch

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

3.7 Estimating Material, Equipment, and Labor

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

Once a repair material has been chosen, the manufacturer's material specifications should be consulted for equipment requirements. Table 4 shows the equipment typically used for the five spall preparation procedures that are discussed in this manual. Table 5 shows the mixing and placement equipment and supplies typically used with some rapid-setting spall repair materials. Table 6 shows the personnel typically used with the five spall preparation procedures. Table 7 shows the personnel typically used for the mixing and placement of some rapid-setting partial-depth spall repair materials.

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

3.8 Overall Cost-Effectiveness

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

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

Equipment	Preparation Procedure[a]				
	S	C	M	W	A
Sounding equipment: rod, chain, or ball-peen hammer	**T**	**T**	**T**	**T**	**T**[b]
Double-bladed concrete saw for joint sawing	**T**	**T**	**T**	**T**	
Single-bladed concrete saw for sawing patch boundaries	**T**				
6.8-kg jackhammer with air compressor	**T**	**T**	**T**[c]		**T**[d]
13.6-kg jackhammer with air compressor	**T**[e]	**T**[e]			
Stiff brooms for debris removal	**T**	**T**	**T**	**T**	**T**
Handtools (pick axe, etc.)	**T**	**T**			**T**
Truck for hauling removed material	**T**	**T**	**T**		**T**
Waterblasting machine				**T**	
Milling machine			**T**		
Sandblasting equipment with directional nozzle, sand, air compressor	**T**	**T**	**T**	**T**	**T**[b]
Airblasting equipment with oil and water filtering capability, air compressor	**T**	**T**	**T**	**T**	**T**[b]

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

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

[c] To remove rounded edges.

[d] Jackhammering may be used for large areas, or when the deteriorated concrete cannot be removed using handtools.

[e] 6.8-kg jackhammers are preferred. 13.7-kg hammers should **never** be used at patch boundaries.

Table 5. Typical mixing and placement equipment and supplies.

Typical Equipment and Supplies[a]	III	Dur	St45	5HP	MC64	SP11	Pen	Pyr	PFL	UPM	Spray
Potable water/hose/pump	T	T	T	T		T		T			
Drum mixer[b] (1.9-2.5 m^3)	T	T						T			
Mortar mixer (0.9-1.2 m^3)			T	T		T					
483-mm elec. drills & 533-mm stainless steel Jiffy mixers	T[c]				T[c]	T[c]	T				
Bonding agent brush/roller	T					T					
Vibrators and/or screeds	T	T	T			T		T			
Trowels	T	T	T	T	T	T		T			
Shovels	T	T	T	T		T		T		T	
Curing compound, applicator, burlap, or plastic sheeting[d]	T	T	T					T			
Insulating blankets[e]	T							T			
Vibratory roller or plate										T	
Electric generator[f]	T	T	T	T	T	T	T	T	T		
Grayco Percat 500[g]									T		
Spray-injection machine[h]											T
Non-water cleaning solvent					T	T	T		T	T	
Compression cylinders/rod	T	T	T	T				T			
Slump cone	T	T	T	T				T			
Air meter, rod, water bulb	T										

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

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

[c] Capable of 400 to 600 rpm.

[d] May be used in hot (> 29°C), windy (> 40 km/h) weather.

[e] In weather below 7°C.

[f] As needed; sufficient for demand.

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

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

Table 6. Typical personnel used for spall repair procedures.

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

Table 7. Typical personnel used for mixing and placing.

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

3.8.1 Cost-Effectiveness Worksheet

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

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

Project Size or Seasonal Partial-Depth Patching Needs

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

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

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount	units	
Expected Number of Patches	_______		(A)
Average Finished Patch Length	_______	mm	(B_1)
Average Finished Patch Width	_______	mm	(B_2)
Average Finished Patch Depth	_______	mm	(B_3)
Expected Total Volume of Finished Patches $[(B_1 \times B_2 \times B_3 \times A) \div 10^9]$	_______	m^3	(C)

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

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

Figure 8. Cost-effectiveness worksheet.

LABOR COSTS

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

EQUIPMENT COSTS

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

Figure 8. Cost-effectiveness worksheet (continued).

SUMMARY COSTS	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	_______	$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	_______	$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) +$ $(P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) +$ $R + S + (T_1 + T_2 + ...)]$	_______	$/day	(W)
User Delay Costs	_______	$/day	(X)
Average Daily Productivity	_______	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	_______	days	(Z)
Total Patching Operation Cost $[U + \{Z \times (V + W + X)\}]$	_______	$	(AA)
Expected Mean Life for Partial-Depth Patches[1] (Duration may vary)	_______	months	(BB)
Time to Pavement Rehabilitation	_______	months	(CC)
Effective Patching Cost Over Time $[AA \times (CC/BB)]$	_______	$	(DD)

[1] Until expected mean life values have been determined, agency experience should be applied. See Appendix B for calculation examples.

Figure 8. Cost-effectiveness worksheet (continued).

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

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

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

Material Cost Variables

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

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

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

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

Labor and Equipment Costs Worksheet Variables

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

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

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

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

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

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

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

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

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

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

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

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

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

Summary Costs

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

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

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

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

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

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

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

(BB) **Expected Mean Life–**An estimate of how long the patches will survive. The amount entered should be in months.

- **(CC)** **Time to Rehabilitation–**An estimate as to the amount of time remaining before rehabilitation will be performed on the pavement surface. The amount should be entered in months.

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

3.8.2 Determining Cost-Effectiveness Inputs

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

4.0 Construction

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

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

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

4.1 Traffic Control

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

4.2 Safety Precautions

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

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

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

4.3 Material Testing

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

4.4 Initial Joint Preparation

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

4.4.1 Removing Old Sealant

If a nonflexible patching material is used, the old sealant in the adjacent joint and 75 mm to 100 mm beyond the patch must be removed for placement of a joint bond breaker. If a flexible polymer material is used, the old sealant should still be removed, and the area adjacent to the patch should be cleaned thoroughly. Bituminous materials do not need any special cleaning.

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

4.4.2 Joint Sawing

When a joint bond breaker is needed, the existing transverse and longitudinal joints next to the repair should be resawn using a double-bladed concrete saw. The depth of the cut should be at least 25 mm deeper than the depth of the repair. The saw cut should extend 50 to 75 mm beyond the repair area in each direction. This sawing is usually done before removing the deteriorated concrete, and must be done before cleaning the repair area. Figure 9 shows the proper dimensions of the saw cut. Water-wash equipment should be used to remove all sawing slurry from the repair area before it dries.

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

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

4.4.3 Sawing Out Joint Inserts

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

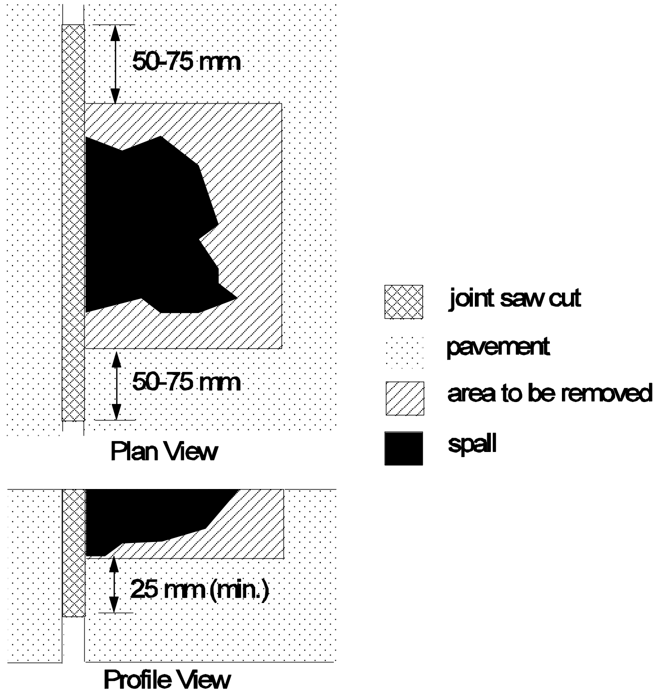

Figure 9. Dimensions of joint saw cut.

