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

Manual of Practice



Federal Highway Administration
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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) <i>Long-Term Monitoring (LTM) of Pavement Maintenance Materials Test Sites</i> 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.

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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

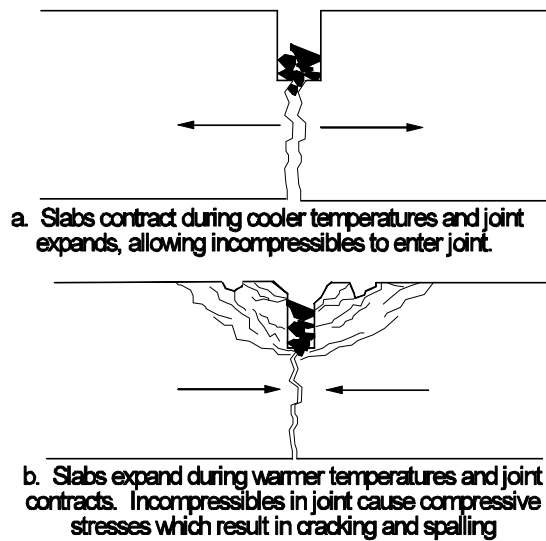


Figure 1. Partial-depth spall caused by incompressibles.

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 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.

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

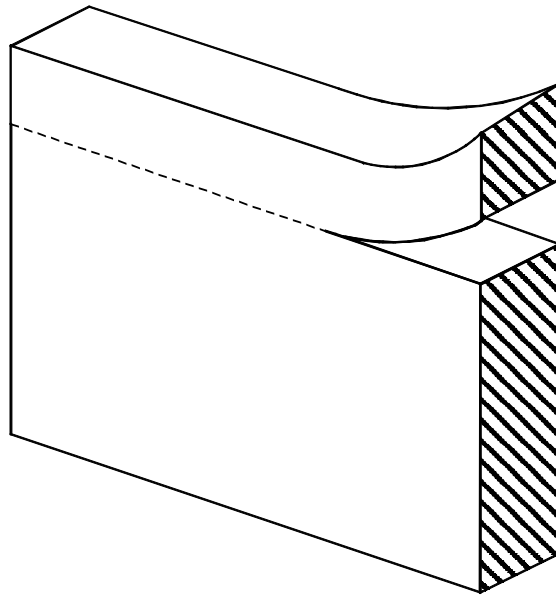


Figure 2. Scored joint bond breaker.

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

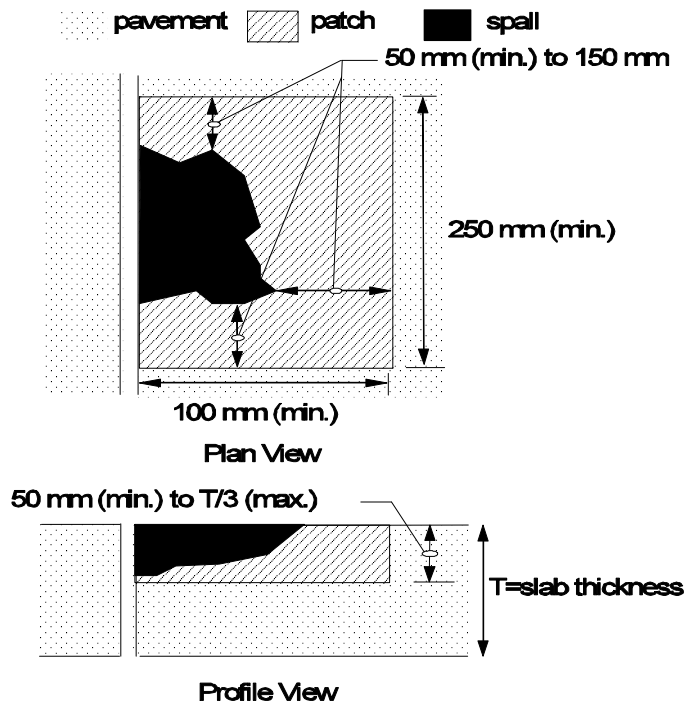


Figure 3. Dimensions of patch at one joint.

