



GUIDE FOR _____

PARTIAL-DEPTH REPAIR OF CONCRETE PAVEMENTS

April 2012



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16. Abstract The purpose of this guide is to help practitioners understand how to select, design, and construct successful partial-depth repairs of concrete pavements. It defines "partial-depth" repairs as everything from very shallow surface repairs to those that extend as deep as the top one-half of the pavement slab. It also provides quality control guidance and troubleshooting information.			
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GUIDE FOR

PARTIAL-DEPTH REPAIR OF CONCRETE PAVEMENTS

April 2012

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About this Guide

The purpose of the *Guide for Partial-Depth Repair of Concrete Pavements* is to provide information about selecting, designing, and constructing successful partial-depth repairs that extend as deep as the top one-half of the concrete pavement slab. This guide is a product of the National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University. The information herein supplements but does not replace the section on partial-depth repairs in the February 2008 edition of the FHWA's *Concrete Pavement Preservation Workshop Reference Manual*, also developed by the National CP Tech Center.

Abbreviations and Acronyms in This Guide

ACPA	American Concrete Pavement Association
ACR	alkali-carbonate reactive
ASR	alkali-silica reactive
DOT	Department of Transportation
FHWA	Federal Highway Administration
MUTCD	Manual on Uniform Traffic Control Devices
MSDS	material safety data sheet
PCC	portland cement concrete
QA	quality assurance
QC	quality control
w/c	water/cement

Figure Sources

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Introduction

Partial-depth repairs are defined as the removal and replacement of small areas of deteriorated (or spalled) concrete pavement. Partial-depth repairs slow or eliminate the spread of spalling distresses that tend to occur under repeated thermal stresses, freezing and thawing, and traffic loading. In addition, partial-depth repairs of deteriorated joints restore a well defined, uniform joint-sealant reservoir prior to joint resealing to keep incompressible material and water out of the joint. As a result, partial-depth repairs restore structural integrity and improve ride quality, extending the service life of distressed pavements.

Highway maintenance crews spend a large amount of time and money each year repairing partial-depth spalls with quick-to-install but temporary (a few months to a few years) repair material. However, when patch materials and construction techniques are properly selected and applied in a timely manner and at appropriate locations, partial-depth repairs can be more cost-effective and can last 10 to 15 years or longer. Because of these advantages, many jurisdictions use partial-depth repairs in their pavement preservation programs. Recent photos of 18th Street in Hopkins, Minnesota (Figure 1 and Figure 2) demonstrate the longevity of well constructed, longitudinal and transverse partial-depth repairs completed in 1991 on a pavement built in 1965.

In the past, partial-depth repairs were considered only if the distress was limited to the upper one-third of the slab and the existing load-transfer devices (if any) were still functional. It was generally believed that deterioration extending below the top one-third of the slab warranted a full-depth repair. It was also commonly thought that the smaller the partial-depth repair, the better its chance of success and that, with most specifications dictating

payment by the square foot, smaller is better. These limitations prevented the use of partial-depth repairs in deteriorated joints deeper than the top one-third of the slab.

In recent decades, however, several cold-weather states have started applying slightly modified partial-depth repair techniques to joints with deterioration as deep as the upper one-half of the slab. Many of these deeper partial-depth repairs have lasted as long as the existing pavements; the majority of them have lasted 10 to 15 years. In general, these repairs have been more cost-effective than any type of asphalt overlay or temporary patching material.

For example, in 1980 Minnesota implemented a modified partial-depth repair on a spalled section of pavement that extended deeper than the top one-third of the slab. Milling machines were used to remove the concrete in the distressed area and form a tapered edge around it. The milled surface was cleaned and a cement grout was applied; then a cement-based repair material was applied. In the 1990s Minnesota's cost-effective method was copied in Wisconsin and Michigan. In the 2000s Kansas, Missouri, Colorado, and South Dakota adopted similar milling approaches to partial-depth repairs. By using new milling equipment and durable concrete mixtures, these states have successfully demonstrated the use of partial-depth repairs in pavements where deteriorated areas extend from one-third to one-half the slab depth. As a result, today partial-depth repairs are used for more joint repairs and at less cost than traditional full-depth repairs.

This guide provides the most current information for selecting, designing, and constructing partial-depth repairs that extend as deep as the top one-half of the pavement slab. It supplements the section on partial-depth repairs in the February 2008 resource, *Concrete Pavement Preservation Workshop Reference Manual* (Smith et al. 2008).



Figure 1. 20-year-old longitudinal and transverse partial-depth repairs in Hopkins, MN (photo taken 2011)



Figure 2. Close-up of partial-depth repair in Hopkins, MN, constructed in 1991 (photo taken 2011)

Training

When completed properly, as described herein, a partial-depth repair can be a very long-lasting and cost-effective solution to shallow joint and crack deterioration. To ensure success and achieve anticipated design life for partial-depth repairs, such repairs need to be accomplished correctly. With poor materials or workmanship, partial-depth repairs may fail in as little as two to three years (ACPA 2006).

It is advisable that training be required for all repair projects that incorporate the recommendations in this publication. This training can be in the form of a video or slide presentation at a pre-construction meeting with the inspectors and the contractor personnel. It should include a thorough review of the specific project plans and special provisions.

Project Selection

Most repair materials used in partial-depth repairs cannot accommodate movement across working joints and cracks, load transfer devices, or reinforcing steel without experiencing high stress and thus material damage. Therefore, partial-depth repairs are appropriate only for certain types of concrete pavement distresses:

- Spalling that is isolated in the upper portion of the slab and caused by freeze-thaw damage as a result of inadequate air-void system, and where the air-void system of the concrete around the patch is adequate for ensuring that the life of the concrete is equal to or greater than the expected life of the partial-depth repair.
- Spalling caused by intrusion of incompressible materials into the joint or crack.
- Spalling caused by poor consolidation, inadequate curing or over finishing.
- Spalling caused by localized areas of scaling, weak concrete, clay balls, or high steel.
- Non-working cracks, either longitudinal or transverse.
- Spalling caused by dowel bar misalignment or lockup, where the misplaced steel can be removed.

Distresses that are not appropriate for partial-depth repair include the following:

- Spalling caused by D-cracking or reactive aggregates such as alkali-silica reactive (ASR), alkali-carbonate reactive (ACR), ettringite, etc.

- Spalling and movement of transverse or longitudinal working cracks caused by shrinkage, fatigue, or foundation movement, unless a partial-depth repair is implemented in combination with dowel bar retrofits to control vertical movement.

Coring of existing pavement can help a designer determine if a partial-depth repair is the correct repair. Figure 3 shows a top view of a small, deteriorated transverse joint before coring revealed the deterioration shown in Figure 4. When the transverse joint is badly deteriorated, as shown in Figure 4, a full-depth repair should be constructed.



Figure 3. View of pavement before core was taken



Figure 4. Core #3 of existing pavement (Figure 3)

Types of Partial-Depth Repairs

This guide describes three general types of partial-depth repairs for joints, cracks, and spalls (Figure 5):

Type 1: Spot repairs between 15 in. and 6 ft in length.

Type 2: Repairs of extended length (greater than 6 ft) of deterioration along a longitudinal or transverse joint (2A) or crack (2B).

Type 3: Spot repairs that extend full-depth at joint intersections or slab edges for short distances.

Type 1—Spot Repairs of Joints, Cracks, and Spalls

Type 1 spot repairs are generally used for small, isolated areas of deterioration (Figure 6) and are not intended for long, continuous partial-depth repairs.

Type 1 spot repairs can be used to repair joint spalling, mid-slab surface spalling or cracking, and severe scaling, and to restore joint reservoirs. They are appropriate in shallow areas, where slab deterioration is located in the upper one-half of the slab.

Type 1 spot repairs are less than 6 ft along a transverse or longitudinal joint or crack. When applied at transverse joints, Type 1 spot repairs are typically used for pavements in which the existing load transfer devices (if any) are still functional.

It should be noted that when spot repair areas are closer than 2 ft apart, they should be combined.

Usually, only about 2 in. of depth is removed to expose sound concrete in the existing joint or crack or at the bottom of the repair area. For surface spalls and scaled areas, the boundary of the repair area should be extended a

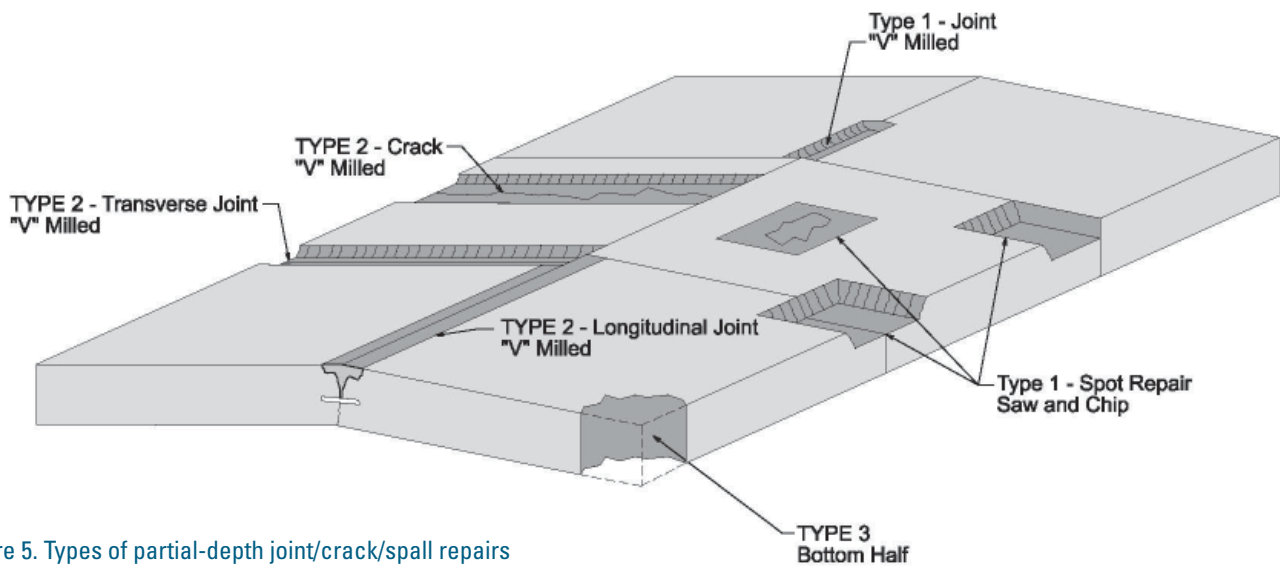


Figure 5. Types of partial-depth joint/crack/spall repairs



Figure 6. Type 1 spot repair candidates; left to right: spalling, crack, joint

minimum of 2 in. beyond the boundary of the distressed area. This will expose sound concrete, which is needed in order for a proper bond to develop between the concrete patch material and the existing pavement.

For joints and cracks, the top dimension is designed to be a minimum of 5 in. on each side of the joint/crack to minimum a depth of 2 in. with a tapered edge from 30 to 60 degrees to the bottom of the joint/crack.

The most common method of removal is the saw-and-chip method. When the saw-and-chip method is used to form the edges of the repair, the edges are tapered using a small (10- to 30-lb) jackhammer to remove the vertical edges left by the sawing operation.

For spot repairs at joints, joint compression relief is provided at a minimum for the top half of the joint with a ¼-in. compressible material, such as waxed cardboard or STYROFOAM™ insulation. Compression relief must be provided for the full depth of the patch and should extend at least ½ in. beyond if possible.

Figure 7 shows the typical detail for saw-and-chip method of a spot repair. (Details about concrete removal and repair are found under Construction Steps for Partial-Depth Repairs and in Appendix A.)

Figure 8 shows a typical section for a milled Type 1 spot repair. As long as there is an adequate volume of repairs to be made on a particular project, milling for spot repairs can be completed faster than the saw-and-chip method and can be very cost-effective (see Appendix A for details).

Payments for Type 1 joint repairs (less than 6 ft in length) are generally by the square foot of completed patch. Partial-depth repairs of cracks of any length are always paid by the square foot.

Type 2—Extended-Length Repairs

Extended-length partial-depth repairs are repairs in longitudinal or transverse joints (Type 2A) or cracks (Type 2B) longer than 6 ft and extending as deep as one-half the depth of the concrete pavement slab (Figure 9).