4.5 Removing the Deteriorated Concrete

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

4.5.1 Saw and Patch

In the saw-and-patch procedure, a single-bladed concrete saw is used to cut the boundaries of the patch and to make removing the deteriorated concrete easier, as shown in figure 10. The saw cut should be 25 mm to 50 mm deep and usually extends 50 mm to 75 mm beyond the patch boundaries to obtain that depth for the entire length and width of the patch. The cut boundary should have straight, vertical faces and square corners. Vertical boundaries reduce the spalling associated with thin or feathered concrete along the repair perimeter. The recommended dimensions of the repair boundaries are shown in figures 3 through 6. For large areas of repair, the area to be removed may be sawed in a shallow crisscross or waffle pattern to facilitate concrete removal, as shown in figure 11. Water-wash equipment should be used to remove sawing slurry from the repair area before it dries.

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

Removal near the repair boundaries must be completed with 4.6-kg to 6.8-kg hammers fitted with *spade bits*, because *gouge bits* can damage sound concrete. Spade bits are shown in figure 12. Jackhammers and mechanical chipping tools should be

Figure 10. Sawing patch boundaries with a small handheld saw.

Figure 11. Sawing pattern for large repair areas.

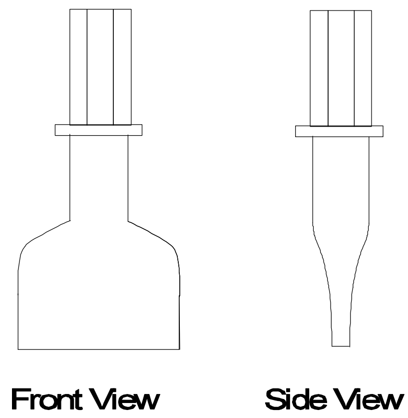

Figure 12. Spade bits.

operated at an angle less than 45 degrees from vertical as shown in figure 13.

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

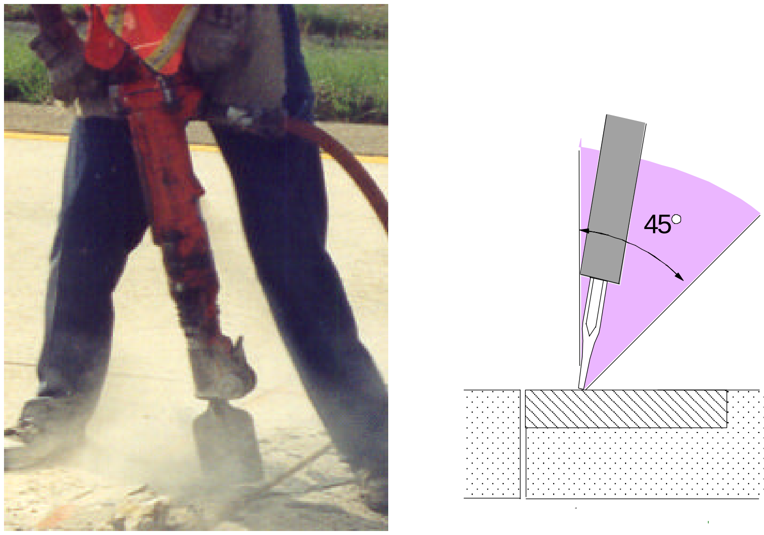

Figure 13. Using a jackhammer.

Figure 14. Sounding repair area with a steel rod.

4.5.2 Chip and Patch

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

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

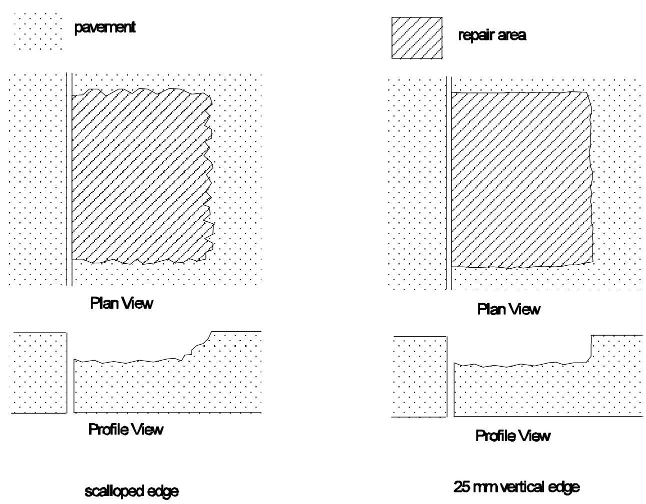

Figure 15. Scalloped edge and 25-mm vertical edge.

4.5.3 Mill and Patch

In the mill-and-patch procedure, all unsound concrete within the marked area is removed to a minimum depth of 50 mm using a carbide-tipped milling machine. The small amount of material that remains at the patch corners must be removed by light jackhammering or sawing. Whenever possible, the milling machine should be oriented such that the rounded edges of the hole it produces are parallel to the direction of traffic. The proper orientation of the rounded edges of the milled patch is shown in figure 7. If this orientation is not possible, the rounded edges should be made vertical using a light jackhammer.

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

4.5.4 Waterblast and Patch

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

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

Figure 16. Protective shield around waterblasting operation.

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

All unsound concrete within a marked spalled area should be removed to a minimum depth of 50 mm with neat vertical faces. Then the repair area must be tested again for soundness. Any additional unsound concrete must be removed by continued waterblasting. A full-depth repair must be used if the deterioration is found to be deeper than the top third of the pavement slab, or if reinforcing bars or mesh are reached.

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

4.5.5 Clean and Patch

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

4.6 Cleaning the Repair Area

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

4.6.1 Sandblasting

Sandblasting, shown in figure 17, is highly recommended for cleaning the surface. It removes dirt, oil, thin layers of unsound concrete, and laitance. Sandblasting equipment consists of a compressed air unit, a sand dispenser, hoses, and a wand with a venturi-type nozzle. The compressed air must be free of oil and water, since a contaminated surface will prevent bonding. The air quality can be checked by placing a cloth over the air compressor nozzle and visually inspecting for oil. Sandblasting is generally not used under adverse conditions.

Figure 17. Sandblasting.

4.6.2 Airblasting

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

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

4.6.3 Sweeping

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

4.7 Final Joint Preparation

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

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

The bond breaker should have a scored top strip as shown in figure 2. It should extend 25 mm below and 75 mm beyond the repair boundaries, as shown in figure 18a. The extension will prevent the repair material from flowing into the joint during placement. Figure 18b shows a bond breaker installed improperly, as there is not enough length to extend beyond the repair boundary along the top (longitudinal) edge of the repair area. The bond breaker should be slightly wider than the joint

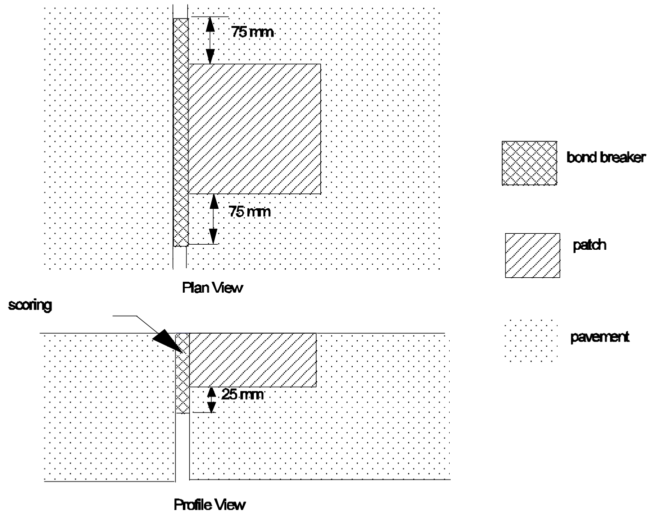

Figure 18a. Correct dimensions of joint bond breaker placement at one joint.

