CONCRETE PAVEMENT CPTP TECHNOLOGY PROGRAM

Concrete Pavement Rehabilitation and Preservation Treatments

TechBrief

The Concrete Pavement Technology Program (CPTP) is an integrated, national effort to improve the long-term performance and cost-effectiveness of concrete pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, CPTP's primary goals are to reduce congestion, improve safety, lower costs, improve performance, and foster innovation. The program was designed to produce user-friendly software, procedures, methods, guidelines, and other tools for use in materials selection, mixture proportioning, and the design, construction, and rehabilitation of concrete pavements.

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U.S. Department of Transportation
Federal Highway Administration

This technical brief describes several concrete pavement rehabilitation and preservation treatments that were examined under Federal Highway Administration Special Project 205. The purpose and application of each treatment are reviewed, followed by a brief summary of application, materials, design, and construction recommendations.

INTRODUCTION

Under Federal Highway Administration (FHWA) Special Project 205 (SP-205), the construction and performance of several rehabilitation and preservation treatments were studied. The goal of this project was to re-examine many of the concrete pavement restoration techniques previously evaluated in the 1980s and to provide updated guidance on the design and construction of these techniques. Specific treatments evaluated under the project include:

- Joint resealing
- Slab stabilization
- Partial-depth repairs
- Full-depth repairs
- Load transfer restoration
- Diamond grinding and grooving

These treatments were evaluated at 30 sites located in Georgia, Michigan, Minnesota, and South Dakota. In addition, several demonstration projects were conducted under SP-205 to evaluate innovative pavement rehabilitation technologies, including the placement of a bonded concrete overlay preceded by load transfer restoration (LTR), the investigation of alternative LTR configurations and designs, and the use of millabrading to remove studded tire damage from concrete pavement surfaces. The results of these studies are documented in several State highway agency reports (Hubbard and Williams 1999; Hunt 1999; Embacher 2001).

A brief summary of the various treatments evaluated under SP-205—including highlights of recommended best practices for their application, design, and construction—is presented in the following sections. More information on these treatments, including detailed design and construction guidelines, is presented elsewhere (American Concrete Pavement Association [ACPA] 1993, 1994, 1995, 1998, 2000; FHWA/ACPA 1998; Hall et al. 2001; Hoerner et al. 2001; Peshkin et al. 2004).

JOINT RESEALING

Joint sealing and resealing is a commonly performed concrete pavement maintenance activity that serves two purposes: (1) minimizes water infiltration (thereby reducing distresses such as pumping and faulting) and (2) prevents intrusion of incompressibles in the joints (thereby reducing distresses such as joint spalling and blowups). A summary of recommendations for joint resealing is given below (ACPA 1993; Hoerner et al. 2001; Peshkin et al. 2004).

Timing/Applicability

Joint resealing is most appropriate for pavements that are not badly deteriorated. Joint resealing should be performed when the existing sealant material is no longer performing its intended function, as indicated by missing or debonded sealants or sealed joints that contain incompressibles. The optimum time of the year to perform joint resealing is in the spring or fall, when moderate installation temperatures are prevalent. Although joint sealing is currently an item of debate in new concrete pavement construction, it is recommended that all joints previously sealed be considered for joint resealing.

Materials

A range of materials is available for resealing joints in concrete pavements, the two most common being hot-poured, rubberized asphalt sealants (generally conforming to American Society for Testing and Materials [ASTM 2005a] D6690) and silicone sealants (generally conforming to ASTM [2005b] D5893). The hot-poured, rubberized asphalt sealants are less expensive than silicone materials but generally have shorter life expectancies (typically, 4 to 8 years for hot-poured sealants and 5 to 10 years for silicone sealants). Preformed compression seals, while used in new concrete pavement construction, are not commonly used in joint resealing activities. The selection of an appropriate joint sealant material should take into account past performance, local experience, availability of materials, initial and life-cycle costs, expected joint movements, and climatic exposure conditions.

Design

For concrete joint resealing, the effectiveness of the sealant is largely determined by the configuration in which it is placed in the joint. This configuration is referred to as the "shape factor" and is defined as the ratio of the sealant width (*W*) to the sealant depth (*D*) as it is placed in the joint (see Figure 1). Most hot-poured sealants use a shape factor of 1:1; silicone materials use a shape factor of 2:1. A backer rod is often placed in the joint reservoir to achieve the desired shape factor, to control the amount of sealant used, and to prevent three-sided adhesion.

The design width of the joint is based on the expected joint movements, which are related to the slab length, concrete properties, and climatic conditions. Details on computing the expected joint movements are provided in the references.

The recess shown in Figure 1 allows the sealant material to expand; however, some manufacturers of hot-poured materials recommend that the sealant be finished flush with the surface. Silicone materials, on the other hand, should always have a recess. The manufacturer's instructions should be consulted before installing any sealant material.

