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CHAPTER 8 FULL DEPTH CONCRETE REPAIR

This chapter provides an overview of isolated full depth concrete repairs. It presents a description of the effectiveness and limitations of this techniques, as well as material selection, design considerations, and construction procedures. Also included are a troubleshooting guide and a list of important factors to be considered during design and construction of this treatment.

8.1 PURPOSE AND DESCRIPTION OF TREATMENT

Full depth repairs are preventive maintenance techniques that restore isolated slab structural integrity and rideability of the pavement, and deter further deterioration extending the pavements service life. Also, isolated full depth repairs are required to prepare an existing distressed pavement prior to a structural overlay or a restoration project.

8.1.1 Full Depth Repair

Full depth repair involves the full-depth slab removal followed by cast-in-place replacement of full lane-width areas of an existing rigid pavement. Typically the minimum length requirement is 6 ft (1.8 m); however, when repair areas are closely located it is more cost effective to substitute a larger area. Half lane widths areas are not allowed by Caltrans due to their instability.

Full depth repair can address a wide variety of distresses, including transverse cracks, longitudinal cracks, joint spalling, and blowups. Table 8-1 shows the typical distress types and severity levels where full depth repairs should be applied.

Table 8-1 Distresses addressed by full depth repairs for jointed concrete pavements (FHWA, 2001)

| Distress Type | Severity Levels that Require Full Depth Repair |
|---|--|
| Transverse cracking | Medium, High |
| Longitudinal cracking | Medium, High |
| Corner break | Low, Medium, High |
| Spalling of joints | Medium ¹ , High |
| Blowup | Low, Medium, High |
| Reactive aggregate spalling ² | Medium ¹ , High |
| Deterioration adjacent to existing repair | Medium ¹ , High |
| Deterioration of existing repairs | Medium ¹ , High |

¹ Partial-depth repairs can be used if the deterioration is limited to the upper one-third of the pavement slab

² If the pavement has a severe material problem (such as reactive aggregate), full-depth repairs may only provide temporary relief from roughness caused by spalling. Continued deterioration of the original pavement is likely to result in redevelopment of spalling and roughness.

8.2 MATERIALS AND SPECIFICATIONS

A wide variety of materials are available for full depth repairs. The selection of the adequate material will depend on the project's environmental, design, and funding requirements. Repair materials include conventional portland cement concrete (PCC) mixtures, special cements, proprietary materials, and bituminous materials.

8.2.1 Materials Selection

Repair materials are selected based on available curing time, climatic conditions, material cost, equipment requirements, mixing and placing time, desired service life, and the size and depth of the repairs. Material properties, such as strength gain, modulus of elasticity, bond strength, scaling resistance, sulfate resistance, abrasion resistance, shrinkage characteristics, coefficient of thermal expansion, and freeze-thaw durability, should also be included in the selection process. Repair materials must be compatible in strength and volume stability with the existing pavement.

8.2.2 Cementitious Materials

PCC mixtures are the most widely used material for full depth repairs. However, specialty cement mixtures and specialty materials have also been successfully used for full depth repairs to meet with short opening time requirements, but their cost is much higher than conventional PCC mixtures and they are usually more difficult to handle. A good rule of thumb for selecting the material for PCC slab repairs is to use the most convenient material that meets the lane closure requirements (Caltrans, 2004).

High early strength cementitious mixtures have been widely used for full depth repairs. The high early strength can be achieved on PCC mixtures by reducing the water to cement ratio (w/c), increasing the cement content, adding chemical accelerators, and by adding high-range water reducers.

Caltrans allows the contractor to select the replacement concrete material on the basis of the available lane closure time and the strength requirements. Rapid Strength Concrete (RSC) shall be in conformance with Caltrans SSP No. 40-020. Caltrans uses three types of RSC mixes (Caltrans, 2004):

- Specialty or proprietary cement mixes may be used on short construction windows and can meet opening strength requirements with 2 to 4 hours of cure time under typical placement conditions.
- Mixes of Type III portland cement with non-chloride accelerators may also be used for short construction windows and can meet opening strength requirements with 4 to 6 hours of cure time under typical placement conditions. A high-range water-reducing admixture may be used to disperse cement particles and reduce the extra water necessary for thorough mixing.
- Mixes of Type III portland cement with non-chloride accelerators may be used for longer construction windows. These types of mixed can achieve strength requirements with at least 24 hours of cure time under typical placement conditions.