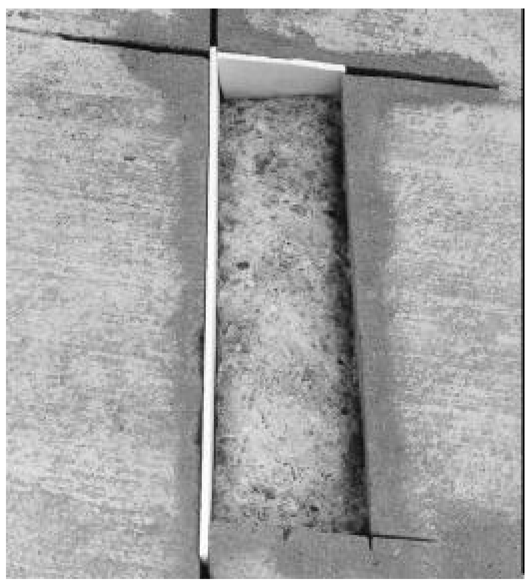

Figure 18b. Incorrectly installed bond breaker at two joints.

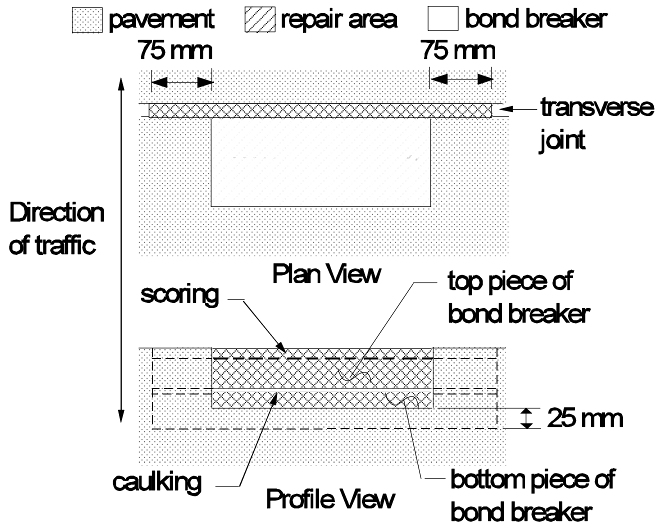

Figure 19. Joint bond breaker that has been stacked and caulked.

so that it is slightly compressed when installed. The scored top strip must later be torn off and the resulting joint reservoir filled with an appropriate joint sealant. Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for more information on selecting appropriate dimensions for the joint reservoir and joint bond breaker, and for appropriate joint sealing materials and methods (Evans and Romine, 1993b).

4.7.1 Preparing Transverse Joints

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

4.7.2 Preparing Centerline Joints

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

4.7.3 Preparing Lane-Shoulder Joints

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

4.7.4 Using Flexible Repair Materials

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

4.8 Pre-Placement Inspection of the Repair Area

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

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

4.9 Mixing the Bonding Agent

Some partial-depth patching materials require epoxy or proprietary bonding agents. Epoxy bonding agents should be mixed carefully according to the manufacturer's instructions. An electric drill with a Jiffy mixer may be used to mix the two epoxy components for the required time.

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

4.10 Mixing the Repair Material

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

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

4.10.1 Cementitious Concretes

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

The proportions of water, aggregate, and cement depend on the type of material selected. A rapid-setting Type III PCC mix generally includes an air-entraining agent, an accelerating agent, and a superplasticizer. In addition to the cement itself, rapid-setting cementitious materials need clean water and a manufacturer-specified gradation of aggregate. Some proprietary materials (e.g., Duracal) also need sand. Most

Figure 20. Adding carefully measured components to a drum mixer.

cementitious materials require that the water be added to the running mixer, followed by the aggregate, and then the cement. Warm water may be needed at air temperatures below 13ºC, while ice water may be needed at higher temperatures. The manufacturer's recommendations for proportions, mixing sequence, and mixing times for each component should be followed exactly.

4.10.2 Polymer Concretes

Polymer concretes, such as epoxies (e.g., MC-64), methyl methacrylates (e.g., SikaPronto 11), and polyurethanes (e.g., Percol FL, Penatron R/M-3003), are generally mixed with a

Jiffy mixer or a mortar mixer, as specified by the material manufacturer.

The materials usually consist of two or more premeasured liquid components, or a liquid component and cementitious components. The different components are generally mixed separately and then in combination. Mortar mixers are used for mixing large batches of liquid components and for mixing cementitious components with aggregate. Jiffy mixers are used for mixing small batches of liquid components, as shown in figure 21. Liquid mixtures are either mixed with or poured over a specified gradation of oven-dried aggregate. The manufacturer's recommendations for mixing sequence, component amounts, and mixing times should be followed exactly.

4.10.3 Bituminous Materials

Bituminous cold mixes (e.g., UPM High-Performance Cold Mix) are generally mixed at a local plant using the manufacturer's mix design. They may also come premixed in drums, buckets, or bags. When patching spalls with a spray-injection machine (e.g., AMZ, Rosco), the machine mixes asphalt emulsion heated to approximately 57°C and aggregate. An experienced operator should carefully control the volume of each component. The asphalt and aggregate are sprayed out under pressure. Care should be taken not to overfill or to spill material outside of the repair area.

Figure 21. Using a jiffy mixer.

4.11 Applying the Bonding Agent

A bonding agent should be applied after cleaning the repair area and just before placing PCC repair materials. The manufacturer's directions must be closely followed when using epoxies or other manufactured grouts. The bottom and sides of the repair area must be thoroughly coated by brushing the grout or epoxy onto the concrete as shown in figure 22. Spraying may be appropriate for large repair areas. Excess bonding agent should not be allowed to collect in pockets. The placement of the bonding agent should be timed so that it is tacky when the repair material is placed.

Figure 22. Applying bonding agent.

4.12 Placing the Repair Material

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

4.12.1 Cementitious Concretes

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

4.12.2 Polymer Concretes

Some polymer concretes may be installed under adverse conditions of low temperatures and wet *substrates* with reasonable success (Stingley, 1977). However, these materials perform better when installed under more favorable conditions.

Due to their high heat of hydration, some polymer concretes, such as epoxies (e.g., MC-64), and methyl methacrylates (e.g., SikaPronto 11) are placed in lifts no more than 38 to 50 mm deep. The time between lifts should be that recommended by the manufacturer. These materials have also been placed in one lift during partial-depth spall repair with no adverse effects.

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

Figure 23. Pumping polymer into a patch that was prefilled with aggregate (cover aggregate also being placed).

4.12.3 Bituminous Materials

Some bituminous mixes may be installed under adverse conditions of low temperatures and wet substrates with reasonable success (Stingley, 1977). However, these materials perform better when installed under more favorable conditions.

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

4.13 Consolidating and Compacting

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

Three common methods of consolidation are:

- Using internal vibrators with small heads (less than 25 mm in diameter).
- Using *vibrating screeds*.
- Rodding or tamping and cutting with a trowel or other handtools.

