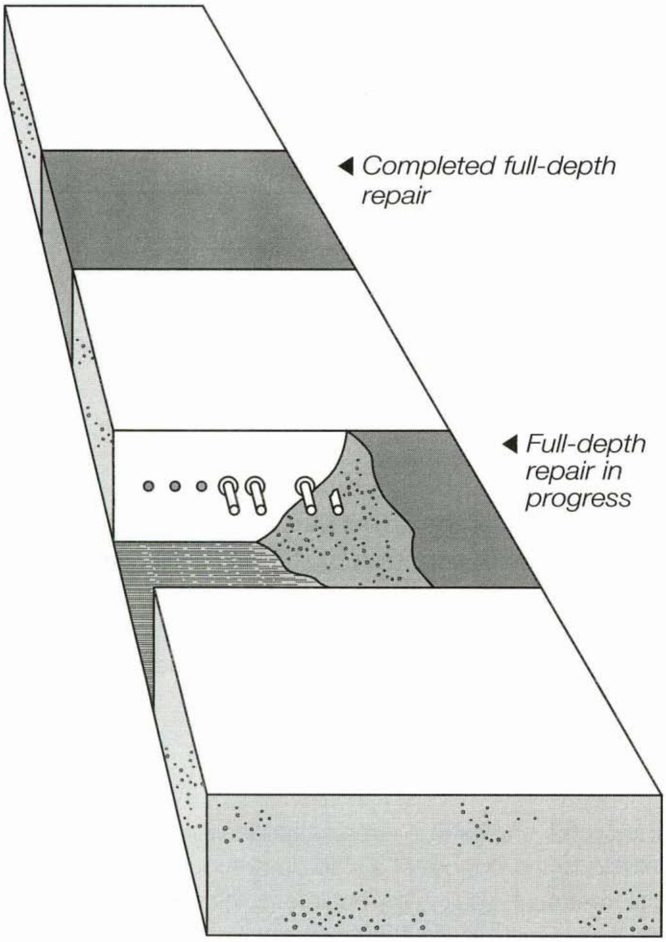
CONCRETE PAVING Technology

Guidelines For Full-Depth Repair



PURPOSE

This publication provides guidance for repairing concrete pavement slabs with structural and joint deterioration. These recommendations apply to pavements for roads, highways and airports, and distinguish requirements for jointed concrete pavements and continuously reinforced concrete pavements.

INTRODUCTION

Full-depth repair or full-depth patching entails removing and replacing at least a portion of a slab to the bottom of the concrete, in order to restore areas of deterioration. Full-depth repairs can improve pavement rideability and structural integrity and can extend pavement service life. At airports, full-depth repairs restore problem areas that produce small concrete fragments, which can cause foreign-object damage (fod) to jet engines. Table 1 (*next page*) lists the concrete pavement distresses that require full-depth repair (1,2).

Joint Deterioration — Joint deterioration includes any cracking, breaking or spalling of slab edges on either side of a transverse or longitudinal joint; it is the most common distress that requires full-depth repair (2). Excessive compressive stresses that result from the presence of incompressibles in transverse joints often cause this deterioration. Incompressibles can prevent joint closure when slabs expand in warm weather. In extreme cases, very high compressive stresses can cause blowups at the joint. Joint deterioration also occurs from concrete durability problems like low air content, D-cracking or alkali-silica reactivity.

Visible spalls that extend 75–150 mm (3–6 in) from the joint are moderately severe and may indicate that more deterioration is taking place below the slab surface (3). It is the below-surface spalling and cracking that requires full-depth replacement. Partial-depth

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Table 1. Type and severity of distress that requires full-depth repair (1,2).

DISTRESS TYPE	MINIMUM SEVERITY LEVEL REQUIRING FULL-DEPTH REPAIR[2]
JOINTED PAVEMENT:	
Blowup	Low
Corner Break	Low
Durability (D-Cracking, Alkali-Silica Reactivity)	Moderate
Joint Deterioration[1]	Moderate (with faulting ≥ 6 mm [0.25 in])
Random Transverse Cracking[1]	Moderate (with faulting ≥ 6 mm [0.25 in])
Random Longitudinal Cracking[1]	High (with faulting ≥ 12 mm [0.5 in])
CONTINUOUSLY REINFORCED PAVEMENT:	
Blowup	Low
Durability (D-Cracking, Alkali-Silica Reactivity)	High
Punchouts	Moderate (with faulting ≥ 6 mm [0.25 in])
Random Transverse Cracking[1]	Moderate (with steel ruptures & faulting ≥ 6 mm [0.25 in])
Random Longitudinal Cracking[1]	High (with faulting ≥ 12 mm [0.5 in])

[1] *Partial-depth repair is recommended if deterioration is only within upper third of slab.*

[2] *For high-volume highway pavement (low-volume and low-speed roads may tolerate more deterioration; airport pavements may tolerate less deterioration due to concern over foreign-object damage).*

repair is acceptable for most surface spalls at joints, cracks and mid-slab locations where the deterioration extends less than one-third the slab depth (2,4). In most cases, below-surface spalling exists where D-cracking is present. If there is not an obvious durability problem, coring is necessary to determine if deterioration exists below the slab surface. For more information on partial-depth repairs see ACPA publication *Guidelines for Partial-Depth Repairs* (5).

Other contributors to joint deterioration include subbase-pumping, dowel-socketing and keyway failure. These are load-induced distresses that occur at joints with inadequate load transfer for trucks, airplanes or other heavy vehicles. Poor installation or poor maintenance of metal or plastic-tape joint inserts also can cause joint deterioration.

Transverse Cracking — Some cracks that extend through the depth of a slab can begin moving and functioning as joints. Transverse cracks that function as joints are "working cracks" and are subject to about the same range of movement as transverse joints. When sealed properly, these cracks can perform well for many years. However, it may be necessary to restore pavement integrity with full-depth repairs and to remove working cracks that develop severe spalling, pumping or faulting.

It is possible to retrofit dowel bars in transverse working cracks as long as they are not spalling. Retrofitting dowels in these circumstances will likely cost much less than a full-depth repair.

Working cracks develop from one or more of these causes:

- Lock-up of the dowel bars in a nearby joint.
- Rupture or corrosion of steel in jointed-reinforced slabs.
- Poor joint spacing design.
- Loss of aggregate interlock along the crack face.
- Excessive load-deflection from poor subbase or subgrade support.
- Inadequate joint sawing.

Transverse cracks that remain tight (hairline) and do not extend to the bottom of a slab do not require any special treatment, sealing or repair (e.g., plastic shrinkage cracks). Most plastic shrinkage cracks remain very tight and extend into the slab about 25–50 mm (1–2 in). These hairline cracks do not allow much water to penetrate the pavement substructure and rarely deteriorate or influence the serviceability of a concrete pavement (6).

Longitudinal Cracking — When longitudinal cracks deteriorate to a high-severity condition, they warrant full-depth patching (1,3–6). A high-severity condition indicates that a crack is greater than 12 mm (0.5 in) wide, spalling extends more than 150 mm (6 in) from the crack, and faulting is greater than 12 mm (0.5 in). If the condition is less severe, the following procedures are sufficient:

- Partial-depth repair.
- Cross-stitching.
- Retrofit dowel bars.
- Sawing and sealing.

Cross-stitching is an alternative repair for longitudinal cracks in fair (low-severity) condition (7,8). The purpose of cross-stitching is to maintain aggregate interlock. The tie bars used in cross-stitching prevent a crack from vertical and horizontal movement or widening. If load transfer is a concern, retrofitting dowel bars is another viable technique for improving a longitudinal crack. More information about both procedures is available in reference 1, 7 or 8.

Shattered Slabs & Corner Breaks — Corner breaks and intersecting cracks develop in slabs receiving marginal support from the subbase or subgrade. Any heavy loads that pass over these slabs cause large vertical slab deflections and high tensile stresses in the concrete. Over time the deflecting slabs will pump subbase or subgrade fines out from beneath the slab, leading to voids and eventual cracking over the uneven support. Shattered slabs also may result from frost heave or swelling soil problems.

Full-depth repair is necessary to repair corner breaks and slabs with more than one intersecting crack. These are both signs of support problems and lack of structural strength.

Punchouts — Punchouts in continuously reinforced concrete pavements require full-depth repair. They form after many load cycles when the longitudinal steel ruptures along the faces of two closely spaced cracks (usually less than 0.6 m [2 ft] apart). A longitudinal crack will connect the transverse cracks about 0.6–1.5 m (2–5 ft) from the pavement edge or a longitudinal joint. Upon further loading, the small segment of concrete—no longer with adequate load transfer—punches into the subbase. Punchouts also can occur where transverse cracks split into a Y about 0.6–1.5 m (2–5 ft) from a longitudinal edge or joint (3,9).