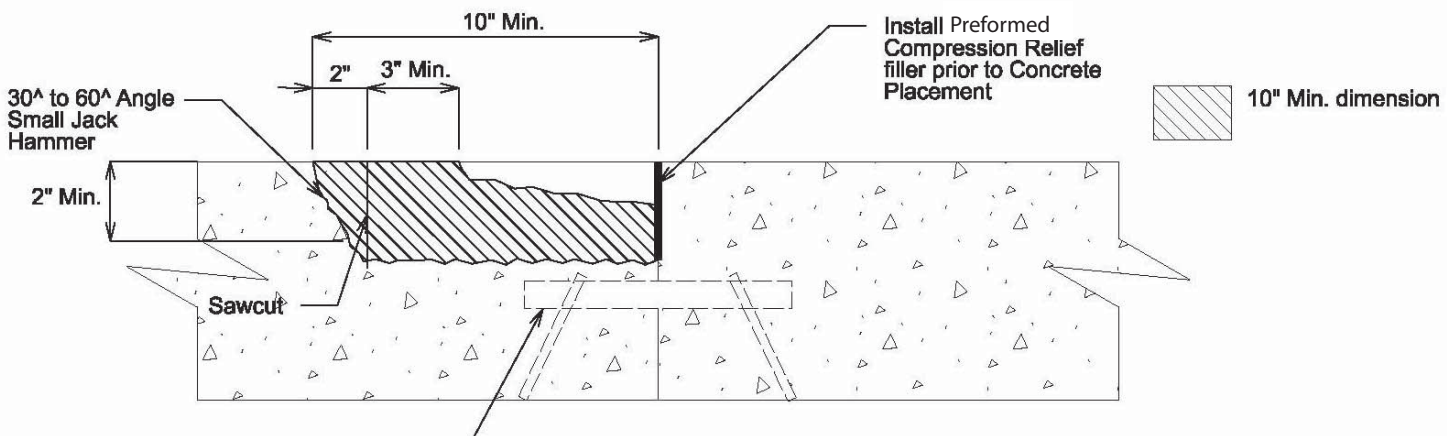


Figure 7. Type 1 (saw and chip) spot repairs

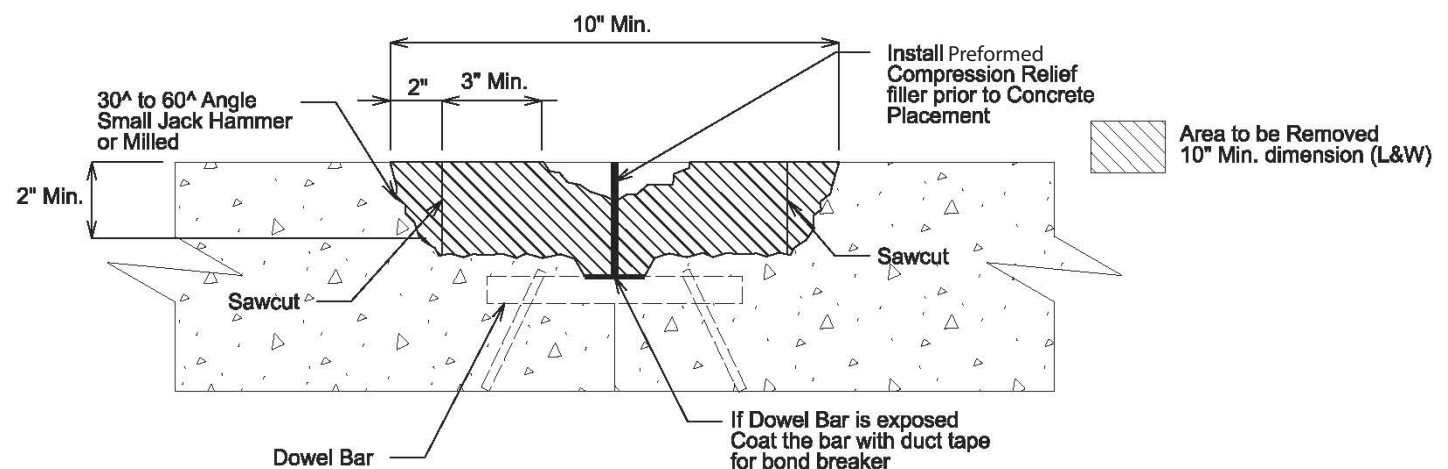


Figure 8. Type 1 (milled) spot repairs

Pressure or compression stress relief is constructed differently in Type 2A and 2B repairs. For Type 2A repairs (at joints), the joint is re-established, typically by sawing. For Type 2B repairs (cracks), a preformed joint compression material is installed in the crack itself.

Sawing to re-establish compression stress relief for repairs at joints must be accomplished for the full depth of the repair material and, if possible, ¼-in. deeper. The timing of sawing is dependent on weather conditions, the mix design, and traffic restrictions on the project, but sawing must be completed quickly to prevent random cracks from forming when the pavement moves due to temperature changes. If such cracking occurs, the repair should be replaced at the contractor's expense according to a recommended 30-day warranty.

Tooling can be used to develop the initial joint, but sawing the entire depth of the patch repair material must still be

done as soon as possible and is needed to provide the necessary compression relief space to allow the joint to open and close properly.

Except for the provision of pressure relief, the procedure for constructing extended-length joint/crack repairs is the same as for spot repairs. Milling is generally the preferred method for removing the existing pavement and forming the edge for Type 2 repairs because, due to the length of Type 2 repairs, milling is likely to be more cost-effective than the saw-and-chip method. Small jackhammers are used only in small areas of delamination that may be found after milling.

Figure 10 shows a typical Type 2A repair without deterioration below the dowels (also see Appendix A).

Payments for Type 2A joint repairs are generally by the linear foot for the entire patch along either a longitudinal or transverse joint. Payments for Type 2B crack repairs are



Figure 9. Candidates for Type 2 extended-length repair; left to right: longitudinal joint, transverse crack, transverse joint

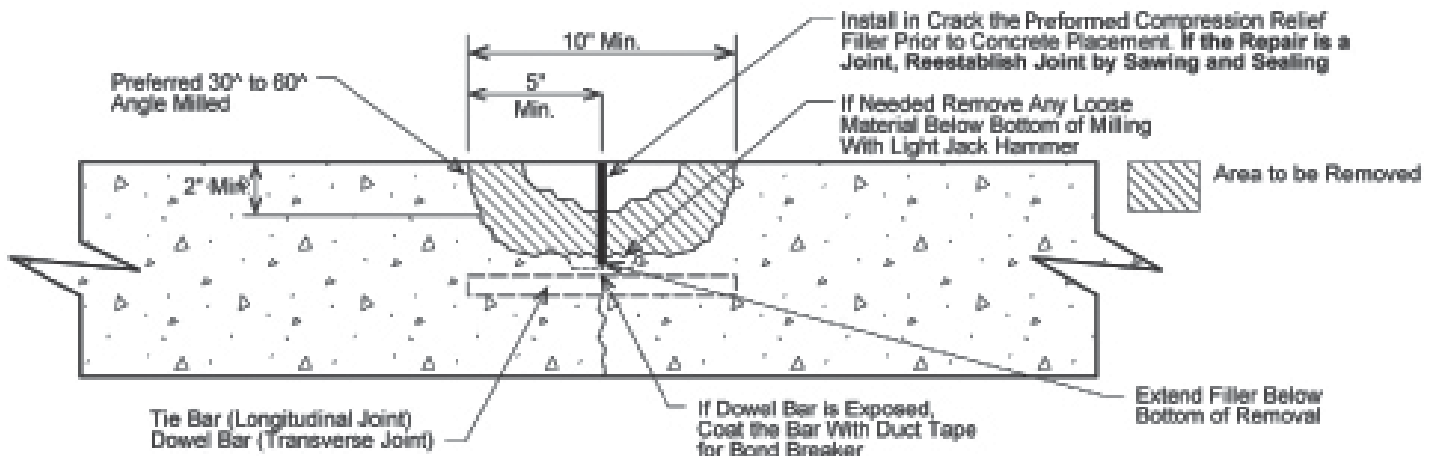


Figure 10. Type 2 (milled) extended-length repair

by square foot (like Type 1) because the milled area may have to be widened to ensure a bondable area of at least 3 in. on each side of the crack at the bottom of the repair.

Type 3–Bottom-Half Spot Repairs

Occasionally one or more corners or the edge of a concrete pavement will deteriorate to the full depth for a short distance, as in Figure 11. Type 3 repairs are used for such spot locations where the deterioration exceeds $T/2$ in depth, thus ultimately requiring a full-depth repair.

Type 3 repairs at the outer edges of the pavement slab should not protrude into the pavement transversely more than 18 in. at the bottom of the repair. A longitudinal Type 3 repair can be longer than 18 in. along the centerline but cannot extend into either lane transversely more than 18 in. If the transverse length of the repair exceeds 18 in. into either lane, a full-depth repair is recommended.

Figure 12 provides the detail for Type 3 bottom-half repairs (also see Appendix A). The same grout and patch materials are used as for Types 1 and 2 repairs.

Payment for the overall repair has two parts: Payment for the Type 3 bottom-half area is by square foot; the top



Figure 11. Candidates for Type 3 bottom-half corner joint repair

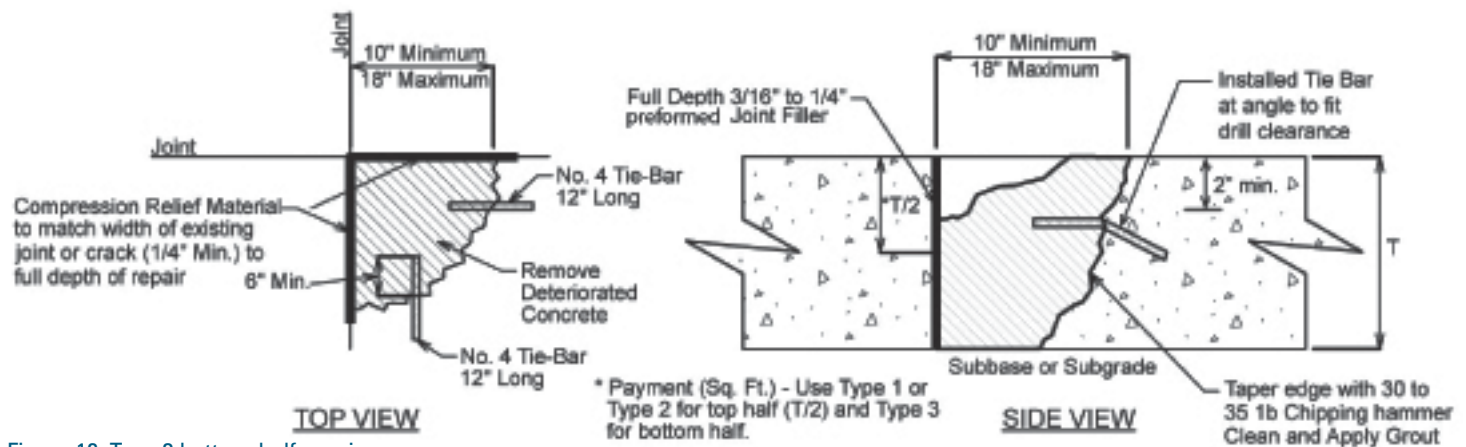


Figure 12. Type 3 bottom-half repairs

half may be a Type 1 or Type 2B repair payment. Since the Type 3 repair will have a sloping face, payment should be measured at mid-depth of the pavement thickness.

Costs/Payment Methods

The costs of a partial-depth repair are largely dependent on the size, number, and location of the repair areas, as well as the materials used. Allowable lane closures and traffic volume also affect production rates and costs.

Typical Costs

The typical average cost for partial-depth repairs has been \$25 to \$30 per square foot or \$15 to \$25 per linear foot. If there are major quantities of longitudinal repairs, the cost can be as low as \$12 to \$20 per square or linear foot. If night work is involved, repair costs can be as high as \$55 to \$60 per square or linear foot. Normally the larger the repair quantities, the lower the costs per unit of measure, primarily because the cost for milling equipment is spread over the number of patches.

Payment Methods

The following dialog outlines a general payment approach based on types of partial-depth repairs. This approach may be modified to fit a jurisdiction's preference.

Payment for partial-depth repairs can be determined in one of two ways: by linear foot of repair area or by square foot of repair area.

Length/Linear Foot

Payment by linear foot is reserved for Type 2A partial-depth repairs of longitudinal or transverse joints longer than 6 ft.

Linear measurements for payment should be made to the nearest foot of repair length. The repair will be close to 1-ft wide, given that most milling machines carry either a 10-in. or a 12-in. head. If extra width is needed to accommodate contractor equipment, this should also be addressed in the contract documents.

Area/Square Footage

Payment by square foot is intended for use in all other partial-depth repair situations:

- Type 1 joint and crack repairs.
- Type 2B random crack repairs.
- Type 3 bottom-half spot repairs.

Measurements should be taken to the nearest tenth of a foot and rounded to the nearest square foot for payment of each individual repair area. Minimum size of repair for payment is one square foot for each individual repair.

Measurement for Type 3 repairs is done at the mid-depth of the pavement, due to the sloping edge of the repair.

Repair Failures

It is advisable to write specifications that ensure a 30-day warranty on all partial-depth repairs done in sound concrete. This requires a contractor to replace any repairs that fail for any reason, except unsound concrete.