Installation

The effectiveness of the joint sealant installation is also highly dependent upon the quality of the instal-

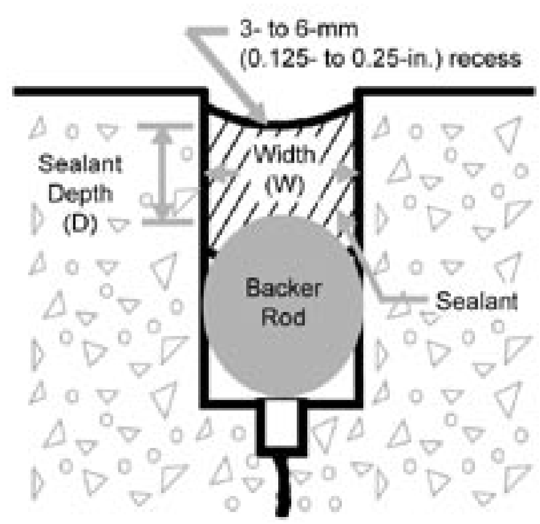

Figure 1. Joint shape factor.

lation. Of utmost importance is that the sidewalls of the joint are properly cleaned and free of dust, dirt, laitance, and moisture prior to the installation of the sealant material. This is commonly accomplished through sawing the existing joint with a diamond-bladed saw, which not only removes the old sealant but also serves to shape the width of the new reservoir. After sawing, the reservoir is thoroughly cleaned using a sandblasting operation on both faces of the joint. This is followed by air blowing, which should be performed immediately before sealant installation in order to remove any remaining sand, dirt, and dust from the joint.

The width of the sidewall refacing should be kept to an absolute minimum in order to keep the joint reservoir from becoming too wide, which can contribute to poor sealant performance and pavement noise from wheel slap. From that same standpoint, using long-life sealants that minimize the number of refacing operations is also desirable.

Summary

In order to achieve maximum performance, the proper sealant must be selected and designed for the prevailing conditions, and proper installation and inspections practices must be followed.

SLAB STABILIZATION

Slab stabilization, also called undersealing, subsealing, or pressure grouting, is the pressure insertion of a flowable material beneath a concrete slab. The purpose of slab stabilization is *not* to lift the slab, but rather to fill voids beneath the slab so that deflections are reduced and, consequently, deflection-related distresses, such as pumping or faulting, are prevented or minimized. However, in order for slab stabilization to be most effective, other concrete pavement restoration methods, such as LTR, may also be required to help control joint deflections. Recommendations for slab stabilization follow (ACPA 1994; Hoerner et al. 2001; Peshkin et al. 2004).

Timing/Applicability

To be most effective, slab stabilization should be performed prior to the onset of pavement damage caused by loss of support. It is most often performed at areas where pumping and loss of support occur, such as beneath transverse joints and cracks. The typical thickness of the voids being filled by this technique is generally less than 3 mm (0.125 in.).

Materials

Desirable characteristics for materials used for slab stabilization include fluidity (ability to flow into very small voids) and durability (ability to resist traffic and environmental loadings). Over the years, a wide range of materials has been used for slab stabilization, the most common being cement-flyash grouts, asphalt, and polyurethane. Traditionally, the most commonly used material has been cement-flyash grout mixture, with some recent increase in the use of polyurethane.

Design

Slab stabilization should only be performed at joints or cracks where voids are known to exist; the use of "blanket" applications of slab stabilization over an entire project is not recommended. There are a number of ways to identify the presence of voids beneath a pavement:

- The presence of certain distresses such as joint and crack faulting, pumping, and corner breaks are indicative that loss of support has occurred.
- A falling weight deflectometer (FWD) may be used to measure joint and crack deflections to help determine whether loss of support has occurred. An FWD can also be used to make estimates of the quantity of grouting material required to adequately fill the voids. Deflection testing is currently the most common approach used for locating and estimating the size of voids. Several deflection-based void detection methods are available. For example, some agencies specify maximum corner deflection criteria as indicators for the presence of voids, whereas others plot the magnitude of corner deflections at different load levels to assess whether full support exists under slab corners.
- Other nondestructive methods, such as ground penetrating radar and infrared thermography,

can also be used to indicate voids or areas of loss of support.

Typically, a pattern of one to three holes is used at locations that have been identified as having voids. The holes should be placed close enough to achieve a flow of grout from one insertion hole to another when a multiple-hole pattern is used. It is often necessary to experiment the first few days of slab stabilization to arrive at an optimal hole pattern.

Construction

The basic construction process for slab stabilization is the same, regardless of the type of material used. First, at appropriate areas identified as needing slab stabilization, a 32- to 50-mm (1.25- to 2-in.) hole is drilled through the concrete slab, typically using a pneumatic or hydraulic rotary percussion drill. It is generally recommended that the downward pressure on the drill be limited to 890 N (200 lbf) to avoid conical spalling at the bottom of the slab. Injection holes should be drilled or cored just beyond the bottom of the slab when a granular subbase is present, and to the bottom of the subbase if it is stabilized (because voids can often form there). After the hole is drilled, a grout packer is used to inject the material into the hole while preventing material extrusion or backup. During this process, several precautions are taken in order to ensure that the voids are being filled and the slab is not being lifted. These precautions include monitoring the elapsed pumping time, monitoring slab pressures, and monitoring lift with a Benkelman Beam. At least one agency pours water into the hole after grout injection, and if the water does not flow, then the void is considered to be filled. It is again emphasized that the purpose of slab stabilization is to fill voids beneath the slab and not to actually raise or lift the slab.

Post-testing

Followup deflection testing should be conducted 24 to 48 hours after the slab stabilization operation to assess its short-term effectiveness in terms of reduced deflections. This testing may also suggest the need for adjustments in the hole pattern to ensure more widespread coverage. The long-term effectiveness of slab stabilization can be determined only by monitoring the subsequent performance of the pavement.