DESIGN

With good design and construction practices full-depth repairs should perform for as long as the surrounding concrete slabs. Many full-depth repairs are made during restoration projects that include procedures like slab stabilization, diamond grinding and joint resealing; the surface of these repairs are exposed to traffic. Other full-depth repairs are covered by a layer of new material, like bonded-concrete or asphalt overlays. However, the same design considerations apply for either situation (4,10).

The following are important design considerations:

- Pavement type (jointed or continuously reinforced).
- Patch size (for distress and subgrade conditions).
- Load transfer (dowels versus other methods).
- Concrete materials (requirements for opening to traffic).

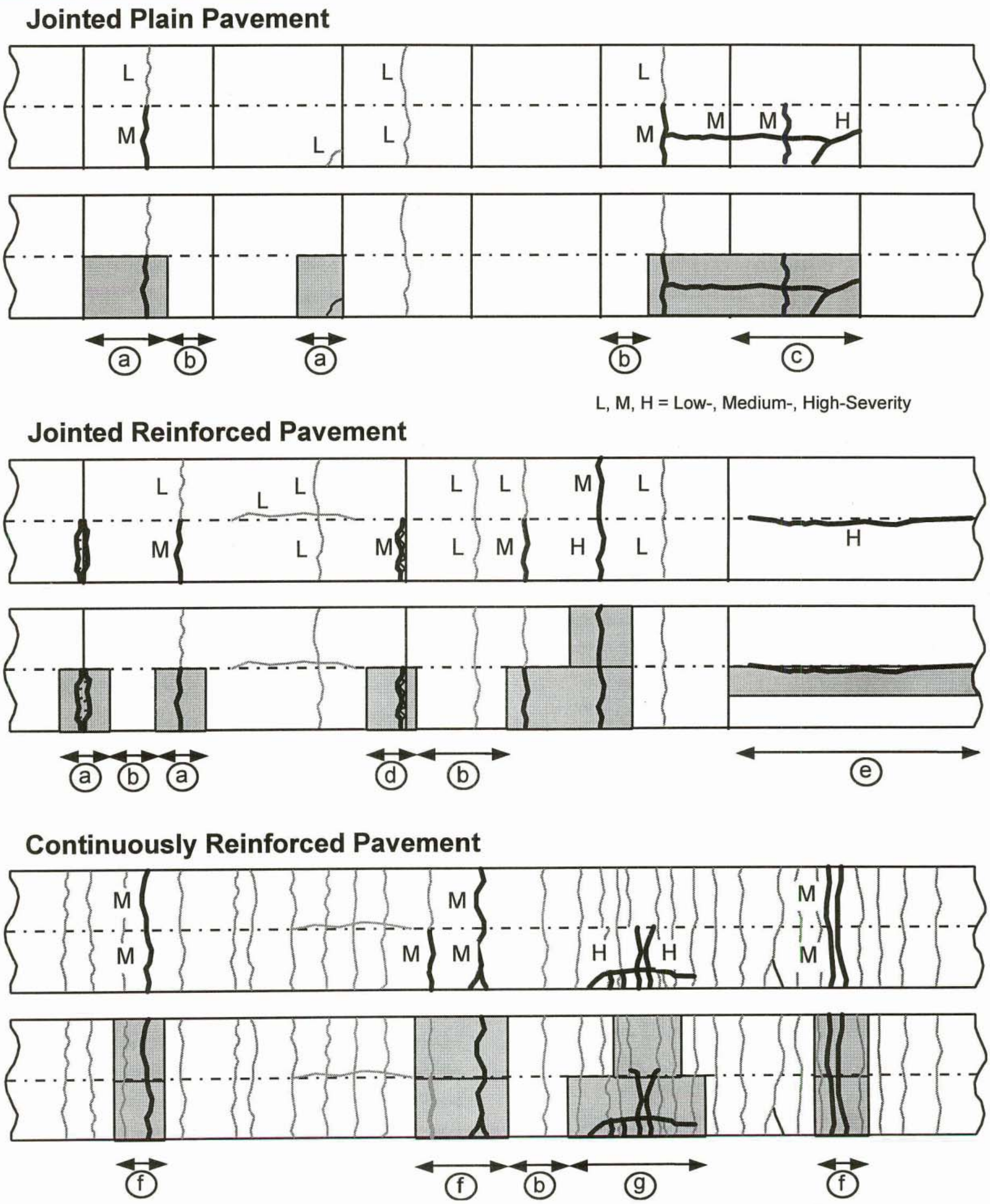
Size —

To size a repair, it is necessary to know the extent of typical deterioration on the pavement. Each repair should replace the concrete and all significant distress. It is advantageous to set repair sizes to go beyond the limits of any subbase voids created from the erosion action of pumping. Figure 1 (*next page*) provides examples of how to define repair areas for various distresses on both jointed and continuously reinforced concrete pavements.

Good judgment is essential in defining the limits for full-depth repairs, particularly where more deterioration exists than is visible on the slab surface. Some engineers attempt to cut costs by limiting patch size despite the expanse of deterioration, which can reduce the repair's ability to extend pavement service life. In freeze-thaw climates below-slab deterioration may extend 1 m (3 ft) beyond visible distress (3,4).

Except for some low-traffic situations, full-depth repairs of transverse distresses should extend the full width of one lane to ease sawing and removal operations. Repair boundaries should be parallel and should not form interior corners in the old concrete. Cracks may develop from interior corners of patches with irregular shapes. Parallel, full-width repair boundaries should perform better (11).

The minimum patch length for repairing transverse joints and cracks depends on the use of dowels in the transverse patch joints. A minimum patch length of 2 m (6 ft) in the longitudinal direction is acceptable where the patch joints use dowel bars. This provides a patch large enough to resist rocking under heavy traffic, and provides adequate room in the removal



a. End at existing joint if possible; minimum length is 2 m (6 ft) for doweled joints; 2.5–3.0 m (8–10 ft) for aggregate interlock joints.
b. Check distance between patches and nearby joints (see Table 2).
c. Replace the entire slab if there are multiple intersecting cracks.
d. Extend the patch beyond joint by 0.3 m (1 ft) to include dowels, even if there is not any deterioration on one side of the joint.
e. For high-severity cracks only; begin and end longitudinal patches on transverse joints; keep the joint off known wheelpaths.
f. Extend perimeter beyond nearby cracks to get to solid concrete, even if the nearby cracks do not require repair.
g. Remove the full length of any deteriorated longitudinal cracks; remove all punchouts.

Figure 1. Examples of repair limits for various distresses (2,4).

area for dowel-hole drill rigs and other equipment. Smaller patches can rock under heavy traffic and can punch into the subbase if load transfer is inadequate (4,11).

For undoweled patches in low-volume roads or general aviation airports, use a minimum patch length of 2.5–3.0 m (8–10 ft). This extra length will provide more patch stability by further distributing load stresses on the subgrade.

The crack spacing, expanse of deterioration, and length necessary for splicing or coupling steel reinforcement will control the length of patches in continuously reinforced concrete pavements. A minimum length of 2 m (6 ft) should provide adequate room for steel-splicing and other preparation work during construction (4,11).

It may be necessary to extend the size of patches beyond the minimum length when marking the pavement removal areas just before construction. The following are recommendations for common layout situations:

- If the patch boundary at minimum width falls within 2 m (6 ft) of an existing undoweled transverse joint that does not require repair, extend the patch to the transverse joint (4).
- If the boundary at minimum width falls on an existing doweled transverse joint, and the other side of the joint does not require repair, extend the patch beyond the transverse joint by about 0.3 m (1 ft) to remove the existing dowels (4).
- If the boundary at minimum width falls on a crack in a continuously reinforced pavement, extend the patch beyond the crack by 0.15 m (0.5 ft).
- If the boundaries of two minimum-width patches are within the distances noted in Table 2, combine two patches into one large patch.

Combining two smaller patches into one large patch often can reduce repair cost. Transverse joint perimeters are a fixed cost in full-depth repairs. These costs, which increase slightly for thicker pavements, include: sawing, sealing, and drilling and grouting dowel bars in the holes or chipping the patch face. The costs of materials (patching and curing concrete) vary on the patch thickness, width and length. Table 2 provides an estimate of the distance between patches when the cost of additional patch material is

Table 2. Minimum cost-effective distance between two patches.

SLAB THICKNESS	PATCH (LANE) WIDTH m (ft)			
mm (in)	2.7 (9)	3.0 (10)	3.3 (11)	3.6 (12)
175 (7)	5.2 (17)	4.6 (15)	4.3 (14)	4.0 (13)
200 (8)	4.6 (15)	4.0 (13)	3.7 (12)	3.4 (11)
225 (9)	4.0 (13)	3.7 (12)	3.4 (11)	3.0 (10)
250 (10)	3.7 (12)	3.4 (11)	3.0 (10)	2.7 (9)
275 (11)	3.4 (11)	3.0 (10)	2.7 (9)	2.4 (8)
300 (12)	3.0 (10)	2.7 (9)	2.4 (8)	2.4 (8)
375 (15)	2.4 (8)	2.4 (8)	2.1 (7)	2.0 (6)

equivalent to the cost of removing two patch joints (one from each patch). When two patches will be closer than the distances shown in the table, it is probably more cost-effective to combine them into one large patch. However, the longest patch length should not exceed the pavement's longest slab length.