Allowing for Design Changes

Contract documents should address the possibility that, after the deteriorated concrete is removed, a decision may be made to change the type of repair. This prevents delays and misunderstandings between the construction personnel and contractor. For example, if a corner distress is found to extend into the bottom half of the slab, then the distressed area below the mid-point of the slab will require a Type 3 repair.

Summary

Under the model just discussed, payment calculations for the three types of partial-depth repair are as follow:

- Type 1—Conventional spot joint/crack/spall repair: Pay by square foot.
- Type 2—Extended-length joint/crack repair: Pay by linear foot for joints (Type 2A) and by square foot for cracks (Type 2B).
- Type 3—Bottom-half spot repair: Pay bottom half by square foot as a second payment (first payment for top half is a Type 1 or a Type 2 repair).

Design Issues

Properly constructed partial-depth repairs can last 15 years or more if constructed in sound concrete. Design life varies with condition of existing concrete, the extent of the deterioration, and future traffic loads.

When designing a partial-depth concrete repair project, the first step is to determine the existing pavement design and coarse-aggregate type. Aggregates should be subject to a strict review to make sure the existing pavement structure can last as long as the intended repairs. It is also important to determine the type of pavement: jointed plain concrete, mesh dowelled concrete, or continuously reinforced concrete pavement. If the pavement is a jointed plain pavement, determine whether it uses dowel bars or aggregate interlock-type transverse joints.

During the design phase, it is helpful to include any construction inspectors who will be on the repair project. This ensures that the person administering the construction project understands the philosophy of the designer for selecting the type of repair on deteriorated joints or cracks.

In designing projects, the quantity is not always known for Type 3 bottom-half repairs because the information available is based on cores or sounding. The quantity will be known only after the top half of the deteriorated pavement is removed (Type 1 spot repair).

Material Selection

The primary repair materials to be selected are the repair (or patch) mixture and the bonding agent.

Mixtures

The repair mixture selection for partial-depth repairs depends on several factors:

- Allowable lane closure time / strength of repair mixture required for opening
- Shrinkage characteristics
- Coefficient of thermal expansion
- Ambient temperature
- Cost
- Size of repair
- Estimated performance

Properties

Selection of the proper repair mixture should be based on a determination of its desired properties. Currently, the most widely reported property used for mixture selection is the strength of the repair mixture at a given time (e.g., when the patch needs to be opened to traffic).

Most highway agencies use flexural strength as the determining factor for opening strength for full-depth repairs because pavement failures from traffic loads are generally caused by tension in the bottom of the pavement slab. However, a partial-depth patch is unique in the way it carries loads. The flexural or tensile stresses are carried by the existing concrete pavement, and the partial-depth patch experiences compression only. Therefore, it is wholly appropriate to base mixture selection for partial-depth repairs on compressive strength at opening rather than on flexural strength. Samples of opening strength requirements are listed in Table 1.

Moreover, a partial-depth patch is confined and supported by the existing concrete, so the minimum patch strength required to carry traffic without experiencing damage is lower (typically, 1,600 to 1,800 psi) than that required for a conventional full-depth repair concrete mixture (typically, 3,000 psi or higher).

In addition to strength, two properties that affect the short- and long-term performance of a patch mixture are shrinkage and coefficient of thermal expansion, especially as compared to the existing concrete pavement. Drying shrinkage of most repair materials is greater than normal concrete and, when the material is restrained, can induce a tensile stress as high as 6,900 kPa (1,000 psi) (Emmons, Vaysburd, and McDonald 1993). Differential expansion between the repair material and the surrounding concrete can also be detrimental and should be considered during the design stage of a project.

Table 1. Example Opening Strength Requirements for Partial-Depth Repairs

Opening Strength Requirements		
State	Flexural (psi)	Compressive (psi)
New York		1,527 (10.5 MPa)
Kansas	300	1,800
Missouri		1,600
Michigan	300	1,800
Minnesota	500	3,000
Colorado		2,500
Nebraska		3,625

Another important property of the repair mixture is its freeze-thaw durability. A study of the properties of repair materials found that the freeze-thaw durability of many of them is unacceptable, especially under severe exposure conditions (Smoak, Husbands, and McDonald 1997). Materials with rapid strength-gain characteristics may be particularly susceptible to durability problems because of the accelerated nature of the material and the reduced curing times. The composition of modern cements is such that they gain higher strengths earlier but have a lower long-term strength gain; this may affect the long-term durability of the concrete (Van Dam et al. 2005). Depending on the application, early-opening times may be desired, which can significantly reduce the available curing time. The early-strength criterion and enhanced durability may be most effectively achieved by using high quality materials, by reducing the water-to-cement (w/c) ratio, and by increasing the aggregate volume, as long as workability is maintained (Van Dam et al. 2005).

The FHWA/SHRP *Manual of Practice, Materials and Procedures for Rapid Repair of Partial-Depth Spalls in Concrete Pavements* (Wilson, Smith, and Romine 1999b) states that premature partial-depth patch failures can be attributed to several material-related causes, including the following:

- Thermal incompatibility between the repair material and the pavement.
- Incompatibility between the joint bond breaker and the joint sealant.
- Inadequate cure time prior to opening repairs to traffic.
- Incompatibilities between the climatic conditions during repair replacement and the materials or procedures used.
- Extreme climatic conditions during the life of the repairs that are beyond the capabilities of the repair material.

Mixture Selection

Because of the multitude of factors that go into the selection process, it is impossible to specify a single mixture for all partial-depth repair applications. However, a conventional, high-quality portland cement concrete—specifically, one that uses Type I, II, and III cements—is generally accepted as the most appropriate material for repairing existing concrete pavements. (Various proprietary materials are also available. See Appendix B.)

Type I portland cement, with or without admixtures, is more widely used than most other materials because of its

relatively low cost, availability, and ease of use. The concrete mixture requires the use of small-sized, coarse aggregate, usually no more than ½ in. for the maximum-sized aggregate. The material should be a low-slump mixture of air-entrained concrete having a w/c ratio not exceeding 0.44. Rich mixtures (up to 8 bags of cement, or 446 kg/m³ [752 lb/yd³]) gain strength rapidly in warm weather, but in cool weather the rate of strength gain may be too slow to permit quick opening to traffic. Insulating layers can be used to retain the heat of hydration and reduce curing time.

Patches that include faster-setting materials, such as Type III (HE) cements, typically can be opened more quickly than Type I cement patch mixtures, but can be more difficult to place properly.

A mixture developed by the Minnesota Department of Transportation (DOT), called 3U18, has been very successful for more than 30 years. It results in an 18± hour opening strength of 3,000 psi. Earlier opening times can be achieved with other appropriate admixtures. Strength gain is affected by ambient temperature. Mixing can be done either by hand, ready mix, or mobile concrete mixers. For small projects, this mix can be purchased in 75-lb bags.

The 3U18 mixture is described in the sidebar at right.

Mixtures for Early Opening to Traffic (EOT)

Highway agencies are often required to accelerate the placement and opening of partial-depth repairs to minimize traffic delays and reduce safety hazards for motorists and maintenance crews. This is especially common in areas with high traffic volumes. Generally, such early-opening repairs are expected to be strong enough to carry traffic within 4 to 12 hours after placement, which significantly reduces the available curing time. In the case of high-traffic, high-speed roadways, such repairs are often conducted at night when lower traffic volumes allow for lane closures; the lane(s) must be re-opened after only a few hours.

For early-opening repair projects, cement-based, accelerated-strength mixtures can be designed that, when properly proportioned, mixed, placed, and cured, do not sacrifice long-term durability. Such mixtures contain higher cementitious materials content and admixtures, particularly accelerators.

Whenever higher cement content is used for a repair or patch mixture, contractors need to understand certain principles to ensure the mixture performs as desired: Such

Cementitious 3U18 Recommended for Use in Partial-Depth Repairs

850 lb Type I cement

295 lb water

1,328 lb coarse aggregate

1,328 lb sand

Target w/c ratio 0.35

Type E water reducing and accelerator

6.5 percent air

Maximum 1 in. slump (measured after allowing to set 5 minutes after mixing)

Cure time 18± hr

Fine aggregate gradation 100 percent passing 3/8 in. sieve

Coarse aggregate gradation

- 100 percent passing 3/8 in. sieve
- 55 percent–95 percent passing no. 4 sieve
- Not more than 5 percent passing no. 50 sieve

Source: Minnesota DOT

patch mixtures will have a different microstructure than that of the concrete pavement to which the repair material must bond, with different shrinkages and unexpected interactions that can lead to de-bonding or other failures. In general, the higher the early-opening strength requirement (e.g., 3,000 psi compressive or greater), the higher and/or more complex the cement and admixture content will be, and thus the greater the potential for failure.

If the required early-opening strength is lower (e.g., 1,800 psi compressive), the contractor has more options. For example, this requirement would allow the use of Type I cement and admixtures to reach the required strength in 4 to 6 hours, especially with the use of insulation blankets. Such a mixture would be closer to the existing concrete in terms of shrinkage, stiffness, and coefficient of thermal expansion. It is the similarity of these characteristics that improves the bond between the patch and the existing concrete and ultimately affects the service life of the patch. It is thus likely that requiring a higher early-opening strength (e.g., 3,000 psi compressive) may increase the risk of short-term failures more than requiring a lower early-opening strength (e.g., 1,600 to 1,800 psi).

When using a lower early-opening strength patch mixture (e.g., 1,800 psi), a determination should be made of the equivalent single axle loads (ESALs) the patch will carry before it reaches its “full” strength. For most partial-depth repairs, the amount of traffic loading in the additional 4 to 6 hours the patch continues to gain strength (e.g., from 1,800 psi opening to 3,000 psi desired strength) is small compared to the lifetime loading.

The use of a maturity system that constantly monitors concrete strength and rate of strength gain is an effective method for determining when the patch has achieved minimum required in-place strength for opening to traffic.

Guidelines for Early Opening to Traffic (EOT) Portland Cement Concrete for Pavement Rehabilitation (VanDam et al. 2005) provides a good summary of strength principles for contractors who are selecting accelerated-strength concrete mixtures for partial- and full-depth repairs.

Another option is to use one of the variety of rapid-setting, high early-strength proprietary materials. These “flexible” or “semi-rigid” repair products have been used effectively in partial-depth repair applications. They are typically classified as either cementitious, polymeric, or bituminous. Many highway agencies maintain a qualified products list. See Appendix B for short summaries of these materials, including their benefits and potential drawbacks.

Bonding (Grout) Agents

Portland cement concrete materials generally require the placement of a bonding agent or grout to enhance the bond between the repair material and the existing pavement. Sand-cement grouts have proven adequate when used as bonding agents with concrete repair materials.

A successful grout recipe used by many states for coating all areas of the repair is described below.

- 2 parts Type I cement
- 1 part water (may be more or less to develop a creamy consistency)
- 1 part sand

This sand-cement-water grout mixture produces a mortar with a thick, creamy consistency, which helps to fill any small spalls left by the milling process. However, if it dries out, sand blasting will be needed to ensure a good bond.

The Kansas DOT uses a different approach regarding bonding agents. Its approach is to use a more watery mix

which helps cool and pre-wets the existing concrete pavement before placement. The pre-wetting keeps the existing concrete from pulling water out of the repair mix. The Kansas grout mixture consists of the following:

- 1 part Type I cement
- 3 parts water

Not all repair materials require a bonding agent to promote adhesion. When proprietary mixes are used, they will specify what type of bonding agent, if any, is required. Epoxy bonding agents have been used with both portland cement and proprietary repair material to reduce closure time, with mixed results.

Construction Steps

Construction of partial-depth repairs typically includes the following steps:

1. Determine repair boundaries.
2. Remove concrete.
3. Prepare repair area.
4. Prepare joint.
5. Apply bonding agent (do not allow to dry).
6. Place patch material.
7. Apply curing compound.
8. Optional diamond grinding.
9. Seal joints.

Step 1. Determine Repair Boundaries

The first step is to determine the extent to which the existing concrete has deteriorated and to identify the repair boundaries.

The actual extent of deterioration in a concrete pavement is often greater than the distress that is visible at the surface. In the early stages of spall formation, weakened planes may exist in the slab with no signs of deterioration visible at the surface.

During the survey, the extent of deterioration should be determined by “sounding” the concrete with a steel pipe, chains, or a hammer (Figure 13). Areas yielding a sharp metallic ringing sound are judged to be acceptable, while those emitting a dull or hollow thud are delaminated or unsound. Sometimes it helps to drop a small amount of sand on the questionable concrete and hit the concrete with a hammer, watching the sand bounce in delaminated sections.

