U.S. Department
of Transportation
**Federal Highway
Administration**

# Construction Handbook on PCC Pavement Rehabilitation

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Prepared by
Construction and
Maintenance Division

# PREFACE

This handbook is primarily intended to assist the Federal Highway Administration (FHWA) area engineers when they make highway construction inspections. It can also be used when reviewing specifications, supplemental specifications, and special provisions during the PS&E stage of a project. It is a companion to the design oriented FHWA notebook entitled, "Techniques For Pavement Rehabilitation." Information contained herein is a guide and is not intended as a standard. State highway agencies should use or develop their own specifications. The information in this handbook was selected from current reports prepared by the Transportation Research Board under the National Cooperative Highway Research Program, Michael I. Darter of the University of Illinois, the Portland Cement Association, the American Concrete Pavement Association, and several State highway agencies. Most of the tables and figures contained in this handbook were duplicated from the reference reports. The number of different rehabilitation techniques covered in this handbook are limited at this time. However, the handbook will be expanded to include additional construction techniques for rehabilitating rigid and flexible pavements. The technical guidelines and recommendations have been prepared to reflect the views and opinions of the FHWA Construction and Maintenance Division
(HHO-30).

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# CHAPTER 1

## FULL DEPTH PATCHING OF JOINTED CONCRETE PAVEMENT

### Materials

A 7-to 9-bag per cubic yard mix (94 lbs. per bag) of portland cement Type I, II, or III can be used depending upon opening time to traffic. A 7-bag mix is normally sufficient for most patching work that does not require early opening (4 to 6 hours) to traffic. Mixes with 8 to 9 bags per cubic yard are commonly used for early opening to traffic. The mixture should include an approved air-entraining agent in amounts such that $6 \pm 1.5$ percent of air is entrained in the concrete. Since most concrete placement in patching work is done by hand, it is desirable to have 2- to 4-inch slump in order to provide a workable mix.

Calcium chloride or other accelerating chemical admixtures can be used as an accelerator in the patching concrete provided they are added as specified. Note, calcium chloride can cause corrosion in reinforcing steel and dowel bars. It is recommended that no more than 1 percent calcium chloride be used when the ambient temperature is above 80°F because greater amounts can bring on a flash set. Otherwise, the maximum percentage is generally limited to 2 percent. On warm days, the initial set of the concrete can occur as soon as 30 minutes after the addition of calcium chloride. The ready-mix truck should be rotated an additional 40 revolutions after the addition of the calcium chloride at the site. If calcium chloride is being added at the plant and the concrete consistently arrives at the site too stiff, then the calcium chloride should be added at the site. If, after the addition of calcium chloride at the site, the concrete is still too stiff, the ready-mix plant operator should be notified to increase the slump an appropriate amount within the design range of the w/c ratio or redesign the mix. A concrete mobile equipped with admixture dispensers can provide total on-site mix control.

Early strength can also be obtained by using a water reducing agent or a combination of a water reducing agent and set controlling admixtures, or an approved superplasticizer to the concrete. The superplasticizer should be added at the patching site because of its limited time of effectiveness. It should be added in accordance with the instructions supplied by the manufacturer to provide a workable mix.

Admixtures and combinations of admixtures should be laboratory tested by the State highway agency (SHA) to assure compatibility and satisfactory performance.

### Procedures

It is important that the boundaries of the patch be located as determined by the design engineer. In general, the deterioration near joints and cracks is greater at the bottom of the slab than can be observed on the top of the slab. The minimum length of full depth patches should be 6 feet. Some SHA's do construct 3-, 4-, and 5-foot patches; however, drill rigs used to drill dowel holes can dictate the minimum length of patch.

There are two basic methods to remove the existing deteriorated concrete within the patch area. These are (1) the break up and clean out method and (2) the lift out method. The lift out method will generally provide the best results and the highest production for the same or lower cost. Contractors have developed lifting equipment that provides for safe and rapid removal whenever a substantial amount of work is available. Advantages and disadvantages of each method are listed as follows.

1. Break up and Clean out (Acceptable - with caution)

   a. Advantages - Pavement breakers can efficiently break up the concrete. A front-end loader or backhoe with a bucket and teeth can rapidly remove the broken concrete and load it into trucks. The breaking operation should proceed from the center of the patch area toward the saw cuts at the ends to eliminate damage to the adjoining slabs.

   b. Disadvantages - This method usually disturbs the subbase/subgrade requiring either replacement of subbase material or filling with concrete. It can also damage the adjacent slabs, particularly at the bottom.

2. Lift Out (Preferred)

   a. Advantages - This method generally does not disturb the subbase and does not damage the adjacent slabs. It generally provides a more rapid removal than the break up and clean out method.

   b. Disadvantages - Disposing of large pieces of concrete may cause a problem. Lifting pins and heavy lifting equipment usually are required for the lift out. Otherwise the slab should be sawed into small pieces so that they can be lifted out by a front end loader.

The transverse boundaries of the patch should be sawed to full depth with diamond saw blades. A wheel saw (having carbide steel tips) can be used to make wide cuts on each side of the patch so the center portion can be lifted out. When using this process, full-depth diamond saw cuts should be made just outside the wheel saw cuts because the wheel saw produces a ragged edge that promotes excessive spalling along the joint.

Procedures used for removal should not spall or crack adjacent concrete and should not disturb the subbase or subgrade. This requires that the following aspects be considered.

1. Heavy drop hammers should not be allowed on the job because they can disturb the base and damage adjacent sound concrete.

2. Hydro hammers (large automated jackhammers) should not be allowed near a partial depth saw joint because in most instances they can cause under breaking in the adjacent slab.

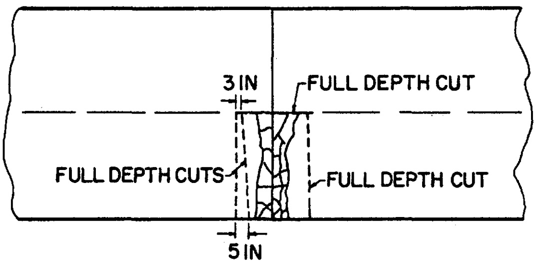
3. Saw cuts can be placed to relieve pressure whenever the temperature is such that the sawn cut has closed and spalling will result when the existing slab is broken or lifted out. A relief cut that should provide adequate results is shown in Figure 1-1.

4. Concrete between narrowly spaced saw cuts at the end of a patch should be removed with air hammers (30 to 40 pounds) and hand tools.

After the existing concrete has been removed, the base/subgrade should be examined to determine its condition. If water or excessive moisture exists in the patch area, it should be removed or dried before the patch concrete is placed. If a drainage problem exists at the patch site, it should be corrected (i.e., outlet drain, transverse drain, edge drain, etc.). If a serious drainage problem exists, the construction engineer should request a drainage analysis. The foundation should be recompacted using mechanical equipment to the satisfaction of the engineer.

An alternative method to compacting disturbed base material is to remove the loose base material and backfill with the PCC patch. However, this method will produce pavement slabs with differential thicknesses which may or may not cause differential frost heave problems and may also create drainage problems.

The time intervals between sawing, concrete removal, and patching should be closely spaced to reduce or eliminate any potential for slab creep. Slab creep causes many problems such as reduction of load transfer developed by aggregate interlock and loosening of seals in contraction joints.




SAW CUTS FOR LIFT OUT METHOD

Figure 1-1

Where transverse joints are staggered, bond breaker material should be placed along the longitudinal joint (see Figure 1-2). Failure to use a bond breaker in this situation will usually cause a corner crack at the longitudinal and transverse joints.

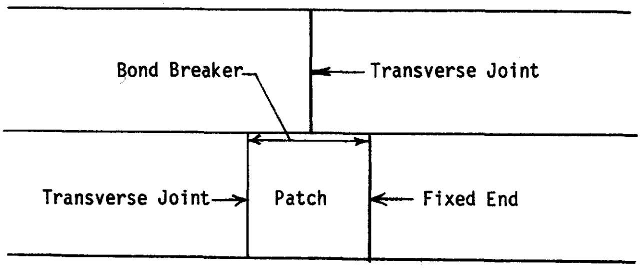



Figure 1-2

## Dowel and Rebar Placement

When specified, holes should be drilled into the face of the existing slab at the specified diameter. The diameters of the holes are only slightly larger than the dowels or rebar to provide proper alignment. They should be located at mid-depth of the slab and spaced as indicated on the plans. Dowels should be carefully aligned (within 1/4 inch) with the direction of the pavement and parallel to the plain of the surface in order to provide free movement. The holes can be drilled rapidly by placing the drills in a frame that holds it in the proper position and provides the means to force the bit into the concrete by lever action. Tractor-mounted equipment is available to drill multiple holes at the same time.

A quick setting, non-shrinking mortar or a high-viscosity epoxy can be used to permanently anchor the dowel or rebar in the hole. The holes should be completely filled around the dowels and rebars to insure that they are permanently fastened to the existing concrete. The bars should be dipped in the epoxy or grout and worked back into the holes for complete coverage around the bar so that it will be securely fixed into place. The end of the dowel bar that extends into the patch area should be greased to provide free movement. Other suitable bond breaking materials can be used besides grease.

Corrosion of dowel bars has become a common problem in areas where deicing chemicals are used. For that reason, the use of coated dowel bars or corrosion resistant dowel bars is recommended.

## Concrete Placement and Finishing

Some of the critical aspects of concrete placement and finishing include (1) adequate consolidation, (2) avoiding a mix that is either too stiff or has too high a slump, and (3) ensuring a level strike-off finish.