Transverse patch size recommendations do not apply for patches repairing high-severity longitudinal cracks. Longitudinal patches should begin and end at existing transverse joints, unless this is impractical for long-jointed reinforced pavements. The patches should be wide enough to remove the crack and any accompanying distress. However, for heavy vehicles (trucks or large aircraft), consider locating the longitudinal joint off the known wheelpaths to avoid edge loads.

Load Transfer —

The boundary joints of full-depth patches require provisions for load transfer. Load transfer refers to the ability of a joint to transfer a portion of a load applied on one slab to an adjacent slab.

Jointed Pavements — For most full-depth repairs of jointed pavements, except light traffic plain pavements, doweled transverse joints are essential for load transfer. Patch boundary cuts usually go all the way through the concrete and leave a smooth face that does not provide any load transfer; dowels connect the existing slab and new patch. Substituting an undercut (inverted-T) transverse patch joint for a doweled patch joint has not worked well (2,11,12). The excavation necessary for this joint design disturbs the subbase beneath the patch and often leads to settlement and differential frost heaving.

Generally, 38-mm (1.5-in) diameter dowel bars provide effective load transfer for full-depth repairs for patches in airport, interstate highway or industrial pavements (13). For light-traffic highways and pavements less than 250 mm (10 in) thick, 32-mm (1.25-in) diameter dowels are acceptable. However, it is prudent to use 38-mm (1.5-in) diameter dowels in a patch of any pavement with poor subbase, subgrade, or drainage condition. Past experience has shown that 25 mm (1 in) diameter dowels are not adequate to withstand the bearing stresses in patch joints (11,13).

At least 175 mm (7 in) of embedment length on either side of a joint is necessary for dowel bars to function well in a transverse patch joint. Many agencies specify a common 450-mm (18-in) long dowel bar that provides 225 mm (9 in) of embedment length. While the extra 50 mm (2 in) length provides for some error in dowel placement, a laboratory study found that the additional embedment length does not add to the performance of the patch (13).

It also is essential to have an adequate number of dowels in the transverse patch joints (Figure 2). A minimum of four dowels in each wheelpath will provide good load transfer for roadway patches. Consider using five dowels in each wheelpath for very heavy traffic, if the subbase is weak or if it was pumping severely before rehabilitation. Use a standard layout for the dowels in patches of airport slabs (14,15).

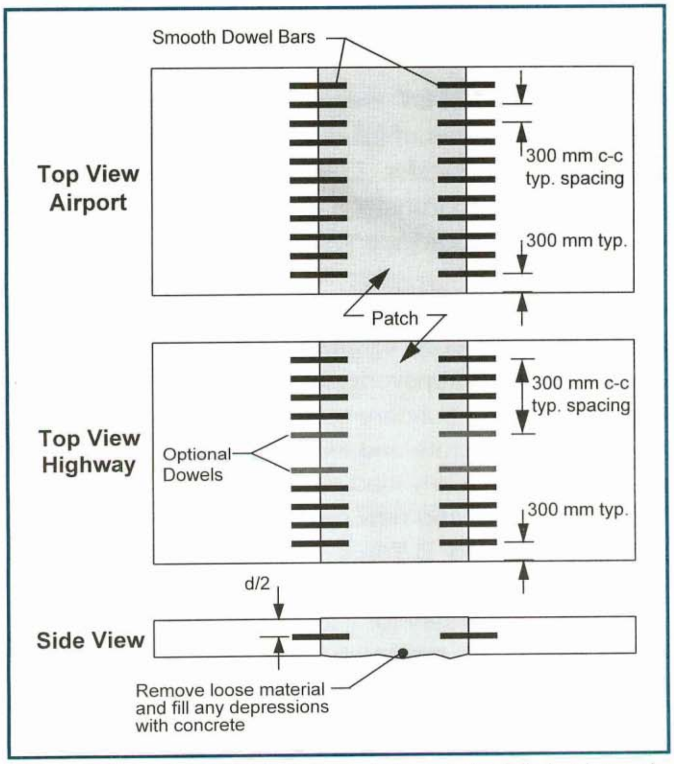


Figure 2. Spacing and layout of dowels for full-depth repair of roadway and airport pavements. Note the use of concrete to fill depressions left in the subbase after removing the old concrete.

Experience on highway pavements has shown that patches with three or fewer dowels per wheel path will eventually fault, rock and pump subbase materials (2,4,11,13). Excessive dowel-bearing stresses cause these problems because the concrete around each dowel can crush under fatigue. The result is a loss of load transfer over repeated load cycles because the dowel holes elongate or socket, and no longer hold the dowels tightly.

To repair transverse cracks or joints in jointed pavements, some agencies also use deformed tiebars of equivalent diameter to the dowels in one transverse patch joint (usually the approach). The tied joint remains tight and somewhat reduces the potential for spalling. However, there are additional considerations with this design, and it is usually preferable to use smooth dowel bars that allow free movement at each transverse joint. Some additional considerations of tying the transverse patch approach joint are:

- The tied joint forces all opening and closing movement at the other patch joint and may slightly reduce load transfer at that joint.
- The sealant in the other joint must handle a greater range of opening and closure movements and may be less reliable.
- The tiebars restrain the patch and can cause cracking in the patch during thermal contraction if the subbase or subgrade beneath the patch is not uniform or produces high friction (see Figure 2).
- Using both dowels and tiebars adds a variable that can lead to confusion during construction.

In freezing climates and regions that use deicing chemicals, the dowels should be corrosion resistant and meet the requirements of American Society of Testing Materials (ASTM) standard A 615 [or Canadian Standards Association standard (CAN/CSA) G30.18] and American Association of State Highway and Transportation Officials (AASHTO) specification M 254 (16,17,18). An epoxy coating 0.1–0.4 mm (0.005–0.015 in) thick should provide adequate corrosion protection.

Figure 3 shows where to use different transverse and longitudinal joint types along the repair boundaries in jointed and continuously reinforced roadway pavements.

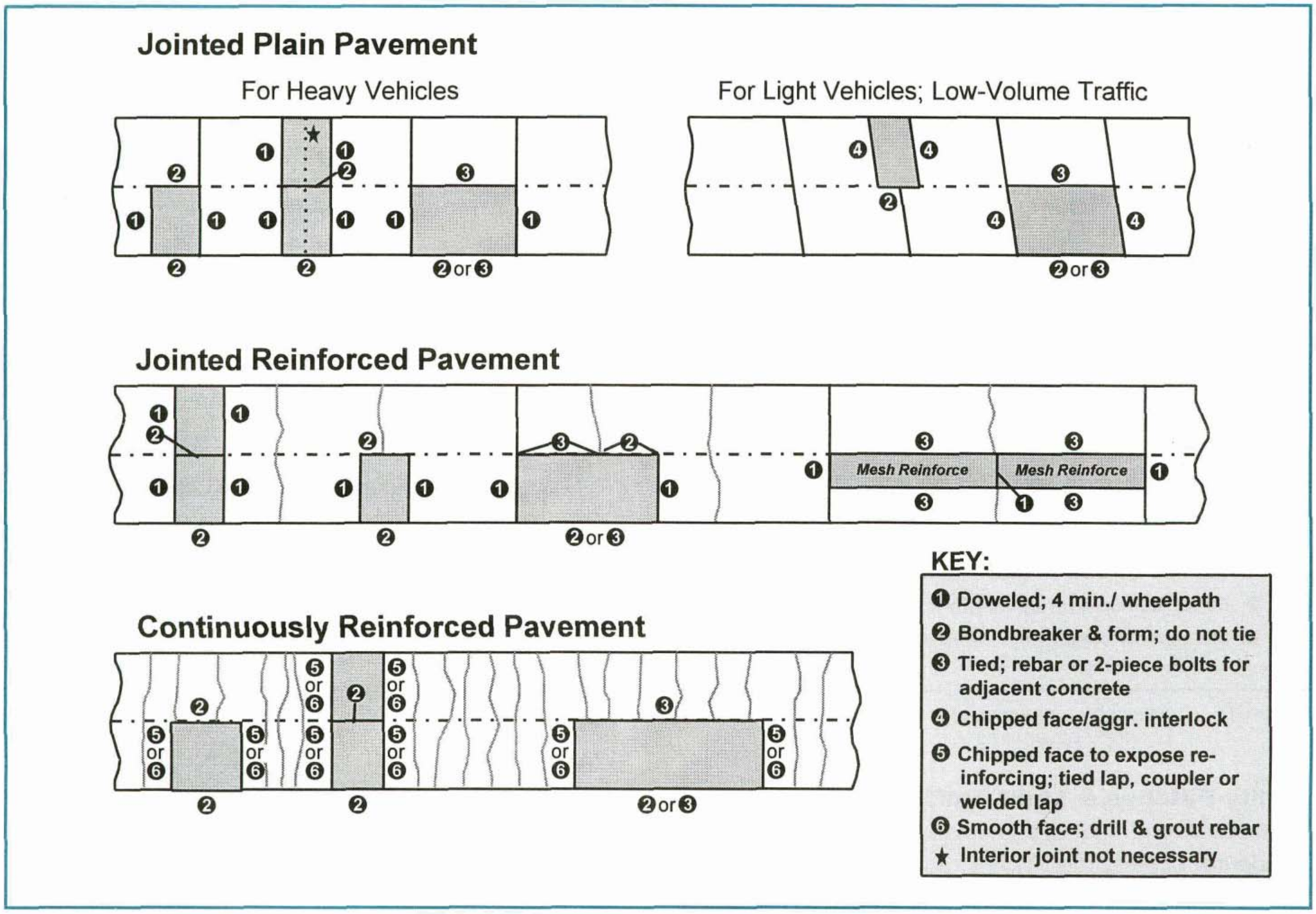


Figure 3. Where to use different transverse and longitudinal joint types in roadway pavement repairs (2,4).