Once the area is identified, the boundaries for sawing or milling are marked on the pavement (Figure 14). To ensure removal of all delaminated concrete, it is a good practice to extend the limits of the repair boundaries 2 to 4 in. beyond the limits determined by sounding tests. Following are suggested minimum dimensions:

- Length: 15 in.
- Width: 10 in.
- Depth: 2 in.

Step 2. Concrete Removal

Deteriorated concrete in the designated repair area should be removed to a minimum depth of 2 in. (refer to Figures 3, 4, and 6) and a maximum depth of one-half the pavement thickness. Only sound concrete should remain.

The preferred shape around the outside of the repair area is a 30- to 60-degree tapered edge from top to bottom. Avoid chipping sound concrete around the repair area. Any secondary chipping or spalling during this process should be removed at no cost to the agency.

Care should be taken not to damage dowel bars during the removal process. One or two adjacent exposed bars can be removed to allow ease of placement of compression material (cardboard, isolation material, or ¼-in. insulation board). The placement of compression relief material at the bottom of the repair is required to re-establish the joint and allow movement of the pavement at the joint area.



Figure 13. Sounding deteriorated concrete using a hammer (left) and steel chain (right)



Figure 14. Deteriorated pavement marked for sawing

If inspection of existing dowel bars shows little or no corrosion, a bond-breaking material or a bridging material (such as duct tape) should be placed on the dowel(s) and approved by the engineer. Dowel bars that are misaligned or exhibit corrosion to a greater degree should be cut off. If this involves more than four adjacent dowels, the engineer should consider a full-depth repair.

Removal of deteriorated concrete may be accomplished using one of these three methods:

- Saw-and-chip removal (Type 1 repairs)
- Mill removal (Types 1 and 2 repairs)
- Chip removal (Type 3 repairs)

Saw-and-Chip Removal (Type 1 Repairs)

The most common method for removing deteriorated concrete in Type 1 partial-depth spot repairs is the saw-and-chip method. First, a diamond-blade saw is used to saw along the marked repair boundary (Figure 15). The saw cuts may be at the marked boundary only or at the marked boundary and in a crisscross pattern across the area to be removed. Then a lightweight (10–35 lb) jackhammer is used to remove the concrete inside the patch boundary, beginning at the center and extending outward. The jackhammer is also used to remove the polished vertical saw cut edge by chipping out concrete 2 in. beyond the saw cut to produce an angle between 30 and 60 degrees and create a rough surface, which is critical for promoting bonding of the patch material to the existing concrete. Failure to bond can be especially problematic along polished vertical edges in corners, especially when high-cement mixes with a tendency to shrink are used.

Care must be exercised not to fracture sound concrete or cause shallow chips adjacent to the repair area, which can be difficult to patch. Some states, such as Kansas, do not allow any chipping beyond the initial saw cuts.

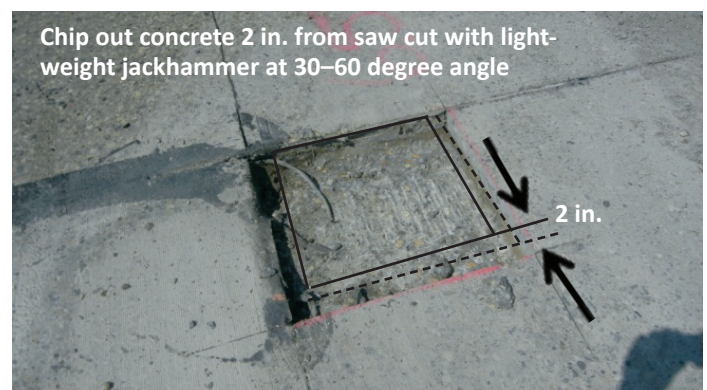


Figure 15: Saw-and-chip removal

Benefits of this method include the following:

- It is cost-effective.
- Most crews are typically familiar with this method.

Drawbacks of this method include the following:

- Water from sawing leaves the area saturated, possibly delaying the repair process.
- Without care, the beginning of spalling can occur at the jackhammer line outside the saw cut.
- This method is time consuming and is not as cost effective for large partial-depth projects as cold milling.

Mill Removal (Types 1 and 2 Repairs)

Cold milling is another option for removing deteriorated concrete. The milling operation can proceed either across lanes or parallel to the pavement centerline (Figure 16 and Figure 17).

Milling along the joint or crack is effective for removing spalling and produces a rectangular-shaped repair area, whereas milling perpendicular to the joint or crack is effective for smaller, individual spalls and produces a dish-shaped repair area.

Midwestern states started using a mill for concrete removal in the early 1980s and have had success leaving the rounded edge for Types 1 and 2 partial-depth repairs (Figure 18, Figure 19, and Figure 20). With the milling system and their own partial-depth repair techniques, Midwestern states have had increased success with all their milled partial-depth repairs compared to saw-and-chip removal when the polished vertical edge is left in place.

Benefits of milling are as follow:

- The patch size is uniform for long-term success.
- The rough, irregular surface promotes bonding.
- Milling is efficient and economical when repairing large areas.
- Debris is easy to remove with a shovel and broom or a skid loader pickup broom.
- Milling requires less labor than jackhammer removal.

Drawbacks of this method are as follow:

- Milling creates a standard size, which may not conform to site.
- Extra milling may be required to widen the original milled channel, especially when milling long cracks (e.g., longitudinal) to create a minimum distance of 3 in. to an outside milled face (Figure 19).
- Equipment and mobilization may be costly for small projects.



Figure 16. Milling along the joint or crack



Figure 17. Dish-shaped milling perpendicular to the joint or crack



Figure 18. Type 1 spot milling



Figure 19. Type 2A joint milling



Figure 20. Type 2B crack milling

The most common mill heads used today are the “V” or rounded head and the vertical edge.

“V” or Round Shaped Concrete Removal. Milled heads manufactured to create a “V” shape (Figure 21 and Figure 22) or round shape (Figure 23 and Figure 24) can be used on transverse and longitudinal joints and cracks. The preferred shape is a tapered edge anywhere from 30 to 60 degrees to the bottom of the joint. The patch material



Figure 21. V-head milling (Types 1 and 2)



Figure 22. V-head milling

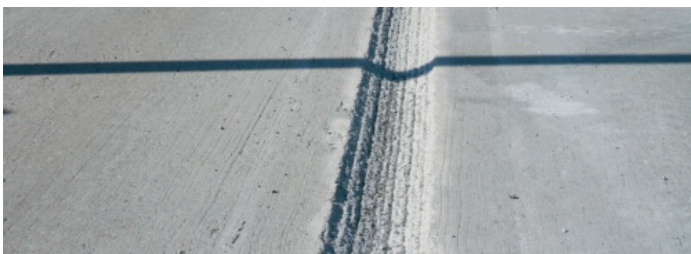


Figure 23. Rounded milling (Types 1 and 2)



Figure 24. Example of rounded milling with rock saw

bonds better to the exposed concrete on a tapered edge than on a vertical edge. The taper also eliminates the corner at the bottom edge of the repair from which high-cement mixes can shrink and prevent bonding. The tapered edge also seems to create less spalling and chipping than a vertical milled edge.

Experience has demonstrated that a tapered V-head mill or rounded mill can be used on all partial-depth repair projects. Milling with the V-head or rounded head has been used very successfully on transverse joints without any additional sawing, with only minor chipping at the edge of the repair. If any chipping does occur, the mill heads need to be checked for sharpness. On occasions when a mill head is not used to form the edges, the edges are tapered using a small jackhammer to remove the vertical edges left by the sawing operation.

Vertical Edge Removal. The states of Kansas and South Dakota modified Minnesota’s milling approach by requiring that a vertical, instead of tapered, edge be left by the mill (Figure 25 and Figure 26). Milling a vertical face can leave more chipping at the top edge, so some states such as Kansas require a saw cut for all transverse joints repaired with partial-depth milling.



Figure 25. Vertical edge milling



Figure 26. Vertical edge mill head

Kansas does not require saw cuts for longitudinal joints unless excessive chipping occurs (Figure 27). This allows the chipped edge to remain on any longitudinal partial-depth repairs, with the knowledge that traffic will not cross the vertical edge very often. Kansas has not had a problem with bonding on either longitudinal or transverse joint partial-depth repairs.

Chip Removal (Type 3 Repairs)

The chipping procedure for Type 3 repairs differs slightly from the saw-and-chip procedure for a Type 1 repair, in that the patch boundaries are not sawed. The deteriorated concrete in the center of the patch is removed using a lightweight jackhammer (less than 35 lb). Care should be taken not to damage the sound pavement (Figure 28). Again, work should progress from the inside of the patch toward the edges, and the chisel point should always be directed toward the inside of the patch. Because No. 4 tie bars must be placed in Type 3 repairs to lock the patch material to the existing concrete pavement (see Figure 12, side view), enough concrete must be removed to allow maneuvering of drilling equipment and to maintain a minimum of 1 in. of new concrete around the tie bars.

Pavement removal for Type 3 repairs can also be partially accomplished with milling. As Figure 29 shows, the right portion of the repair has had spot milling.

full-depth removal on the left side of the photo was accomplished with a jackhammer.

Step 3. Repair Area Preparation

Following removal of the deteriorated concrete, only sound concrete should remain. Check for sound concrete with a hammer (Figure 31) and remove any unsound concrete with a small jackhammer (less than 35 lb).

The surfaces of the repair area must be prepared to provide a clean, irregular surface for the development of a good bond between the repair material and the existing slab. Dry sweeping, sand or water blasting, and compressed air blasting are normally the steps for an adequately clean surface.

Sweeping the partial-depth repair area is necessary to pick up the broken material (Figure 30). This is particularly true when a rock saw is used to remove the pavement. The repair area should then be sand or water blasted (Figure 32 and Figure 33). This is a highly recommended step, as it is very effective at removing dirt, oil, thin layers of unsound concrete, and laitance. Typically, sand blasting has been used, but recently high pressure (3,500 psi) water blasting has been used by some states. Water blasting removes contaminants and leaves the concrete in a desirable saturated-surface dry condition.



Figure 27. Excess chipping from mill

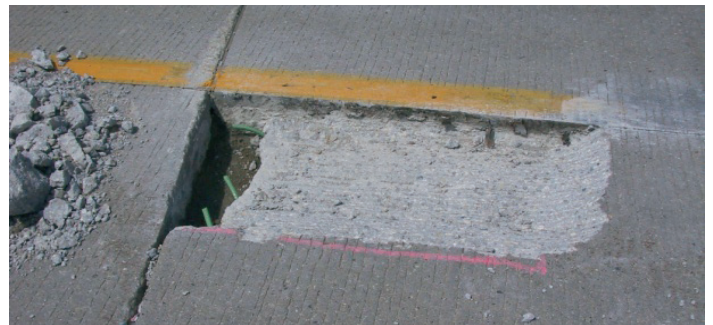


Figure 29. Type 3 repair – Removal by milling and chipping



Figure 28. Type 3 repair – Removal with small jackhammer



Figure 30. Sweeping loose material

Compressed air should be used for the final cleaning. To prevent contaminating the surface with oil from the air compressor, which would prevent the patch material from bonding to the existing concrete, place a cloth over the nozzle and visually inspect it for oil.

The prepared surface must be double-checked immediately prior to applying the bonding grout, and any surface contamination that would reduce the bond between the patch material and the existing concrete must be removed. If the air blasting equipment is no longer available, a leaf blower can be used as a substitute (Figure 34).



Figure 31. Sounding with hammer



Figure 32. Sandblasting to remove loose debris



Figure 33. Air blasting to remove loose debris

Step 4. Compression Relief for Type 1 and Type 2B Crack Repairs

The fourth step is the installation of joint/crack compression relief material for Type 1 repairs and Type 2B crack repairs.

Compression relief is a vital part of a successful partial-depth repair. In fact, the most frequent failure of partial-depth repairs occurs from excessive compressive stresses on the repair material. If insufficient room is provided for thermal expansion, partial-depth repairs placed directly against transverse joints and cracks will be crushed by compressive forces created when the slabs expand (Figure 35 and Figure 36).

In addition to relieving compression stresses, the material must prevent patch material from entering the joint or crack and preventing normal joint movement.

To provide compression relief and re-establish joints and cracks at their original locations, a strip of compressible material is typically placed in Type I joints or cracks and Type 2B cracks. The contractor should provide compression-relief material such as ¼-in. polystyrene or polyethylene isolation material, ¼-in. STYROFOAM™ insulation, or waxed cardboard (Figure 37).

If the compression-relief material is not installed properly, the repair will fail. The inserts are typically required to extend below and outside the patch area. The material should be installed as deep as possible, below the patch area at least ¼ in. and up to an inch if available. It should also extend beyond the patch area at least 3 in. on each side of the exposed crack. Waxed cardboard is easy to cut and fit the irregular nature of random cracks. It also maintains its rigidity for concrete placement. It is advisable to



Figure 34. Using a leaf blower for final removal of any contaminants

use a screwdriver to fit the cardboard into the open crack at the bottom of the repair. If necessary, taking a second pass with the mill or chipping the edge back with a small jackhammer might be needed to ensure enough bonding area for the new patch material at the bottom of the repair.

