PDHonline Course C511 (2 PDH)

Partial-Depth Concrete Pavement Repair

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Concrete: Partial-Depth Repair

1.0 Introduction

Partial-depth repair (PDR) is a concrete pavement restoration technique that corrects localized distress such as spalls, scaling, and popouts in concrete pavements. PDR restores structural integrity and utility of the pavement, and prevents further deterioration, thus extending the pavements service life. Also, partial depth repairs are required to prepare an existing, distressed pavement prior to a structural overlay or restoration project.

PDR involves removing an area of deteriorated concrete that is limited to the top one-third of the slab thickness and replacing it with appropriate repair materials. Depending on the type of repair material used and the repair location, a new joint sealant system may be placed as well. The repair technique can be applied either transversely or longitudinally on the pavement where deteriorations are detected. When applied at appropriate locations, PDR can be more cost effective than full-depth repair. The cost of PDR is largely dependent upon the size, number, and location of repair areas, as well as the materials used. Lane closure time and traffic volume also affect production rates and costs.

2.0 Selection of Candidate Projects

2.1 Pavement Condition

Partial depth repair restores localized surface distresses of concrete pavement within the upper one-third of the slab. It replaces small, deteriorated areas with suitable repair materials. PDR is commonly used to repair low-severity spalling within 6” of the joint and less than 2” deep, but can also be used for low-severity scaling & popouts. If PDRs are being considered, coring should be performed at representative joints to determine the depth of deterioration.

PDR is not appropriate for the following pavement conditions; rather, FULL-depth repair should be considered:

- Cracks extending through the full slab thickness
- Spalls that extend more than 6 to 10” from the joint
- Spalls beyond the top one-third of the slab caused by misaligned dowel bars, D-cracking, or alkali-silica reactivity (ASR)
- Spalls that expose reinforcing steel or dowels
- Pavements that will be cracked and seated, broken and seated, or rubberized prior to overlay

2.2 Climatic Conditions

The wetter and colder the climate, the greater the need for timely PDR. However, spalling can occur in any climate, and proper partial-depth spall repair will help reduce further deterioration. The damage caused by freezing and thawing cycles is a serious problem in jointed Portland cement concrete (PCC). In wet and freezing climates, the continued presence of water on and in the pavement and the use of deicing salts often worsens the damages.

Even in non-freezing climates, any moisture in the concrete can cause corrosion of reinforcing steel in the pavement. Corroding steel creates expansive forces that can lead to cracking, spalling, and debonding of the concrete around it. Reinforcing steel without enough concrete cover is even more likely to corrode. Timely PDR can protect high reinforcing steel that has not yet corroded and can prevent more serious spalling.

Spalling may also occur in dry and freezing climates. Incompressible solids that are trapped in a joint when the adjacent slabs contract during freezing create high compressive stresses in the joint face when the pavements expand during thawing. Early repair of nonfunctioning joint sealing systems, along with any adjacent spalling, can protect the joint from further deterioration.

3.0 Design Considerations

PDR extends the life of PCC pavements by restoring ride quality to pavements that have spalled joints. PDR of spalled areas also restores a well defined, uniform joint or crack sealant reservoir prior to joint or crack resealing. When properly placed with durable materials, these repairs can perform well for many years. The following factors should be considered during the design of PDRs.

3.1 Objective of Partial-depth repair

PDRs may have several objectives. In adverse conditions, a temporary PDR may be needed. In this case, the design should provide for adequate temporary repair life until a permanent repair can be made.

If performing PDR prior to an overlay construction, tolerances are not as stringent. For example, repair edges do not have to be completely vertical and straight, the repair material does not need to wear well, and the joint does not have to be sealed. This is because the overly will reduce the load and environmental stresses on the repair. Furthermore, an overlaid repair material will experience smaller temperature changes than a repair that is not overlaid.

If a spall must be repaired because it presents a hazard to the highway user, but the pavement is scheduled for an upcoming rehabilitation that will destroy the repair, design considerations should reflect this anticipated short service life.

PDR that will not be covered or destroyed in a future rehabilitation will be exposed to traffic and climate for a long time. In this case, it is cost-effective to select high quality materials, repair methods, and workmanship.