Continuously Reinforced Pavements — For full-depth repairs in continuously reinforced pavements, new steel bars are necessary to maintain the continuity of the reinforcing bars that run longitudinally through the pavement. The reinforcing bars maintain load transfer at the closely spaced cracks by keeping the cracks from opening (2,19,20). The new steel attaches to salvaged lengths of the old bars that remain after concrete removal. Reliable methods to attach the new bars include tied splices, mechanical fastened splices and welded splices (Figure 4-*next page*). The bars should rest on supporting chairs if the patch is longer than 1.25 m (4 ft) to avoid bending, sagging or stressing the splices (19).

Tied splices are made by wire-tying the new bars to the exposed steel bars on both transverse sides of the removal area. Larger-diameter reinforcing bars require more old reinforcement exposed for the splice. New bars should be about 100 mm (4 in) shorter than the patch length.

Compared with tied splices, mechanical couplers do not require as much old steel exposure. Most mechanical couplers require about 25–50 mm (1–2 in) overlap (21). Lap lengths necessary for welded splices depend on the size and number of welds. A single 6–mm (0.25–in) weld requires 200 mm (8 in) lap length, and a double weld requires 100 mm (4 in) lap length. To avoid buckling, it is better to weld a separate new bar to each exposed old bar, then use a tied splice to connect the new bars near the center of the patch (2,19,20).

To save construction time, some agencies avoid splicing to the old steel by drilling holes and anchoring all new reinforcing bars into the old concrete. This procedure makes the repair faster because it does not require any hand chipping to expose the lap length of existing reinforcing bars. Holes for reinforcing bars are drilled into the transverse faces to the depth specified for a wire-tied overlap. Hole cleaning and grouting steps should follow those for dowel bars (see page 14).

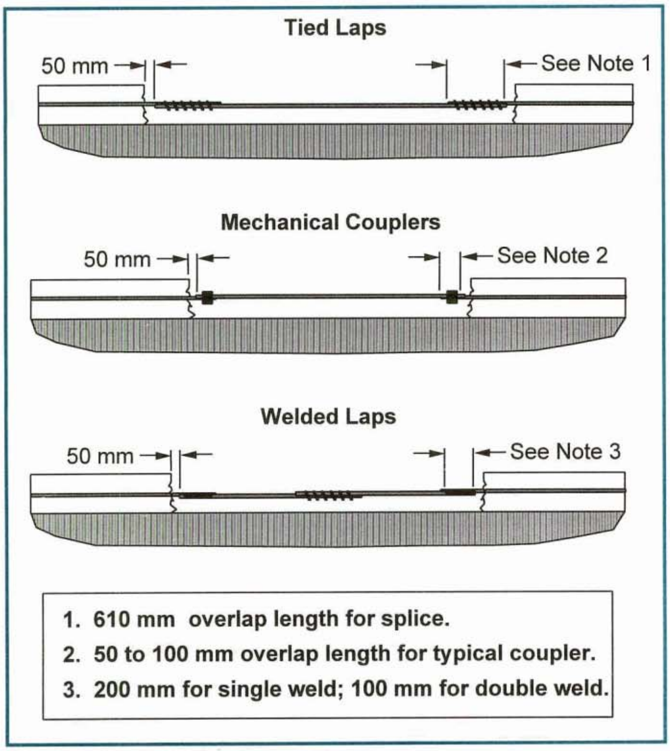


Figure 4. Steel splice techniques for continuously reinforced concrete pavements.

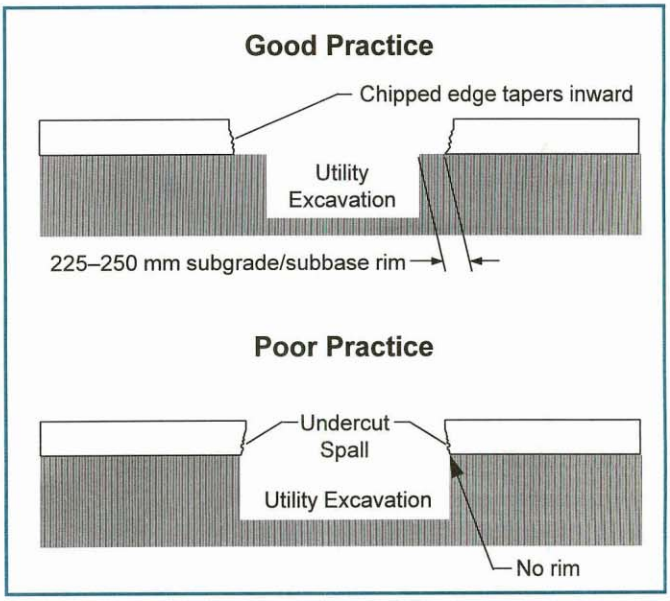


Figure 5. Examples of good and bad chipped faces and subgrade rim for a full-depth patch or utility repair in low-volume pavements.

Utility Patches & Light Traffic — For low-volume pavements that see few heavy loads—such as residential streets, municipal streets and general aviation airports—dowel bars can be excluded in full-depth repairs without sacrificing performance. However, an aggregate-interlock transverse joint is necessary; creating this type of joint requires chipping along the entire transverse patch joint to roughen the vertical face (Figure 5).

Sometimes street pavements require full-depth removal and replacement for utility repair or installation. Plan the boundaries for these patches carefully. Using full slab replacements is ideal, but the patch size will depend on the work below the pavement. It also is desirable to extend the concrete removal area beyond the planned excavation by at least 225 mm (9 in) to create a rim of undisturbed subbase or subgrade. Without this rim an excavation operator might undercut the existing slab while digging the utility trench. Attempting to place and compact fill material in a void beneath an existing pavement is difficult, and the lack of compaction often leads to patch settlement and poor patch joint performance (11).

Patch Materials —

Selecting a durable patch material is an important design element. In general, repairing concrete pavements with a concrete patching material will provide the best performance. Experience has shown that asphalt patching materials do not last as long and can lead to further deterioration of concrete pavements (22,23). Asphalt patches compress and heave when the surrounding concrete slabs expand during warm temperatures. The humped patches create a poor ride and allow nearby joints to open wide permanently. These joints may deteriorate because of diminished aggregate interlock and poor load transfer (23).

Concrete patching materials are durable and have thermal properties similar to the existing concrete. Patch mixes for full-depth repairs often use ASTM C 150 [or CAN/CSA A5-M88] Types I, II or III portland cement (24,25). The target slump ranges from about 50 to 100 mm (2 to 4 in) for finishibility. Most patch mixes require 4.5–7.5% entrained air, but this may vary by climate and the maximum size of the coarse aggregate. Laboratory testing of each patching mix is necessary to ensure that it meets the field requirements.

Agencies often want to open full-depth repairs as soon as possible to alleviate traffic congestion. Mix proportions will depend on the opening requirements. Mixes employing Type III cements or calcium chloride ($CaCl_2$) accelerators are common for the early strength gain necessary for opening. Proprietary cements also are available that gain strength very

Table 3. Approximate time necessary for different mixes to reach a compressive strength of 13.8 MPa (2000 psi) (22,27,28,29).

FOR MIXES USING:	TYPICAL TIME TO OPENING STRENGTH
Certain blended cements	2–4 hours
Sulfo-aluminate cements	2–4 hours
Type III cement with non-chloride accelerating admixture	4–6 hours
Type III cement with calcium chloride ($CaCl_2$) accelerator	4–6 hours
Type I cement with calcium chloride ($CaCl_2$) accelerator	6–8 hours
Type III cement with Type A water-reducing admixture	12–24 hours
Type I (air-entrained paving mix without fly ash)	24–72 hours

quickly. Using insulating blankets (or boards) during the first few hours after placement also can improve the strength development of any mix (2,4,22,26–29). Table 3 provides the approximate time necessary for different mixes to reach strengths necessary for opening to traffic.