1. Each patch should be cast in one continuous full-depth operation. The concrete should be consolidated in place by use of an internal type vibrator. The concrete should be consolidated around the edges of the patch and internally. Internal vibrators for consolidating the concrete should be of an approved mechanical spud type. The vibrators should be capable of visibly affecting the concrete for a distance of 12 inches from the vibrator head.

2. The concrete mixture should have a slump of approximately 2 to 4 inches at the patch site for best placement. However, this may vary depending on additives and construction conditions. A mix too stiff or too fluid could provide serious placement problems. The use of a superplasticizer as discussed previously can help in providing a workable mixture. Workmen should not add excessive water just to get a highly flowable mix as this will weaken the concrete and cause higher shrinkage. Workmen should also not add water to the surface when finishing the concrete because this too will adversely affect the durablity of the concrete surface.

3. Short patches that are generally less than 12 feet can be screeded either transversely or longitudinally. If a pavement is rutted, screeding in the longitudinal direction (placing the screed parallel to the centerline) may be preferable because the patch will match the existing cross section of the pavement. For patches over 12 feet in length, the screed should be placed perpendicular to the centerline.

While the concrete is still plastic, the contractor should test the patch surface for trueness and for being flush with the edges of the adjacent slabs by use of a straightedge and in accordance with the following.

1. For patches 10 feet or less in length, the straightedging should be done by placing the straightedge parallel to the pavement centerline with the ends resting on the existing pavement and drawing the straightedge across the patch. The straightedge should be in contact with the existing pavement while drawing it across the patch and any high or low spots exceeding 1/8 inch should be corrected. If any corrections are made, the surface should be rechecked.

2. All transverse and longitudinal joints should be edged (either by tooling while the concrete is plastic or by sawing) to prevent chipping and subsequent spalling of the edges.

3. The surface of the concrete should be textured to match the surrounding pavement, except when a grinding operation follows.

## Curing and Opening to Traffic

AMBIENT TEMPERATURE AND THE TEMPERATURE OF THE CONCRETE AT THE TIME OF PLACEMENT HAVE BEEN FOUND TO BE THE MOST CRITICAL FACTOR IN THE STRENGTH DEVELOPMENT OF CONCRETE PATCHES. The temperature in the patch concrete will be higher than ambient or cylinder/beam temperatures. This difference ranges from 10° to 30°F at 4 hours after placement for non-insulated patches.

Concrete curing compound should be added as soon as the concrete surface has set sufficiently to apply the curing agent without damage. The curing compound should be applied immediately after texturing at the rate of 1 gallon per 150 square feet.

Portland cement concrete patches should not be placed when the air or base material temperature is below 40°F unless the patch is adequately insulated. Insulation blankets having a minimum thickness of 2 inches should be used. Edges and seams in the blanket should be secured to prevent penetration of wind. Test beams or cylinders should be cured the same as the patch on the job site. Insulation may be used to improve the rate of curing. If an insulation blanket is placed over the patch, the temperature differential at 4 hours may be as high as 40°F. Thus, for rapid curing (particularly in cold weather), it is strongly recommended that insulation blankets be placed over the patch. Class E (ASTM C-208) insulation board works well and is more stationary than blankets.

Polyethylene sheeting should be placed on the concrete surface before placing the insulation. The w/c ratio and rapid setting additives such as calcium chloride also have a significant effect on rapid strength development during the first few hours after placement. The shortest curing time can be obtained by using a combination of calcium cloride, superplasticizer and insulation blankets, Type III cement, and set-retarder (if needed). Table 1-1 provides recommendations on early opening of concrete patches.

Please note that the data in Table 1-1 indicates the strength versus time for a 7 bag mix. The more commonly used 8 and 9 bag mixes produce significantly higher early strength concrete.

There are generally two criteria that may be used to specify when patches can be opened to traffic.

1. Most often, SHA's specify the minimum strength of beams or cylinders. The minimum strength before a patch can be opened to traffic varies widely between agencies (e.g., 300 to 650 psi modulus of rupture). A modulus of rupture of 300 psi for center point loading, or 250 psi for third point loading, or 2500 psi for compressive strength of specimens cured similar to the patch are believed to be adequate for opening to traffic. The actual strength of the patch will be higher than the beams or cylinders because the temperature in the patch will be higher from the heat of hydration.

2. An SHA could specify the mixture and curing procedures and then, based on testing results, set the minimum time to opening to traffic. If this is done, the time to opening should be dependent upon the ambient temperature at time of placement. The recommendations in Table 1-1 are based on laboratory and field tests conducted by the Department of Civil Engineering at the University of Illinois. These recommendations should be carefully considered by an agency before adopting and should be adjusted to local conditions where needed. This data is under evaluation and may be modified in the future.

Table 1-1. Example Minimum Opening Times for Concrete Patches

| Ambient Temperature At Placement (°F) | Minimum Opening Times (Hours)*** | | | |
|---|---|---|---|---|
| | | Regular Patch with Addition of | | |
| | Regular* Patch | Super Plasticizer | Fiberglass** Insulation | Super Plasticizer and Insulation |
| 40 | 42 | 27 | 18 | 12 |
| 44 | 34 | 22 | 16 | 10 |
| 48 | 28 | 18 | 14 | 9 |
| 52 | 24 | 16 | 12 | 8 |
| 56 | 21 | 13 | 11 | 7 |
| 60 | 18 | 12 | 10 | 7 |
| 64 | 16 | 10 | 9 | 6 |
| 68 | 14 | 9 | 8 | 5 |
| 72 | 12 | 8 | 8 | 5 |
| 76 | 11 | 7 | 7 | 5 |
| 80 | 10 | 6 | 7 | 4 |
| 84 | 9 | 6 | 7 | 4 |
| 88 | 9 | 5 | 6 | 4 |

Note: *Regular patch - 7 bags/cu.yd., 2 percent calcium chloride, Type I cement, w/c - 0.4

**Insulation should not be used when the ambient temperature is greater.

***Opening times (hours) are given for a modulus of 250 psi (third point loading), or 300 psi (center point loading) for the patch concrete.

## Method of Payment

Based on the difference in unit cost between small area patching and larger slab requirement, two or more pay items should be included in the pay schedule. For example, one agency has the following three sizes: Type I - less than 5 square yards, Type II - 5 to 15 square yards, and Type III - greater than 15 square yards.

CHAPTER 2

# FULL DEPTH REPAIR
# OF
# CONTINUOUSLY REINFORCED CONCRETE PAVEMENT (CRCP)

## Introduction

Certain types of distress are unique to CRCP and conventional methods of rehabilitation used for jointed concrete pavements may not apply to CRCP.

The most common distress in CRCP is an edge punchout which is simply a section of concrete between transverse cracks that is depressed (punched down) below the surface of the surrounding slab.

## Patch Boundaries

In most cases the base material beneath an edge punchout is disintegrated on all sides of the distress (typically 2-3 feet). Therefore, the overall area of the patch should include the deteriorated base material.

## Tied Steel Patch

The distressed portions of the CRCP and base should be incorporated within the center section of the patch. The end sections and the center section of the patch should be a minimum of 2 feet long (see Figure 2-1).

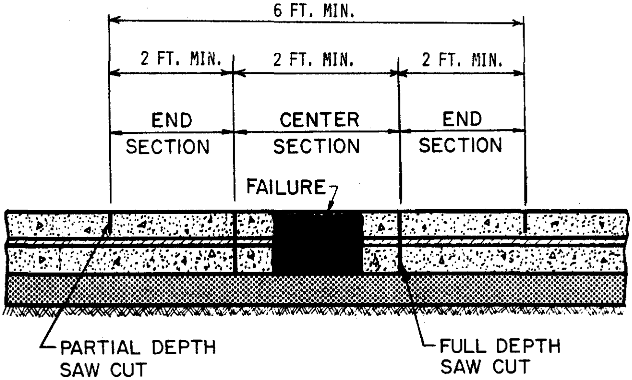



Figure 2-1

Welded Steel Patch

The distressed portion of the CRCP and base should be incorporated within the center section of the patch. The end section of the patch should be a minimum of 8 inches long (see Figure 2-2).

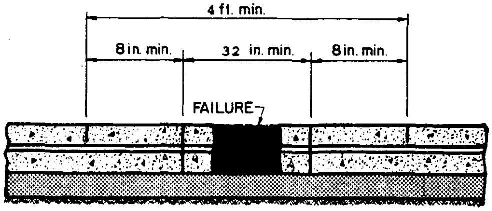



Figure 2-2

Minimum Distance to Crack

The outer patch boundaries should be located at least 18 inches from the nearest transverse crack (see Figure 2-3).

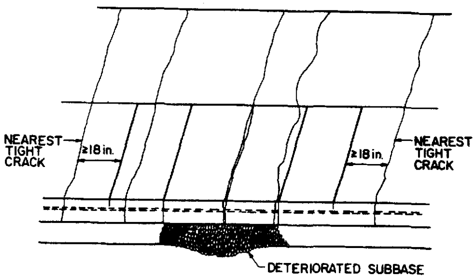



Figure 2-3

Sometimes the crack spacing is small and it is necessary to place the boundary closer than 18 inches; however, it should not be closer than 6 inches. The outer patch boundaries should not cross a transverse crack because it may lead to spalling and breakup in the slab.