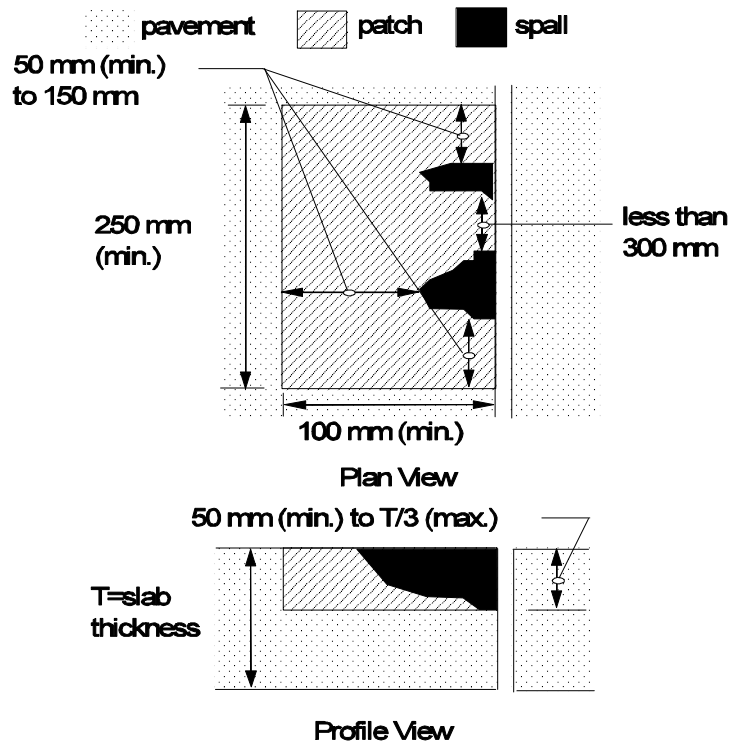


Figure 4. Dimensions of patch at one joint for spall less than 300 mm apart.

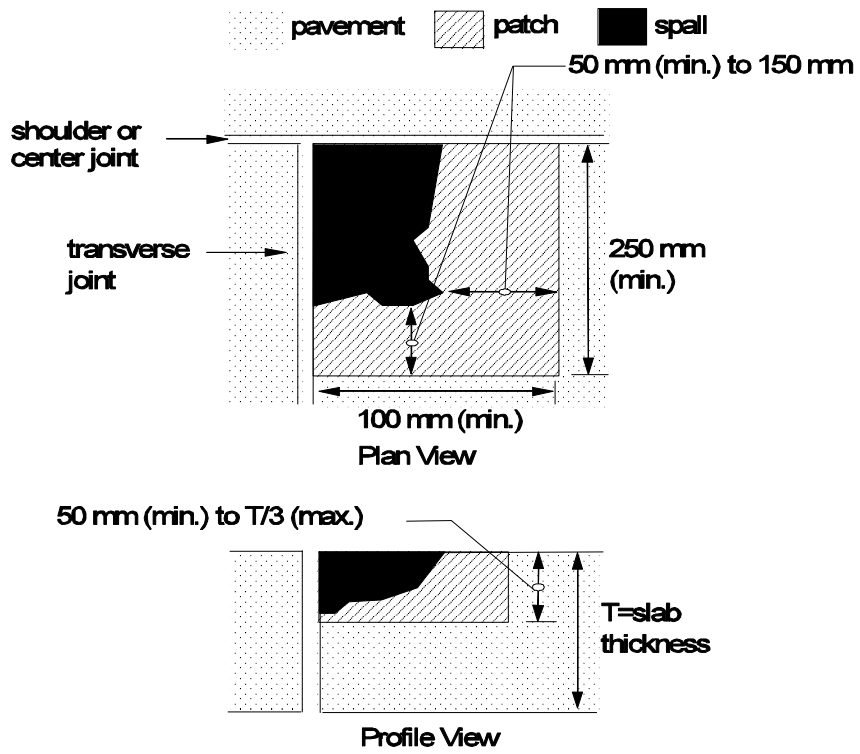


Figure 5. Dimensions of patch at two joints.