Mixes using Type III cement may require slightly more mix water than a similar mix with Type I portland cement. However, too much extra water may cause the concrete to suffer from high shrinkage during curing. A water-reducing admixture will disperse cement particles and reduce the extra water necessary for thorough mixing.

Using a calcium chloride accelerator ($CaCl_2$) requires some special considerations during mixing and field use. Initial set may occur within 30 minutes on warm days, therefore, use only 1% of calcium chloride by weight of cement when air temperature exceeds 27ºC (80ºF) (2,4,19). Up to 2% is acceptable in lower temperatures. For on-site mixing, add calcium chloride in liquid form to the mixer before adding other admixtures (except the air-entraining admixture).

For plant mixing, it can be even more difficult to control the workability of concrete containing calcium chloride accelerators. Trial runs may be necessary to determine how high the slump must be at the plant—sometimes up to 150 mm (6 in)—to produce a reasonable workability for placement at the site. If the air temperatures are moderate (less than 20ºC [68ºF]) then plant mixing is acceptable for calcium chloride accelerators, as long as the plant is less than 15 minutes from the project site (4). This also applies for other accelerators and superplasticizers.

More information on mixes that gain strength quickly is available in American Concrete Pavement Association technical bulletin *Fast-Track Concrete Pavements.*

CONSTRUCTION

The seven main steps in constructing a full-depth patch in concrete pavement are:

- Isolate the deteriorated area.
- Remove the old concrete.
- Repair the subbase and drain rainwater (if necessary).
- Provide load transfer at the joint faces.
- Place and finish the new concrete.
- Cure and insulate the concrete.
- Saw and seal the repair perimeters.

The necessity of each step depends on the type of pavement and the repair location.

Defining Repair Limits —

For contracted repair projects, it is essential that the agency perform a distress survey as close to the contract schedule as possible. Long periods between the field survey, plan preparation and bid opening may lead to an inaccurate description of the actual distress existing when construction begins. In that case, the project plans, engineer's estimate and contractor's proposed quantities will not reflect the repairs necessary for a successful project. This can become a source of confusion and can lead to neglect in marking distress limits or lead to poor selection of repair sizes.

A survey by the project engineer and contractor before construction will define any inaccuracies between the locations and quantities of repairs described on the plans, and the actual conditions in the field. During this survey, all distresses and repair areas must be marked clearly on the pavement with a bright-colored spray paint. However, the engineer and the contractor should still refer to the plans for specific locations of distresses that might not be visible from the surface.

If the project plans contain partial-depth repairs, the project specifications should include a special provision that provides the field engineer freedom to change some partial-depth repairs to full-depth removals if necessary. During construction there may be situations where a distress marked in the plans for partial-depth repair may extend deeper than expected. Partial-depth repairs are only appropriate for spalls within the top one-third of the slab.

Concrete Removal —

Isolating the Area — Before removing deteriorated concrete, it is necessary to first isolate the area from adjacent concrete and shoulder materials using full-depth saw cuts (Figure 6). The full-depth cuts separate the segment of deteriorated concrete and allow room for its removal with minimal damage to surrounding material.

It is preferable to use diamond-bladed saws for full-depth transverse cuts through existing concrete. Diamond-bladed saws produce straight, smooth, vertical faces that improve the accuracy of dowel bar placement. Carbide-tooth wheel saws can cause micro-cracks in the surrounding concrete and are not acceptable for making full-depth perimeter cuts for exposed patches. However, wheel saws are acceptable for making full-depth boundary cuts in pre-overlay repairs for unbonded concrete overlays or for asphalt overlays more than 100 mm (4 in) thick because the saw cuts are covered by additional overlay material.

Wheel saws also are acceptable for making a 100-mm (4-in) wide cut in an asphalt shoulder along the patch area. A wide severance along the shoulder minimizes possible damage to the shoulder during removal and provides room for a wooden form. The isolation cut along a tied concrete shoulder requires a diamond-bladed saw that can extend to full depth and sever any existing tiebars.

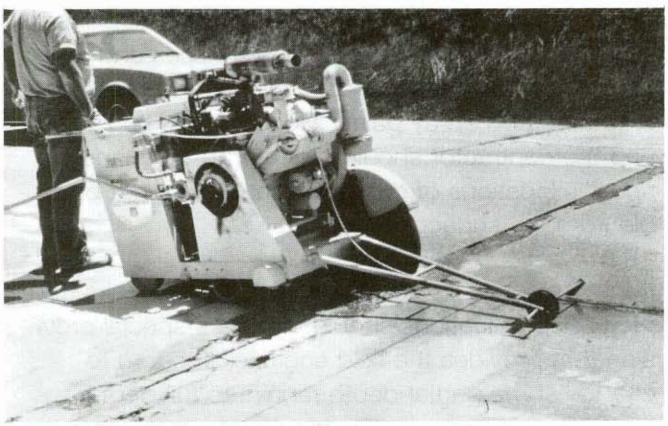


Figure 6. Isolate the repair area using full-depth saw cuts.

An interior or centerline longitudinal joint also requires a full-depth cut through the existing joint reservoir. To avoid spalling damage during removal operations, the saw operator should continue sawing through the joint to ensure that the base of the blade reaches the intersection with the transverse boundary cuts.

Transverse perimeter cuts should extend down about 1/4–1/3 the slab thickness for repairs in continuously reinforced concrete pavements, or for utility cuts and repairs in low-volume roads. Separate full-depth cuts for liftout removal are made closer to the patch interior away from these partial-depth perimeter cuts. The concrete between the cuts provides a buffer to prevent undercut spallling, and allows chipping for aggregate interlock, or for exposing steel reinforcement. Table 4 provides the recommended offset distance between the full-depth and partial-depth cuts.

Table 4. Offset distances between full- and partial-depth cuts for repairs in continuously reinforced pave ments or low-volume roads using aggregate interlock patch joints (2,19,20) .

PATCH TYPE	MINIMUM OFFSET
CRCP with tied steel splice	600 mm (24 in)
CRCP with welded steel splice	100–200 mm (4–8 in)
CRCP with mechanical steel splice	50–100 mm (2–4 in)
Low-volume aggregate interlock or utility	50 mm (2 in)

In hot weather, diamond saw blades may bind while making full-depth transverse perimeter cuts because the slabs are in compression from thermal expansion (11). To alleviate this problem the contractor may elect to saw at night during cooler temperatures, or to provide pressure-relief cuts at an interval of about 180–360 m (600–1200 ft) before starting any boundary sawing (4). Carbide-toothed wheel saws are acceptable for the pressure relief cuts. To avoid damaging adjacent concrete, keep the cuts in the marked patch areas away from the perimeters by about 150–200 mm (6–8 in). The operator should not allow the cut to enter an adjacent slab or penetrate the subbase by more than 12 mm (0.5 in) (11). A contractor also may elect to use one or more wheel saw cuts within each patch area to give torque-claw removal equipment space to grasp the old concrete.

Sawing operations should not precede removal and patch placing operations by more than two days (2). The full-depth cuts along the patch perimeters provide no load transfer and may support only a couple of days of traffic. After that, the subbase can begin to pump and the patch may rock or punch into the subbase, causing unnecessary damage.

Liftout —

It is preferable to lift deteriorated concrete out of place wherever possible (2,4,11). Lifting the old concrete imparts no damage to the subbase and usually is faster and requires less labor than any method that breaks the concrete before removal.

The most common liftout method uses a steel chain connected to lift pins. The contractor drills at least two vertical holes through the old concrete surface, then inserts one lift pin into each hole. The lift pins are either one-piece or two-piece assemblies. Generally, one-piece pins require holes at about a 20° angle; two-piece pins work well in 90° vertical holes, which are somewhat easier to drill. The two-piece pin consists of a small wedge section and a larger pin shaft connected to the chain. The smaller wedge is driven into the hole alongside the pin shaft. Friction between the pin and the hole wall, and forces acting against the wedge keep the pin firmly in place. Using a lift pin arrangement, the contractor fastens the chain to a crane or a front-end loader that is capable of lifting the concrete vertically, then swinging it onto a flatbed or dump truck for removal from the site. For smaller lifting equipment and large removal areas, additional saw cuts may be necessary to divide the slab into smaller segments.

Other lift equipment includes forklifts, vertical bridges, lateral-pressure lifts and a torque claws. These devices may require a 100–mm (4–in) wide wheel saw cut within the patch area to get leverage on the deteriorated concrete segment. They also can lift and deposit the deteriorated concrete onto trucks. Figure 7 shows three common types of liftout equipment.

If the old concrete swings during the lift, it may chip the faces of the remaining concrete. To prevent this damage a 100–mm (4–in) wheel saw cut within the repair area provides some additional space for lateral movement. However, damage during liftout is not entirely avoidable, and it will probably be necessary to extend the repair if the lifting operation significantly damages the remaining concrete.