PARTIAL-DEPTH REPAIRS

Partial-depth repairs are a treatment that addresses surface defects and shallow joint spalling. They are an alternative to full-depth repairs in areas where slab deterioration is located primarily in the upper one-third of the slab, and where the existing load transfer devices (if present) are still functional. Partial-depth repairs restore structural integrity to the pavement and improve its overall ride quality. A summary of recommendations for partial-depth repairs follows (ACPA 1998; Hoerner et al. 2001; Peshkin et al. 2004).

Timing/Applicability

Partial-depth repairs should be used to address shallow spalling on pavements that are structurally sound (no significant fatigue cracking). They are commonly conducted in conjunction with other concrete restoration activities, such as full-depth repairs, diamond grinding, and LTR.

Materials

A variety of materials has been used for partial-depth repair of concrete pavements. The selection of the appropriate material depends on the available curing time, the ambient temperature, the material cost, the desired performance, and the size and depth of the repairs. Often, the selection of the repair material is based on the required opening times for a specific project. Most partial-depth repair materials fall into one of three primary categories—cementitious, polymer-based concrete, and bituminous materials:

- Cementitious materials include conventional portland cement concrete, gypsum-based materials, and magnesium phosphate concretes. Conventional portland cement concrete is the most commonly used partial-depth repair material, and can be formulated to provide opening times of 4 hours or less.
- Polymer-based concrete materials are a combination of a polymer resin, aggregate, and an

initiator. The most common polymer-based concrete materials are epoxy, methyl methacrylate, polyester-styrene, and polyurethane. These materials typically gain strength rapidly but are also very expensive.
- Bituminous materials are a combination of bituminous binder (either an asphalt emulsion or asphalt cement) and aggregate. These materials are inexpensive and widely used as a partial-depth spall repair material, but are often considered temporary patches.

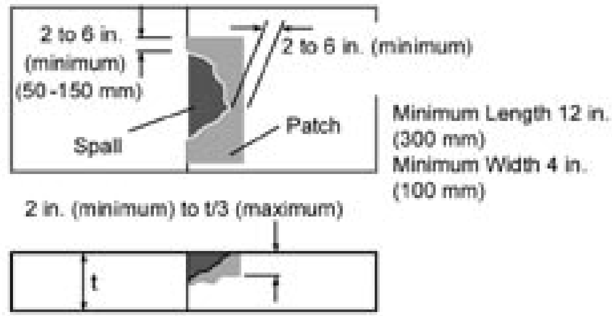

Figure 2. Partial-depth repair dimensions.

Design

As previously mentioned, partial-depth repairs are appropriate for concrete pavement distresses confined to the top one-third of the slab. The most common distress types suitable for partial-depth repairs are transverse or longitudinal joint spalling caused by incompressibles or weak concrete and localized surface defects. Distress types that are not candidates for partial-depth repair are crack spalling, joint spalling caused by dowel bar misalignment or lockup, and joint spalling caused by D-cracking, reactive aggregate, or other materials-related deterioration.

To ensure effective performance, the partial-depth repair should be properly sized. Generally, the area marked for removal should extend 50 to 150 mm (2 to 6 in.) beyond the weakened pavement in each possible direction. Also, a minimum repair length of 300 mm (12 in.) and a minimum repair width of 100 mm (4 in.) are recommended, and the repair should be at least 50 mm (2 in.) deep. Figure 2 summarizes these recommendations (ACPA 1998).

Construction

Effective construction practices are required in order to obtain long-lasting partial-depth repairs. The construction and installation of partial-depth repairs generally consist of the following activities:

1. Repair dimension selection. The extent of deterioration is identified by "sounding" the pavement using a hammer, solid rod, or chain. The boundaries are then marked, keeping in mind the previous sizing recommendations. A square or rectangular shape is recommended, and areas less than 0.6 m (2 ft) apart should be combined into one repair area.
2. Concrete removal. The most common method of concrete removal consists of sawing the perimeter of the repair area to the proper depth using a diamond-bladed saw. The interior portion of the repair area is then chipped out with a light hammer (less than 14 kg [30 lb]). An alternative method that has proven effective is the removal of the deteriorated concrete using a milling machine that is operated either transversely across a joint for smaller, individual spalls, or longitudinally along the length of the joint for larger repair areas.
3. Cleaning. After removal of the concrete, the repair area should be cleaned to remove all loose particles, dirt, and debris that could inhibit bonding. This is generally accomplished by sandblasting, followed by airblasting to remove any sandblasting residue.
4. Joint preparation. For partial-depth repairs placed at joints, a strip of compressible material must be placed in the joint to accommodate horizontal movements, to prevent patching material from infiltrating the joint, and to re-establish the joint. The insert should extend 25.4 mm (1 in.) below and 76 mm (3 in.) beyond the repair boundaries.
5. Bonding agent application. For most repair materials, a thin application of a cementitious grout bonding agent is placed on the exposed patch area to help promote bonding. The bonding agent is placed after the repair area has been cleaned and immediately before the placement

of the repair material.