Width of Patch

In most instances the width of the patch will be equal to a full lane width. Distress types such as wide cracks, large edge punchouts, blowups and other distresses occurring over more than half of the lane should be patched over a full lane width (12 feet).

In some cases, such as a small edge punchout, the width of the patch need not be a full 12 feet. In these cases, a longitudinal boundary can be established. A minimum patch width of 6 feet should be used. Patch widths beween 6 and 12 feet can be used as long as the longitudinal boundary is placed between the reinforcement and the joint does not fall in the center of the wheel path.

Failure Across Two or More Traffic Lanes

Whenever a failure occurs across two or more lanes, it is believed that the following simple procedures will provide additional performance.

1. Patch the passing lane first.
2. Next patch the heavy truck lane.

The above sequence is recommended because the first patch will crack more than the second patch because the first patch has to withstand most of the stresses caused by slab movement. Placing the patch at the end of its expansion cycle (generally in the late afternoon) can reduce crushing caused by expansion. Also, significant contraction can cause cracking. Since the truck lane receives the greatest loadings, it is that patch that should begin its service life with the fewest cracks. Cracks formed in the passing lane patch should not readily break down because of the reduced heavy traffic.

Sawing Patch Area

Sawing all the outer boundaries of a patch is recommended. Experience has shown that the outer boundaries of a patch will spall if cut by jackhammers or other breakout equipment, or if they follow an existing crack. Consequently, the proper sawing equipment should be utilized and light hammers (30-40 lbs.) should be used to remove the end sections.

The outer boundary of the end sections should be a partial depth saw cut 1-1/2 to 2 (see Figure 2-4) inches deep that does not cut the reinforcing steel. The boundary between the center section and the end section should be a full depth saw cut through the reinforceing steel.

If the width of a patch is less than a full lane, the longitudinal boundary should be sawed to a partial depth in order to provide an irregular face for better bond and aggregate interlock.

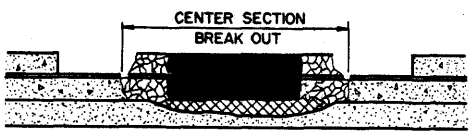



Figure 2-4

## Concrete Removal

There are basically four construction methods used to remove concrete from the center section of a patch area.

1. One procedure is to break up the concrete with jackhammers and shovel it out with hand tools. The advantages of this method are that a minimum of equipment is needed and if the work is done carefully, damage to the base and the adjacent slab is avoided. Unfortunately, this is the most time consuming, labor intensive, and the most expensive method.

2. The removal process can be shortened by using a pavement breaker and a backhoe. Breaking the concrete by dropping a wrecking ball or using a drop hammer should not be permitted because the shock waves can damage the adjacent concrete and disturb the base material.

3. The third method that has been used successfully is to lift the concrete using a front-end loader. The common procedure is to break the concrete with jackhammers on all sides of the center section. The front-end loader is used to lift one end of the slab. Chains are connected to the exposed steel at the other end of the slab and secured to the bucket. The slab is then lifted out and placed in a truck. This method can be accomplished in a shorter period of time and does not damage the base or the adjacent CRCP. Also, this method does not work very well in badly "D" cracked material or where bituminous patches are being removed. Disposal of the slabs can also be a problem.

4. The fourth method uses lifting pins. This procedure requires at least two drilled holes, lifting pins, and equipment capable of lifting the concrete slabs. A 5-inch wide strip of the CRCP center section should be removed to avoid binding (see Figure 2-5).

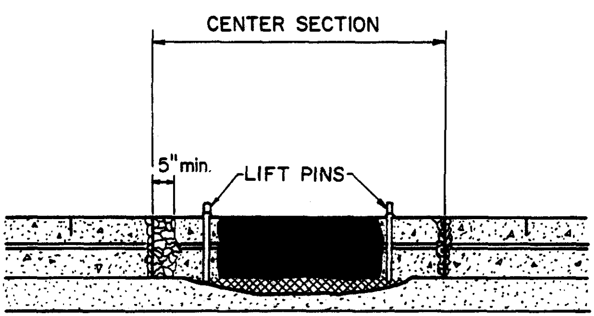



Figure 2-5

Figure 2-6 shows a typical reusable pin that has been used effectively. The holes should be positioned to distribute the load as evenly as possible. The number of pins used will depend on the size and condition of the slab and on the capacity of the chain. This method can be accomplished quickly and normally leaves the base material and adjacent CRCP undisturbed.

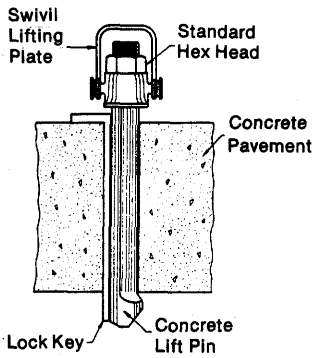



Figure 2-6

End Section

Removal of the concrete from the end sections should be performed in the following manner (see Figure 2-7).

1. The concrete in the two end sections should be carefully removed so as not to damage the reinforcement in the lap area, and to avoid spalling at the bottom of the joint beneath the partial depth saw cut. This task should be acomplished by using light jackhammers (20 to 40 lb. range) and hand tools.

2. The reinforcement should not be bent during removal of the concrete since the bars cannot be properly straightened afterward. Bent reinforcement in the patch area will result eventually in the spalling and failure of the patch because of the large eccentric stresses carried by the reinforcement. Removing the concrete around the reinforcing steel without bending or damaging the steel is difficult.

3. The use of a drop hammer or hydrahammer should not be used in the end sections because this equipment will usually damage the reinforcement and/or cause serious undercutting beneath the partial depth sawed joint. As noted above, it is necessary to limit the size of the jackhammer operating at the joint to minimize undercutting beneath the reinforcement.

4. If a reinforcing rod is mistakenly or accidentally bent, it should be carefully and accurately realigned after the breakout of the concrete.

Figure 2-7

Evaluate the Conditon of the Base

The base should be undisturbed, sound and free of moisture. If the base is disturbed, the loose material should be compacted. If a drainage problem exists, it should be corrected (i.e., outlet drain, transverse drain, edge drain, etc.). If a serious drainage problem exists, the construction engineer should request a drainage analysis.

Tied Reinforcement

The same size reinforcing rods should be placed in the patch and spliced to the reinforcement at the ends of the patch by lapping. The required length of embedment of the existing reinforcement into the patch depends on the size and type of the reinforcement. The minimum embedment lengths are 18 inches for a No. 5 deformed bar and 21 inches for a No. 6 bar (see Figure 2-8). A minimum 2-inch clearance should be provided between the ends of the new rebars and the existing CRCP face to allow for possible expansion. The number and spacing of the new reinforcement should match the existing reinforcement in the pavement.

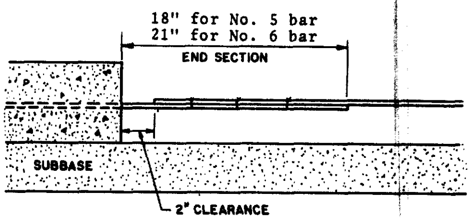



Figure 2-8

Welded Reinforcement

An alternative to tieing the renforcement is to weld the reinforcement using either a double 4-inch weld or a single 8-inch weld (see Figure 2-9).

1. The welds should be 1/4 inches and should be continuous.

2. Welding rail steel (ASTM A616 and AASHTO M42) should not be permitted because the inherent brittleness of the steel can cause the weld to fail.

3. AWS A5.1 E70xx electrodes should be used.

4. Arc strikes outside of the weld area and tack welding should be prohibited.

5. To avoid potential buckling, the reinforcement should be lapped and tied at the center of the patch. The minimum lap length should be 16 inches for a No. 5 bar and 19 inches for a No. 6 bar (see Figure 2-10).

6. Reinforcing bars should be dry when welded.

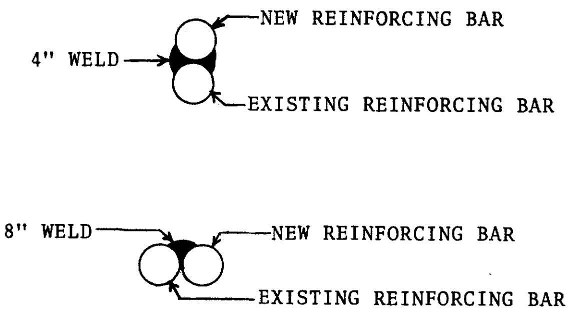



Figure 2-9

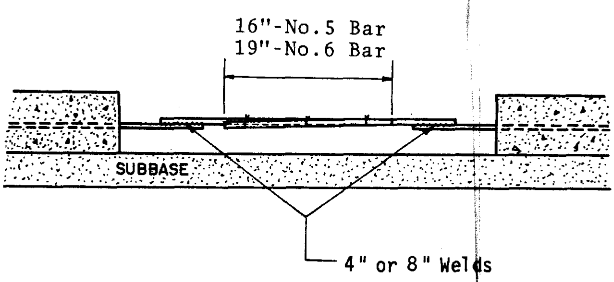



Figure 2-10

Placement

The new reinforcing steel should be placed as follows (see Figure 2-11).

1. Reinforcing steel should be placed with a minimum of 2-1/2 inches of cover. If the existing cover is less than 2-1/2 inches, place the spliced bar under the existing bar.

2. Reinforcing steel should be supported and tied to chairs when the patch length exceeds 4 feet. The chair spacing should be such that uniform unsupported lengths do not exceed 4 feet.