A▶
B▶
C▶

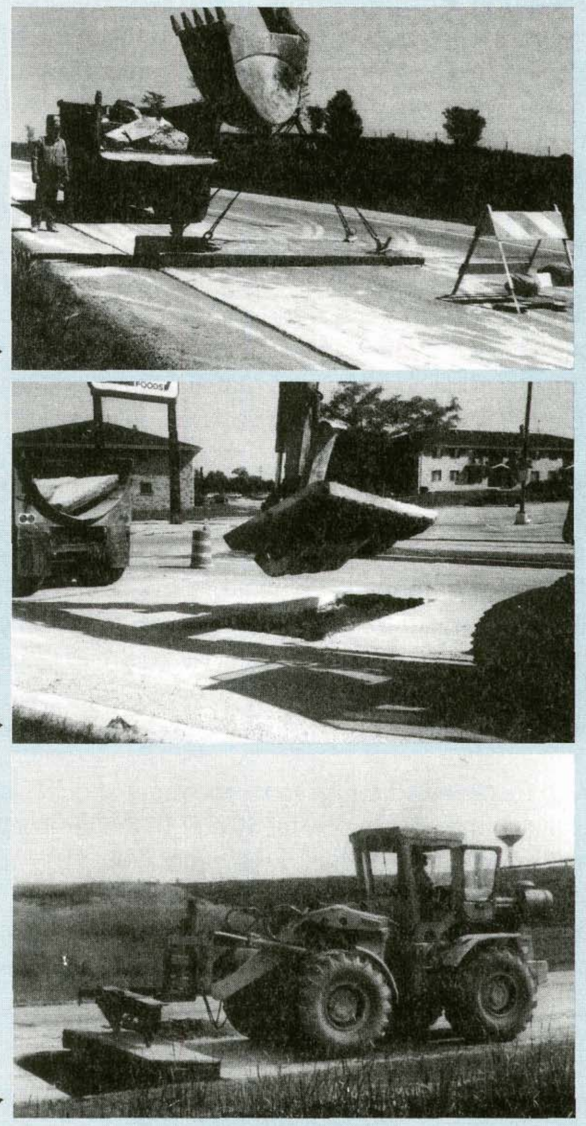


Figure 7. Various liftout devices: (A) pin and chain; (B) torque claw; (C) lateral-pressure.

Breakup —

Sometimes concrete joints are so deteriorated that it is unsafe to remove them by liftout. In these cases it is necessary to break the deteriorated concrete into small fragments for removal by backhoe and hand tools. On large projects and long patches the contractor will use equipment like drop hammers or hydraulic rams for reasonable productivity. For a few repairs it is efficient to break up the entire patch area using jackhammers.

The drawback to the breakup removal method is that it often damages the subbase and requires more repair preparation than a liftout procedure (11).

Breaking Equipment — There are some special considerations necessary when using mechanized breaking equipment like drop hammers or hydraulic rams. Operators must exercise control on the equipment's break energy to minimize damage to the subbase, subgrade and any underground utilities. Excessive break energy may push concrete pieces into granular layers. Then during concrete removal, backhoes must dig into the subbase and pick up more subbase material to remove the broken concrete. This disturbs the supporting layers for the patch and requires additional subbase material to replace the material scooped up during concrete removal (11).

A full-depth buffer saw cut in the patch area minimizes the potential of damaging surrounding concrete during breakup. These cuts arrest the breakage and absorb the energy from the pavement breaker. Buffer cuts should be about 0.3 m (1 ft) away from the perimeter saw cuts within the patch area (Figure 8). Without buffer cuts, the impact can spall the concrete on both sides of a full-depth cut or an existing longitudinal joint.

With mechanized equipment, operators should begin breaking the concrete in the center of the removal area and move outward toward the buffer cuts. The operator should reduce the break energy (drop height) before starting on the area outside the buffer cuts. The equipment can then break the outer region with less chance of damaging concrete beyond the patch perimeter. How much to reduce the drop height may depend on the concrete strength and presence of reinforcement. After the breaking operation is complete, workers with a backhoe and handtools can shovel the broken pieces into trucks for removal from the site.

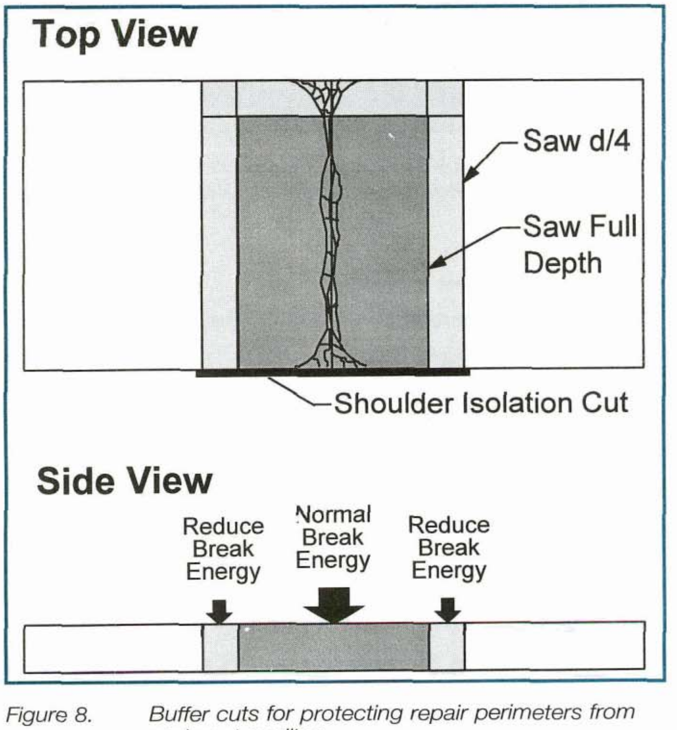


Figure 8. Buffer cuts for protecting repair perimeters from undercut spalling.

Do not use breaking equipment on the concrete between the full- and partial-depth saw cuts at the transverse boundaries of a continuously reinforced pavement repair. It is necessary to salvage the reinforcing bars, so workers should use jackhammers weighing less than 7 kg (15 lb) and attempt not to nick or bend the bars (2). They also should avoid spalling the concrete under the partial-depth cut. It may be necessary to extend the patch If chipping causes damage to 10% of the bars or breaks three or more adjacent bars (2,19).

Jackhammers — Jackhammers are an alternative for small patches and are often the choice of public works departments and local agencies for utility work. Using jackhammers is labor intensive and is usually slower and less cost-effective than using mechanized breakers or liftout. However, they do not require the additional buffer cut along patch boundaries. Breaking should begin in the center of the removal area and continue to the edges. Usually, 13.5-kg (30-lb) or larger pneumatic hammers are used for the majority of the area. To prevent undercut spalling, lighter 7-kg (15-lb) hammers are necessary for chipping within 100–150 mm (4–6 in) of a boundary saw cut.

The chipped edges at the boundary of an aggregate interlock joint should extend down vertically and never undercut the joint (Figure 9). An undercut face provides poor load transfer and increases the potential for repair settlement and punchout.

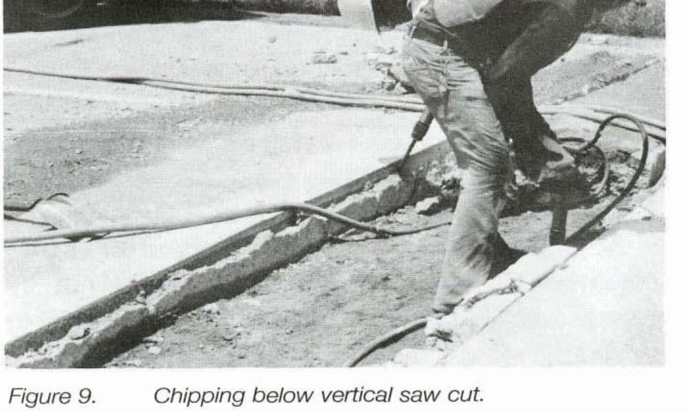


Figure 9. Chipping below vertical saw cut.

Repair Area Preparation —

After removing the old concrete and loose material, the area is ready for subbase preparation and provision of load transfer mechanisms at the boundaries. If removal operations damage the subbase, it may be necessary to add and compact new subbase material; uniform compaction is particularly important in frost areas. It also is necessary to remove and replace soft areas in the subbase. If the repair area fills with rainwater after concrete removal, the water should be pumped out or drained through a trench cut across the shoulder before repairing the subbase.

Ideal backfill materials can reach optimum compaction with small plate compactors that can maneuver in the confined patch area. Select fills are acceptable, but good compaction is often difficult. Vibratory plate compactors should have a centrifugal force rating from 17 to 27 kN (4000 to 6000 lb). For highway and airport repair it may be advantageous to fill any disturbed subbase areas with the patching concrete and eliminate the need to add and compact additional subbase materials (4).