6. Patch material placement and finishing. The repair area should be slightly overfilled to allow for a reduction in volume during consolidation. The material should be adequately consolidated with a small spud vibrator to remove entrapped air. A stiff board can be used to screed the repair surface and make it flush with the existing pavement, working toward the perimeter of the repair to establish contact and enhance bonding to the existing slab. The surface of the repair should be textured to match that of the surrounding slab.
7. Curing. Proper curing is very important to prevent rapid moisture loss in partial-depth repairs. Commonly, a white-pigmented curing compound is applied as soon as the water sheen has disappeared from the repair surface. Typical application rates are about 2.5 to 4.9 m^2/L (100 to 200 ft^2/gal). For early opening to traffic, or in cold-weather conditions, insulating blankets may be needed to help accelerate the rate of strength gain.

Summary

The performance of partial-depth repairs depends on many factors. However, when directed at the right distresses, when appropriate repair materials are used, and when properly placed, these repairs can perform well for many years, especially when conducted as part of a comprehensive repair program employing other treatments (e.g., diamond grinding, joint sealing).

FULL-DEPTH REPAIRS

Full-depth repairs are concrete repairs that extend through the full thickness of the existing concrete slab. Full-depth repairs are used to restore the rideability of the pavement, to prevent further deterioration of distressed areas, or to prepare the pavement for an overlay. Because full-depth repair involves complete removal and replacement of deteriorated areas, this technique can be used to address a wide variety of concrete pavement distresses. General guidelines on the use of cast-in-place full-depth repairs for jointed plain concrete pavement (JPCP) designs are presented below (ACPA 1995; Hoerner et al. 2001; Correa and Wong 2003; Peshkin et al. 2004).

Timing/Applicability

Full-depth repairs are effective in addressing many types of deterioration, including blowups, corner breaks, transverse cracking, longitudinal cracking, and severe joint spalling. They are most applicable to pavements in which deterioration is limited to a few joints and cracks (i.e., not widespread over the length of the project). Severe deterioration throughout the entire length of the project indicates the need for structural improvements (i.e., overlay or reconstruction).

Materials

The most widely used material for full-depth repairs is conventional portland cement concrete. With this material, virtually any opening time can be met (from 1 hour to 24 hours or more), depending on the needs of the project. Typically, high early strengths in concrete mixtures are achieved by reducing the water-to-cement ratio, using a well-graded aggregate, increasing the cement content, and adding a chemical accelerator. However, faster setting mixes generally have higher costs and special handling requirements. Therefore, a good rule of thumb in selecting the material for a concrete pavement full-depth repair project is to use the least exotic (most conventional) material that will meet the opening requirements. A National Cooperative Highway Research Program report examines the durability of high early-strength concrete mixtures for full-depth repairs (Van Dam et al. 2005).

Design

The design considerations for full-depth repairs consist of repair dimensions and load transfer requirements. The repair dimensions must fully encompass the extent of deterioration, including what is not visible on the surface. Minimum repair dimensions of 1.8 by 3.7 m (6 by 12 ft [one lane width]) are recommended to provide repair stability and prevent longitudinal cracking within the patch. For the same reason, the minimum dimensions of the remaining slab should also be at least 1.8 m (6 ft) long. Figure 3 shows the recommended repair dimensions.

For most full-depth repairs of jointed concrete pavements, dowel bars placed across the transverse joints are essential for load transfer. On interstate-type pavements, at least four to five dowels should be located in each wheel path to provide effective load transfer (see Figure 3). Larger diameter dowels (38 mm [1.5 in.]) should be used for slabs 25.4 cm (10 in.) or greater, whereas 32-mm (1.25-in.) dowels should be used for slabs less than 25.4 cm (10 in.) thick. Smooth, epoxy-coated dowel bars are recommended for both transverse repair joints.

Construction

As with partial-depth repairs, full-depth repairs must be properly constructed in order to perform well. The construction and installation of full-depth repairs involves the following steps:

1. Repair dimension selection. The entire extent of the distress should be included within the repair area, keeping in mind that significant deterioration may be present beneath the slab and not visible on the surface. The extent of deterioration beneath the slab surface may be identified through coring and deflection studies. The minimum repair dimensions previously described should be observed, and consideration should be given to entire slab replacements if the remaining slab length is less than 1.8 m (6 ft).

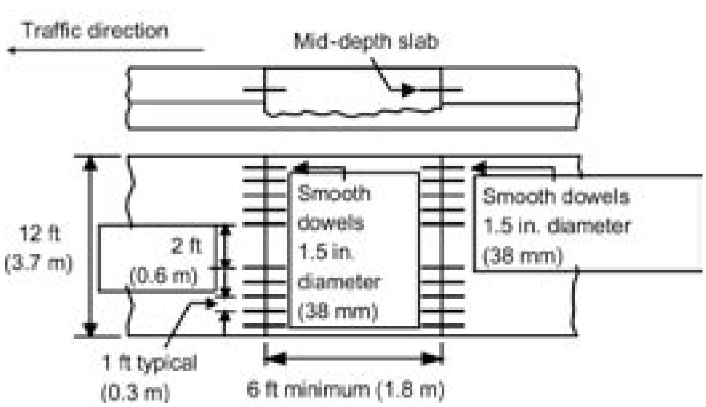

Figure 3. Dimensions and doweling recommendations for full-depth repairs.