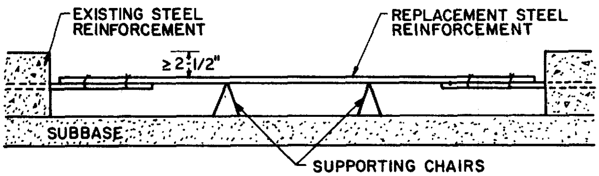



Figure 2-11

Bonding

A neat cement grout (cement plus water) should be applied to the joint faces immediately before concrete placement. The joint faces should be dry when the grout is applied.

## Materials and Curing and Opening to Traffic

See Chapter 1. The materials, curing, and minimum opening time are the same for patches in jointed concrete pavement and CRCP (see Table 1-1).

## Time of Placement

The change in ambient temperature in the initial 24-hour period following the placement of the patch is the most critical external factor affecting the success of a CRCP full depth repair. The full depth repair should be scheduled, to the maximum extent possible, when the change in the ambient temperature is at a minimum.

In addition, casting of a patch before noon is not recommended, especially during the summer months, because the expansion that generally occurs in the afternoon will crush the patch.

## Method of Payment

Full depth repair of CRCP can be paid by the square yard in place.

CHAPTER 3

# PARTIAL DEPTH PATCHING OF CONCRETE PAVEMENTS

## Introduction

This chapter covers permanent partial depth patching of portland cement concrete (PCC) pavements. This type of patching involves the repair of spalls at joints and/or cracks and other distresses which can be repaired by partial depth patches.

Spalls that extend below the midpoint of the slab cannot effectively be partial depth patched (e.g., pavement with "D" cracking that has deteriorated the bottom of the joints and cracks). A full depth patch should be placed in these cases.

The performance of partial depth patches has been excellent on many projects; however, the performance has been unsatisfactory on some projects. The failures are caused by lack of bond, compression failures of patches at joints, incompatible patch material, improper use of patch material, insufficient consolidation, differences in the coefficient of thermal expansion between the concrete slab and patch material, and improper cure. The working tolerances of some of the proprietary patch materials are too tight for normal construction practices. When properly placed with a durable patch material, the repair should last the remaining life of the pavement.

## Materials

The type of patch material that should be used will depend upon such factors as the amount of time available before opening to traffic, ambient temperature, cost, size, and depth of patches.

Portland cement concrete can be formulated to produce accelerated strength gain by using Type I or Type III portland cement and calcium chloride (or other accelerator) to obtain a minimum strength of 3000 psi in 24 hours, The plastic concrete should have an air content of 6 $\pm$ 2 percent. The slump should be 1 to 2 inches at the time of placing. Type III cement, with and without admixtures, has been used for patch mixtures longer and more widely than most other materials. It is low cost, easily available, and simple to use. The strength gain of rich mixtures (up to 8 bags) is rapid during warm weather and can be used when early opening (4 to 6 hours) to traffic is required. One disadvantage is that in cool or cold weather the rate of strength gain may be too slow to permit quick opening to traffic. Portland cement grout can develop an adequate bond for patches opened to traffic in 4 to 6 hours, however, it is questionable in cool to cold weather. An epoxy bonding agent can be used to produce high early bond strength in both hot and cold weather. The engineer should be assured that the epoxy bonding agent is compatible with the patch mix and the existing concrete prior to its operational use.

Normal set (3000 psi in 3 days) portland cement concrete patch materials may be used where the patch is protected from traffic for 24 hours or more. A cement grout (discussed later in more detail) may be used as a bonding agent. The patch mixture should be placed and consolidated to eliminate essentially all voids at the interface between the patch and adjacent concrete. All patches should be finished to the cross-section of the existing pavements.

A high percentage of repair projects requires patches to be opened to traffic within 4 to 6 hours. To meet this schedule, a wide variety of rapid setting and/or high early strength patching materials are available.

When using a proprietary patching material, it is important that the manufacturer's recommendations be followed closely. Handling, mixing, placement, consolidation, screeding, and curing of the patching material should be in accordance with the manufacturer's written instructions. The SHA should review and/or test the various patch materials to determine their compatibility and performance with the existing concrete.

Detailed information on patch material performance can be obtained from the FHWA Report No. FHWA-RD-74-55, entitled, "Concrete Patching Materials."

Available epoxy resins have a wide range of setting times. Epoxy concrete mixes should be compatible with the concrete in the pavement. Differences in the coefficient of thermal expansion can cause a patch to fail.

Preparation of Patch Area

The success of partial depth patching depends upon developing an adequate bond to sound existing concrete so it is important that proper surface preparation be done. This involves sounding the existing concrete with a steel rod, carpenter's hammer, chain or other device to determine the patch limits. Frequently, all the delaminated concrete is not removed. Therefore, the patch limits should be extended beyond the detected delaminated or spalled area by 3 to 4 inches to assure removal of all unsound concrete.

A 2-inch deep saw cut should be made around the perimeter of the patch area to provide a vertical face at the edge. When hard aggregate exists, a 1-inch depth saw cut is adequate. Vertical faces are necessary when using PCC as the patch material. Vertical faces may not be necessary for certain types of patching materials such as polymer concrete and epoxy concrete. Manufacturers of these types of materials make claims that the bonding strength of their material is strong enough to be used on tapered edges. States should assure themselves that such claims are valid. Manufacturers of proprietary patching material such as polymer and epoxy concretes, try to offset the generally higher cost of the patching material by eliminating the need for a sawed vertical joint.

Concrete within the patch area should be removed with pneumatic tools until sound concrete is reached. If the unsound concrete extends below the dowels, strong consideration should be given to full depth repair of the joint.

Where spalling has been caused by a metal insert such as a unitube, the spalls usually start at the bottom fin of the insert about 2-1/2 inches below the surface. When repairing this type of spall, it is recommended that the insert be sawed out along the entire length of the joint to avoid further spalls. The joints can then be resealed.

Small spall areas along joints generally do not need repair and the limits on the size of the spalls before repair, if required, can be set. For instance, areas less than 6 inches in length and 1-1/2 inches in width at the widest point need not be repaired but filled with a sealant (unless a preformed compression seal is to be used, then even small spalls must be repaired.

When removing the concrete within the patch area, it is important that proper equipment be used in order to prevent fracturing the concrete below the patch. Fractured concrete causes debonding of the patch. Pneumatic and hydraulic hammers should generally range from 15 to 30 pounds. Heavy hammers can result in fracturing the concrete below the required depth.

Cold milling equipment can and is being used to remove deteriorated concrete. The primary application of this equipment has been to remove large quantities of deteriorated concrete usually caused by "D" cracking or reactive aggregate. It should be noted that the cold milling process can produce fractured aggregate in the remaining layer of concrete. For that reason it is recommended that the cold milling process be expanded to remove all fractured material in order to provide a surface of sound concrete on which to bond the patching material. It has not been determined at this time whether sandblasting can remove all the fractured material left in place by the cold milling process.

Diamond sawing, either used alone or in conjunction with cold milling equipment, is a rapidly evolving process that may be an economical and satisfactory technique for removing spalled or deteriorated concrete.

After removal of the concrete, the surface of the patch area should be sand blasted followed by air blasting in order to remove all loose particles and dust. This generally requires shielding from traffic in adjacent lanes and/or some method of effective dust control.

The State highway agency should specify or approve a removal process that has been field tested.

Compression failure at joints is a major cause of patch failures. Compression failures occur simply because the proper spacing between the two faces of the joint is not provided. If the face of the patch (at the joint) extends beyond the face of the existing slab, the face of the patch will become a point loading when the slabs expand and the joint goes into compression. During certain periods of the year when nights are cool and daytime temperatures are high, the expansion and contraction cycles become more critical in partial depth patches.

In order to eliminate this type of failure, inserts should be placed in the joint to maintain the proper space between the patch and the adjacent panel. Styrofoam has been used for this purpose to separate the patch from the adjacent slab. In addition, the joint should be resawed to provide the proper shape factor for the sealant reservoir.

Placing Patch Materials

After the patch area is properly cleaned, a bonding agent should be applied. The type of bonding agent will depend upon the bond development requirements for opening to traffic. If early opening is required (4 to 6 hours), an epoxy agent should be used. A prime coat of epoxy-resin binder, thinned with three parts toluene to seven parts epoxy binder, by volume, should be applied to the dry, cleaned surface and sides of the repair area except for the adjacent joint face or crack. The prime coat should be applied in a thin coating and scrubbed into the surface with a stiff-bristled brush. A pressurized spray would be justified for large quantities. When spraying, care must be taken to apply the grout evenly. Placement of the concrete should be delayed until the epoxy becomes tacky.

When patches can be closed to traffic for a longer period of time (24 to 72 hours), a portland cement grout may be used for bonding the patch. The cement grout should be composed of cement and sufficient water to produce a mortar with a thick, cream consistency. The grout is scrubbed evenly on the dry surface of the patch. Excess grout should not be permitted to collect in pockets. The concrete patch material should be placed before the bonding grout begins to set.

When using an epoxy patch material, it should be used in accordance with the manufacturer's recommendations. Prior to placing the patch, the cavity is usually primed with a thin coating of epoxy resin binder scrubbed into the surface. The epoxy concrete or mortar is then placed in the cavity in layers generally not exceeding 2 inches. The time interval between placing of additional layers should be such that the temperature of the epoxy concrete does not exceed 140°F at any time during hardening.

Finishing, Curing and Opening to Traffic

Refer to these sections in Chapter 1 and see Table 1-1.