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

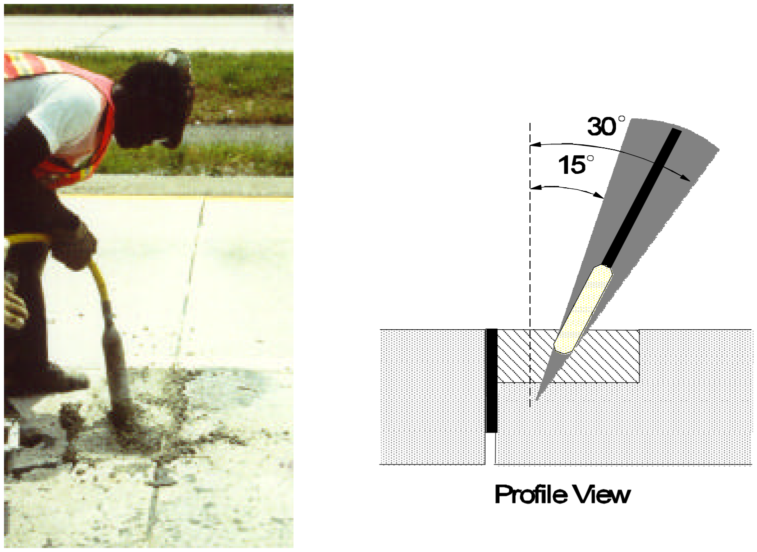

Figure 24. Using an internal vibrator.

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

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

4.14 Screeding and Finishing

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

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

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

4.15 Curing

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

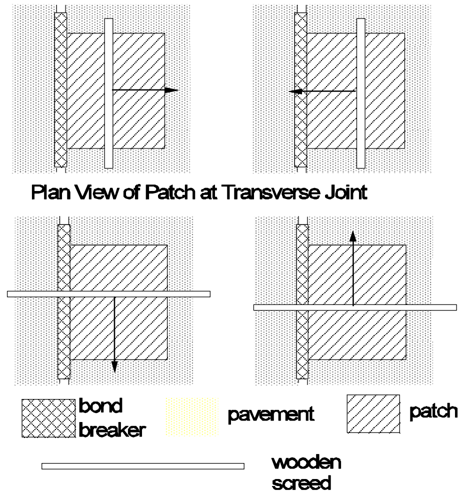

Figure 25. Screeding the patch.

Figure 26. Finishing the patch.

4.15.1 PCC Patching Materials

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

4.15.2 Proprietary Patching Materials

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

4.16 Joint Sealing

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

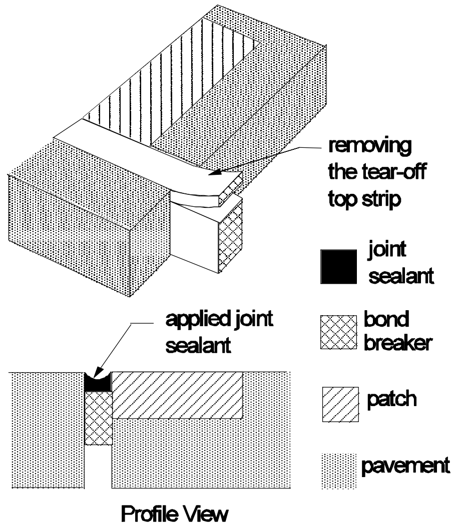

Figure 27. Removing the tear-off top strip of a joint bond breaker.

the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for more information on proper joint sealing practices (Evans and Romine, 1993b).

4.17 Cleanup Requirements

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

4.18 Opening to Traffic

Compressive strength requirements for paving concrete are generally specified at 20,700 kPa at 28 days. The repair concrete should develop an equal or greater strength by the time it receives traffic loadings. However, to minimize lane closures, traffic loadings may be allowed on a patched area when the repair concrete has attained the minimum strength needed to ensure its structural integrity. The compressive strength required for the opening of partial-depth patches to traffic may be lowered because of their *lateral confinement* and shallow depth.

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

4.19 Inspection

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

5.0 Evaluating Partial-Depth Patch Performance

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

5.1 Data Required

To determine the effectiveness of a given patch type (material-procedure combination), field surveys must be conducted periodically. The highway agency must record the survival life for all patches placed so that the mean service life can be calculated for the patch type. The main emphasis for the field survey is to verify the continued survival of the patches, to document those that have failed, and to note distresses evident in the surviving patches, which may indicate the failure mode of the patch.

For calculating the cost-effectiveness of a partial-depth spall repair patching operation, it is necessary to estimate the expected mean repair life of the patches. Table 8 shows one alternative for documenting survival information and generating a mean repair life value for a situation when the time until repair is to be approximately 48 months. For a situation where the time until repair would be approximately 24 months, the maximum service life recorded for each individual repair would be 24 months.

Table 8. Sample patch performance data.

Patch No.	Survival at Month No.								Life at Month No.		
	1	3	6	12	18	24	36	48	24	36	48
1	U	U	U	U	U	U	U	U	24	36	48
2	U	U	U	U	U	U			24	24	24
3	U	U	U	U	U	U	U	U	24	36	48
4	U	U	U	U	U	U	U	U	24	36	48
5	U	U	U	U	U				18	18	18
6	U	U	U	U	U	U	U	U	24	36	48
7	U	U	U	U	U	U	U	U	24	36	48
8	U	U	U	U	U	U	U	U	24	36	48
9	U	U	U	U	U	U	U	U	24	36	48
10	U	U	U	U					12	12	12
11	U	U	U	U	U	U	U	U	24	36	48
12	U	U	U	U	U	U	U	U	24	36	48
13	U	U	U	U	U				18	18	18
14	U	U	U	U	U	U	U	U	24	36	48
15	U	U	U	U	U	U			24	24	24
16	U	U	U	U	U				18	18	18
17									0	0	0
18	U	U	U	U	U	U	U		24	36	36
19	U	U	U	U	U				18	18	18
20	U	U	U	U	U				18	18	18
Mean Service Life									21	27	33

5.2 Calculations

The mean patch service life is calculated simply by averaging the individual service life values recorded for each patch being monitored. The true mean service life cannot be determined until all of the repairs have failed.

The mean service life for the example shown in table 8 is 33 months. This value is valid for calculating cost-effectiveness for situations where the time until rehabilitation will be approximately 48 months. For situations where the time until rehabilitation will be 24 or 36 months, the mean service life for the data shown in table 8 would be 21 or 27 months, respectively.

Appendix A

Material Testing Specifications

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

A.1 Rapid-Setting Cementitious Concretes

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

Initial set time, minimum	15 min
Compressive strength ASTM C 39, 3 hours	6.9 MPa
Compressive strength ASTM C 39, 24 hours	20.7 MPa
Bond strength of epoxy-resin systems ASTM C 882	1.4 MPa
Bond strength of concrete overlay and patching materials, California test	1.4 MPa
Flexural strength ASTM C 78	3.1 MPa
Freeze-thaw resistance ASTM C 666, Procedure A (150 cycles)	15 grams
Scaling resistance ASTM C 672 (100 cycles)	5
Surface abrasion resistance California Test T550	25 grams

Thermal compatibility
ASTM C 884 . . . . pass

A.2 Rapid-Setting Flexible Polymer Concretes

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

Initial set time, minimum . . . . 15 min
Bond strength of epoxy-resin systems
ASTM C 882 . . . . 1.4 MPa
Bond strength of concrete overlay and
patching materials, California test . . . . 1.4 MPa
Freeze-thaw resistance
ASTM C 666, Procedure A (150 cycles) . . . . 15 g
Scaling resistance
ASTM C 672 (100 cycles) 5
Surface abrasion resistance
California Test T550 . . . . 25 g
Thermal compatibility
ASTM C 884 . . . . pass

A.3 Bituminous Materials

Bituminous patching materials shall meet the agency's suggested guidelines for acceptance as approved materials. Tests for workability, stripping, drainage, and cohesion are highly recommended. Additional tests suggested by other agencies and proprietary material manufacturers may also be used. Consult Appendix A of *Materials and Procedures for the Repair of Potholes in Asphalt Pavements–Manual of Practice* for more information on compatibility and acceptance tests for bituminous cold mix materials (Wilson and Romine, 1993).