2. Concrete removal. After marking the limits of the repair, the boundaries are cut full depth using a diamond-bladed saw. This isolates the repair area from the adjacent concrete. The deteriorated concrete is then removed from the repair area using either the lift-out method or the breakup method. In the lift-out method, lift pins are placed in drilled holes in the deteriorated slab and hooked with chains to a front-end loader or other equipment capable of vertically lifting the slab. The concrete is then lifted out in one or more pieces. In the breakup method, the concrete to be removed is broken up using a jackhammer, drop hammer, or hydraulic ram, and then removed using a backhoe and hand tools. The lift-out method is preferred because it does not disturb the base and is usually faster and less labor intensive.
3. Repair area preparation. All base, subbase, and subgrade materials that have been disturbed or that are loose should be removed and replaced, preferably with concrete because it can be difficult to achieve adequate compaction in the limited repair area. Any water should be removed, and the repair area should be allowed to dry before placing new material. It is very difficult to adequately compact granular material in a confined repair area.
4. Load transfer. Obtaining effective load transfer across the repair joints is critical to the performance of the repairs. In this step, the epoxy-coated dowel bars are installed by drilling holes on 300-mm (12-in.) centers at mid-depth of the exposed face of the existing slab using gang drills. The dowel holes must be drilled slightly larger than the diameter of the dowel (see Figure 4) to allow room for the anchoring material (typically either a cement grout or epoxy adhesive). The drilled holes should be cleaned with compressed air before the anchoring material is placed at the back of the hole. Then the dowel is inserted into the hole using a slight twisting motion to

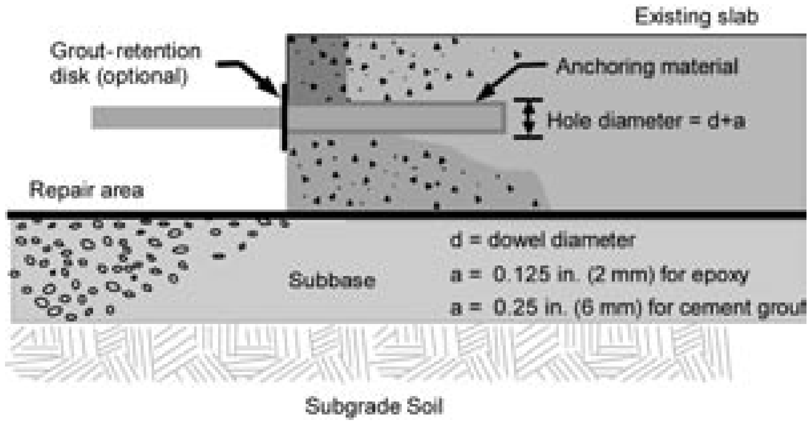

Figure 4. Dowel bar anchoring.

uniformly coat the dowel with the anchoring material. Some agencies place a grout-retention disk (a thin, donut-shaped plastic disk) over the dowel and against the slab face to prevent the anchoring material from flowing out of the hole and to create an effective face at the entrance of the dowel hole (the location of the critical bearing stress). After placement, the protruding end of the dowels should be lightly oiled or greased to facilitate movement.

5. Concrete placement and finishing. The concrete should be placed after the repair area has been prepared and the load transfer devices installed. Critical aspects of concrete placement and finishing for full-depth repairs include attaining adequate consolidation (especially around the edges of the repair) and finishing the surface level with the surrounding concrete. The repair should be struck off two or three times in a transverse direction to ensure that its surface is flush with the adjacent concrete. Following placement, the surface should be textured to match that of the surrounding concrete, although this is less important if the entire project is to be diamond ground.
6. Curing. As soon as possible after texturing, the concrete should be covered with white-pigmented curing compound, wet burlap, or polyethylene sheeting to prevent moisture loss. In general, a normal application of a pigmented curing compound (typically, 4.9 m^2/L [200 ft^2/gal]) gives the best results. The need for early opening may sometimes require the use of insulation blankets to accelerate hydration and provide higher early strengths.
7. Sawing and sealing. In the final step of the repair process, the transverse and longitudinal repair joints should be sawed or formed and then sealed. This will reduce spalling (by lowering the initial point-to-point contact between the existing slab and newly placed repair) and will minimize the infiltration of water.
8. Opening to traffic. Commonly, the full-depth repair is opened to traffic when it has achieved a minimum flexural strength of 2067 kPa (300 lbf/in.^{2}) or a minimum compressive strength of 13,780 kPa (2000 lbf/in.^{2}).

Summary

If properly designed and constructed, full-depth repairs can provide near-permanent rehabilitation of the distressed areas. The effectiveness of full-depth repairs depends strongly on the installation of the repairs at the appropriate time in the life of the pavement and on the proper design and installation of the load transfer system.

LOAD TRANSFER RESTORATION

Load transfer restoration (LTR), also called retrofitted load transfer, refers to the placement of load transfer devices across joints or cracks in an existing jointed concrete pavement. This increases the transfer of loads across these discontinuities, thereby reducing pavement deflections and subsequent pumping, faulting, and corner breaks. LTR is often used on concrete pavements that were constructed without dowel bars at the transverse joints, but may also be performed at transverse cracks that have developed in an existing jointed concrete pavement to prevent the crack from deteriorating. Guidelines on the use and installation of LTR follow (FHWA/ACPA 1998; Hoerner et al. 2001; Peshkin et al. 2004).