Flowable-fill materials are ideal for deep utility excavations. Flowable fills do not need compaction and flow easily to fill the trench. The mixtures contain portland cement, sand, fly ash and water and develop typical 28-day compressive strengths of about 0.3–0.7 MPa (40–100 psi). Flowable fills provide enough strength to prevent settlement, but are easy to remove using a bucket on a backhoe or front-end loader if future excavation is necessary. However, it is possible for utility pipes to shift out of alignment from buoyancy in the flowable fill. To avoid this, a two-phase approach first creates a partial-depth bed of flowable fill beneath the pipe, and then completes the backfill to the top of the excavation.

Drilling Dowel Holes — Dowel bars slip into holes drilled into the edge of the existing slab. It is preferable to drill the holes using automatic dowel drilling rigs rather than single, hand-held drills. It is difficult for laborers to drill consistent holes using hand-held drills because they are heavy and do not have an alignment guide or jig.

Dowel drill rigs contain one or more drills attached parallel in the rig's frame. The frame acts as the alignment-jig to control drill alignment and wandering. All drill rigs are capable of height, depth and spacing adjustments. Some allow simultaneous or independent drill operation and provide a control for the feed pressure on each drill. Simultaneous drilling improves productivity. Independent drill operation permits use of larger rigs for most dowel-spacing designs and enables the operator to continue working should one drill break down (30). However, single, frame-mounted or hand-held drills are necessary where there is not enough room for the multiple-drill rigs.

Dowel drilling rigs either mount on a boom or on a frame with wheels. The boom-mounted rigs attach to a large machine like a backhoe or loader. Boom-mounts allow the drill rig to rotate 360° so the operator can drill both sides of a patch without moving the large machine. The wheel-mounted units are self-propelled and can motor the drill rig between repairs. Some wheel-mounted drill rigs ride on the slab surface and reference the hole-location from the slab surface; other rigs ride in the patch area on the subbase or subgrade. The subbase-reference units require additional adjustments to level and locate the holes where the subbase surface is not uniform. Figure 10 (*next page*) shows common drill equipment.

It may be necessary to adjust the location of dowel holes from the plan requirements. Sometimes cracks, heavy mesh reinforcement or other obstructions exist at the plan location for a hole. It is better to adjust the hole away from an obstacle or eliminate the hole, rather than attempt to drill and place a dowel at a questionable location.

Both standard pneumatic or hydraulic percussion drills are acceptable for drilling dowel holes (13). Both drill a typical dowel hole in about 30 seconds. Standard pneumatic drills cause slightly more spalling on the slab edge when starting to drill because they impart more impact energy than hydraulic drills. However, with good installation techniques, there is no difference in the performance of dowels anchored in holes drilled with either hydraulic or pneumatic equipment (13).

The hole diameter necessary for dowel installation depends on the anchoring material (2,4,13). Cement-based grout requires a hole diameter 5–6 mm (0.20–0.25 in) larger than the nominal outside dowel diameter. Epoxy anchoring materials are softer than either the steel dowel or concrete, and therefore provide better performance with a tighter fit. The hole diameter for epoxy materials should be about 2 mm (1/16 in) larger than the nominal dowel diameter.

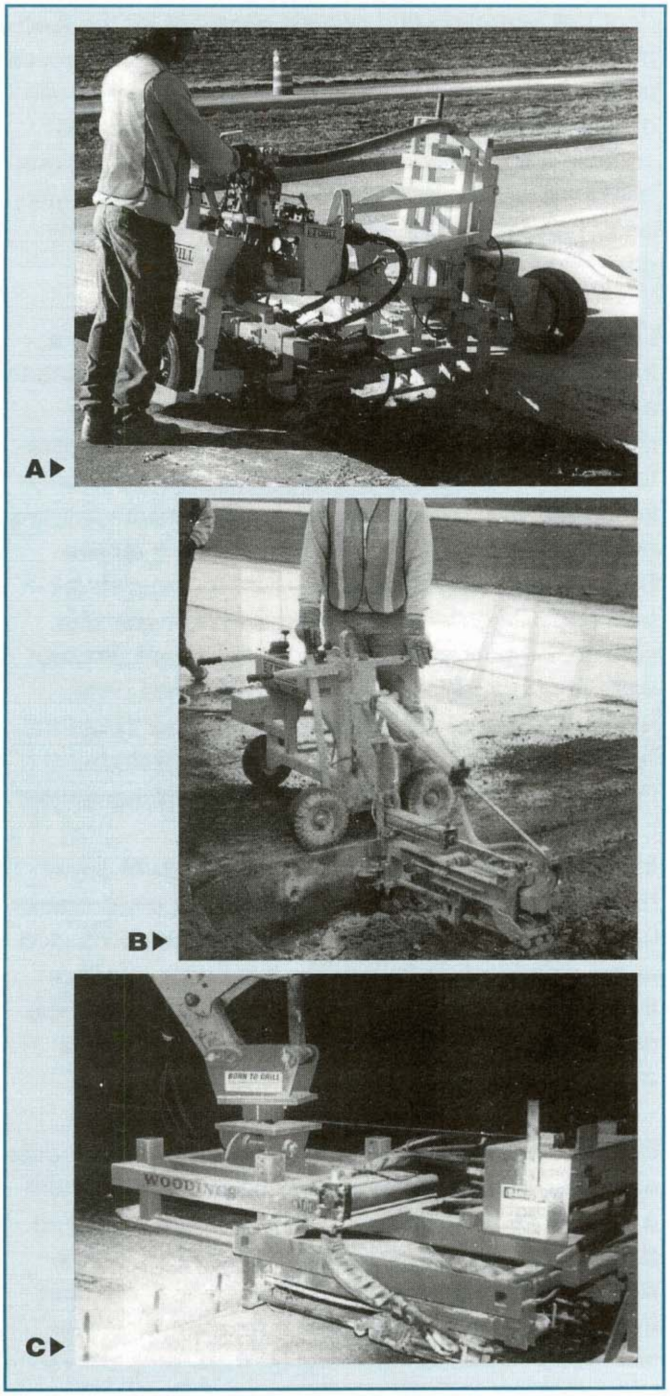


Figure 10. *Drilling holes with: (A) self-propelled, subbase-reference gang drill; (B) self-propelled, slab-reference single drill; (C) boom-mounted gang drill.*

At least one agency uses a compression fit without an anchoring material to install dowels in concrete containing medium-hard trap rock aggregate. While this appears to perform with the harder aggregate, it was found unsuitable for softer (limestone) aggregates in a laboratory study (19).

Installing Dowels —
After drilling, it is necessary to clean out the dowel holes with compressed air. The operator should insert an air nozzle into the hole to force out all dust and debris. Dust and dirt prevent the epoxy or non-shrink grout from bonding to the concrete around the hole perimeter. Oil also prevents good bonding, therefore, an operator should occasionally check the air for oil and moisture contamination from the compressor. The compressor should deliver air at a minimum of 3.4 m^3/min (120 ft^3/min) and develop 0.6 MPa (90 psi) nozzle pressure.

When placing the anchoring material, use a long nozzle that feeds the material to the back of the hole. This assures that the anchoring material will flow forward along the entire dowel embedment length during insertion and decreases the likelihood of leaving voids between the dowel and the concrete (2,4,13). Prefabricated epoxy cartridges are available that supply enough material for one or two holes; a more cost-effective system for large projects uses a pressurized injection system from bulk epoxy containers (31). For epoxies, the injection wand on the installation unit should contain an auger-type mixing spindle that mixes a two-part epoxy. For non-shrink cementitious grouts, a caulk-gun-type tool is preferable. Do not use any method that attempts to pour or push the anchoring material into the hole.

While inserting each dowel, the laborer should twist the dowel about one full revolution to evenly distribute the material around the dowel's circumference. Without the twist, most of the anchoring grout will remain along the bottom of the bar and voids will be present along the top of the bar.

Sometimes the anchoring material flows out while inserting the dowels. A plastic grout-retention disk provides a barrier that prevents the escape of epoxy or grout (Figure 11) (13). When metered properly, some anchoring material should be visible from the sides of the disk after installation. If no grout can be seen, there may not be enough in each hole. If retention disks are not available, a laborer should trowel some extra grout around the dowel. This is not an ideal installation, but is preferable to leaving a void.

It may be necessary to adjust the mix if it is difficult to control loss of anchoring material. Ideal anchoring materials will remain in the hole without a retention disk (4,22). Non-shrink, cementitious anchoring materials stiffen with time after mixing. Because this changes their installation properties, mix small batches for more uniform consistency.