Appendix B

Sample Cost-Effectiveness Calculations

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

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

Each example considers the placement of 200 partial-depth patches with an average finished patch length of 457 mm, width of 229 mm, and depth of 51 mm. Therefore, for all examples, the expected total volume of the finished patches is 1.07 m^3. The average daily wage for the maintenance worker is assumed to be $120 in each example. Other data vary from example to example.

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

B.1 Example 1

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

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

Patches prepared per hour	= 7
Work hours per day	= 8
Material cure time	= 4 hr
Number of hours available for preparation	
and placement (work hours - cure hours)	= 4 hr
Average preparation rate	
(7 patches/hr) × (0.006 m^3/patch)	= 0.042 m^3/hr
Average daily productivity	
4 hr × 0.042 m^3/hr × (1 patch/0.006 m^3)	= 28 patches
Estimated number of days for patching (rounded up)	
200 / 28	= 8 days

The mean patch survival life is estimated at 50 months for a situation where a rehabilitation will be placed in approximately 60 months. Figure B-1 shows the completed cost-effectiveness worksheet for this example.

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount	units	
Expected Number of Patches	200		(A)
Average Finished Patch Length	457	mm	(B_1)
Average Finished Patch Width	229	mm	(B_2)
Average Finished Patch Depth	51	mm	(B_3)
Expected Total Volume of Finished Patches $[(B_1 \times B_2 \times B_3 \times A) \div 10^9]$	1.07	m^3	(C)

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

Material 1 = Patching Material "A"			
Material 1 Purchase Cost	172	$\$/m^3$	(D_1)
Expected Material 1 Needs	1.23	m^3	(E_1)
Material 1 Shipping Cost	0	$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	211	$	(G_1)
Material 2 = Bonding Agent			
Material 2 Purchase Cost	12	$/L	(D_2)
Expected Material 2 Needs	56.2	L	(E_2)
Material 2 Shipping Cost	0	$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	675	$	(G_2)
Material 3 = Joint Bond Breaker			
Material 3 Purchase Cost	1.075	$/m	(D_3)
Expected Material 3 Needs	152.5	m	(E_3)
Material 3 Shipping Cost	0	$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	164	$	(G_3)
Material 4 = Curing Compound			
Material 4 Purchase Cost	2.6	$/L	(D_4)
Expected Material 4 Needs	7.7	L	(E_4)
Material 4 Shipping Cost	0	$	(F_4)
Total Material 4 Cost $[(D_4 \text{ x } E_4) + F_4]$	20	$	(G_4)

Figure B-1. Example 1 cost-effectiveness worksheet.

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

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

SUMMARY COSTS

	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	1070	$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1520	$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) +$ $(P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) +$ $R + S + (T_1 + T_2 + ...)]$	860	$/day	(W)
User Delay Costs	1000	$/day	(X)
Average Daily Productivity	28	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	8	days	(Z)
Total Patching Operation Cost $[U + \{Z \times (V + W + X)\}]$	28,110	$	(AA)
Expected Mean Life for Partial-Depth Patches[1]	50	months	(BB)
Time to Pavement Rehabilitation	60	months	(CC)
Effective Patching Cost Over Time $[AA \times (CC/BB)]$	33,732	$	(DD)

[1] Until expected mean life values have been determined, agency experience should be applied. See chapter 5 for calculation examples.

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

B.2 Example 2

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

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

The mean patch survival life is estimated at 45 months for a situation where a rehabilitation will be placed in approximately 60 months. Figure B-2 shows the completed cost-effectiveness worksheet for this example.

ESTIMATE OF PROJECT SIZE OR SEASONAL PARTIAL-DEPTH PATCHING NEEDS

	amount	units	
Expected Number of Patches	200		(A)
Average Finished Patch Length	457	mm	(B_1)
Average Finished Patch Width	229	mm	(B_2)
Average Finished Patch Depth	51	mm	(B_3)
Expected Total Volume of Finished Patches $[(B_1 \times B_2 \times B_3 \times A) \div 10^9]$	1.07	m^3	(C)

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

Material 1 = Material B

Material 1 Purchase Cost	278	$\$/m^3$	(D_1)
Expected Material 1 Needs	1.23	m^3	(E_1)
Material 1 Shipping Cost	0	$	(F_1)
Total Material 1 Cost $[(D_1 \times E_1) + F_1]$	342	$	(G_1)

Material 2 = Joint Bond Breaker

Material 2 Purchase Cost	1.14	$/m	(D_2)
Expected Material 2 Needs	152.5	m	(E_2)
Material 2 Shipping Cost	0	$	(F_2)
Total Material 2 Cost $[(D_2 \times E_2) + F_2]$	174	$	(G_2)

Material 3 = _________________

Material 3 Purchase Cost	0	$/___	(D_3)
Expected Material 3 Needs	0	_____	(E_3)
Material 3 Shipping Cost	0	$	(F_3)
Total Material 3 Cost $[(D_3 \times E_3) + F_3]$	0	$	(G_3)

Material 4 = _________________

Material 4 Purchase Cost	0	$/___	(D_4)
Expected Material 4 Needs	0	_____	(E_4)
Material 4 Shipping Cost	0	$	(F_4)
Total Material 4 Cost $[(D_4 \text{ x } E_4) + F_4]$	0	$	(G_4)

Figure B-2. Example 2 cost-effectiveness worksheet.

LABOR COSTS

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

EQUIPMENT COSTS

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

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

SUMMARY COSTS

	amount	units	
Total Material Cost $(G_1 + G_2 + G_3 + G_4 + ...)$	516	$	(U)
Total Daily Labor Cost $[(H \times I) + (J \times K) + L]$	1280	$/day	(V)
Total Equipment Cost $[M + N + (O_1 + O_2 + ...) + (P_1 + P_2 + ...) + (Q_1 + Q_2 + ...) + R + S + (T_1 + T_2 + ...)]$	860	$/day	(W)
User Costs	1000	$/day	(X)
Average Daily Productivity	28	patches/day	(Y)
Estimated Number of Days for Patching Operation $(A \div Y)$	8	days	(Z)
Total Patching Operation Cost $[U + \{Z \times (V + W + X)\}]$	25,636	$	(AA)
Expected Mean Life for Partial-Depth Patches[1]	45	months	(BB)
Time to Pavement Rehabilitation	60	months	(CC)
Effective Patching Cost Over Time $[AA \times (CC/BB)]$	34,181	$	(DD)

[1] Until expected mean life values have been determined, agency experience should be applied. See chapter 5 for calculation examples.

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

Appendix C

Material and Equipment Safety Precautions

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

C.1 Materials

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

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

- To avoid ingestion during mixing, placing, and cleaning:
  - Wear eye protection.
  - Wash hands (even if gloves have been worn) before handling anything that will go into the mouth (e.g.,

lunch containers, silverware, food, drinks, tobacco, gum, etc.).