3.2 Selection of Repair Boundary

An important step in constructing a successful PDR is the identification and removal of all deteriorated concrete. The actual extent of the deterioration in the concrete may be greater than is visible at the surface. In the early stages of spall formation, weakened planes often exist in the pavement with no sign of deterioration visible at the surface. Refer to Section 4.2 for more details.

3.3 Selection of Materials

Material selection for PDR should consider the following factors: mixing time and required equipment, working time, temperature range for placement, curing time, aggregate requirements, repair area moisture conditions, cost, repair size, and bonding requirements.

3.3.1 Cement Materials

3.3.1.1 Normal Concrete Mixtures

- Portland cement type I, II, or III is typically used for partial depth repairs.
- Normal set concrete can be used when the repair material can be protected from traffic for more than 24 hours.
- Normal set concrete should NOT be used when the air temperature is below 40 °F (4 °C). At temperature below 55 °F (13 °C), a longer curing period or insulation may be required.
- Size of coarse aggregate must not exceed half the minimum repair thickness.
- Type I cement is popular because of its relatively low cost, availability, and ease of use.
- Type III cement or an accelerated repairs admixture is used for repairs that need to be opened to traffic quickly. An insulating layer can be placed on the hydrating PCC to retain the heat of hydration thereby increasing the rate of strength development.

3.3.1.2 Specialty Cement Mixtures

- Gypsum-based (calcium sulfate) repair materials, such as Duracal and Rockite, can be used in any temperature above freezing or for rapid strength gain. However, gypsum concrete does not perform well when exposed to moisture or freezing weather, and the presence of free sulfates in the typical gypsum mixture may be promote steel corrosion in reinforced PCC.
- Magnesium phosphate cement mixtures are characterized by a high early strength, low-permeability, and good bonding to clean dry surfaces. However, they are extremely sensitive to water content and aggregate type (especially limestone); very small amounts of excess water can significantly reduce strength.

- High alumina cement mixtures produces a rapid strength gain concrete with good bonding properties (to dry surfaces) and very low shrinkage. However, they should not be used because a significant strength loss is likely to occur due to chemical conversions in the calcium aluminate cement during curing.
- Accelerating admixtures/additives may achieve high early strengths and reduce the time to opening. Premature deterioration can be developed due to insufficient curing time. Some states prohibit calcium chloride (CaCl2) accelerators due to problems with excessive shrinkage and dowel corrosion.
- Alumina powder may be used as an admixture with Type I, Type II, or Type III cement to counteract shrinkage. However, the reactivity of aluminum powder can be difficult to control in field proportioning, particularly in small batch operations. The use of alumina powder may also decrease the bond strength and patch abrasion resistance.

3.3.2 Polymer Materials

Polymer concretes are characterized by their quick set in comparison to normal concretes. They are both more expensive and quite sensitive to certain field conditions, such as temperature range. Polymer concretes are a combination of polymer resin, aggregate, and a set initiator. They are categorized by the type of resin used: epoxies, methacrylates, polyester -styrenes, and urethanes.

- Epoxy mixtures have excellent adhesive properties and low permeability. However, they are not thermally compatible with normal concrete, sometimes resulting in early repair failure. The use of larger aggregate can improve their thermal compatibility with concrete and reduce the risk of debonding. Epoxies are available with a wide variety of setting times, placement temperature ranges, strengths, bonding capabilities, and abrasion resistance properties. The selection of a particular epoxy mixture should be based on the project's environmental conditions and construction constraints. Epoxy concrete should not be used to repair spalls caused by reinforced steel because it can accelerate the corrosion of the steel in the adjacent, unrepaired concrete by creating a highly cathodic area.
- Methyl methacrylate concretes have relatively long working times (30 - 60 minutes); high compressive strengths; good adhesion to clean, dry concrete; and a wide placement temperature range between 40 and 130 °F (5 - 55 °C). But many of them produce fumes, which are a health hazard and can ignite if exposed to a spark or flame.
- Polyester-styrene concrete has very similar properties to methyl methacrylate concrete, but posses a much slower rate of strength gain. This limits its usefulness for PDR.
- Polyurethane concrete consists of a two-part polyurethane resin mixed with aggregate. They set very quickly (~90 seconds). Two types are available: the older type which is moisture sensitive and will foam in contact with water; and the newer ones which claim to be moisture tolerant and can be placed on wet surfaces.