In general, more compression relief is better than less.

If, as shown in Figure 38, the removal of deteriorated concrete reveals a hole extending to the bottom of the pavement, compression relief is required the full depth of the hole. This can be accomplished with waxed cardboard or ¼-in. STYROFOAM™ cut to fit the variable-sized hole. (If the hole is large enough to allow drilling and placement of reinforcing steel, it is considered a Type 3 repair.)

Note: Normally, the compression relief material (or at least the upper portion) will be removed by sawing before the joint is sealed.

Step 5. Bonding Agent Application (sand-cement grout)

After cleaning the surface of the existing concrete and immediately prior to placing the repair material, the concrete surface must be coated with a sand-cement grout or bonding agent to ensure complete bonding of the repair material to the concrete.

For Type 3 bottom half repairs, No. 4 tie bars need to be installed at mid-depth (see Figure 12) *before* coating the surface with grout.

Use the same grout for all types of repair. Recipes for cement grout can be found at the end of the Material Selection section on page 10. Epoxy grouts can also be used, especially with short working times such as night-time work.

The contractor should mix the grout by mechanical means to the consistency of thick cream. The life of the grout in the mixing container should not exceed one hour.

The grout should be applied by brushing with a soft brush (epoxy-based) or scrubbing it with a stiff bristle broom (cement-based) onto the existing concrete surface until it coats all vertical and horizontal surfaces; see Figure 39.

The grout must be placed immediately before the repair material. It is critical that the grout does not set before the repair mixture is placed. If the grout dries out after application and before placement of the patch material, the contractor should sand blast and regrout.

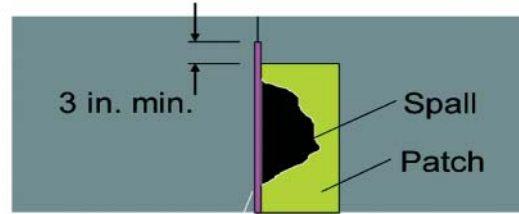


Figure 35. Illustration of joint preparation using bond breaker



Popout & Breakage



Expansion → ← Expansion

Figure 36. Illustration of joint preparation without bond breaker



Figure 37. View of cardboard cut to fit irregular random crack



Figure 38. View of hole exposed at intersection of a joint and a crack



Figure 39. Placement of cement grout as bonding agent

Step 6. Patch Material Placement

Use common practices for hot-weather and cold-weather concrete placement conditions. Generally, repairs at air temperatures below 40°F are not advisable, due to the small amount of concrete patch material.

General patch material placement guidelines are as follow:

- Batch in small quantities.
- Consolidate the patch material on larger patches using vibrators or vibrating screeds. Smaller patches are consolidated using small spud vibrators or by-hand rodding and tamping.
- Texture the surface of the repair to match that of the surrounding slab as much as possible, unless diamond-grinding is the final texture.
- Floating toward the edge is recommended. It is important to work the material away from the center of the patch and toward the edges to promote bonding. This action will help pinch the edge of the repair together with the existing pavement (Figure 40).

Repair Material Mixing

For Type I and Type 3 repairs, the volume of material required for a partial-depth repair is usually small (0.5 to 2.0 ft³). Small drum or paddle-type mixers with capacities of up to 2.0 ft³ are often used. Based on trial batches, repair materials may be weighed and bagged in advance to facilitate the batching process. Batches can also be mixed (by volume) using 5-gallon buckets for each ingredient in the same manner as continuous mobile concrete feed mixers that proportion concrete mixes by volume.

Careful observation of mixing times and water content for prepackaged rapid-setting materials is important because of the quick-setting nature of the materials. Mixing longer than needed for good blending reduces the already short time available for placing and finishing the material. For

long joint/crack repairs, ready-mix or mobile crete trucks can efficiently produce the required quantities (Figure 41).

Placement and Consolidation of Material

The placement and consolidation procedure begins by slightly over-filling the area with repair material to allow for a reduction in volume during consolidation. Portland cement concrete and most of the rapid-setting, proprietary repair materials should not be placed when the air temperature or pavement temperature is below 40°F. At temperatures below 55°F, additional precautions, such as the use of warm water, insulating covers, and longer cure times, may be required. Some polymer concretes may be installed under adverse conditions such as low temperatures and wet substrates with reasonable success; however, even these materials will perform better when installed under more favorable conditions.

Almost all repair materials require consolidation during placement. Consolidation provides a more dense mixture by releasing trapped air from the fresh mix, thereby contributing to the overall performance of the patch. Failure to properly consolidate concrete results in poor repair durability, spalling, and rapid deterioration. The common consolidation methods are as follow:

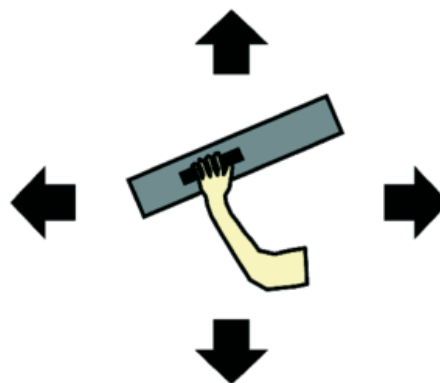


Figure 40. Finishing tip: move from inside to outside



Figure 41. Placement of repair material

- Use of internal vibrators with small heads (less than 25 mm or 1 in. in diameter).
- Use of vibrating screeds or roller screeds.

The internal vibrator and the vibrating screed give the most consistent results. The internal vibrator is often more readily available and is used most often, although very small repairs may require the use of hand tools. The tools used should be small enough to easily work in the area being repaired.

The vibrator is held at a slight angle (15 to 30 degrees) from the vertical and moved through the repair in such a way as to vibrate the entire repair area (Figure 42). Many times, workers place a foot on the waxed cardboard or other compression material during concrete vibration, so it does not float out of the crack at the bottom of the repair. Do not use the vibrator to move material from one place to another within the repair, which may cause segregation.

Adequate consolidation is achieved when the mix stops settling, air bubbles no longer emerge, and a smooth layer of mortar appears at the surface.

Care must be exercised to trowel toward the edge of the repair, particularly for Type 1 repairs and Type 2B crack repairs on both sides of compression relief material such as waxed cardboard (Figure 43, Figure 44, and Figure 45).



Figure 42. Consolidation of repair material for Type 2A joint repair



Figure 43. Concrete placement while holding waxed cardboard

This approach helps to restore the ride to an acceptable level. (Diamond grinding can be used to restore ride and texture in conjunction with partial-depth repairs; see Step 8.)

Sawing Relief Joints

Type 1 and Type 2A joints have been successfully sawed to create compression relief. However, it is important to re-establish the joint before the fast-setting concrete mix develops a random crack and to use the 30-day warranty if a random crack develops. Tooling of the joint can be done to help create a weak plane during concrete placement (Figure 46), followed by sawing as soon as possible (Figure 47).

The full depth of the partial-depth repair plus ¼ in. should be sawed with care and as soon as possible after concrete



Figure 44. Troweling toward the edge of the repair



Figure 45. Concrete placement for Type 1 repair using waxed cardboard



Figure 46. Tooling the joint



Figure 47. Sawing following tooling the joint

placement without causing excessive raveling. The set time of a mix will help determine the time to saw.

It should be noted that sawing Type 1 and Type 2A joints for joint sealing is different from sawing for compression relief. If a compression relief material was used it will be removed during joint sealing operations.

If complete joint resealing is specified, all Type 1 repairs will be widened for joint resealing operations to the same width as the adjacent joint. If only the repair area is to be sealed, the width of the joint reservoir will be wider than the crack under the repair. In these cases it is common for the existing joint reservoir on either side of a Type 1 repair to be wider than the sealed joint in the repair area.

Screeding and Finishing

Partial-depth repairs typically cover only a small percentage of the pavement surface and have little effect on skid resistance. However, the surface texture of the patch material should match that of the existing pavement as closely as possible. Partial-depth repairs are usually small enough so that a stiff board can be used to screed the repair surface on each side of the compression relief material and make it flush with the existing pavement. At least two passes should be made to ensure a smooth repair surface.

The final finishing procedure is to paint a sand-cement grout, the same grout used for bonding, at the edges of

the repair to impede delamination of the patch (Figure 48). This ensures that a high percentage of cementitious material is available to glue the edges of the patch material to the existing concrete, helping to prevent the infiltration of moisture that can lead to delamination if water at the interface freezes in cold weather.

Saw cuts that extend beyond the patch perimeter at patch corners can also be filled with grout to help prevent moisture penetration that may negatively affect the bond.

Figures 49, 50, 51, and 52 show completed joint repairs.

Step 7. Curing

Because partial-depth repairs have large surface areas in relation to their volumes, moisture can be lost quickly. Therefore, curing is an important component of the construction process and must be effectively conducted to prevent the development of shrinkage cracks, which may cause the repair to fail prematurely.

The most effective curing procedure in hot weather is to apply a white-pigmented curing compound as soon as bleed water evaporates from the repair surface (Figure 53). Some agencies require that curing compound be applied at 1.5 to 2 times the normal application rate to prevent shrinkage cracks in the repairs. Moist burlap and polyethylene sheets may also be used and, in cold weather, insulating blankets or tarps may be required, to help retain heat. Curing of proprietary repair materials should be conducted in accordance with the manufacturer's recommendations.

After the concrete repair has been placed and cured, excess compression relief board is cut (Figure 54).

The opening time for traffic is mix and temperature dependent. Generally, compressive strengths of approximately 2,000 psi are required by most agencies before the partial-depth repair is opened to traffic.



Figure 48. Placement of grout at edge of partial-depth repair



Figure 49. Completed Type 1 crack repair



Figure 50. Completed Type 2A joint repair



Figure 51. Completed Type 2B crack repair



Figure 52. Completed Type 3 repair



Figure 53. Curing of repair material

Step 8. Optional Diamond Grinding

Rehabilitation techniques such as partial-depth repairs may result in increased roughness if not finished properly. This is typically due to differences in elevation between the repair areas and the existing pavement. It is often desirable to smooth the transition between partial-depth repairs and the existing concrete pavement with diamond grinding, leaving one smooth surface (Figure 55).

Step 9. Joint Sealing

The final step in the process is sealing the joint (Figure 56). Joint sealing helps ensure that incompressibles don't enter the joint and cause additional spalls to occur.



Figure 54. Cutting excess compression relief board of Type 2B crack repair



Figure 55. Diamond grinding of partial-depth patch



Figure 56. Joint sealing

Short-Term Repairs

When joint or crack deterioration occurs in the bottom half of the pavement or below the dowel bar(s), a full-depth repair is generally warranted. Sometimes, however, a short-term partial-depth repair (Figure 57) may be an option until a more permanent solution can be applied. The life of this type of patch depends on many factors and can be as short as a year or as long as several years.

With dowel-bar pavements, deterioration below the dowel bars is removed by sand blasting. A bond breaker must be applied on the entire surface of the exposed dowel bar. Waxed cardboard or similar material, perhaps supplemented with sand, must be used for compression relief.

The compression relief material needs to reach the bottom of the repair, where possible. If exposed dowels are present and it is impossible to place a compressible material full depth, then sand may also be used:

- If only one or two bars are exposed, cut the bar(s); see Figure 58. If more than two bars are exposed, coat the bars with an approved bond breaker (e.g., duct tape).
- Fill the void with clean concrete sand to provide a form for the partial-depth concrete patch mix and to allow horizontal movement of the concrete panels; see Figure 59.
- If excessive sand is used, it might be necessary to double the thickness of the waxed cardboard or other compression relief material to accommodate the large movement allowed by the sand.
- Caution: The use of sand to provide compression relief below dowel bars can be successful on a limited basis. The extent of the use of sand will determine the life of



Figure 58. Typical full-depth deterioration at edge of transverse joint



Figure 59. Proper use of sand to prevent lockup of joint

the partial-depth repair. As increasing amounts of sand are needed to fill the void, it will be more difficult to estimate the expected life of the partial-depth repair.