Concurrent Work

The following sequence of operations is recommended.

1. Full depth repair
2. Subsealing
3. Partial depth repair
4. Diamond grinding
5. Joint and crack resealing

Measurement and Payment

Partial depth patching should be paid for at the contract unit price per square foot. Such payment should be full compensation for: all required sawing; removing the asphaltic concrete patching material or the spalled, broken or damaged portland cement concrete; cleaning the surface by sandblasting; furnishing, placing, finishing and curing the concrete patch, and forming a new transverse and longitudinal joint including all equipment, materials, labor, and incidentals necessary to complete the work.

# CHAPTER 4

# SUBSEALING AND SLABJACKING OF CONCRETE PAVEMENTS

## Subsealing

Subsealing is a nondestructive technique that fills voids under the pavement without raising the slab, displaces pockets of free water that contribute to pumping and erosion, and reduces the cracking and faulting that results from poor drainage and nonuniform slab support. New methods, materials, and equipment have been developed to accomplish this work more rapidly and efficiently.

Subsealing is done after slab replacement and full depth patching. Partial depth patching, should be done after subsealing has been completed. Some contractors suggest a minimum length of 2 miles of pavement be made available for subsealing at one time to accommodate the various operations involved and to achieve the greatest efficiency from labor and equipment.

Since the purpose of subsealing is to stabilize the slab by filling the voids without lifting the slab, it is important to detect upward movement of the slab during the subsealing operation. If lifting occurs, more voids will be created under the pavement along with higher stresses in the slabs. Therefore, lifting should be avoided. Some slight movement may be unavoidable; specifications usually allow no more than 0.05 inches. Lift can be monitored by beam devices (equipped with sensitive dial gauges) in contact with the pavement and shoulder.Extrusion of grout from cracks, transverse or shoulder edge joints is another indication that voids have been filled.

The stability of the slabs should be tested 24 hours after the subsealing is completed. If stability is not achieved, a slab should be regrouted and retested 24 hours later. New holes should be drilled for each regrouting operation. If a slab is still unstable after two attempts to underseal, then consideration should be given to replacing the particular slab.

Voids often exist under the shoulder as well as under the mainline pavement. With good grout distribution, the grout should also fill these voids. However, being narrower and generally somewhat thinner, the shoulder pavement may be more readily lifted by the grout under pressure. Raising of the shoulder must be avoided; the measuring device must be closely monitored to detect the point where all voids have been filled and lifting begins so that subsealing can be stopped.

Slabjacking

Slabjacking is a technique that raises the concrete pavement slabs to restore rideability. That is, its purpose is to restore the original (or an acceptable) profile. To be successful, slabjacking should be done with care. When it is done correctly, slabjacking can be more economical than slab replacement and it is usually completed in less time with minimum interference with traffic. If voids exist along with slab settlement, slabjacking can also restore the structural integrity of the pavement.

Generally, an arrangement of string lines and blocks is used to determine the desired elevation (Figure 4-1). The string line is usually positioned about 1 inch above the desired grade. Gauge blocks placed on the slab indicate the progress of lifting. As the blocks approach the stringline, the rate of lifting is slowed and pumping is stopped completedly when the blocks touch the line.

Slabjacking is usually not possible or always practical when the temperature is high because the slabs have expanded and the joints are in compression. On the other hand, when correcting a profile deficiency of greater length, such as over an embankment settlement, the work will more likely be successful when the slab is in full compression and the joints tight, so that an entire run of depressed pavement can be lifted uniformly. This must be done a small amount at a time, working progressively toward the low point in the depression or outward from it as previously discussed.

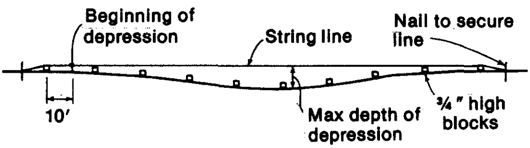



Figure 4-1

When a section of pavement is on a vertical curve, the offset distances must be calculated and applied to the height of the gauge blocks to properly set the profile of the surface.

Pumping and jacking should normally start at the lowest point in a depressed area and work outward in both directions. Greater amounts of jacking are necessary at the low points during the jacking sequence.

Lifting should be done in increments of approximately 1/4 inches with frequent changes in injection locations to keep slab stresses to a minimum and avoid cracking. The rate of grout injection should be uniform and as slow as possible (consistent with economy), usually 1/2 cu. feet per minute to a to 2 cu. feet per minute. Initial pumping is usually at the slower rate and is increased as lifting progresses. As the desired elevation is approached, the lifting rate should be reduced.

Regrouting in new drill holes and further slabjacking are necessary when grout is extruded from joints, cracks, or the pavement edge before the target elevation is reached.

Proper control of grout pressure is the single most important factor affecting slabjacking. Gauged pressures for slabjacking are usually in the range of 50 to 250 psi, with an occasional need for additional pressure of up to 600 psi to initiate lifting. Gauges should be continually monitored for sudden pressure changes. A rapid increase could signal a stoppage of flow that could be followed by a build up of pressure and an excessive lift and cracking if pumping were to continue. A sudden reduction in pressure could indicate a loss of lift from subsurface leakage, escaping grout at slab edges, and so on.

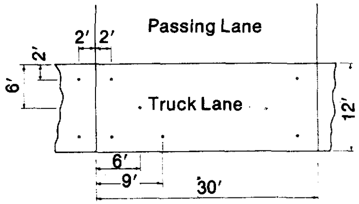
Hole Patterns

Grout holes should be drilled in a pattern determined by the SHA in consultation with the contractor.

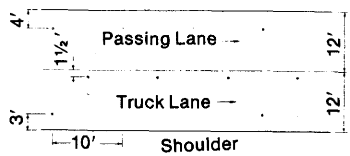
Hole patterns for effective distribution of cement grout are not easily determined in advance. Some preliminary testing is often necessary to locate holes in a way that will ensure good grout distribution. When a hole pattern is selected for repetition in each panel, the pattern should provide sufficient holes to permit grout to reach all voids existing beneath the pavement.

Hole patterns vary with the concrete pavement design, whether jointed plain, jointed with mesh reinforcement, or continuously reinforced. Each design varies in panel length, performance characteristics, and distress patterns, and subsealing techniques should be adjusted accordingly. Grout subsealing contracts should have enough flexibility in the specifications to allow the engineer to take advantage of the expertise of specialty contractors who are usually skilled in determining grout hole locations.

Figure 4-2 shows typical hole patterns used by States for two designs; one plain pavement with short panels and the other continuously reinforced concrete without joints.




Typical hole pattern used in subsealing under plain pavement.




Typical hole pattern in CRC pavement.

Figure 4-2

The use of a fixed hole pattern can result in forcing grout into areas under slabs where subsealing is not required. Predetermining the void locations as discussed in the following section "Void Detection" may be a more efficient and economical approach.

The American Concrete Pavement Association (ACPA) is currently experimenting with a technique that includes drilling two holes about 2 feet from the joint on the "leave" side of the slab. Early results show no difference in deflection or in amount of grout used in these two locations. These experiments were on plain pavements with short joint spacings. Since it is likely that most voids under a pavement with this design are located at or just ahead of the joint, this variation in hole pattern is a logical one. It gives promise of being more effective while reducing the cost of both materials and labor. However, this may not be applicable in all cases. There can be pumping action that produces voids on each side of the joint.

Hole patterns for slabjacking are normally different than those for subsealing and they should be determined in the field taking into consideration the following: the size or length of the pavement area to be raised; the elevation difference; subgrade and drainage conditions; and location of joints and cracks. An example of a jacking hole pattern and profile are shown in Figure 4-3.

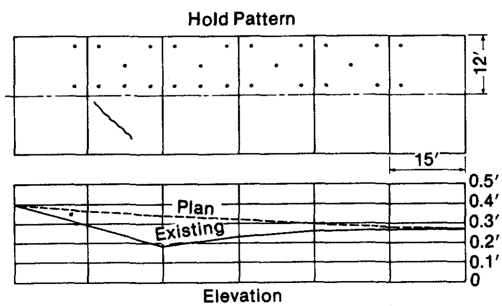



Figure 4-3

## Void Detection

Several methods of void detection are in use. Perhaps the simplest is a visual inspection of the pavement to locate areas of distress. The following visual observations can indicate the presence of voids.

1. Depressions or holes at the edge of the shoulder.

2. Ejected base or subgrade material deposited at the edge of the shoulder.

3. Vertical movement at joints or cracks.

4. Faulting at joints or cracks.

The two most common methods for measuring slab movement are the (1) loaded vehicle and (2) deflection devices.

1. LOADED VEHICLE. Two gauges are needed that can measure slab movement to 0.001 inches. The Benkelman Beam is often used for this type of measurement. A gauge mount should be positioned with one gauge referenced to the corner of each slab on both sides of the joint near the shoulder edge perpendicular to the pavement joint. The gauges should then be zeroed with no load on the slab on either side of the joint. A load truck should then be moved into position and stopped with the center of the 18 kip loaded axle about 1 foot behind the joint and the outside test wheel about 1 foot from the pavement edge. Both gauges should then be read. The loaded truck should then be moved across the joint to a similar position about 1 foot past the joint. Both gauges should again be read. This procedure is used for each joint to be tested.

2. DEFLECTION DEVICES. Deflection devices such as the Falling-Weight Deflectometer, Dynaflect, Road Rater, Heavy Load, and Thumper measure the deflection response of a pavement under a dynamic load. The loading plate should be placed as close as possible to the slab corner. Load transfer should be measured with sensors that are placed adjacent to the joint or crack on the loaded and unloaded side.