The FHWA mentions the following special cements which have been used for full depth repairs (FHWA, 2001):

- Rapid set cement (RSC), which is similar to Type K expansive cement, can provide the strength required for opening to traffic in 2 to 6 hrs. This special cement was modified to reduce the expansion difficulties usually associated to expansive K cements.
- Regulated set portland cement (RSPC) has similar components as the ordinary portland cement, but up to 20 to 25% of the calcium aluminate phases have been replaced with calcium fluoroaluminate. RSPC set time can be regulated from 2 to 30 minutes by the use of a set retarder.

Table 8-2 shows some properties of various cementitious materials used nationally.

Table 8-2. High Early-strength mix design and approximate opening times (FHWA, 2001)

| Mix Component | Type I (GADOT) | Type III (Fast Track I) | Type III (Fast Track II) | RSPC | Rapid Set Cement |
|---|---|-------------------------|--------------------------|------|------------------|
| Cement, (lb/yd ³) | 755 | 644 | 745 | 613 | 652 |
| Flyash, (lb/yd ³) | – | 73 | 81 | – | – |
| Course Aggregate, (lb/yd ³) | 1803 | 1399 | 1311 | 1709 | 1808 |
| Fine Aggregate, (lb/yd ³) | 1034 | 1366 | 1308 | 1406 | 1006 |
| w/c Ratio | 0.40 | 0.40 to 0.48 | 0.40 to 0.48 | 0.41 | 0.45 |
| Water Reducer | – | yes | yes | – | – |
| Air Entraining Agent | As needed to obtain air content of 6 ± 2 percent. | | | | |
| CaCl ₂ % wt. cement | 1.0 | – | – | – | – |
| Opening time | 4 hr | 24-72 hr | 12-24 hr | 4 hr | 4-6 hr |

1 kg/m³ = 1.69 lb/yd³

8.2.3 Bituminous Materials

Bituminous materials are not recommended for permanent repairs of rigid pavements because they allow excessive horizontal movements of the slabs, provide no load transfer across the transverse joints, and may lead to rapid deterioration. They should be only considered as a short-term or temporary repair.

8.3 ENGINEERING CONSIDERATIONS

Full depth repairs performance can be highly improved through proper design. This section provides necessary design considerations for full depth repairs, such as project selection, concurrent work considerations, repair locations and boundaries, and load transfer devices.

8.3.1 Project Selection

Full depth repairs should be used for rigid pavements with deterioration limited to isolated slab; and not widespread over the entire project length. Structurally deficient pavements may require a structural enhancement, such as an overlay or tied rigid shoulders, instead of a simply isolated full depth repair. Pavements with moderate to severe material problems (e.g., ASR) and pavements with

base or subgrade problems, as indicated by differential settlements, are not good candidates for isolated full depth concrete repair.

8.3.2 Concurrent Work

The sequence of the repairs is very important when isolated full depth repairs are done as part of a comprehensive pavement restoration project. Slab stabilization should be done before full depth repairs to prevent any accidental spalling that can occur during the full depth repair. Isolated full depth repairs should be done concurrently or after partial depth repairs for an adjacent slab are done. If necessary, diamond grinding should follow the full depth repairs, and then finish with joint resealing as needed.

8.3.3 Repair Locations and Boundaries

A visual survey must be conducted to identify and mark the distressed areas. Engineering judgment, coring, deflection studies, and sounding techniques; such as striking the concrete surface with a hammer, steel rod or by dragging a chain; should be used to define the extent of the deterioration beneath the surface and determine the repair boundaries.