Timing/Applicability

LTR is most effective on jointed concrete pavements that have poor load transfer (deflection load transfer of 70 percent or less) at joints and/or transverse cracks, but also have significant remaining structural life. The optimum time to use this technique is when the pavement is just beginning to show signs of distress, such as pumping and the onset of faulting. Pavements with little remaining structural life (as evidenced by a substantial amount of slab cracking) and pavements with durability distresses (such as D-cracking or reactive aggregate) are not good candidates for LTR. Generally, good candidates for LTR are projects with average faulting between 2.5 and 3.8 mm (0.10 and 0.15 in.) and with less than 10 percent of the slabs cracked. Diamond grinding is almost always performed after the placement of retrofitted dowel bars to restore rideability.

Materials

Many different types of devices have been used to restore load transfer across joints and cracks, but smooth, round, epoxy-coated dowel bars have exhibited the best long-term performance. These devices provide shear load transfer while also permitting horizontal opening and closing of the joint or crack in response to daily and seasonal temperature and moisture fluctuations.

A repair or backfill material is used to encase the load transfer device in the existing pavement. Desirable properties of the repair material include little or no shrinkage, thermal compatibility with the surrounding concrete, good bond strength with the existing (wet or dry) concrete, and the ability to rapidly develop sufficient strength to carry the required load. Generally, cementitious materials that work well for partial-depth repairs also work well as a backfill material for LTR.

Design

In order for the retrofitted dowel bars to be effective in restoring load transfer, they must be of sufficient size and placed in a suitable configuration. A minimum dowel diameter of 32 mm (1.25 in.) is recommended, with larger, 38-mm (1.5-in.) diameter, dowels suggested for high-volume pavements. The dowels are commonly 450 mm (18 in.) long. Three dowel bars are placed in each wheelpath (four or five may be required for pavements subjected to heavy traffic) and spaced 300 mm (12 in.) apart. Figure 5 illustrates recommended layouts for retrofitted dowels.

Construction

The installation of retrofitted dowel bars consists of the following steps:

1. Slot cutting. The slots for the dowel bars should be created with a diamond saw slot cutter. This device makes two parallel cuts for each dowel slot, and the “fin” area between the cuts is then broken up with a light jackhammer. The slots must be parallel to the centerline of the pavement and cut to the prescribed dimensions. Typically, the maximum depth of the slot is just slightly over half the slab thickness, so that the dowel is located at mid-depth; the slot length is just over 0.9 m (3 ft), depending on the dowel length, so that the dowel can lie flat across the bottom of the slot without hitting the curve of the saw cut; and the slot width is typically between 65 and 100 mm (2.5 and 4 in.), selected to match the chair width so it fits snuggly in the slot. Figure 6 provides a cross section of an LTR installation.
2. Slot preparation. Small jackhammers (less than 14 kg [30 lb]) or hand tools are used to break up and remove the concrete fin for each slot. The bottom of the slot must be flattened with a small hammerhead mounted on a jackhammer. The depth of removal must be monitored to ensure

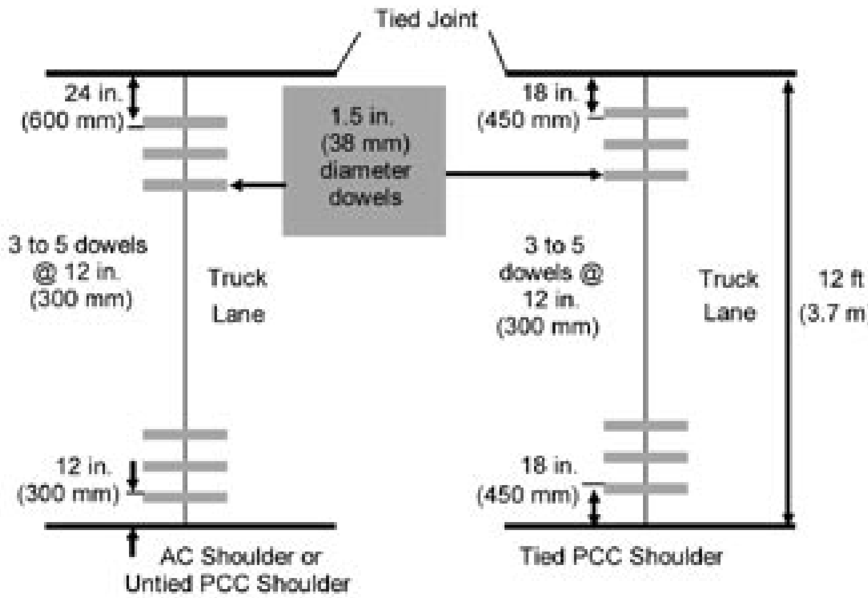

Figure 5. Recommended retrofitted dowel design (AC=asphalt concrete; PCC=portland cement concrete).

that the dowels will be located at the mid-depth of the slab. After removal of the concrete, the slots are thoroughly sandblasted to remove dust and sawing slurry and to provide a prepared surface to which the repair material can bond. This is followed by airblasting and a final check for cleanliness before the dowel and patch material are placed. Immediately prior to placement of the dowels or patch material, the joint or crack in the slot is caulked with a silicone sealant to prevent intrusion of the backfill material.