- ý Wash hands before touching the face, eyes, nose, mouth, or any other part of the body.
- ý Avoid inhaling fumes and vapors (use respirators if required).
- ý Use in well-ventilated areas.

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

C.2 Equipment

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

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

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

Appendix D

Inspection Checklists for Construction

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

D.1 Plans and Specifications

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

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

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

G 1. Delivery and storage requirements.
G 2. Equipment requirements.
G 3. Material requirements.

G 4. Material mixing procedure requirements.
G 5. Patch preparation procedure requirements.
G 6. Installation procedure requirements.
G 7. Weather condition limitations.
G 8. Traffic control requirements.
G 9. Material disposal requirements.
G 10. Safety requirements.

End-result specifications must contain the following information:

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

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

D.2 Equipment

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

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

D.3 Material Quality

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

D.4 Field Installation

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

G 1. Exact locations and dimensions of all spalls to be patched. (The boundaries should be clearly marked.)

G 2. Traffic control requirements and lane closure time limitations.

G 3. Methods for preparing and cleaning repair areas, for mixing and placing the repair materials, and for reinstalling a joint sealant system.

G 4. Recommended accessory materials and instructions for their use.

G 5. Material properties and working tolerances;
   - G working times.
   - G time to traffic at the anticipated mixing and placement temperatures.
   - G moisture conditions allowable during placement.
   - G temperatures allowable during mixing and placement.

G 6. Mixing times, components, proportions, and sequences.

G 7. Criteria for approval of all cleaning and installation equipment and processes.

G 8. Criteria for final approval of the repair work.

G 9. Any localized variations from the specified methods.

G 10. Procedures in the event of hot, cold, and/or wet weather.

G 11. Material disposal requirements.

G 12. Safety requirements for all equipment and procedures and MSDS's.

D.5 Preparing the Repair Area

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

G 1. **Sounding:**

- G a solid steel rod, chain, or ball-peen hammer is used to sound the spalled area before and after the deteriorated concrete is removed.
- G all deteriorated concrete is removed using the specified method until all parts of the repair area yield a clear ringing sound when they are sounded.

G 2. **Sawing:**

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

G 3. The **water-wash** equipment is removing all sawing and/or waterblasting slurry from the repair area before it dries.

G 4. **Jackhammering:**

- G jackhammers of the specified weight are removing all deteriorated concrete to the specified depth, without fracturing the sound concrete below the repair or undercutting or spalling any sawed boundaries.
- G chiseling is begun in the center of the repair area and proceeds outward.
- G only light jackhammers are used near the patch boundaries.
- G if patch boundaries have not been sawed, the hammering is producing rough, vertical edges (not scalloped edges into which the repair material will have to be feathered).

- G spade bits (not gouge bits) are being used.
- G jackhammers are being operated at an angle less than 45 degrees from the vertical.

G 5. **Milling:**

- G the carbide-tipped milling machine is removing all deteriorated concrete to the specified minimum depth.
- G any material that remains at the patch corners is removed by light jackhammering or sawing.
- G whenever possible, the milling machine is oriented such that the rounded edges of the milling hole are parallel to the direction of traffic.
- G if this is not possible, the rounded edges are chipped into straight, vertical edges.
- G edge spalling is minimized.

G 6. **Waterblasting:**

- G a protective shield has been built around the repair area before waterblasting if traffic is passing in the next lane.
- G the waterblasting equipment has been calibrated to remove the specified depth of concrete.
- G operation parameters are not changed throughout the remainder of the project unless the concrete changes (e.g., the aggregate hardness differs from one pavement section to another).
- G the waterblasting equipment is removing all deteriorated concrete to the required depth, and is producing neat, vertical faces at the patch boundaries.
- G waterwashing equipment is used to wash the waterblasting slurry from the repair area before it dries.

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

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

G 9. **Sandblasting:**

- G the sandblasting equipment is uniformly cleaning the faces of the repair area. This typically requires that the nozzle be held 25 mm to 50 mm from the pavement and that several passes be made.
- G no old sealant, oil, or dried sawing and/or waterblasting slurry remains in the repair area.
- G the sandblasting equipment does not introduce oil or moisture to the repair area.
- G after sandblasting, the entire surface area of the patch hole contains freshly exposed concrete.

G 10. **Airblasting:**

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

G 11. **Compressed air** is removing all old sealant, sand, dirt, and dust from the pavement surface so that it cannot re-enter the repair area, especially on windy days or when traffic passes next to the cleaned repair areas.

G 12. **Recleaning:**

- G the repair area is **re-checked for cleanliness** just before material placement.
- G cleaned repair areas that have been recontaminated by rain, dew, dirt, or oil are cleaned again in a manner that restores the original cleanliness. This may require sandblasting and airblasting, or merely airblasting.
- G cleaned repair areas that are left overnight are, at a minimum, airblasted again.

G 13. **The repair area** is allowed to dry if a moisture-sensitive repair material will be used. (Water on the surface of the repair area during material installation may severely reduce the ability of the material to bond to the surface, depending on the material type. Watch for heavy dew that may collect in the repair area and remain after the surface is dry.)

G 14. **Scored bond breaker:**

- G a strip of scored bond breaker is placed at the joint-patch interface 25 mm deeper than the repair, and extends at least 50 mm to 75 mm beyond the repair boundaries.
- G the bond breaker is either of the appropriate height or is stacked and latex-caulked when necessary so that there are no gaps through which the repair material can flow.
- G a true, straight joint line is maintained when installing the bond breaker.

G 15. **Bonding agent:**

- G the bonding agent sprayer or brush is applying a thin layer of bonding agent uniformly over the repair area.
- G the bonding agent is still tacky when the repair material is placed.

G 16. **Safety:**

- G all required **operator safety equipment** is in use.
- G all required safety precautions are followed.

D.6 Installing the Patch

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

D.6.1 Mixing

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

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

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

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

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

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

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

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

G 8. The mixing equipment is **cleaned with the solvent specified by the material manufacturer** immediately after use.

G 9. The mixing of the bonding agent and repair material is scheduled such that the **bonding agent** is tacky when the repair material is placed.

G 10. Disposal of all **wasted materials and solvents** follows the manufacturer's specifications and State ordinances.

G 11. All required **operator safety equipment** is in use.

G 12. All required **safety precautions** are followed.

Material that has begun to set during mixing, or material that is too wet, should not be placed. It should be discarded, and the mixing process begun again; a *retarding agent* may need to be added. The mixing time or amount of water may also need to be adjusted.

D.6.2 Placement

During placement, the following items should be regularly checked to ensure that they meet the requirements. Not all steps will be required for all materials.

G 1. The repair material is placed in a **clean repair hole**, under the **specified moisture conditions**, using the **specified placement methods.**

G 2. The **bonding agent** thoroughly coats the bottom and sides of the repair area, but does not collect in any pockets.

G 3. The **material** is placed when the bonding agent is still tacky.

G 4. The repair hole is **slightly overfilled** with the repair material for those materials that require consolidation or compaction.

G 5. A **shovel** is used (**not** a wheelbarrow or a bucket) to place repair materials that contain aggregate, so that segregation does not occur.

G 6. The repair **material** is not placed below or above its permissible placement temperature range.

G 7. **Deep repairs** are placed in lifts to control heat development, when specified.

G 8. A pencil **vibrator or handtools** are used to release trapped air from the mix.

G 9. The **vibrator** is held at 15 to 30 degrees from the vertical, and is moved through the concrete by lifting it up and down to vibrate the entire area until the mix stops settling, air bubbles no longer emerge, and a smooth layer of mortar appears at the surface.

G 10. A bituminous cold mix patch is compacted to release trapped air using a **vibratory roller or plate** until it is level with the pavement.