Deflection testing should be performed between the hours of midnight and 10 a.m. to avoid the problems caused by temperature differential (slab curl) and slab expansion (joint closure).

## Drilling

Holes drilled through the slab should be vertical and carefully made so that they are circular and the plugs can fit tightly to completely stop grout extrusion when adjacent areas are grouted. Grout holes are generally 1-1/4 inches to 2 inches in diameter. There does not appear to be an advantage or lifting superiority attributable to larger hole sizes. Fewer breakouts are produced at the bottom of the slab with smaller-diameter drills. Hole diameters of 1-1/4 inches to 1-1/2 inches are recommended. When specifying the hole diameter, the SHA should use a range (such as the above) rather than one specific size in order to best utilize the contractor's existing equipment. Otherwise, a contractor (or subcontractor) will be forced to purchase new drills, packers, etc., which will be reflected in the cost of the project.

Grout holes can be made with any type of drill that will produce a clean hole with no surface spalling or breakouts on the underside of the slab. Most drilling is done with pneumatically operated rotary percussion drills with carbide tips. Typically, this type of equipment can drill a hole in less than 1 minute.

High speed drills mounted on a large rubber-tire tractor are frequently used. The drill frame is sometimes weighted to increase drill pressure. The question has been raised whether drilling at high speed under added pressure will break the concrete at the bottom of the slab. Studies by the New York Department of Transportation found that the size and weight of rock drills were very important factors in the amount of damage sustained by the pavement. Units with a hammer weight of 45 pounds were satisfactory; drills of greater weight and greater downward pressure resulted in cone-breakout damage to the underside of the slab and subsequent radial cracking. There was also a greater frequency of transverse cracks through the drill holes when the heavier machines were used.

Some caution should be exercised in determining the optimum drill size and weight and proper drilling procedures in order to correlate maximum drilling efficiency and economy with minimum damage to pavement.

Depth of the grout holes will vary with underlying materials and construction. In general, drilling should be through both the pavement and the base. Experience has shown that voids are sometimes found under a stabilized base. The bottom of the grout injection pipe should not be any lower than the bottom of the concrete slab to allow grout to fill all voids below the concrete slab as well as those that may exist below the base (Figure 4-4). Where grout flow is difficult to get started, washing or blowing out a small cavity at the bottom of the grout hole will furnish a supply of grout to help initiate its flow to surrounding voids.

For safety and economy, drilling should be done just prior to pressure grouting so that both crews can be protected by the same traffic control devices. For the same reasons, it is also wise to confine the drilling and grouting operations to a single traffic lane at one time.

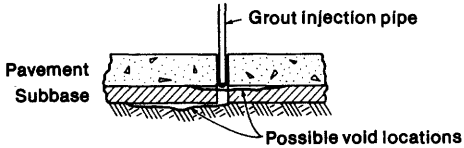



Figure 4-4

## Grout Mixing, Pumping, Distribution

Modern grouting contractors use highly mobile, self-contained units to carry all equipment and material components for the subsealing operation. Dry materials are normally packaged in uniform-volume bags or measured by weight if in bulk.

Mixing water is metered from a supply truck. Dry materials are normally proportioned on a volumetric basis for better control. The mixer should be capable of thorough, homogeneous mixing, and should be the positive shear type for thorough mixing. One specialty contractor using cement-pozzolan grout recommends use of a high-speed colloidal mixer operation in the range of 800 to 2000 revolutions per minute in order to attain a true colloidal mix that will keep the solids in suspension and resist dilution by free water being displaced from under this pavement.

The pump should be capable of applying 50- to 250-pound psi pressure at the outlet end of the discharge pipe. The pump should be of the positive displacement type and should be equipped with horizontal mixing paddles. The agitation from such mixing maintains a uniform consistency and assists in feeding the grout to the pumping unit.

After the holes are drilled in the pavement, pumping proceeds by lowering the grout injection pipe into successive holes. An expanding rubber packer is used to seal the open space between pipe and drill hole. The discharge end of the pipe should not extend below the bottom of the pavement so that any voids between pavement and base will be filled with grout. The injection pipe carrying the grout to the drill hole should be equipped with a return line to the pump hopper so that the grout mixture can be continuously circulated during periods when no grout is being placed.

For proper distribution of grout, the injection pressure should be in the range of 50 to 250 psi. The lower pressures should be used where void filling only is being done. Greater pressures may be needed for slabjacking, but pressures that are too high can contribute to radial cracking at drill holes.

Grout quantities can be estimated and checked by the hole and by the joint. Typical quantities run from 2 to 8 cubic feet of dry materials per joint and/or 0.6 to 1.0 cubic feet per hole. The higher quantities are for pavements with severe pumping and more voids.

## Grout Mix Requirements

Materials for pressure grouting should yield a grout mix that remains insoluble, incompressible, and nonerodible after it is pumped in place and has hardened. The slurry should be flowable with low internal friction so it can move through small openings and follow water channels to fill existing voids. At the same time, the grout mix should have sufficient body to displace free water from under the slab and should develop adequate strength and durability.

Pozzolanic materials have recently come into more general use in pressure grouting mixes because they produce greater strength and improved workability. The types of pozzolans include those occurring naturally (volcanic ash, diatomaceous earth) and those artifically produced in the combustion of coal (fly ash). These materials are classified under American Society for Testing and Materials (ASTM) Designation: C618. The predominantly spherical shape of the pozzolan particles and their fineness allow the grout to penetrate more steadily into the shallow voids under the pavement. Pozzolans in combination with the free lime resulting from cement hydration provide additional cementation, enhancing the possibility of greater stability in the cement-pozzolan grout. A typical mix design is:

1 part cement, Type I or Type II
3 parts pozzolan, natural or artificial
Water for proper fluidity

A one to three cement-pozzolan mixture should develop sufficient strength to preclude grout erosion that could result from hydraulic action under a heavily trafficked pavement. Cement-fly ash grouts have been shown to lose fluidity within approximately 20 to 30 minutes after placement. Since the grout is normally confined and cannot be displaced laterally, it is capable of supporting traffic loads long before the set times shown by accepted test methods. Results of laboratory tests and the successful return of treated slabs to full traffic immediately following grouting have given rise to recommendation that vehicular traffic be permitted on newly grouted slabs 1 hour after pressure grouting is completed.

Use of admixtures with cement-fly ash grout mixes should be done with care. Laboratory tests have shown a variety of reactions between pozzolans admixtures. Each admixture should be tested and evaluated prior to final approval. These admixtures may be water reducers, fluidifiers, expanding agents to offset shrinkage or calcium chloride.

If the ambient temperature is below 50°F, an accelerator could be used subject to approval by the SHA. When calcium chloride is added, it should be thoroughly premixed with the water before the dry ingredients are added. When dry ingredients are added to a mixed batch to thicken its consistency, they must be in the specified ratio.

Subsealing or slabjacking should not be performed when the ambient air temperature is 35°F or below, or when the subgrade is frozen.

Consistency Tester

The required water content is determined by a flow cone. A flow cone of the type and dimensions developed by the Corps of Engineers (Figure 4-5) is commonly used to periodically check the consistency of the grout. The time required to empty the cone measures the flowability of the grout mixture. This flow in seconds (time of efflux) is determined by Corps of Engineers Test Method No. CRD-C611-80. Flow cone requirements and instructions are readily available.

Consistency should be checked by the flow cone method twice each day. The flow time generally varies between 10 and 16 seconds for subsealing depending on the type of material in the grout. At the beginning of a slabjacking operation, the flow time of the grout mixture should be between 16 and 25 seconds to allow a more fluid mixture to lift the slab uniformly. However, if this grout consistency fails to lift the slab, the grout mixture should be gradually changed to a lesser flow (stiffer mix) in order to increase the pressure and lift the slab.

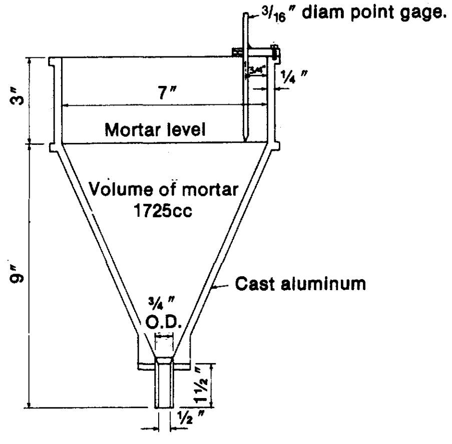



Figure 4-5

As required by the SHA, the contractor should submit mill certifications for the cement, physical, and chemical analysis for the pozzolans, grain structure analysis for the limestone dust, and independent laboratory testing of the grout slurry. Test results of the slurry should include 1 day, 3 day, and 7 day strengths, flow cone times, shrinkage and expansion observed, time of initial set, and water retentivity.

## Plugging and Clean Up

After grouting has been completed at each hole, the packer should be removed and the hole plugged immediately with a tapered wooden plug. The tapered plugs, however, are only temporary. When sufficient time has elapsed to permit the grout to set sufficiently so that back pressure will not force it from the hole, the temporary wooden plugs should be removed. Each hole should be permanently sealed flush with the pavement surface with a fast setting sand/cement or polymer concrete mix approved by the engineer.

Grout and cement slurry on the pavement or shoulder surface should be broomed and washed off to avoid unsightly discoloration and to remove the grout or slurry before it bonds to the surface.