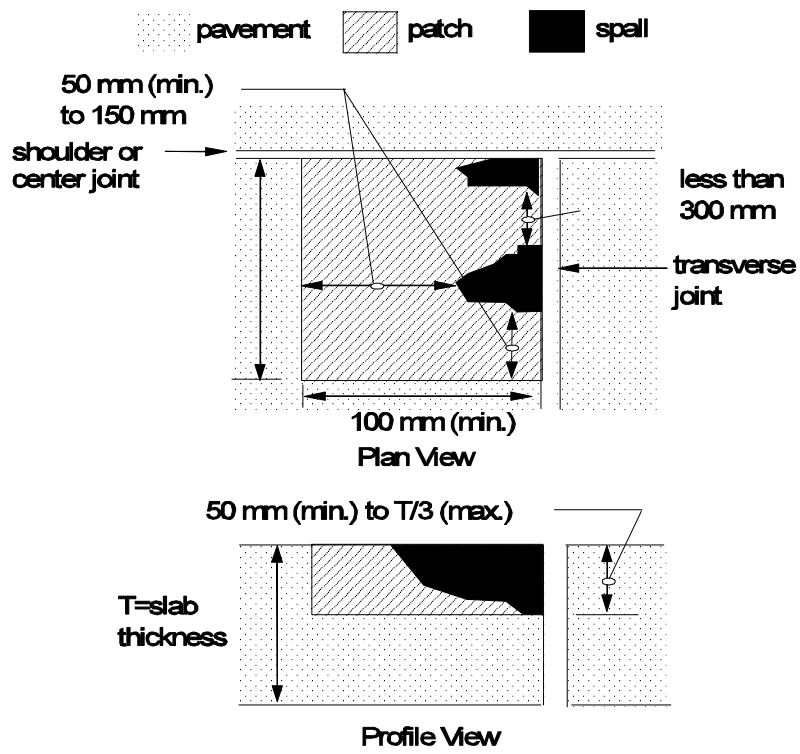


Figure 6. Dimensions of patch at two joints for spalls less than 300 mm apart.

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 m², the patch may be larger than needed, because the smallest milling head currently available provides a 0.09 m² 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

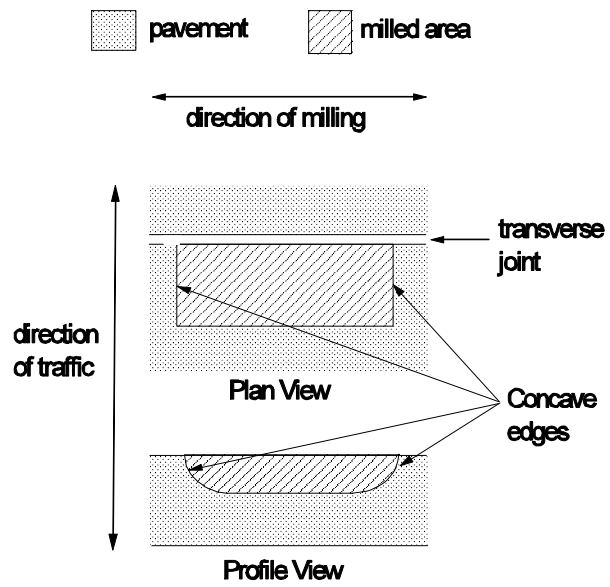


Figure 7a. Recommended orientation of milled patch.



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 m²/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 m²/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 × B ₂ × B ₃ × A) ÷ 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 × 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 × 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 × 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 × E ₄) + F ₄]	_____	\$	(G ₄)

Figure 8. Cost-effectiveness worksheet.

LABOR COSTS			
	amount	units	
Number in Repair Crew	_____		(H)
Average Daily Wage per Person	_____	\$/day	(I)
Number in Traffic Control Crew	_____		(J)
Average Daily Wage per Person	_____	\$/day	(K)
Supervisor Daily Wage	_____	\$/day	(L)
EQUIPMENT COSTS			
Material Truck	_____	\$/day	(M)
Traffic Control Truck and Signs	_____	\$/day	(N)
Patch Preparation Equipment (e.g., concrete saw, jackhammer, milling machine, waterblaster)	_____	\$/day	(O ₁)
	_____	\$/day	(O ₂)
Cleaning Equipment (e.g., sandblaster, airblaster)	_____	\$/day	(P ₁)
	_____	\$/day	(P ₂)
Mixing Equipment (e.g., mortar mixer, Jiffy mixer)	_____	\$/day	(Q ₁)
	_____	\$/day	(Q ₂)
Consolidation/Compaction Equipment (e.g., pencil vibrator, vibrating screed, vibratory roller)	_____	\$/day	(R)
Extra Equipment Truck	_____	\$/day	(S)
Miscellaneous Equipment (e.g., spray-injection machine, joint sealing equipment, etc.)	_____	\$/day	(T ₁)
	_____	\$/day	(T ₂)

Figure 8. Cost-effectiveness worksheet (continued).

SUMMARY COSTS			
	amount	units	
Total Material Cost ($G_1 + G_2 + G_3 + G_4 + \dots$)	_____	\$	(U)
Total Daily Labor Cost [($H \times I$) + ($J \times K$) + L]	_____	\$/day	(V)
Total Equipment Cost [$M + N + (O_1 + O_2 + \dots) +$ ($P_1 + P_2 + \dots$) + ($Q_1 + Q_2 + \dots$) + $R + S + (T_1 + T_2 + \dots)$]	_____	\$/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).

- (B₂) **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.)
- (B₃) **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 (B₁), width (B₂), and depth (B₃). 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.