G 11. Disposal of all **wasted materials and solvents** follows the manufacturer's specifications and State ordinances.

G 12. **Field testing** is conducted as appropriate for the patching materials, such as testing beams or cylinders for strength and quality control.

G 13. All required **operator safety equipment** is in use.

G 14. All required **safety precautions** are followed.

D.6.3 Material Finishing and Curing

During finishing, the following items should be regularly checked to ensure that they meet the requirements. Not all steps will be required by all materials.

- G 1. The repair material is **troweled** level with the pavement before finishing.
- G 2. The repair material is **screeded** with a stiff board, using at least two passes.
- G 3. The repair material is **worked toward** the patch edges to enhance bonding with the existing slab.
- G 4. The **saw cuts** are filled with excess mortar or epoxy, or are filled with joint sealant during the joint resealing process.
- G 5. The patch surface is **finished** to match the surface of the surrounding pavement.
- G 6. Appropriate **curing methods** are used so that shrinkage cracks do not develop.
  - G **curing agents** are applied uniformly to the patch.
  - G the **water** used for curing is clean.
  - G **insulating covers and longer cure times** are used at cooler temperatures, as specified by the material manufacturer.
- G 7. Disposal of **wasted repair material, curing compound, and cleaning solvents** follows the manufacturer's specifications and State ordinances.
- G 8. **Traffic** is not allowed on the pavement until the material has developed the strength necessary to carry traffic without being damaged.
- G 9. All required **operator safety equipment** is in use.
- G 10. All required **safety precautions** are followed.

D.6.4 Joint Resealing

Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for information regarding the inspection of the joint resealing process (Evans and Romine, 1993b). In addition to the inspection criteria listed in that manual, when using a scored bond breaker, the following criteria should be met:

- G 1. **Joint resealing or filling** is conducted after a minimum curing time of 1 week.
- G 2. Immediately before joint resealing or filling, the **top strip** is torn off of the scored bond breaker, leaving a uniform, clean, dry reservoir.
- G 3. Before resealing or filling the joints, **low-pressure air cleaning** is used if dust or dirt has blown into the joints after removal of the tear-away top strip.

D.7 Final Inspection

During installation and before approval, the partial-depth patches should be individually inspected, ensuring that the patch meets the highway agency's criteria, and noting the presence and severity of any distresses. The final inspection should include the following:

- G 1. The patch is **bonded** firmly to the existing pavement and has not separated from the sidewalls.
- G 2. The patch is **level** with the surface of the existing pavement.
- G 3. The patch contains **no cracks** (other than fine hairline shrinkage cracks) or bubbles.

G 4. All material that has spilled on the pavement has been **removed**.

G 5. **No debris** has been left on the pavement.

Consult the *Materials and Procedures for Repair of Joint Seals in Concrete Pavements–Manual of Practice* for information regarding final inspection of the joint sealant system (Evans and Romine, 1993b).

Appendix E

Partial List of Material and Equipment Sources

This appendix contains a partial listing of material and equipment manufacturers. Addresses and phone numbers are provided for manufacturers and/or suppliers who can provide the inquirer with information regarding products, installation practices, safety procedures, costs, and local suppliers.

MSDS's, where applicable, should be available from all manufacturers. Information regarding the safe use of all materials and equipment should be carefully followed to ensure worker safety and the safety of the traveling public.

Inclusion of a particular material, piece of equipment, or supplier in this list does not serve as an endorsement of that material, equipment, or supplier. Likewise, omission from this list is not intended to carry negative connotations for the materials, pieces of equipment, and suppliers omitted.

E.1 Partial-Depth Patching Materials

E.1.1 Manufacturers of Cementitious Concretes

Euclid Chemical Company
19218 Redwood Road
Cleveland, OH 44110-2799
(216) 531-9222
(800) 321-7628
www.euclidchemical.com

Five Star Highway Products, Inc.
425 Stillson Road
Fairfield, CT 06430
(203) 336-7900

Fosroc International Limited
55 Skyline Drive
Planview, NY 11802
(516) 935-9100
www.fosroc.com

Hartline Products Company, Inc.
2186 Noble Road
Cleveland, OH 44112
(216) 451-6573

L&M Construction Chemicals, Inc.
14851 Calhoun Road
Omaha, NE 68152
(402) 453-6600

Master Builders
23700 Chagrin Boulevard
Cleveland, OH 44122-5554
(800) 628-9990
www.masterbuilders.com

United States Gypsum Company
Industrial Gypsum Division
125 South Franklin St.
Chicago, IL 60606-4678
(312) 606-4000
(800) 874-4968
www.usg.com

E.1.2 Manufacturers of Polymer Concretes

Accelerated Systems Technology Corporation
140 Chaparral Court
Suite 100
Anaheim, CA 92808
(714) 263-9074

HC Epoxy Company, Inc.
862 East 19th Street
Tucson, AZ 85719
(602) 624-7929

GeoChem, Inc.
P.O. Box 838
Renton, WA 98057-0838
(425) 227-9312
www.geocheminc.com

Pyrament/Lone Star Industries, Inc.
340 North Sam Houston Parkway, East
Houston, TX 77060
(800) 633-6121

Sika Corporation
201 Polito Avenue
Lyndhurst, NJ 07071
(201) 933-8800
www.sika.com

The Burke Company
P.O. Box 5818
San Mateo, CA 94402
(415) 349-7600
(800) 423-9140

Thoro System Products
Department PWM
7800 N.W. 38th Street
Miami, FL 33166

E.1.3 Manufacturers of Bituminous Materials

Unique Paving Materials Corporation
3993 E. 93rd Street
Cleveland, Ohio 44105-4096
(800) 441-4881
www.upm.com

E.1.4 Manufacturers of Bonding Agents

Master Builders
23700 Chagrin Boulevard
Cleveland, OH 44122-5554
(800) 628-9990
www.masterbuilders.com

The Burke Company
6433 East 30th Street
Indianapolis, IN 46219
(317) 543-4475

E.2 Partial-Depth Patching Equipment

E.2.1 Manufacturers of Sawing Equipment

Cimline, Inc.
2601 Niagara Lane
Minneapolis, MN 55447
(800) 328-3874
www.cimline.com

Target Products Division
4320 Clary Boulevard
Kansas City, MO 64130
(816) 923-5040

Vermeer Manufacturing Company
Route 2
P.O. Box 200
Pella, IA 50219
(515) 628-3141

E.2.2 Manufacturers of Spray-Injection Equipment

Zimmerman Equipment Corporation
1000 South Thompson Lane
P.O. Box 110098
Nashville, TN 37211
(615) 833-5705

Wildcat Manufacturing Company, Inc.
Highway 81
P.O. Box 523
Freeman, SD 57029
(605) 925-4512

Rosco Manufacturing Company
1001 S.W. First St.
P.O. Box B
Madison, SD 57042
(605) 256-0240

Duraco Industries, Inc.
P.O. Box 6127
Jackson, MS 39288-6127
(601) 932-2100

E.2.3 Manufacturers of Waterblasting Equipment

FLOW Services
23500 64th Street
Kent, WA 98032
(800) 446-3569, Ext. 900

E.2.4 Manufacturers of Milling Equipment

Cedarapids, Inc.
916 16th Street, N.E.
Cedar Rapids, IA 52402
(319) 363-3511

Vermeer Manufacturing Company
Route 2
P.O. Box 200
Pella, IA 50219
(515) 628-3141

E.2.5 Manufacturers of Jackhammers

Atlas Copco Berema, Inc.
161 Lower Westfield Road
Holyoke, MA 01040
(800) 284-2373
(413) 536-0600

E.2.6 Manufacturers of Compacting Equipment

Stone Construction Equipment, Inc.
Corporate Offices/Northern Manufacturing Plant
32 East Main Street
P.O. Box 150
Honeoye, NY 14471-0150
(800) 888-9926

Glossary

***Admixture*–**A substance added to a mixture during mixing.

***Adverse patching conditions*–**Climatic conditions in which the air temperature is below 40°F (4°C) and the repair area is saturated with surface moisture.