Longitudinal Perimeters — Longitudinal patch perimeter joints also require preparation before adding the

Figure 11. *Grout-retention disk for holding in anchoring epoxy or mortar during dowel bar insertion.*

Figure 12. *Worker placing bondbreaking board along longitudinal joint between patch and adjacent lane. Note: if the patch is longer than 4.5 m (15 ft) use tiebars or wigglebolts to tie the patch to the adjacent lane.*

new concrete. Full slab replacements and most repairs longer than 4.5 m (15 ft) require tiebars or two-part threaded couplers spaced along the longitudinal joint at 750 mm (30 in). Drill holes accommodate #10M to #20M (No 4 to No 6) deformed reinforcing bars with an embedment length that will provide good pullout resistance. Single, hand-held drills are acceptable because alignment is not critical. Anchor the tiebars or wiggle bolts using the same anchoring grout used for dowels.

For most repairs less than 4.5 m (15 ft) long, it is preferable to place a bondbreaking board along any longitudinal face with an existing concrete lane or concrete shoulder (Figure 12). Long-jointed pavements can require bond breaker for greater repair lengths. The thin, 5-mm (0.25-in) fiberboard or similar material should match the repair area depth and length and sit flush with the longitudinal face of the repair. The bondbreaker allows the patch and the old concrete to move independently and prevents lateral restraint stresses during thermal length-change cycles.

A wooden form is necessary along the outside edge of repairs next to asphalt shoulders. The form should be sturdy to prevent rupturing and be made from straight boards that produce a uniform surface elevation.

Placing Concrete —

Concrete should be placed soon after preparing the subbase, installing dowels, and positioning side forms and bondbreaker materials. A long delay exposes the open repair area to rainfall and poses a traffic hazard. Any manholes, or other in-pavement structures also must be in position and adjusted to the appropriate elevation before placing the concrete for utility repairs.

Place concrete into the repair area from ready-mix trucks or other mobile batch vehicles. The chute operator should distribute the concrete evenly to avoid the need for excessive shoveling (Figure 13). Attaining good concrete consolidation around dowel bars and along the patch perimeter is important to long-term performance (11). Any honeycombing reduces concrete strength and durability. Vertical penetrations of a standard spud vibrator will adequately mobilize the patching concrete. Do not drag the vibrator through the mix—this may cause segregation and loss of entrained air.

Figure 13. *Chute operator and laborer filling a patch area and vibrating concrete in a suburban roadway patch.*

Finishing & Texturing — Both vibratory screeds, and 3-m (10-ft) straight edges are good tools to strike off and finish a repair surface. For short repairs (<3 m [<10 ft]) it is better to pull the finishing tool across the pavement with the blade parallel to the longitudinal joint. The tool rests on the old concrete on both sides of the repair, and follows the surface of the adjoining slabs, which ensures that the patch surface meets the surface profile and provides a smooth ride. For repairs longer than 3 m (10 ft) it is necessary to finish the surface longitudinally with a vibratory screed.

The repair's surface texture should be similar to that on the surrounding pavement. Burlap drag and transverse tine surfaces are common. For tined surfaces, the distance between combs for the patch texture should be similar to the distance between combs on the existing surface.

Curing — Curing provisions are necessary for a satisfactory moisture and temperature condition in the patching concrete after placement (32). In general, a liquid-membrane-forming curing compound that meets ASTM C 309 material requirements is adequate (33). The materials create a seal that limits mix water evaporation and contributes to thorough cement hydration. Some agencies specify a white-pigmented compound (Type 2, Class A) that is easy to see after application. Other agencies specify a resin-based curing compound that meets ASTM C 309, Type 2, Class B requirements and may not contain a white pigment, but can produce a better evaporation barrier. An application rate of about 5.0 m^2/L (200 ft^2/gal) is sufficient for either material.

Insulation mats increase the concrete temperature and accelerate strength gain. For high-early strength patch mixes, the first few hours are the most critical for good curing. Therefore, the contractor should apply the curing compound and insulation as soon as possible after finishing the surface. To prevent moisture loss and to protect the surface, place one layer of polyethylene sheeting on the patch surface under the insulating boards or mats (2,4,19).

Insulating boards may not be necessary—and could cause cracking—in warm temperatures. The purpose of insulation is to aid early strength gain in cool ambient temperatures. After removing the boards, thermal shock may induce shrinkage cracks if the boards create excessive heat in the concrete. Reference 26 provides more detailed information.

Smoothness — A good finishing technique can develop an adequate transition between the patch and the old concrete. However, if the pavement contains many closely spaced patches, it may be difficult to develop a surface smoothness comparable to modern standards. In these cases, and for most contracted projects, consider applying a ride specification comparable to the local ride specification for new concrete pavements. Patched pavements that do not meet a specified ride requirement will require correction by diamond grinding. Grinding should precede joint sealing operations.

Joint Sealing — The final step in proper construction of a full-depth concrete repair is to form or saw transverse and longitudinal joint sealant reservoirs at the patch boundaries. Sealed perimeter joints will reduce spalling at the patch joints (2,4,11). Figure 14 shows a completed patch with sealed joints. For more information on proper techniques for sealing joints see ACPA publication *Joint and Crack Sealing and Repair for Concrete Pavements* (1).

Opening to Traffic — There are two methods to determine when to open full-depth repairs to traffic (22):

- ◆ Specified minimum strength.
- ◆ Specified minimum time after completing placement.

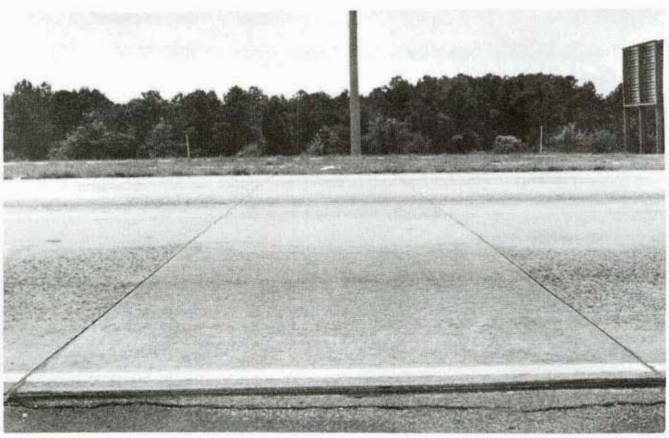


Figure 14. Completed patch with sealed joints.

For most concrete pavement applications, it is preferable to measure the concrete strength to determine when it is acceptable for traffic. This is not always true for concrete repairs, particularly where quick opening is not critical. Most patch mixes fall into one of three categories for opening to traffic: 4 to 6 hour, 12 to 24 hour and 24 to 72 hour (conventional). Contractors often use conventional mixes in repairs on large projects, in non-traffic areas or in other situations where quick opening is not necessary; specifying a minimum time after placement is sensible for these situations (22).

For the 12 to 24 hour and 4 to 6 hour mixes, time criterion does not provide the information necessary to allow traffic on as soon as possible. Small variations in air temperature also can influence concrete strength development. Therefore, a strength test using portable beam test devices, portable cylinder test devices, maturity meters, or pulse-velocity devices is preferable to a specified time requirement (22,28,34). Table 5 provides minimum opening strengths necessary for full-depth repairs.

PAYMENT

Most specifications for contracted repair projects structure payment for full-depth repairs by area (square meter [square yard]). Variations in the actual patch thickness and lateral dimensions are common for most projects due to:

- Original construction thickness variation.
- Loss of subbase materials during concrete removal.
- Extending patch length for unseen deterioration.
- Changing to full-depth repair from partial-depth repair.

Contractors must account for these unknown factors in developing bid prices for a contracted project. A more equitable cost accounting system would split the payment and include an item for concrete volume.

ADDITIONAL INFORMATION

Additional information on full-depth repair of concrete pavements is available from the American Concrete Pavement Association.

Table 5. Minimum opening strength necessary for full-depth repairs (34,35,36).

Slab Thickness	Strength for Opening to Traffic MPa (psi)			
	Repair Length [<3 m (<10 ft)]		Slab Replacements	
	Compressive[1]	3rd-Point Flexural	Compressive[1]	3rd-Point Flexural
150 (6.0)	20.7 (3000)	3.4 (490)	24.8 (3600)	3.7 (540)
175 (7.0)	16.5 (2400)	2.6 (370)	18.6 (2700)	2.8 (410)
200 (8.0)	14.8 (2150)	2.3 (340)	14.8 (2150)	2.3 (340)
225 (9.0)	13.8 (2000)	1.9 (275)	13.8 (2000)	2.1 (300)
+250 (+10.0)	13.8 (2000)	1.7 (250)	13.8 (2000)	2.1 (300)

1. It is difficult to correlate compressive strength (f'_{cr}) to low values for flexural strength (f_r). The relationship $f_r = 0.79 \cdot \sqrt[0.79]{f'_{cr}}$ was used to develop the compressive strengths for f_r from 2.1 to 3.1 MPa (300 to 450 psi). The relationship $f_r = 9 \cdot \sqrt{f'_{cr}}$ was used to develop the compressive strengths for $f_r > 3.1$ MPa (450 psi).

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