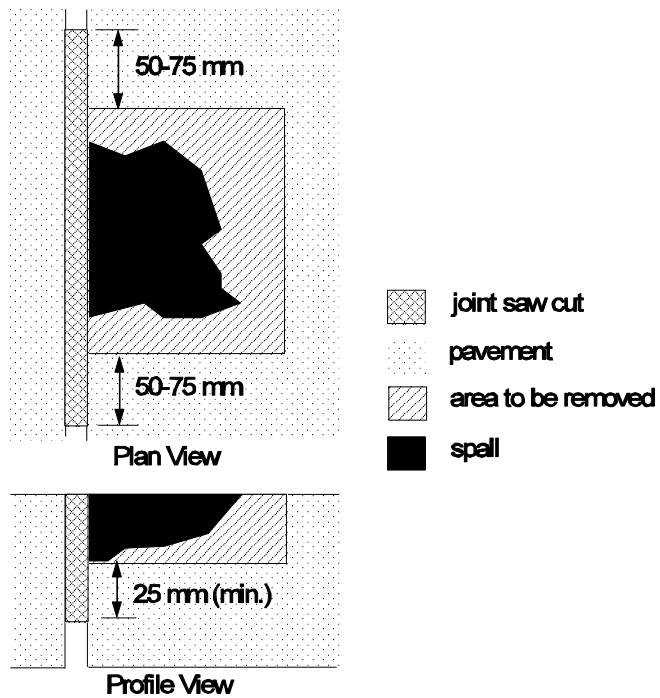


Figure 9. Dimensions of joint saw cut.

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.

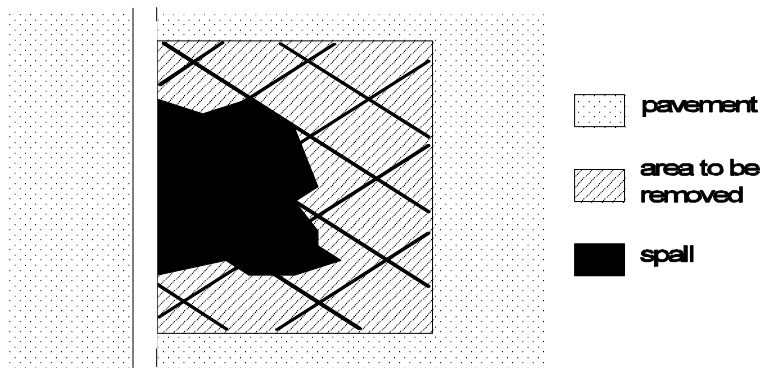


Figure 11. Sawing pattern for large repair areas.

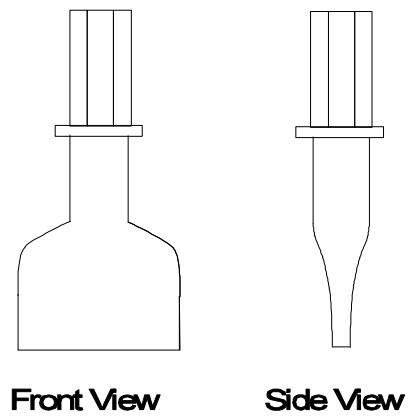


Figure 12. Spade bits.

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.

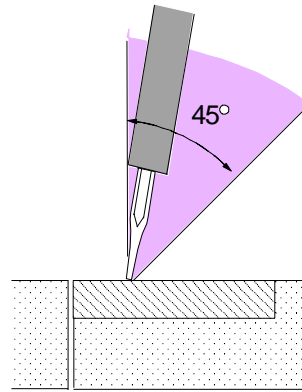


Figure 13. Using a jackhammer.



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.

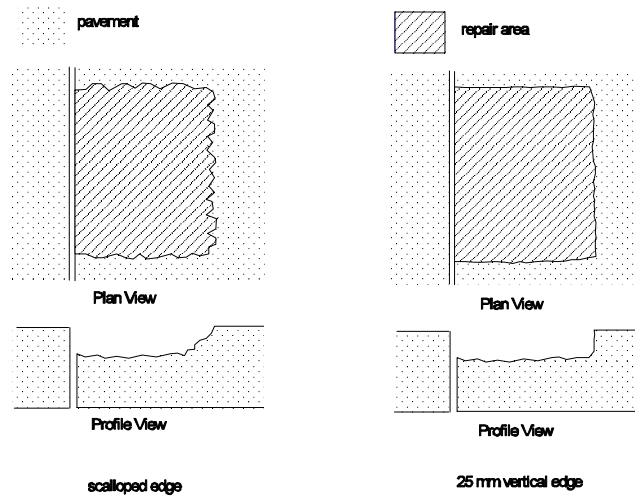


Figure 15. Scalloped edge and 25-mm vertical edge.

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