4.0 Construction

With good design and construction practices, PDR should last as long as the surrounding concrete pavement. The most frequent causes of performance problems are related to misuse of the technique, poor repair material, and careless installation.

4.1 Find Deteriorated Concrete

The first step in a successful PDR is the identification and removal of all deteriorated concrete. Unsound concrete is commonly located by "sounding out" the delaminated area. Sounding is done by striking the concrete surface with a steel rod or ball-peen hammer, or by dragging a chain along the surface. The rod, hammer, and chain will produce a clear ring when used on sound concrete and a dull response on deteriorated concrete. In addition to sounding, coring may also be used to find deterioration.

Figure 1. "Sounding" with ball-peen hammer (left) and steel chain (right)

4.2 Determine Repair Boundaries

Include all deterioration within the repair boundaries. Clearly mark each boundary with brightly-colored spray paint to outline the removal area. To ensure the complete removal of all bad concrete, use the following guidelines:

- Repair boundaries should be square or rectangular
- Minimum length = 12” (300 mm)
- Minimum width = 4” (100 mm)
- Extend the repair limits beyond the delamination marks or visible spalls by 3 to 4” (75-100 mm)
- Do not repair a spall that is less than 6” (150 mm) long and less than 1.5” (35 mm) wide
- Combine repairs less than 12” (300 mm) from each other
- Repair the entire joint length if there are more than two spalls along a transverse joint

Figure 2. Marking Area for Removal

4.3 Remove Deteriorated Concrete

Three methods for removal are described below:

4.3.1 Sawing & Chipping. First use a diamond-bladed saw to define the boundaries of the repair section. Depth of cut is 1 to 2" (25-50 mm), and cuts should be straight & vertical. After sawing the boundaries, chip the concrete in the repair section either by hand, or mechanically with a light pneumatic hammer (<30 lb [13.5 kg]). Material removal should start near the center of the repair section and proceed towards (but not up to) the edges. Near the edges, remove material with lighter equipment (10-20 lb [4.5-9.0 kg]) until good concrete is exposed. For better control and to prevent damage to good concrete, observe these tips:

- Use the lightest hammer that will break the section
- Operate mechanical chipping tools at a 45-degree angle
- Use spade bits instead of gouge bits

Depth of the repair should not exceed one-third of the pavement thickness. If more chipping is necessary to find sound concrete, or dowel bars are exposed, switch to full-depth repair.

Figure 3. Diamond-bladed saw for Sawing & Chipping

4.3.2 Carbide Milling. Some States have successfully used carbide-tipped milling machines for PDR. Use a milling machine with a kilowatt rating on the high-end for its class. Milling machines with 12 to 18" (300 - 450 mm) wide cutting heads have proven efficient and economical, particularly when used for large area. To prevent excessive removal and damage to dowel bars, the machine must have a mechanism that will limit penetration of the milling head to a preset depth. Depending on the equipment and the lane closure conditions, the milling machines can operate either across lanes or parallel to the pavement centerline. Milling across lanes is effective for spalling along an entire joint. For smaller, individual spalls, either orientation is effective. Periodically check the milling head for missing teeth and replace as needed.

Figure 4. Milling Operation

4.3.3 Water blast & patch. A high-pressure (15,000 - 30,000 psi) water jet is used to remove damaged concrete. Skilled personnel should set the pressure of the equipment to remove deteriorated concrete only. The jet should reduce most of the damaged concrete to a fine slurry, thus minimizing hauling costs. The resulting slurry & debris must be removed immediately, before the slurry sets. Shields should be installed to protect traffic from the high pressure jets. The resulting rough, irregular surface promotes good mechanical interlock between the repair material and the existing slab.

4.4 Cleaning

The purpose of cleaning is to remove residue & loose particles from the repair section before applying the bonding agent. Removing this matter will increase the contact area between the bonding agent and the existing concrete, thus improving the bond between the existing concrete and the repair material.

After removing the concrete within the delaminated area, check the bottom by sounding for remaining weak spots. Either chip away the weak areas or consider a full-depth repair if the deterioration goes too deep. The exposed faces of concrete should be blasted free of loose particles, oil, dust, traces of asphaltic concrete and other contaminants before placing patching materials.

The two methods of blasting are sandblasting and high-pressure water blasting. High-pressure water blasting (14,500 – 29,500 psi) is preferred where dust control is critical in urban environments. However, to avoid damage, the equipment must be capable of adjustments that will allow removal of only weakened concrete.