3. Dowel bar placement. Before placement of the dowel in the slot, it should be coated with a bond-breaking material to facilitate movement. Expansion caps can be placed at both ends of the dowel to allow for any joint closure after installation of the dowel. The dowels are typically placed on support chairs and positioned in the slot so that the dowel rests horizontally and parallel to the centerline of the pavement at mid-depth of the slab. A rigid filler board material is placed at the midpoint of the dowel to maintain the integrity of the joint or crack and prevent the repair material from infiltrating and resisting movement.
4. Backfill material placement. The backfill material should be carefully placed in the slot, making sure not to bump the dowel bar out of position or displace the filler board. A small spud vibrator should be used to consolidate the patching material. A curing compound should be placed on the patching material to minimize shrinkage. Depending upon the type of backfill material, the pavement may be opened to traffic in as little as a few hours.

Summary

When properly constructed, and when applied to the right pavement, the performance of projects with retrofitted dowel bars has generally been good. In particular, the Washington State Department of Transportation (WSDOT) has had success with the technique, having retrofitted more than 362 km (225 lane-miles) of concrete pavement. Recent papers by WSDOT summarize their experiences and lessons learned (Pierce et al. 2003a, 2003b).

DIAMOND GRINDING AND GROOVING

Diamond grinding and diamond grooving refer to two distinct types of concrete pavement surface restoration methods. Diamond grinding is the removal of a thin layer of concrete (generally about

6 mm [0.25 in.]) from the surface of the pavement. This is accomplished using special equipment outfitted with a series of closely spaced, diamond saw blades. Major applications for diamond grinding are to remove surface irregularities (most commonly joint faulting), to restore a smooth-riding surface, to increase pavement surface friction, and to reduce pavement noise.

Diamond grooving is the establishment of discrete grooves in the concrete pavement using diamond saw blades. The major objective of grooving is to break up the flow of water across a pavement surface, thereby improving tire-pavement contact and reducing the potential for hydroplaning and wet-weather accidents. Grooving may be performed either transversely or longitudinally, but it is more commonly performed longitudinally on highway projects due to ease of construction.

A summary of recommendations on the use of diamond grinding and diamond grooving follows (ACPA 2000; Correa and Wong 2001; Hoerner et al. 2001; Peshkin et al. 2004).

Timing/Applicability

Diamond grinding is most effective when performed on pavements prior to the development of significant faulting or loss in serviceability. Generally, average project faulting on the order of 2.3 to 3.3 mm (0.09 to 0.13 in.), or a serviceability value between 3.8 and 4.0, are recommended as trigger values for grinding. Diamond grinding is not recommended for pavements with significant slab cracking or severe durability distress (such as D-cracking or alkali-silica reactivity).

Diamond grooving should be performed on pavements that have exhibited a significant number of wet-weather accidents. The grooving can be conducted in localized areas where accident rates are high (such as on curves or at intersections) or along the entire length of the project if hydroplaning and wet-weather accidents are a problem over the entire project. Diamond grooving should also be considered if diamond grinding exposes soft coarse aggregate (such as limestone) that is known to polish quickly. The use of diamond grooving in conjunction with diamond grinding would extend the time before another treatment would be needed to restore the surface texture to a safe level. The pavements should be otherwise structurally sound and functionally adequate.

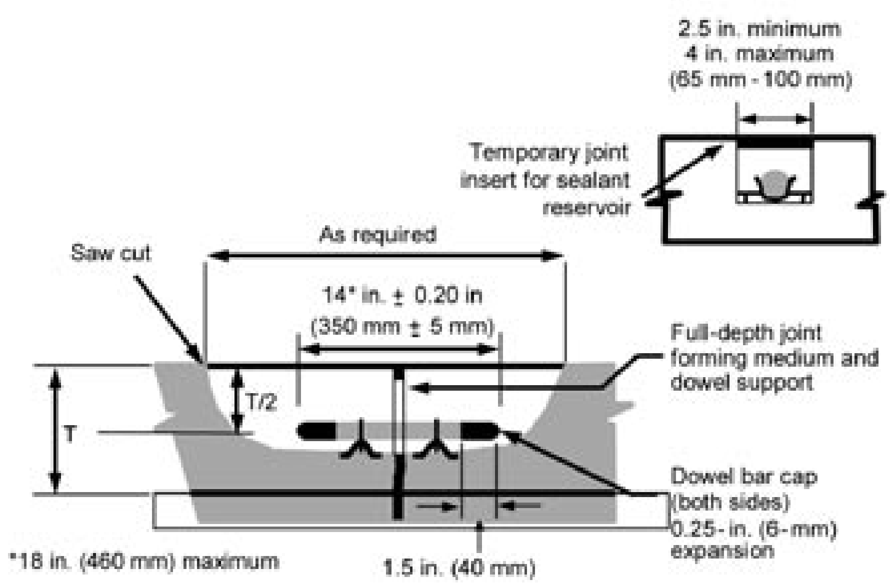

Figure 6. Retrofitted load transfer device.

Design

For both diamond grinding and diamond grooving, the most important design element is the spacing of the blades on the grinding head. For diamond grinding, the spacing is based on the hardness of the aggregate in the existing concrete, with softer aggregates (such as limestone) requiring a wider spacing than harder aggregates (such as granite); this allows the "fins" to break off under traffic. Recommended groove widths, land areas, and grooving depths for diamond grinding are shown in Figure 7.

The recommended cutting pattern for diamond grooving is also shown in Figure 7. This standard pattern, consisting of a uniform spacing of 19 mm (0.75 in.) between grooves, is recommended regardless of the type of coarse aggregate.