Caltrans specifies that a replacement slab joint or a full depth repair joint must be at least 6.6 ft (2 m) from the nearest crack or joint (Caltrans, 2004).

FHWA recommends the following minimum repair dimensions for full depth repairs (FHWA, 2001):

- **Doweled or Tied Repair.** A minimum length of 6 ft (1.8 m) and a full-lane-width repair are recommended to minimize rocking, pumping, and breakup of the slab (Darter, Barenberg, and Yrjanson 1985; Snyder et al. 1989).
- **Non-doweled or Non-tied Repair.** The minimum recommended repair lengths are 6 ft (1.8 m) for pavements with low truck traffic volumes and 8 to 10 ft (2.4 to 3.0 m) for pavements with medium to high traffic volumes.
- **Partial-lane-width repairs** are generally not recommended due to their relative instability.

FHWA also provides the following guidelines on developing repair boundaries for jointed concrete pavement (FHWA, 2001):

- Long repairs have a tendency to crack at mid-slab; therefore, repairs longer than 10 to 13 ft (3 to 4 m) should be constructed with either an intermediate joint to prevent cracking, or steel reinforcement to hold the cracks tight, should they occur (Darter, Barenberg, and Yrjanson, 1985, Carmichael et al, 1989).
- The repair boundary should not be too close to an existing transverse crack or joint; otherwise, adjacent slab distress will occur. A minimum distance of 6 ft (1.8 m) is recommended from the full-depth repair joint to the nearest transverse crack or joint (Darter, Barenberg, and Yrjanson, 1985; ACPA, 1995).
- A boundary that would fall at an existing doweled transverse joint (distress at one side of the joint only) should be extended 1 ft (0.3 m) to include the existing joint. Attempts at salvaging the existing dowel system, even if the dowels are properly aligned and corrosion-free, frequently result in damage to dowel bars and the adjacent slab during the concrete breakup and cleanout operations (ACPA, 1995, FHWA, 1985). If distress is present on only one side of an existing non-doweled joint, that joint may be used as a boundary.

- Cracks located 10 ft (3 m) or farther from the joint can be repaired individually or, if severe enough, the entire slab can be replaced.

Caltrans specifies that the absolute minimum slab repair should be the full slab width by 6.5 ft (2 m) and the repair slab should be at least 6.5 ft (2 m) from the nearest crack or joint (Caltrans, 2004). Any repair longer than 15 ft (4.6 m) shall be provided with a new transverse joint (Caltrans, 2004 and Caltrans, 2006a).

8.3.4 Load Transfer Devices

Transverse joint load transfer design is essential to the performance of full depth repairs. Adequate load transfer devices minimize differential movement of the slabs which causes spalling, rocking, pumping, faulting and breakup of adjacent slabs. The use of mechanical load transfer devices is highly recommended for any type of road. Residential streets with less than a 100 trucks or buses per year should be the only type of road where aggregate interlock alone may be adequate to transfer the loads between concrete slabs.

Mechanical load transfer devices include:

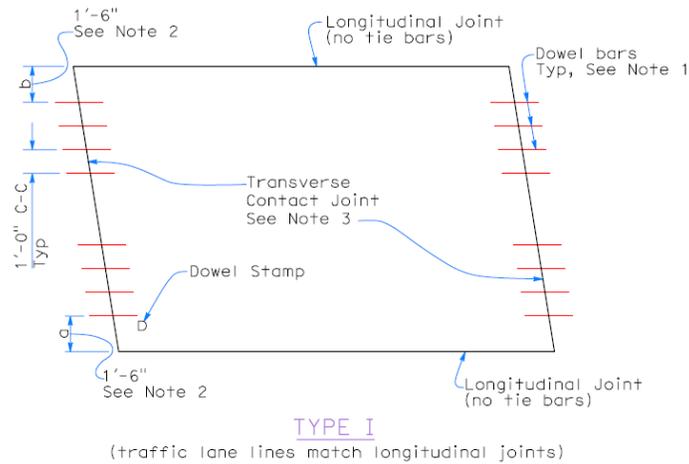
- Dowel bars. Dowel bars are smooth steel bars used at transverse joints. They allow free horizontal movement of the slabs. For full depth repair joints at least one doweled joint should be installed to allow free horizontal movement of the repair area.
- Tie bars. They are deformed rebars used along the longitudinal joint, usually 1 in. (25 mm) in diameter. Tie bars are anchored into the existing slab. These bars allow no horizontal movement of the joint and should be epoxy-coated to improve corrosion resistance.