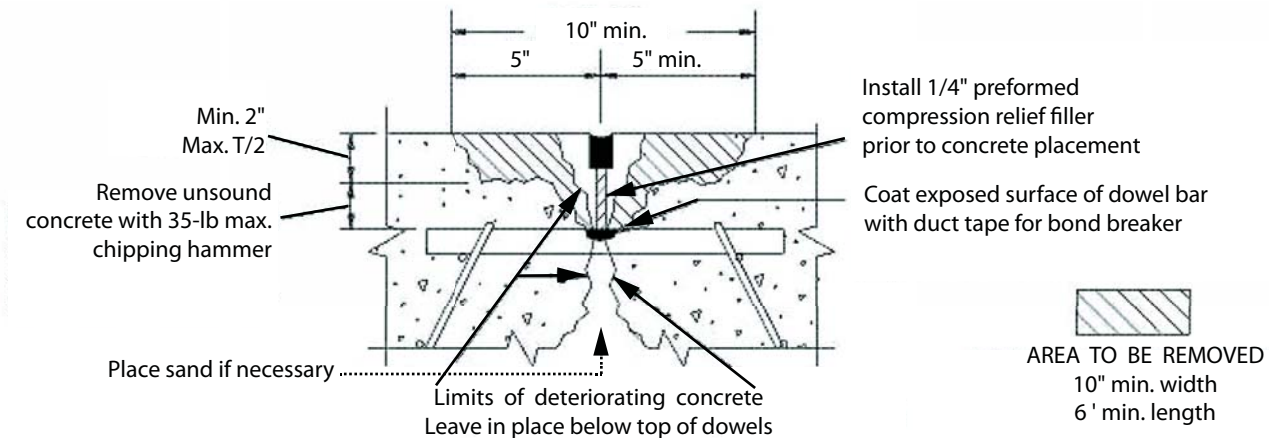


Figure 57. Crack or joint repair when deterioration is in the lower half of the slab

Greatly reduced repair life can be expected by constructing a patch as shown in Figure 60. This procedure can be used to hold a pavement together for a short time, the length of which will be greatly influenced by traffic, weather conditions, and condition of the existing concrete. It is also advisable to remove the 30-day warranty on patches such as that shown in Figure 60. This patch should have been a full-depth repair but was completed as a partial-depth repair due to other reasons.

Quality Control

The combination of proper design procedures and sufficient construction quality control (QC) is extremely important in achieving well performing partial-depth repairs. On many partial-depth repair projects where QC inspections have been less stringent, performance has typically been found to be unsatisfactory; see Figure 61. Following are some of the common causes of failure:



Figure 60. Poor candidate for partial-depth repair (too much sand used, which shortens life)



Figure 61. Failed Type 2A repair on an Interstate highway

- Inappropriate use.
- Lack of bond.
- Compression failure (due to failure to re-establish the joint).
- Variability in the effectiveness of repair material.
- Improper use of repair materials.
- Insufficient consolidation.
- Incompatibility in thermal expansion between the repair material and the original slab.

This section summarizes a checklist that was compiled to facilitate successful design and construction of well performing partial-depth repairs (FHWA 2005). Although these procedures do not necessarily ensure the long-term performance of a specific repair, the topics remind both the agency and contractor of specific design and construction practices that can influence the performance of the repair. The checklist is divided into general categories: preliminary responsibilities, equipment inspections, weather limitations, traffic control, and project inspection.

Preliminary Q/C Responsibilities

As a first step of the QC process for a given project, agency and contractor personnel should collectively conduct a review of project documentation, scope, intended construction procedures, and material usage and associated specifications. Such a collective review is intended to minimize misunderstandings in the field among agency designers, inspectors, and construction personnel. The preliminary review should include the following items:

Document Review

Review the following documents:

- Bid/project specifications and design.
- Applicable special provisions.
- Agency application requirements.
- Traffic control plan.
- Manufacturer's specific installation instructions for selected patch material(s).
- Manufacturer's material safety data sheets (MSDSs).

Project Scope Review

Verify the following:

- Pavement conditions have not significantly changed since the project was designed and that a partial-depth repair is still appropriate.

- The estimated number of partial-depth repairs agrees with the number specified in the contract.
- Quantities to be placed, allowing flexibility if additional deterioration is found below the surface.
- Criteria for identifying when partial-depth repairs will become full-depth repairs, such as when deterioration extends below the top one-third of the slab, and how payment will be adjusted.

Materials Review

Verify the following:

- Selected patch material is of the correct type and meets specifications.
- Patch material is obtained from an approved source or is listed on the agency Qualified Products List, as required by the contract documents.
- Patch material has been sampled and tested prior to installation, as required by the contract documents.
- Additional or extender aggregates have been properly produced and meet requirements of contract documents.
- Material packaging is not damaged (leaking, torn, or pierced bags, for example) to prevent improper use.
- Bonding agent meets specifications.
- Curing compound meets specifications.
- Joint/crack re-former material (compressible insert) meets specifications (typically, polystyrene foam board, or 0.5-in.- (12 mm-) thick/waxed cardboard).
- Joint sealant material meets specification requirements.
- Sufficient quantities of materials are on hand for completion of the project.

Equipment Inspections

A second step in the QC process involves the inspection of all equipment that will be utilized in the construction of the partial-depth repairs. Ensuring that construction equipment is in good working order helps avoid construction-related problems. The inspections should include the following equipment:

Concrete-Removal Equipment

Verify the following:

- Concrete saws are of sufficient weight and horsepower to adequately cut the existing concrete pavement to the depth required along the patch boundaries, as required by the contract documents.
- Concrete saws and blades are in good working order.
- Pavement milling machines are power-operated, self-propelled; cold milling machines capable of removing concrete as required by the contract documents.
- Milling machines used for concrete removal are equipped with a device that allows them to stop at preset depths to prevent removal of more than the top third of the slab and to prevent damage to embedded steel.
- Maximum rated weight of removal jackhammers is less than 14 kg (35 lb).
- After concrete removal, the patch area is prepared by sand blasting or water blasting and is as clean as possible to promote bonding of the patch material.

Patch-Area Cleaning Equipment

Verify the following:

- Sand blasting unit is adjusted for correct sand rate and is equipped with and uses properly functioning oil/moisture traps.
- Air compressors have sufficient pressure and volume to clean the patch area adequately in accordance with contract specifications.
- Air compressors are equipped with and use properly-functioning oil and moisture filters/traps. (This can be accomplished by passing the air stream over a board and examining it for contaminants.)
- Volume and pressure of water blasting equipment (if used) meet specifications.

Mixing and Testing Equipment

Verify or ensure the following:

- Auger flights and paddles within auger-type mixing equipment are free of material buildup that can result in inefficient mixing operations.
- Volumetric mixing equipment, such as mobile mixers, are in good condition and calibrated on a regular basis to properly proportion mixes.
- The concrete testing technician meets the requirements of the contract documents for training/certification.
- All material test equipment required by the specifications is available on site and in proper working condition (typically includes slump cone, pressure-type air meter, cylinder molds and lids, rod, mallet, ruler, and 10-ft [3 m] straight edge).

Placing and Finishing Equipment

Verify or ensure the following:

- A sufficient number of concrete vibrators (1 in. [25 mm] diameter or less) are available on site and in proper working condition.
- All floats and screeds are straight, free of defects, and capable of producing the desired finish.

Other Equipment

Verify or ensure the following:

- A steel chain, rod, or hammer is available to check for unsound concrete around the patch area.
- Grout application brushes (if necessary) are available.

Weather Limitations

Immediately prior to the start of the construction project, check these weather-related concerns:

- Review manufacturer installation instructions for requirements specific to the patch material being used.
- Ensure air and surface temperature meets manufacturer and contract requirements (typically 4°C or 40°F and above) for concrete placement.
- Ensure patching does not proceed if rain is imminent.

Traffic Control

The traffic control plan should be reviewed by field personnel prior to construction. Specifically, the following pre- and post-construction traffic-related items should be verified:

- The signs and devices used match the traffic control plan presented in the contract documents.
- The setup complies with the federal or local agency *Manual on Uniform Traffic Control Devices* (MUTCD) or local agency procedures.
- Traffic control personnel are trained/qualified, according to contract documents and agency requirements.
- Unsafe conditions, if any, are reported to a supervisor.
- The repaired pavement is not opened to traffic until the patch material meets strength requirements presented in the contract documents.
- Signs are removed or covered when no longer needed.

Project Inspection

During the construction process, careful project inspection by construction inspectors can greatly increase the chances of obtaining well performing partial-depth patches. The inspection should include the following items, organized by construction activities:

Concrete Removal and Cleaning

Verify or ensure the following:

- The concrete surrounding the area to be patched is checked for delamination and unsound concrete, using steel chain, steel pipe, or hammer.
- The boundaries of unsound concrete are marked at least 2 in. (51 mm) beyond the area of deterioration.
- Concrete is removed by either (1) saw cutting the boundaries and jack hammering interior concrete or (2) using a cold milling machine.
- Concrete removal extends at least 2 in. (50 mm) deep and does not extend below one-third of the slab depth, and load transfer devices are not exposed.
- After concrete removal, the patch area is cleaned by sand blasting or water blasting to remove any dirt, debris, or laitance.
- The patch area is cleaned by air blasting. A second air blasting may be required immediately before placement of bonding agent if patches are left exposed longer than specified in the contract documents.

Patch Preparation

Verify or ensure the following:

- Compressible material (joint/crack re-formers) is inserted into existing cracks/joints in accordance with contract documents. Joint inserts are typically required to extend both below and outside the patch area by $\frac{1}{4}$ in. (6 mm). When a patch abuts a bituminous shoulder, ensure that a form is used to prevent patch material from entering the shoulder joint.
- Bonding agent (epoxy- or cement-based) is placed on the clean, prepared surface of existing concrete immediately prior to the placement of patch material, as required by the contract documents. If the bonding agent shows any sign of drying before the patch material is placed, it must be removed by sand blasting, cleaned with compressed air, and re-applied.)
- Cement-based bonding agents are applied using a wire brush; epoxy bonding agents, a soft brush.

Placing, Finishing, and Curing Patch Material

Verify the following:

- Quantities of the patch material being mixed are relatively small to prevent material from setting prematurely.
- The fresh concrete is properly consolidated using several vertical penetrations of the surface with a hand-held vibrator.
- The surface of the concrete patch is level with the adjacent concrete using a straight edge in accordance with contract documents. (Material should be worked from the center of the patch outward toward the patch boundary to prevent pulling material away from the boundary.)
- The surface of the fresh patch material is finished and textured to match the adjacent surface.
- The perimeter of the patch and saw-cut run outs (if saws are used) are sealed using grout material. (Alternatively, saw-cut run outs can be sealed using joint sealant material.)
- Adequate curing compound is applied to the surface of the finished and textured, fresh patch material in accordance with contract documents.
- Insulation blankets are used when ambient temperatures are expected to fall below 40°F (4°C), and blanket cover is continued until concrete attains the strength required in the contract documents.

Resealing Joints and Cracks

Verify the following:

- The compressible inserts are sawed out to the dimensions specified in the contract documents when the patch material has attained sufficient strength to support concrete saws.
- Joints are cleaned and resealed according to contract documents.

Cleanup Responsibilities

Verify the following:

- All concrete pieces and loose debris are removed from the pavement surface and disposed of in accordance with contract documents.
- Mixing, placement, and finishing equipment is properly cleaned for the next use.

Troubleshooting

This section is a guide to the most common partial-depth failures and is not meant to explain all failed patches. The five most common problems are as follow:

1. Inadequate compression relief, generally because the compression material was not placed deep enough.
2. Shrinkage cracks, which are generally due to inadequate or improper curing. Such cracks can propagate and promote loss of patch bond.
3. Early de-bonding of batch material, which is generally due to bonding grout having been placed too early. Early de-bonding will cause the patch to sound hollow within 30 days.
4. Deterioration around the completed patch, because either the patch was too small or the patch material failed.
5. Deterioration of the patch itself, generally due to low air content or low strength.

Compression Relief Failures

It is important that when the joint or crack closes, the first point of contact is not the partial-depth repair material. If compression relief is not provided in the joint or crack, either by sawing or by the use of compression material, the partial-depth patch will fail when the joint or crack moves. See Figure 62.

When a joint is sawed to provide compression relief, the final joint width for the full depth and length of the patch must be slightly wider than the existing crack below the repair. The final joint width for sealing can be less than the adjacent sealed joint width as long as it is wider than the crack below the repair.

It is also imperative that the compression relief material or space be deep enough and wide enough to accommodate any joint movement below the partial-depth repair.

Many times with compression relief failure, only one side of the joint or crack will fail. In Figure 63, only the material under the hammer has lost bond due to lack of compression relief the full length of the repair. The remainder of this repair past the hammer handle is working.

Often compression relief-related failures can be repaired using the same partial-depth patch system and paying extra attention to the adequate placement of the compression relief material or space.

Curing Failures

Late or inadequate curing can reduce the ultimate strength of the patch by as much as 40 percent. Scaling can also occur if curing is not done in a timely manner.

Many mixes used in partial-depth patches are fast-setting to allow early opening to traffic. It is especially imperative in such situations that curing compounds be applied quickly and thoroughly, and blankets used if appropriate, to ensure that these mixes achieve their anticipated strength on time.

The use of a properly mixed quality sealer helps prevent shrinkage cracking. Shrinkage cracking (Figure 64) is usually not a major problem, but needs to be monitored.