Construction

Diamond grinding equipment uses diamond blades mounted in series on a cutting head. The width of the cutting head is typically between 120 and 127 cm (48 and 50 in.), and there are about 50 to 60 blades per foot of width. Grinding should be performed continuously along a traffic lane for best results, and should start and end perpendicular to the pavement centerline. Grinding is typically conducted on multi-lane facilities using a mobile single-lane closure, allowing traffic to be carried on any adjacent lanes. Because of the relatively narrow width of the cutting head, more than a single pass of the grinding equipment will be required. Generally, a minimum of 95 percent of the area within any 0.9 by 30.5 m (3 by 100 ft) test area is required to be textured by the grinding operation.

Diamond grooving equipment uses fewer diamond blades on the cutting head, and as a result, the head width can be substantially greater than that used for diamond grinding; some equipment has grinding head widths of 1.8 m (6 ft) or more. As previously indicated, grooving is most commonly performed longitudinally along the pavement. Typically, only localized areas (such as curves) are grooved, instead of an entire project length. However, data from surface friction and wet-weather crashes can be used to determine the extent of grooving required.

Grinding and grooving operations produce a slurry consisting of ground concrete and water. This slurry is picked up by on-board wet-vacuums, and is either discharged onto the grass slopes adjacent to the shoulder (if permitted) or hauled away for disposal. Local environmental regulations should be consulted to determine acceptable disposal solutions.

Summary

The performance of both diamond grinding and diamond grooving has been successful when properly applied to the right pavements. Diamond grinding produces smoothness values approaching (and in some cases exceeding) those typically obtained for new pavement construction, and also provides an immediate improvement in the surface friction of the pavement. However, the smoothness and friction values will decrease over time, with service lives of 8 to 10 years being typical for faulting to

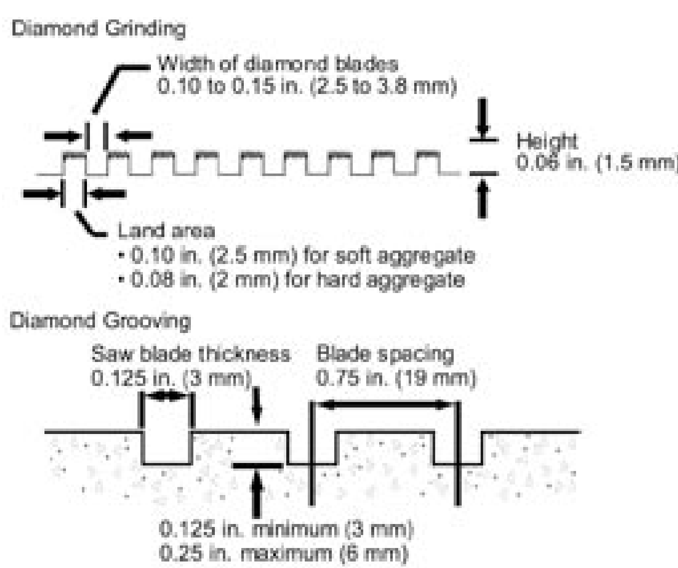

Figure 7. Dimensions for grinding and grooving.

redevelop to the degree that diamond grinding is again required (Rao et al. 2000). Factors affecting the service life of diamond grinding include traffic loadings, existing pavement condition, climate, and concurrent repair/restoration work (e.g., patching, undersealing, and retrofitted load transfer). Diamond grooving has been shown to provide immediate reductions in wet-weather accidents (Peshkin et al. 2004).

SUMMARY

Under FHWA Special Project 205, a variety of concrete pavement rehabilitation and preservation treatments were studied. These treatments include joint resealing, slab stabilization, partial-depth repairs, full-depth repairs, load transfer restoration, and diamond grinding and grooving. This document briefly describes these techniques and provides a summary of their application, installation, and performance. More detailed design and construction information on these treatments is found in several industry publications (ACPA 1993, 1994, 1995, 1998, 2000; FHWA/ACPA 1998), National Highway Institute reference manuals (Hoerner et al. 2001; Peshkin et al. 2004), and Transportation Research Board documents (Hall et al. 2001).

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THE CONCRETE PAVEMENT TECHNOLOGY PROGRAM

The Concrete Pavement Technology Program (CPTP) is a national program of research, development, and technology transfer that operates within the Federal Highway Administration (FHWA) Office of Pavement Technology.

The CPTP includes some 30 research and demonstration projects, each of which is delivering products for improved design, construction, repair, and rehabilitation of concrete pavements.

The focus areas for the CPTP include advanced designs, optimized concrete materials, improved construction processes, rapid repair and rehabilitation, and user satisfaction. The CPTP continues to produce implementable products that result in safer, smoother, quieter, and longer lasting concrete pavements. Longer lasting pavements, in turn, contribute to FHWA's success in the areas of safety, congestion mitigation, and environmental stewardship and streamlining.

Technology transfer of products resulting from the CPTP is being accomplished under CPTP Task 65. This 5-year activity was initiated in September 2003 and is overseen by an Executive Expert Task Group (ETG) that includes State Department of Transportation (DOT) chief engineers and representatives from industry and academia.

An Engineering ETG, made up of pavement and materials engineers from State DOTs, FHWA field offices, plus representatives from industry and academia, reviews the technical aspects of CPTP products.

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