***Bonding agent*–**A substance that promotes good bonding between the pavement surface and a repair material placed on the surface.

***Breaking and seating*–**The breaking and compaction of a continuously-reinforced concrete pavement, reducing the amount of reflective cracking in the overlay.

***Calcium aluminate concrete*–**A high alumina (Al_2O_3) cementitious concrete.

***Chemical conversion*–**A chemical process that results in a change in the nature, structure, or properties of a substance.

***Compact*–**To release trapped air and reduce volume using compression.

***Compression failure*–**The crushing of a repair due to the expansion of the surrounding pavement during freeze-thaw cycles.

***Compression recovery*–**The property of being able to regain original shape and volume after being compressed.

***Compressive strength*–**The maximum compressive stress a material can withstand before failure.

***Compressive stress*–**A stress that causes an elastic body to shorten in the direction of the applied force and that causes an inelastic body to rupture.

***Consolidate*–**To release trapped air from fresh concrete mix by using vibration.

***Cracking and seating*–**The breaking and compacting of a plain concrete pavement, reducing the amount of reflective cracking in the overlay.

***D-cracking*–**Durability cracking; a pattern of cracks running parallel and close to a joint or linear crack caused by freeze-thaw expansion of large, nondurable aggregate.

***Debonding*–**The partial or complete loss of bond between two materials, such as between a patch and a slab.

***Diamond grinding*–**A surface restoration in which patterns are cut into hardened concrete with closely spaced diamond saw blades to correct surface distresses.

***Epoxy concrete*–**A polymer concrete containing epoxy resin (a flexible, thermosetting resin made by polymerization of an epoxy compound).

***Feathering*–**The thin placement of patching materials because of curved or angled patch edges that do not allow adequate depth of placement.

***Free sulfate*–**A chemical group containing sulfur and oxygen ($-SO_4$) that is free to react chemically with other chemical groups.

***Full-depth spall repair*–**The removal of an area of deteriorated concrete the entire depth of a pavement slab, and its replacement with a repair material along with the restoration of load transfer devices.

***Full lane-width patch*–**A patch that extends the entire width of a lane.

***Gouge bit*–**A curved chisel tip used in jackhammering that is not recommended for partial-depth spall repair.

***Gypsum-based concrete*–**A cementitious concrete that contains gypsum, a common sulfite mineral.

***Heat of hydration*–**The heat given off when molecular water is incorporated into a complex molecule with molecules such as those found in cementitious mixes.

***High alumina concrete*–**A cementitious concrete that contains a higher amount of alumina (the native form of aluminum oxide) than regular concrete.

***High early-strength materials*–**Patching materials that gain high strength levels early in their curing period.

***High molecular weight methacrylate concrete*–**A cementitious concrete containing high molecular weight methacrylate, an acrylic resin or plastic made from a derivative of methacrylic acid ($C_4H_6O_2$).

***Hydration rate*–**The rate at which molecular water is incorporated into a complex molecule with molecules such as those found in cementitious mixes.

***Incompressible*–**A material that resists compression, such as stones, sand, or dirt, in a crack or joint reservoir that is closing.

***Joint bond breaker*–**A strip of polyurethane, polyethylene, or fiberboard that is placed in a joint to prevent a patch placed at that joint from bonding to the adjacent slab.

***Joint insert*–**A metal or plastic strip inserted into fresh concrete to form a weakened plane and induce cracking at a desired location.

***Joint sealant system*–**All components that function to seal joints, including the sealant material, surrounding concrete, and the sealant-concrete interface.

***Laitance*–**A residue left on a surface, such as the dried residue left on pavement after a wet-sawing operation.

***Lateral confinement*–**Being held in place from the sides.

***Latex caulking*–**The filling and water sealing of a space with a latex material.

***Load transfer devices*–**Devices such as dowel bars that transfer the traffic load from one slab across a joint to the adjacent slab and that reduce the relative deflection across that joint.

***Magnesium phosphate concrete*–**A cementitious concrete that contains magnesium phosphate, a metallic element (Mg) bound to a phosphate group ($-PO_4$).

***Methyl methacrylate concrete*–**Cementitious concrete containing methyl methacrylate ($C_5H_8O_2$), a volatile, flammable liquid that readily polymerizes.

***Opaque*–**Not transparent to rays of light.

***Operating parameters*–**Equipment settings, such as speed, pressure, and number of overlapping passes.

***Partial-depth spall*–**An area of deteriorated concrete that is limited to the top third of a concrete pavement slab.

***Polymer*–**A chemical compound or mixture of compounds formed by polymerization and consisting of repeating structural units; a substance made of giant molecules formed by the union of simple molecules.

***Polymer resin*–**A resin that is a polymer; see polymer and resin.

***Polyurethane concrete*–**A concrete consisting of aggregate mixed with a two-part polyurethane resin, a resin of repeating structural units of urethane ($C_3H_7NO_2$).

***Preformed compression seal*–**A preformed seal, generally made from neoprene, that can be compressed and inserted into concrete joints for sealing purposes.

***Proprietary*–**Something that is used, produced, or marketed under the exclusive legal right of the inventor or maker.

***Radiant heat*–**Heat that radiates from the sun.

***Rapid-setting materials*–**In the context of this manual, patching materials that set within 30 minutes of mixing.

***Resin*–**Any of a class of solid or semi-solid organic products of natural or synthetic origin with no definite melting point, generally of high molecular weight. Most resins are polymers.

***Retarding agent*–**A substance added to a cementitious material mixture that initially slows down the rate of hydration, allowing a longer period of workability.

***Rubblization*–**The breaking of a concrete pavement into pieces smaller than 304.8 mm in diameter and its compaction, reducing the amount of reflective cracking in the overlay.

***Saturated*–**Full of moisture; having voids filled with water.

***Scalloped*–**Having a series of curves in its edges.

***Segregation*–**The separation of cement and aggregate.

***Set initiator*–**An admixture that triggers the setting of a material.

***Shape factor*–**The ratio of the width to depth of a sealant.

***Shrinkage cracks*–**Fine hairline cracks that develop as a result of water loss and volume reduction during curing.

***Skid resistance*–**The resistance of a pavement to tires sliding over its surface; generally a function of the macro- and micro-texture of the pavement surface.

***Slab jacking*–**The lifting of a slab at a low point to restore it to its original elevation and rideability.

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

***Spade bit*–**A flat, spade-shaped chisel tip used in jackhammering that is recommended for partial-depth spall repair.

***Spalling*–**The cracking, breaking, or chipping away of concrete fragments in a pavement.

Spall–A small broken or chipped segment of concrete normally occurring along a joint or crack.

Substrate–A base layer, such as the repair surface, upon which a material is applied or placed.

Thermal compatibility–Compatibility between the thermal properties of two materials, such as similar amounts of thermal expansion resulting from a given temperature increase in the two materials.

Thermal expansion–The increase in volume of materials due to an increase in temperature.

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

Vibrating screed–A leveling device drawn over freshly poured concrete that is vibrated to allow consolidation of the material.

Waterblasting machine–A machine controlled by a mobile robot that produces a high-pressure water jet capable of removing deteriorated concrete.

Weight and volume stability–Structural strength due to sufficient patch weight and volume.

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