Figure 62. Repair failure because the compression relief material did not extend to end of repair area



Figure 63. Compression relief failure of (Type 1) partial-depth crack repair on a city street

Following is a list of curing compounds and sealers and the pros and cons of each:

- Water-based curing compounds are easy to obtain, but the water-retention properties of these compounds reduce their caliber compared to the other curing and sealing products listed below.
- Linseed oil curing compounds have good curing properties and help prevent shrinkage cracking.
- Waxed-based curing compounds are very good and help to prevent shrinkage cracking.
- Poly alpha methylstyrene (AMS) is a curing compound and sealer. It has high solids content and requires constant mixing. When mixed properly, however, it provides a good cure and helps to prevent most shrinkage cracking.

Debonding of Patch

Debonding of partial-depth repair may occur if the bonding grout is placed too early (Figure 65 and Figure 66). The concrete patch mix material must be placed immediately after placement of the bonding grout. If the bonding grout shows any signs of drying, such as a white color, it must be sand blasted and re-done.

Many states incorporate a 30-day warranty into the specifications primarily to catch this particular problem. If a debonding failure occurs, it usually does so within the first 30 days of service.

Deterioration around Patch

Deterioration adjacent to a completed patch is usually one of two causes: either the repair area was not made large enough to remove all the deteriorated concrete, or the existing pavement is suffering from an early form of material- or mix-related failure.

To prevent the first problem, the inspector must sound the pavement around the patch area before and after removal to ensure all deteriorated concrete is removed. The left side of Figure 67 shows how a previous repair (black color) failed after the patch was installed, primarily because the patch was too small. The same problem is shown in the right picture in the wheel line.

Figure 68 is an example of city street with D cracking in its early stages along the joint areas. This partial-depth repair will last only as long as the D cracking in the existing pavement does not worsen considerably. The picture was taken after one year of service of the repair.

Deterioration of Patch

The first place to check when the partial-depth mix is failing is the air content of the patch material. In freeze thaw environments the patch mix should have the same air requirements as the existing pavement, generally around 5 percent to 8 percent. Next check the compressive strengths of the test cylinders during concrete patch placement.



Figure 64. Shrinkage cracks in partial-depth repair



Figure 65. Debonding of patch at end of Type 2 repair



Figure 66. Close up of debonded area at end of a Type 2A partial-depth repair

Summary

The proper completion of four basic steps is required to have a successful partial-depth repair:

1. Remove all the deteriorated concrete. Determine the cause of the failure and remove any misplaced steel.
2. Clean the patch area.
3. Provide for compression relief wider than the movement expected in the pavement.
4. Cure properly. Due to thin section of repair material, this step must be performed to ensure a long-lasting repair.



Figure 67. Patches that are too small



Figure 68. D crack repair

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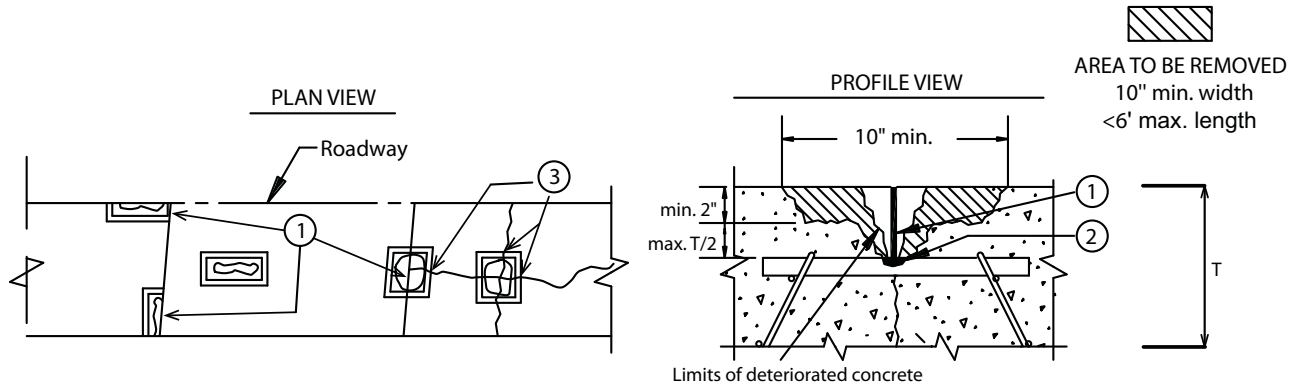
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PARTIAL-DEPTH REPAIR TYPE 1 - SPOT REPAIR (SR)

(Spot repair of joints, cracks, and spalls, less than 6' max. length)

GENERAL DESCRIPTION: REMOVE CONCRETE, FURNISH AND PLACE CONCRETE, SAW AND SEAL JOINTS/CRACKS.



JOINT and CRACK RE-ESTABLISHMENT shall be accomplished as quickly as possible to prevent failure.

Type 1 at Joints

- ① Joint compression relief for the upper part of the joint will be of equal width to the joint on either side of the repair. Compression relief will be provided either by installing preformed joint filler (such as wax-coated cardboard) as wide as the existing joint (1/4-in. min.) before concrete placement or by tooling the plastic concrete, then accomplishing a relief saw cut (1/4-in. min. width) to the full depth of the repair as soon as possible after concrete placement.
- ② If dowel bar is exposed, coat exposed area with duct tape as a bond breaker to allow movement of the joint.

Type 1 at Cracks

- ③ Preformed compression material such as wax-coated cardboard (3/16-in. to 1/4-in. thick) should be installed as deep as possible in the crack (below the patch area at least 1/2 in., up to an inch if possible) to provide compression relief.

WORK TO BE DONE

- 1 Define removal area and payment based on sq-ft of area to be patched, with a min. depth of 2 in.
- 2 Remove all concrete including unsound concrete using either saw-and-chip (35-lb max hammer) or milling. Remove concrete to limits shown in detail, with a min. depth of 2 in. and a max. depth of T/2 or the top of the dowels. The sides of the removed area must be tapered 30 to 60 degrees from vertical.
- 3 Prepare surfaces:
 - Clean exposed surfaces by sand blasting and air blasting.
 - Coat any exposed dowel surfaces with duct tape as a bond breaker.
 - Immediately before placing the repair material, apply bonding grout to exposed concrete surfaces.
- 4 Restore joints and cracks by installing preformed filler (3/16-in. min.) as described above.
- 5 Furnish and place specified concrete mix. Finish to grade, slope, and texture. Seal edges with grout of specified concrete mix. Apply cure.
- 6 Saw and seal joints and cracks according to specifications.

BASIS OF PAYMENT

- Type 1 partial-depth repairs are based on square feet of repair area. Measurements should be taken to the nearest tenth of a foot and rounded to the nearest square foot. Minimum size of repair for payment is one square foot.
- The 30- to 60- degree taper, preformed filler, and sawing and sealing are incidental to Type 1 repairs.

DATE: April 9, 2012

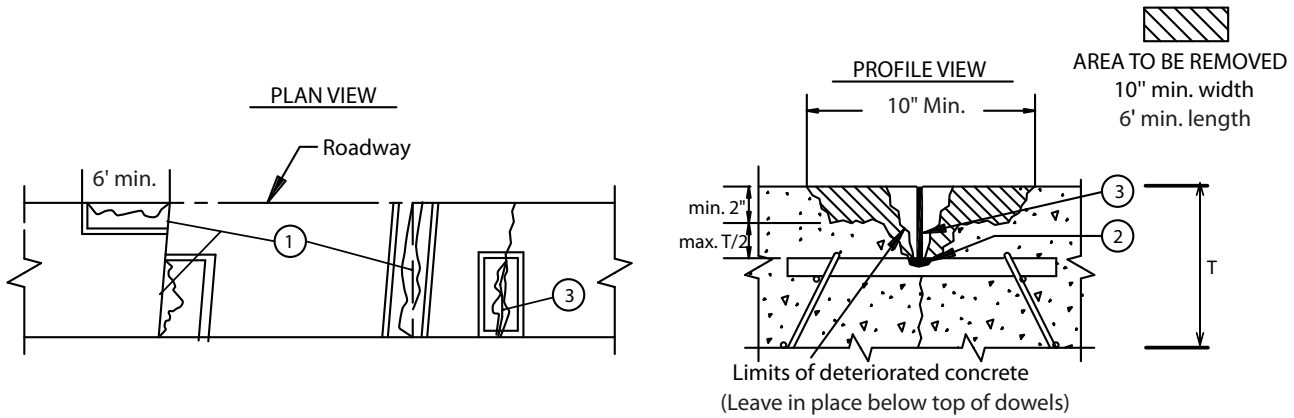
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SCALES/SHORTS
 SHEET/TITLES
 SCHEDULES
 SIZES
 SLOPES

PARTIAL-DEPTH REPAIR TYPE 2 - EXTENDED LENGTH (LJCR)

(Long [6' or greater] repairs of longitudinal and transverse joints [Type 2A] and cracks [Type 2B])

GENERAL DESCRIPTION: REMOVE CONCRETE, FURNISH & PLACE CONCRETE, SAW, AND SEAL JOINTS/CRACKS.



JOINT (2A) and CRACK (2B) RE-ESTABLISHMENT shall be accomplished as quickly as possible to prevent failure.

Type 2A at Joints

- ① Joint compression relief for the upper part of the joint will be of equal width to the joint on either side of the repair. Compression relief will be provided with a saw cut (1/4-in. min. width) to the full depth of the repair (and, if possible, 1/2-in. deeper) as soon as possible after concrete placement.
- ② If dowel bar is exposed, coat exposed area with duct tape as a bond breaker to allow movement of the joint.

Type 2B at Cracks

- ③ Preformed compression material such as wax-coated cardboard (3/16-in. to 1/4-in. thick) should be installed as deep as possible in the crack (below the patch area at least 1/2 in., up to an inch if possible) to provide compression relief.

WORK TO BE DONE

- 1 Define removal area, with a 2-in. min. (T/2 max.) depth, 10-in. min. width, and 6-ft min. length.
- 2 Using milling and chipping hammer (35-lb max. hammer), remove all concrete including unsound concrete to limits shown in detail (min. depth of 2 in. and a max. depth of T/2 the pavement depth or the top of the dowels), tapering the sides of the removed area 30 to 60 degrees from vertical.
- 3 Prepare surfaces:
 - Clean exposed surfaces by sand blasting and air blasting.
 - Coat any exposed dowel surfaces with duct tape as a bond breaker.
 - Immediately before placing the repair material, apply bonding grout to exposed concrete surfaces.
- 4 Restore cracks by installing preformed filler (3/16-in. min.) as described above.
- 5 Furnish and place specified concrete mix. Finish to grade, slope, and texture. Seal edges with grout of specified concrete mix. Apply cure.
- 6 Saw and seal joints and cracks according to specifications.

BASIS OF PAYMENT

- Type 2A (joint) repairs are based on linear feet of repair. Linear measurements should be made to the nearest foot of repair length.
- Type 2B (crack) repairs are based on square feet of repair area. Measurements should be taken to the nearest tenth of a foot and rounded to the nearest square foot. Min. size of repair for payment is one square foot.
- The 30- to 60- degree taper, preformed filler, and sawing and sealing are incidental to all Type 2 repairs.

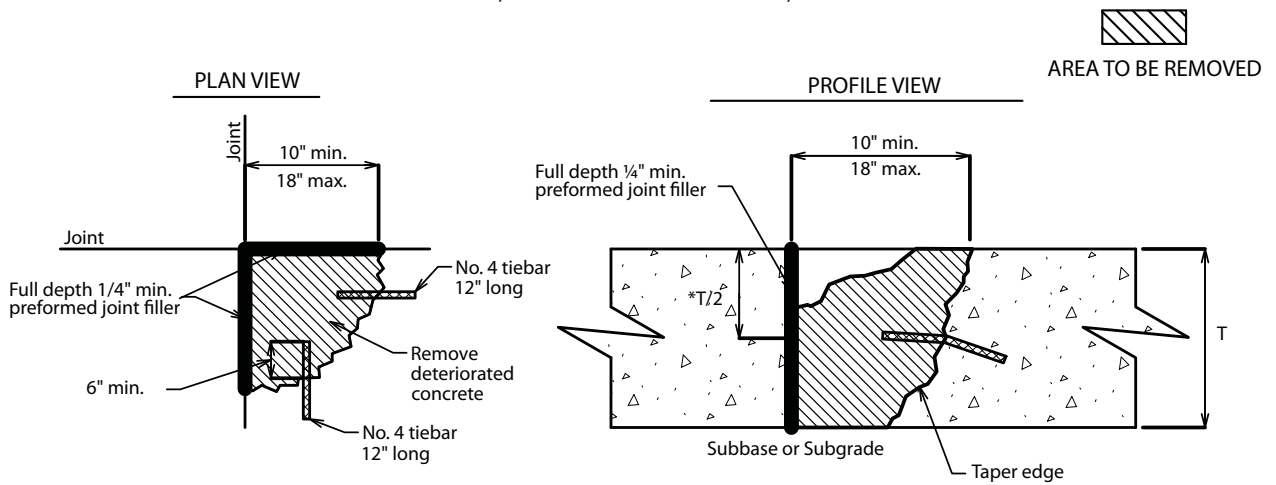
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PARTIAL-DEPTH REPAIR TYPE 3 - BOTTOM-HALF REPAIR (BHR)

(Bottom-half spot repair at corner or edge; NOT intended to be placed in wheel paths)

DESCRIPTION: REMOVE CONCRETE, INSTALL REINFORCING STEEL, FURNISH & PLACE CONCRETE.