Airblow the repair area to remove dust and blast residue. Direct the debris away from the repair area so that wind and traffic will not carry it back. Dust and dirt prevent the repair material from bonding to the old concrete. The air compressor should deliver air at a minimum of 2.6 yd^3 (3.4 m^3) per minute and develop 90 psi (0.63 MPa) nozzle pressure. Even if the equipment has a filter, check the air for oil and moisture contamination that could prevent bonding between the repair material and existing concrete. Place a clean cloth over the nozzle and blow air through the cloth, and examine it for any discoloration from contamination.

Figure 5. Left: Sand Blasting of Repair Areas. Right: Airblow to Remove Dust and Debris.

4.5 Placing the Joint Insert

PDR next to joints or cracks require a compressible joint insert, also known as a bond breaker. Its purpose is to ensure that the repair material conforms to the original edges of the slab. In doing this, the insert also prevents repair material from infiltrating the joint cavity, thereby preserving the gap between the slabs for their expansion‐contraction cycle. Without this insert, repair material can infiltrate the joint and harden, diminishing the gap between slabs. When adjacent slabs expand toward each other during hot weather, they will compress the repair material between (a.k.a , point ‐bearing) until compressive stresses are high enough to cause pop‐outs or delamination.

Common compressible insert materials are Styrofoam, polyethylene, or asphalt ‐impregnated fiberboard. The insert should have a scored stop strip and extend 1” (25 mm) below and 3” (75 mm) beyond the repair boundaries to prevent the repair material from flowing into the joint. An additional saw cut may be necessary to allow the insert to fit properly.

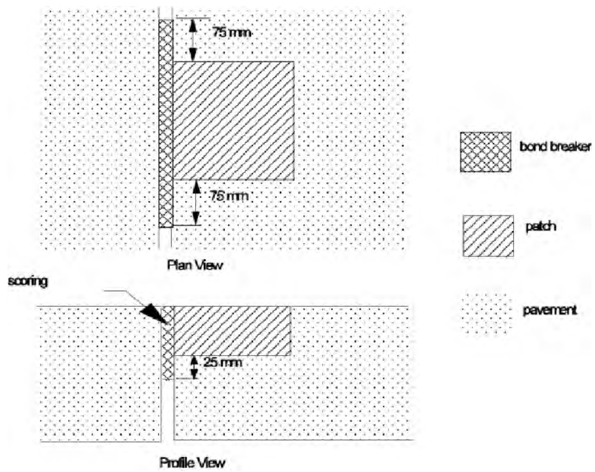

Figure 6. Plan & profile view of joint insert placement at one joint


Figure 7. Joint Insert

4.6 Applying Bonding Agent

A bonding agent is required on partial depth repairs to enhance the bond between the existing concrete and the repair material. Sand‐cement grouts and epoxy agents have been widely used on these types of repairs.

- Sand‐cement grouts have performed adequately when the repairs are protected from traffic for 24 to 72 hours. The recommended mixture for sand‐cement grout consists of one part sand and one part cement by volume, with sufficient water to produce a mortar with a thick, creamy consistency.
- Epoxy bonding agents have proven adequate when repair closure time needs to be reduced to 6 hours or less. They have been used with both PCC and proprietary repair materials.

Check the repair area for any dust or sandblasting residue before placing a bonding agent. The area should be clean and dry. Wiping the area while wearing a dark brown or black cotton glove will easily indicate a dust problem. Airblow again if the dust has settled back in the repair area. Once clean, apply a thin, even coat of bonding agent over the entire patch area, including the repair walls or edges. Contact time for cement grout should not exceed about 90 minutes, and it must not dry before the placement of the repair material. Scrubbing the bonding materials in with a stiff‐bristled brush works well to get the materials into surface cavities. Epoxy agents may permit a less vigorous application. Overlapping the pavement surface also will help promote good bonding.

Figure 8. Application of Bonding Agent

4.7 Placing the Repair Material

Careful control of mixing times and water content is very important because of the quick setting nature of repair materials. Do not allow the addition of extra water to the concrete mix to achieve better workability because of the resulting reduction in concrete strength and increased shrinkage potential.