## Allowable Curing Time

Specifications for the time allowed to permit traffic on grouted slabs vary considerably. The cure time ranges from 30 minutes to 3 hours depending on the mix composition and the degree of confinement of the grout.

## Method of Payment

The following are three common methods of payment. An SHA should use whatever method best suits its particular project.

1. Pay quantity per test location (i.e., joint or crack). Payment per location should include both the initial testing and any subsequent testing (e.g., the contractor should be paid only once for the deflection testing no matter how many times retested).

2. Pay quantity per hole drilled. Payment includes drilling, plugging, and hole sealing.

3. Unit price by volume or weight of dry material(s). Should include mobilization, water, additives, equipment, labor, and all other materials necessary to mix and pump the grout.

## Summary

While it may appear that subsealing and slabjacking are simple processes of drilling and pumping, the procedures described require considerable expertise to successfully correct unsatisfactory conditions without damage to the pavement. If slabjacking is not done uniformly, it very often causes cracking.

The techniques applied in subsealing and slabjacking are not precisely defined; the process is as much an art as a science. The success of a project is largely dependent on the skill and expertise of the contractor and the crew doing the grout injection. Because it is a highly specialized operation requiring trained personnel and equipment designed for a particular purpose, this type of work is particularly suited to specialty contractors experienced in successfuly performing these restoration procedures.

# CHAPTER 5

# DIAMOND GRINDING OF JOINTED CONCRETE PAVEMENTS

## Introduction

Diamond grinding is used to restore profile and cross-section; eliminate rough ride due to faulting, slab warping, and wheel ruts; and to restore a good skid resistant texture to the pavement surface.

The cost of grinding is primarily dependent upon the amount of material to be removed and the hardness of the aggregate. On a typical project the cost of grinding for soft aggregate is in the range of $2 to $3 per sq. yd., for medium hard aggregate, $3 to $5 per sq. yd., and for hard aggregate $5 to $8 per sq. yd. (1981). Costs are also affected by the size of the project, traffic control procedures, work hours, slurry disposal, and the degree of smoothness specified.

The cost effectiveness of diamond grinding is significantly changing with current equipment and blade developments. These developments include larger and more powerful equipment (6 foot cutting width), different types of segmental cutting heads and blade development to increase the life of blades.

## Blade Spacing

The single most important factor affecting the pavement rideability and texture is the spacing of the diamond saw blades. Blade spacing in the cutting head can be varied to improve the life and friction factor of the texture.

Basically, blade spacing is determined by the hardness of the aggregate in the concrete pavement. The following is general criteria for blade spacing for soft aggregate (susceptible to polishing) and hard aggregate.

For soft aggregate, the spacing should be wider to provide more "land area" between the blades for a longer lasting texture. The grinding chip between the blades, should be 0.080 inch minimum and have an average thickness of 0.100 inch (Figure 5-1).

Surface Texture

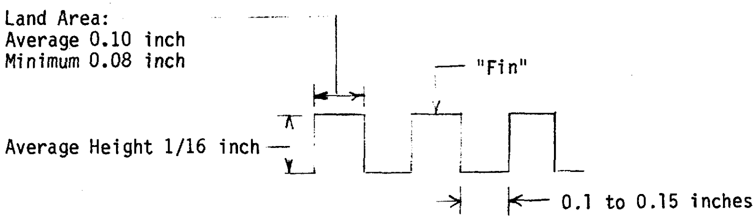



Figure 5-1

For the purpose of this chapter, we will define the hardness of aggregate by the Los Angeles Abrasion Number (L.A. Abrasion No.). However, the L.A. Abrasion No. is not and should not be used as the only criteria to judge the hardness of aggregate.

Hard - up to 40
Medium - 40 to 50
Soft - over 50

For hard aggregate, the spacing should provide for less land area than for soft aggregate (Figure 5-2).

Surface Texture

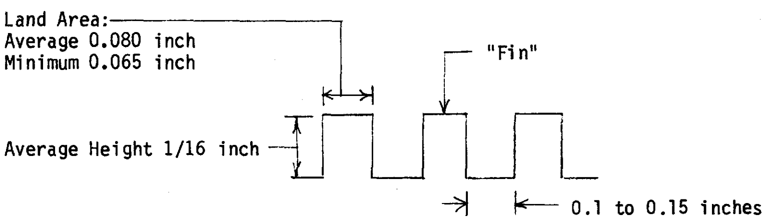



Figure 5-2

The blade spacing is the most important factor in producing the proper surface texture. The precise blade spacing should be determined for variations in the type of aggregate. Immediately after grinding, the "fins" have a somewhat uniform rectangular shape. However, the fins are designed to break off under traffic to form a corduroy type surface that produces a good skid texture and a high quality riding surface.

## Grinding Procedures

The plans should designate the areas of pavement to be ground. Water is used to cool the cutting head of the grinding machine. The slurry produced from grinding can be removed by one of two methods. It can be vacuumed from the surface and pumped into a tank truck with baffles which is costly, or it can be deposited directly on the grass shoulders which has not proven to be detrimental. A suitable disposal site should be provided when pumping adjacent to the roadway is not possible.

The grinding limits should be clearly shown on the plans and should include the transition or stop lines at bridges and ramps. The maximum overlap between passes should be 2 inches.

Grinding production is typically 50 machine hours per lane mile, but this will vary considerably with aggregate hardness and the roughness of the pavement. The direction of grinding should be the option of the contractor in order to minimize construction costs.

## Rideability

There are several methods used to measure the roughness of pavements. These include the California or Rainhart Profilograph, the Mays Ride Meter, PCA or Wisconsin Road Meter, GM Profilometer, and the BPR Roughometer.

It has been demonstrated on numerous projects that diamond grinding can produce a smoother pavement surface than new construction. This should be reflected in the SHA's rideability specification. As an example, SHA's using a profilograph specify a profile index of 12 inches per mile for construction and 7 inches per mile for diamond grinding. The above is only an example and the engineer should always consider cost effectiveness when specifying the profile index.

Where ruts are being eliminated by grinding, a string line can be used to check the transverse profile.

Specifications should permit feathering over portions of the surface when steel is found near the surface.

When an isolated low spot is encountered, the specification should not require grinding the low spot if it requires lowering the overall profile of the pavement. The cost effectiveness of the extra expenditure is highly questionable.

Transverse joints and random cracks should be inspected to insure that adjacent surfaces are in the same plane. Misalignment of the planes of the surfaces should not exceed 1/16 inch. In any 3 foot by 100 foot test area at least 95 percent of the surface should be textured.

## Concurrent Work

Slab stabilization by subsealing, full-depth replacement and spall repair should be completed before grinding. Experience indicates, that ground pavements without subsealing (when needed) can significantly reduce the life of the restored smooth profile. Resealing joints should follow the grinding operation to insure proper sealant depth.

## Method of Payment

Grinding can be paid for by the square yard. The contract price per square yard for grinding concrete pavement should be full compensation for furnishing all labor, materials, and equipment in accordance with the prescribed sections of the SHA's specifications and as shown on the plans.

# CHAPTER 6

## BONDED PCC RESURFACING OVER EXISTING CONCRETE PAVEMENTS

### Introduction

This chapter describes the concept of overlaying existing rigid pavement with bonded portland cement concrete to improve the structural integrity, improve the ride, increase the carrying capacity, improve the skid resistance, and extend the useful life of the original structure. Construction techniques will be discussed as well as those items which require particular attention in order to make an overlay project successful. Topics discussed will be surface preparation, bonding grout application, placement, jointing, finishing, texturing, curing and testing requirements, and basis of payment. Bonded PCC can be considered operational or experimental depending on the experience in a given State. This technique has proven successful on many projects. Like all other rehabilitation techniques, bonded PCC overlays require good quality control.

Surface Preparation The existing concrete surface must be cleaned of all deteriorated or contaminated material including tire rubber, dirt, oil drippings, and old lane line markings. The development of high production, self-propelled cold-milling equipment (CMI Roto-Mill, Galion Road Planer, Barber-Green Dynaplane, etc.) and improvements in air, water, sand, and shotblasting techniques (Gomaco) have resulted in high production cleaning processes. A general description of surface preparation equipment follows.

1. Milling/Scarifying Equipment - Consists of a power-operated, mechanical scarifier capable of uniformly scarifying or removing the old surface in a satisfactory manner to the depths and cross section required. Other types of removal devices may be used if their operation is suitable and if they can be demonstrated to perform to the satisfaction of the engineer. States commonly specify the removal of 1/4 inch of existing concrete surface.

2. Sandblasting - The sandblasting operation is generally used as a cleaning operation (not a removal operation), to remove loose chips of concrete, dried slurry resulting from the milling operation, and any contaminants that would interfere with the bond of the overlay. Adjacent traffic and property should be adequately protected and dust control should be maintained in order to provide good visibility in the work area. This cleaning normally involves removal of only 1/32 to 1/16 of an inch. A properly sandblasted surface should be cleaned to a point where the aggregate colors are clearly visible. The surface should then be power broom swept and/or blown off to yield the best results. Highway production sandblasting equipment usually requires and includes dust abatement.

3. Shotblasting - Shotblasting is similar to sandblasting except steel shot is used in place of sand as the abrasive element. There is equipment available that operates by bombarding the surface with steel pellets, thrown by a centrifugal blast wheel, rotating within a cleaning head. There is no loss or waste of abrasive media. Reusable pellets and contaminants rebound into a separator which automatically recycles the shot to the blastwheel, while dust and surface contaminants are discharged into the dust collector.