WORK TO BE DONE

- 1 Define removal area $T/2$ below in-place surface.
- 2 Remove all deteriorated concrete to limits shown in detail. Taper the sides of the removed area 30 to 60 degrees from vertical with a 35-lb max. chipping hammer.
- 3 Prepare surface:
 - Clean exposed surfaces by sand blasting and air blasting.
 - Coat any exposed dowel surfaces with approved bond breaker.
 - Immediately before placing the repair material, apply bonding grout to exposed concrete surfaces.
- 4 Furnish and install No. 4 reinforcement tiebars at mid-depth, as shown in detail. Ensure that there is at least 1 in. of concrete around the bar. Place with an approved non-shrink grout.
- 5 Restore joints and cracks by installing preformed joint filler such as wax-coated cardboard ($3/16$ -in. to $1/4$ -in. thick) as deep as possible in the crack (below the patch area at least $1/2$ in., up to an inch if possible) to provide compression relief.
- 6 Furnish and place specified concrete mix. Finish to grade, slope, and texture. Seal edges with grout of specified concrete mix. Apply cure.
- 7 Saw and seal joints and cracks according to specifications.

BASIS OF PAYMENT

- Payment for Type 3 repairs (bottom half of repair area) is based on square feet of repair area. Since the repair will have a sloping face, payment should be measured at mid-depth of the pavement thickness. Measurements should be taken to the nearest tenth of a foot and rounded to the nearest square foot. Minimum size of repair for payment is one square foot.
- Payment for the top half of the repair is treated as a Type 1 or Type 2B repair, both of which are based on sq ft. The 30- to 60-degree edge taper will be included in the top half measurement.
- The 30- to 60-degree edge taper, furnish and installation of preformed joint filler (such as wax-coated cardboard) are incidental to the repair.

DATE: April 9, 2012

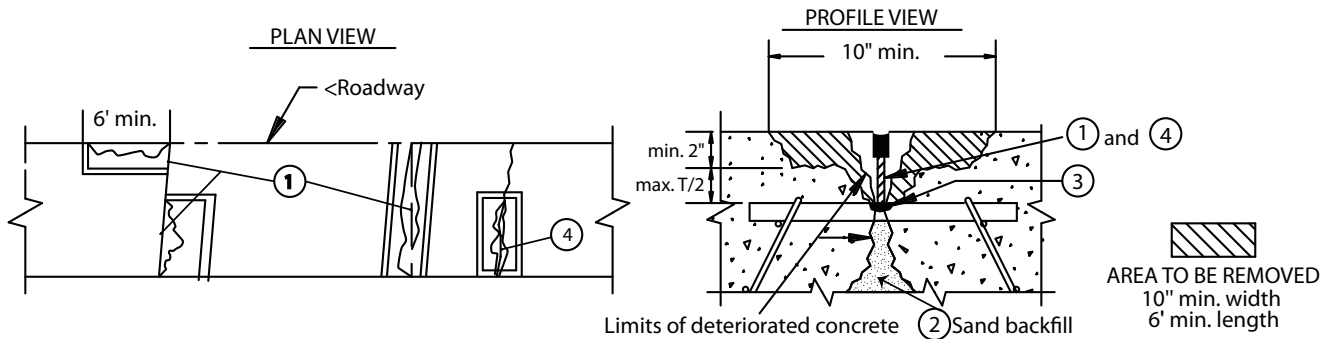
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SHORT-TERM PARTIAL-DEPTH REPAIR

(Temporary repair of joints (longitudinal and transverse) and cracks where deterioration occurs in bottom half of slab, or below top of dowel bar.)

DESCRIPTION: REMOVE CONCRETE IN TOP HALF, PROVIDE COMPRESSION RELIEF, FILL VOID IN LOWER HALF WITH SAND, FURNISH & PLACE CONCRETE, SAW AND SEAL JOINTS AND CRACKS.



JOINT and CRACK RE-ESTABLISHMENT shall be accomplished as quickly as possible to prevent failure.

Type 1 at Joints

- ① Joint compression relief for the upper part of the joint will be of equal width to the joint on either side of the repair. Compression relief will be provided by installing preformed joint filler (such as wax-coated cardboard) as wide as the existing joint (¼-in. min.) before concrete placement.
- ② Joint compression relief for the lower part of the repair (below the top of the dowel bars) will be provided by extending the preformed material through the full depth of the deterioration and at least ½ in. beyond. If that is impossible, the sand backfill (see "Work to Be Done," below) must provide or supplement compression relief for this area.
- ③ If only one or two dowel bars are exposed, cut the bar(s). If more than two bars are exposed, coat the bars with an approved bond breaker such as duct tape.

Type 1 at Cracks

- ④ Preformed compression material such as wax-coated cardboard (⅜-in. to ¼-in. thick) should be installed as deep as possible in the crack (below the patch area at least ½ in., up to an inch if possible) to provide compression relief.

WORK TO BE DONE

- 1 Define removal area with a min. depth of 2 in., min. width of 10 in., and min. length of 6 ft.
- 2 In the top half of the slab, remove all concrete including unsound concrete using either saw-and-chip (35-lb max hammer) or milling. Remove concrete to limits shown in detail to a max. depth of T/2 or the top of the dowels. The sides of the removed area must be tapered 30 to 60 degrees from vertical.
- 3 In pavements with dowel bars, remove deterioration in the bottom half of the slab (below the top of dowel bars) by sand blasting.
- 4 Fill the void in the bottom half of the slab with clean sand to provide a form for the concrete patch mix and to supplement compression relief in this area.
- 5 Prepare surfaces:
 - Clean exposed surfaces by sand blasting and air blasting.
 - As described in 3 above, cut or coat any exposed dowel bar surfaces with duct tape as a bond breaker.
 - Immediately before placing the repair material, apply bonding grout to exposed concrete surfaces.
- 6 Restore joints and cracks as described above.
- 7 Furnish and place specified concrete mix. Finish to grade, slope, and texture. Seal edges with grout of specified concrete mix. Apply cure.
- 8 Saw and seal joints and cracks according to specifications.

BASIS OF PAYMENT

- Short-term partial-depth repairs are paid as either Type 1 or Type 2 partial-depth repairs. The 30-day warranty may be waived based on the amount of sand needed to complete the repair. A shorter life is to be expected, depending on the amount of deterioration, and a change to a full-depth repair may be needed.
- The 30- to 60- degree edge taper, preformed filler, and sawing and sealing are incidental to short-term partial-depth repairs.

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Appendix B: Proprietary Repair Materials

Several rapid-setting and high-early-strength proprietary materials have been developed for partial-depth repairs (Patel, Mojab, and Romine 1993; Smoak, Husbands, and McDonald 1997 ACI 2006). These various “flexible” or “semi-rigid” concrete repair products have been used effectively in partial-depth repair applications.

Proprietary materials typically possess a much lower stiffness than conventional repair products, which results in lower stress development in the material under a wide range of thermal variations. Moreover, these materials form a strong bond to the existing concrete substrate and can be opened to traffic very quickly, often in as little as 1 hour. Some of these materials also have the ability to bridge joints or cracks, thus eliminating the need to re-establish the joint or crack in the repair.

The manufacturer’s directions should be closely followed when installing these products and in determining appropriate application conditions (moisture and temperature), bonding agent requirements, material preparation, material installation (including lift thicknesses), and opening requirements.

Such proprietary repair materials are generally classified cementitious, polymeric, or bituminous. This appendix introduces the specific material types included within each of the three categories and presents any mix-related concerns associated with each.

Polymer-Based Concretes

Polymer-based concretes are formed by combining polymer resin (molecules of a single family or several similar families linked into molecular chains), aggregate, and an initiator. Aggregate is added to the resin to make the polymer concrete more thermally compatible with the concrete (which would otherwise lead to debonding), to provide a wearing surface, and for economy.

The main advantage of polymers is that they set much quicker than most of the cementitious materials. However, they are expensive and can be quite sensitive under certain field conditions.

Polymers used for pavement repairs can be classified into four categories: epoxies, methacrylates, polyester-styrenes, and urethanes.

Epoxy Concrete

Epoxy concrete repair materials are impermeable and have excellent adhesive properties. When used, it is important that the epoxy concrete be compatible with the concrete in the pavement. Differences in the coefficients of thermal expansion between the repair material and the concrete can cause repair failures, but the use of larger aggregate increases the volume stability and helps reduce the likelihood of debonding (ACPA 1998). Deep epoxy repairs must frequently be placed in multiple lifts to control heat build-up.

Methyl Methacrylate Concrete

Methyl methacrylate (MMA) concretes and high molecular weight methacrylate (HMWM) concretes have long working times, high compressive strengths, and good adhesion. Furthermore, they can be placed over a wide range of temperatures, from 4 to 54°C (40 to 130°F) (ACPA 1998). However, many methacrylates are volatile and may pose a health hazard to those exposed to the fumes for prolonged periods (Krauss 1985).

Polyester-Styrene Concrete

Polyester-styrene polymers have many of the same properties as methyl methacrylates, except that they have a much slower rate of strength gain, which limits their usefulness as a rapid repair material. Polyester-styrene polymers generally cost less and are used more widely than methyl methacrylates (Krauss 1985).

Polyurethane Concrete

Polyurethane repair materials generally consist of a two-part polyurethane resin mixed with aggregate (ACPA 1998). Polyurethanes are generally very quick setting (90 seconds), which makes a very quick repair. Some polyurethanes claim to be moisture-tolerant; that is, they can be placed on a wet substrate with no adverse effects. These types of materials have been used for several years with variable results (Krauss 1985).

Other Polymeric Materials

There are a number of other polymeric materials available for partial-depth repairs, most of which exhibit rapid strength gain and a high degree of impermeability. Furthermore, some of these materials exhibit certain elastic properties that allow them to be placed across a joint without the need for an insert to maintain the joint.

Cementitious Materials

Proprietary cementitious materials include gypsum-based (calcium sulfate) products, magnesium phosphate, and high alumina (calcium aluminate) cements.

Several proprietary portland cement-based repair materials are available to achieve high-early strength for partial-depth repairs.

Gypsum-Based Concrete

Gypsum-based (calcium sulfate) repair materials gain strength rapidly and can be used in any temperature above freezing. However, gypsum concrete may not perform well when exposed to moisture and freezing weather (ACPA 1998). Additionally, the presence of free sulfates in the typical gypsum mixture may promote steel corrosion in reinforced pavements (Good-Mojab, Patel, and Romine 1993).

Magnesium Phosphate Concrete

Magnesium phosphate concretes set very rapidly and produce a high-early-strength, impermeable material that will bond to clean dry surfaces. However, this type of material is extremely sensitive to water, either on the substrate or in the mix (even very small amounts of excess water can reduce strength). Furthermore, magnesium phosphate concrete is very sensitive to aggregate type (for example, some limestones are not acceptable) (Good-Mojab, Patel, and Romine 1993). In hot weather (i.e., above 32°C [90°F]), many commonly available mixes experience short setting times (e.g., 10 to 15 minutes).

High Alumina Concrete

Calcium aluminate cements gain strength rapidly, have good bonding properties (on a dry surface), and very low shrinkage. However, due to a chemical conversion that occurs in calcium aluminate cement, particularly at high temperatures during curing, strength loss over time is likely to occur; consequently, these materials are not recommended for use as a patching material (ACPA 1998).

Bituminous Materials

Bituminous materials are often used as temporary repair materials on concrete pavements or for patches prior to overlaying, particularly when the existing concrete pavement is too D-cracked or otherwise deteriorated to permit full-depth repairs.

Bituminous materials have the advantage of being relatively low in cost, widely available, easy to place with small crews, and easy to handle, and they can be opened to traffic almost immediately. However, because the joint cannot be re-established when using bituminous mixtures, and proper repair techniques are not typically utilized, they are not recommended for permanent repairs.

Results from the Federal Highway Administration's (FHWA) long-term monitoring of partial-depth repairs showed that bituminous repair materials performed well for a period of 3 to 4 years, but generally experienced rapid failure after a point where the bituminous material had oxidized and become more brittle (Wilson, Smith, and Romine 1999a).

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