The volume of material required for a PDR is usually small. Ready - mix trucks and other large equipment may be used if a sufficient number of repair areas are prepared ahead of time and if the working time of the material is sufficient long to allow placement of the entire amount of the material. For PDR, repair materials are typically mixed on site in small mobile drums or paddle mixers. Place concrete into the repair area from wheelbarrows, buggies, or other mobile batch vehicles. For small repairs, shovel the patch material. Where the repair material is mixed in repair area with the truck's chute, slightly overfill the repair area to compensate for consolidation.

Repair materials should be placed under favorable environmental conditions. Portland cement concrete and most proprietary repair materials should not be installed under adverse conditions, such as air or pavement temperatures below 40° F (4º C) or in wet substrates. Placement when temperatures are below 55 °F (13 °C) will required the use of warm water, insulation covers, and longer curing periods.

During placement, slightly overfill the repair area to allow for volume reduction during consolidation. Use a small spud vibrator with a diameter of <1 inch (25 mm) to vibrate the fresh concrete; this will eliminate any voids, especially at the interface of the repair and existing concrete. Hold the vibrator about 15° - 30° to vertical. Vibrate the entire repair area, especially around the edges of the repair, but do not drag the vibrator through the mix because this may cause segregation and loss of entrained air. Use small penetrations of the vibrator throughout the repair area. It should be lifted up and down and not moved horizontally. On very small repairs, hand tools should be sufficient to work the repair material and attain adequate consolidation.

4.8 Finishing

Finish the repair surface to meet the elevation of the surrounding pavement. Trowel the patch outward, from the center toward the edges, to push the repair material against the walls of the patch. This technique provides a smooth transition and increases the potential for high bond strength. Do not trowel from the edges to center, because this will pull the material away from the edges. For projects with many repairs, match the existing surface texture for a more uniform appearance. For small repairs, and projects that include diamond grinding, texturing is not important.

4.9 Curing

Curing is very important because of the large surface area of these small repairs compared to the small volume of repair material. This relationship is conducive to a rapid moisture loss and is different from most other concrete applications. Neglecting to cure the repairs or waiting too long to apply the curing compound will likely result in excessive material shrinkage and delamination of the repair.

Apply a liquid‑membrane‑forming curing compound evenly and sufficiently. Use well‑maintained pressure spraying equipment that will allow an even application. An application rate of about 5.0 m^2/liter is sufficient. Where early opening of the pavement to traffic is required, it maybe beneficial to place insulation mats over the repairs. This will hold in heat from hydration and promote increased strength gain for cementitious materials.

Figure 9. Application of Curing Compound

4.10 Joint Sealing

After the patch has gained sufficient strength, the joint can be resealed. Resealing the joint is extremely important, because it will help prevent moisture and incompressible material from causing further damage. Both longitudinal and transverse repair joints should be sealed. Joints should be sawed or formed, sandblasted, air blasted, and a backer rod should be inserted and joint sealant applied.

5.0 Opening to Traffic

Compressive strength requirements for paving concrete are generally specified at 3,000 psi (20.7 MPa) at 28 days. The repair concrete should develop an equal or greater strength by the time it receives traffic loads. However, to minimize lane closures, traffic loadings may be allowed on a patched area when the repair concrete has attained the minimum strength needed to assure its structural integrity. The compressive strength required for the opening of PDR to traffic may be lowered because of their lateral confinement and shallow depth.

The specifications of rapid‑setting proprietary mixes should be checked for recommended opening times. Cylinders or beams can be tested for strength to determine what opening time will be allow the repair material to develop enough strength.

6.0 Performance

PDR performance depends on many factors. Studies show that when PDR are properly installed and when quality control during construction is good, 80 to 100 percent of the repairs perform well after 3 to 10 years of service. When properly placed with an appropriate and durable material and combined with good joint sealant maintenance practices, PDR should last long as the rest of the pavement. However, improper design and construction practices, combined with poor quality control and inspection, result in poor performance. The most frequent causes of PDR failure are:

- Inappropriate use of PDR
- Improper selection of repair materials
- Poor construction techniques
- Lack of bond between the repair and the pavement
- Drying of bonding agent
- Compressive failure
- Variability of the repair material
- Improper use of repair material
- Insufficient consolidation
- Incompatible thermal expansion between the repair material and the original slab
- Late Curing
- Feathering of the repair material