4. High-Pressure Waterblasting - High pressure waterblasters used for this purpose produce pressures in the range of 6000 to 10000 psi and are capable of removing many contaminants. Some equipment is capable of blasting with water and sand or other abrasives. This method of cleaning should not be used alone, but in combination with a primary cleaning method such as milling or shotblasting.

Most agencies specify the method and depth of surface cleaning rather than specifying a cleaned surface. The following sequential steps describe the commonly used methods to clean an existing PCC pavement in preparation for a PCC bonded overlay.

Step 1 - If an asphalt overlay exists, it should be completely removed by whatever method is the most practical.

Step 2 - Cold milling or shot blasting is the primary cleaning methods used to clean the existing PCC surface. It may be necessary to broom and/or vacuum after cold milling to remove debris.

Step 3 - Sandblasting or waterblasting is the secondary cleaning step that removes loose chips and latents. Normally, neither are required after shotblasting.

Step 4 - Airblasting is the final cleaning step used to remove dust and incidental debris. This step should be done just prior to applying the grout.

Step 5 - The surface should be completely dry. Surface moisture will weaken the bond between the overlay, grout, and existing surface.

In areas of surface deterioration, milling can be used to remove unsound concrete. Areas requiring partial depth scarification can be determined by visual inspection, sounding with hammers, dragging chains, coring, etc. These areas usually contain "D" cracked aggregate or reactive aggregate. When partial depth patches are required, refer to Chapter 3 of this handbook. If full depth repairs are needed, refer to Chapters 1 and 2 of this handbook.

## Bonding Grouts

Basically, there are two grout mixtures, (1) cement and water and (2) cement, sand, and water. Sufficient water is added so it can be applied with a stiff brush or broom to the old concrete in a thin, even coating that will not run or puddle in low spots.

The following mix designs for grout are suggested by the PCA:

| Grout Mix With Sand | | Grout Mix Without Sand | |
|---|---|---|---|
| Cement | 1376 lbs. | Cement | 1726 lbs. |
| Sand* | 1419 lbs. | Water | 853 lbs. |
| Water | 914 lbs. | | |

*Allowing 3 percent for moisture

Note: The water cement ratio should be no higher than 0.62 (7 gallons per bag of cement).

The grout should be agitated prior to and during its use. It should be used within 90 minutes from the time it is initially mixed to the time it is covered with the overlay. A grout of portland cement and water, applied by pressure spray, is being used by several SHA's because the operation has demonstrated a savings in time, cost, and labor.

Care should be exercised to insure that all parts of the surface receive a thorough, even coating and that no excess grout is permitted to collect in pockets. The inspector should make sure that grout properly covers the corner areas of the slabs where the maximum curling of the concrete occurs. This is the most likely place for debonding of the overlay.

The rate of applying grout should be limited so the grout does not become dry before it is covered with new concrete. The grout should be applied immediately in front of the paver. During delays in the surfacing operations, should the surface of the grout indicate an extensive amount of drying by a whitish appearance, additional grout should be applied. In areas where the grout becomes thoroughly dried, the grout should be removed by sandblasting or other acceptable method.

## Placement

Slip-form paving has been used almost exclusively since 1970 for PCC overlaying. Slip-form paving techniques are essentially the same for resurfacing construction as for original construction. The following are recommended during a slip-form operation.

1. The thickness between the new surface profile and the prepared surface should be checked before paving begins. Should problems exist in obtaining the minimum depth due to crown or surface irregularities, the existing pavement can be rescarified or the new profile can be adjusted.

2. The engineer should advise or consult with the contractor on the method to be used to relocate existing the joints so accurate joint saw cuts can be made in the new concrete.

3. The concrete should be placed per SHA specifications.

Side dumping and concrete distributors are recommended. End dumping is not recommended. Operating concrete trucks on the prepared surface present serious potential problems because the bonding medium is disturbed. Trucks contaminate the surface by tracking mud and dripping oil and grease on the clean surface. If end dumping is used, cleaning equipment should be readily available to remove oil spills and dirt. If this type of cleaning is done properly, it will add cost and slow the speed of the paving train.

When placing a concrete overlay, the temperature of the existing pavement surface is of particular concern. The rapid cooling of the existing pavement surface may result in shrinkage stresses in the resurfacing, which can cause cracking before joints can be formed. In addition, a hot surface will cause curling or warping of the resurfacing during the initial cure period. The latter effect can be especially detrimental to establishing bond. Scheduling construction during the spring, fall, or nighttime can alleviate the problems associated with hot weather conditions. Some SHA's have established 85°F as the cut-off for placing bonded PCC overlays.

Jointing

The joints in bonded concrete overlays should be given careful consideration if the overlay is to function properly. It is important that all working joints in the original pavement be reproduced in the overlay. Working joints are those joints that open and close with temperature variation and are not tied together by reinforcing bars. These are usually transverse contraction or expansion joints as opposed to longitudinal joints. Joints in the overlay should be directly over the joints in the old pavement and of equal or slightly greater width. All transverse contraction and expansion joints should be sawn the full depth of the overlay and longitudinal joints can be sawn 1 inch deep. If the joint in the overlay is narrower than the joint in the existing pavement, high stresses will develop during expansion and will usually cause debonding and spalling at the joint.

Although the need for joints in bonded resurfacings matching those in the existing pavement is recognized, their construction has created problems. Only small differences in locations of the joints can result in reflection cracking in the resurfacing. It is also not uncommon to find irregular joints in older pavements, or even worse, irregular cracks that are functioning as joints.

Joint construction in bonded concrete resurfacing has been accomplished by several means including depressed grooves in the plastic concrete, which are sometimes later widened by sawing; use of inserts installed in the plastic concrete; and sawing of the hardened concrete, including "green sawing," only a few hours after the concrete has been placed. Sawing has been the predominent method used to construct joints but reflection cracking has sometimes occurred within inches of the sawed groove. In these cases, it was presumed that the crack initiated at the bottom of the resurfacing before the saw cut was completed and then progressed along a path of least resistance to the surface, which may or may not be through the sawed groove. Early sawing, within 6 hours or less after placement, has been used to minimize this type of cracking.

All existing joints should be functioning properly before the concrete overlay is placed. A backer rope can be placed at the top of an existing joint if it is needed to prevent concrete from filling the reservoir or the joint. When concrete is placed over an expansion joint it is necessary to make two cuts in the plastic concrete and remove the thin center section of concrete.

### Finishing and Texturing

Finishing and texturing operations are the same for concrete resurfacing as for ordinary concrete pavement construction.

### Curing

As with any concrete pavement, adequate protection during the early curing period is extremely important to the success of concrete resurfacing. The most commonly used curing medium has been a white-pigmented, membrane-forming compound, which is sprayed onto the surface (at approximately twice the normal rate) following the finishing and texturing operation. Other types of curing media include wet burlap, polyethylene sheeting, and where temperatures may fall below 34°F, insulated blankets, etc. The curing medium is applied as soon as possible without damaging the surface texture.

Proper and adequate curing is more critical for bonded concrete resurfacing than for ordinary pavement construction. It is during the early curing stage that shrinkage and/or curling can create stresses at the interface that may exceed the bond strength and cause debonding, especially at the corners and edges of slabs. It is therefore, important to protect the bonded resurfacing not only from moisture loss but also from sudden extreme temperature changes.

Testing and Opening to Traffic

The following tests can be used as a general guide.

1. Slump - The slump of concrete, tested at time of placement, measured in accordance with AASHTO T119, should be 1-1/2 inches, plus or minus 1/2 inch.

2. Percent Entrained Air - The entrained air content of the fresh, unvibrated concrete, at the time of placement, as determined by AASHTO T152, should be 6.5 percent, plus or minus 1.5 percent.

3. Bonded Strength - The bond strength at the interface between old and new PCC should be a minimum of 200 psi when tested in accordance with "Method of Test for Determining the Shear Strength of Bonded Concrete." Test Method No. Iowa 406, June 1978, as developed by the Office of Materials, Iowa Department of Transportation.

4. Compressive Strength and Opening to Traffic - The pavement should not be opened to traffic until the concrete bonded overlay has attained a compressive strength of 3500 psi and has attained an age of 5 days. Construction traffic and other traffic in special cases could be allowed on the overlay when it has attained a compressive strength of 3000 psi or an age of 3 days. Concrete compressive cylinders should be tested in accordance with ASTM C39.

Note: Bond strengths as determined by a shear test, may frequently be 400 psi or more but strengths of 200 psi or even less may be adequate. The value of 200 psi as a desirable bond strength, has generally been accepted as a guide.

Basis of Payment

The following major items can be paid by the square yard.

1. Asphalt Removal. Should include complete removal and disposal.

2. Cold Milling or Shotblasting. Should include removal to the specified depth and disposal.

3. Sandblasting or Waterblasting. In the case of sandblasting, this item should include dust control.

4. Brooming and/or Airblasting. Should include disposal.

5. Partial Depth Repair. Should include removal and repair to specified depths.

6. Full Depth Repair. Includes removal and repair.

7. PCC Bonded Overlay. Should include placing, finishing, texturing, and curing the concrete; placing the grout; and sawing and sealing the joints.

It is understood that all of the above items should include full compensation for all labor, equipment, and materials to complete the work in accordance with the plans and specifications. Incidental items of work should be paid according to the SHA's customary procedure.

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