The use of 1.8 ft. (46 mm) long and 1.5 in. (38 mm) diameter dowel bars is recommended for most interstate pavements; 1.25 in. (32 mm) diameter dowel bars may be acceptable for light traffic and for pavements less than 10 in. (250 mm) thick. The use of 1 in. (25 mm) diameter dowel bars for full depth repairs is discouraged because they have proved to be inadequate to withstand the bearing stresses in repair joints (ACPA, 1995). Caltrans does not recommend the use of dowel bars for pavements less than 7 in. (180 mm) thick (Caltrans, 2004).

Caltrans provide the following guidelines for load transfer design (Caltrans, 2004):

- 3 dowel bars spaced 1 ft. (300 mm) on center in each wheel track for non-truck lanes
- 4 dowel bars spaced 1 ft. (300 mm) on center in each wheel track for truck lanes
- Since lane striping is subjected to change, Caltrans has allowed for 9 dowel bars to be spaced evenly across the transverse joint. However, a design which concentrates the bars in the wheel tracks with a spacing of 1 ft. (300 mm) is highly recommended.
- If the location of striping is uncertain, use 12 dowel bars at 1 ft. (300 mm) spacing
- For new transverse joints located 7.5 ft. (2.3 m) or less from the existing slab transverse joint, tie bars may be installed at 2 ft. (600 mm) on center along the new construction joint in lieu of the dowel bars.

The dowel bar design shown in Figure 8-1 is recommended by Caltrans for truck lanes (Caltrans,2006a).



NOTES:

1. For details not shown see Standard Plan P10.
2. Where the existing outer shoulder pavement is asphalt concrete pavement, the "a" dimension shall be 1'-0" and the "b" dimension shall be 2'-0".
3. For detail see Transverse Contact Joint for existing concrete pavement detail on Standard Plan P10.

Figure 8-1 Caltrans dowel bar design (Caltrans Standard Plan P8, 2006)

8.3.5 Typical Item Codes

Typical Caltrans item codes for full depth concrete repair project are given in Table 8-3.

Table 8-3 Typical item codes for an isolated full depth concrete repair project

| Item Code | Description |
|-----------|---|
| 120090 | Construction area signs |
| 120100 | Traffic control system |
| 128650 | Portable changeable message sign |
| 150846 | Remove concrete pavement |
| 150306 | Repair spalled concrete |
| 156515 | Repair spalled and unsound surface area |
| 401108 | Replace concrete pavement (rapid strength concrete) |
| 406100 | Dowel bar retrofit |
| 413101 | Repair corner breaks |
| 413111 | Repair spalled joint |
| 413114 | Replace joint seal (existing concrete pavement) |
| 413115 | Seal joint (existing concrete pavement) |
| 420201 | Grind existing concrete pavement |
| 511040 | Concrete surface finish |
| 511055 | Concrete surface texture |
| 515028 | Repair spalled surface area |

Note: Standard special provision must be referred for specific item codes proposed for the project.

Caltrans Standard Materials and Supplemental Work Item Codes can be found at the following web site:

http://i80.dot.ca.gov/hq/esc/oe/awards/#item_code

8.4 CONSTRUCTION PROCESS

8.4.1 Traffic Control and Safety

Traffic control is required both for the safety of traveling public and the construction personnel. Traffic control should be enforced before equipment or personnel enter the work zone. Caltrans project specifications and Caltrans Code of Safe Operating Practice should be followed. Traffic is not allowed on repair areas until the curing period and the joint sealing process are completed.

Depending on the project location, size, and amount of repair work, one of the following types of traffic control alternatives may be considered:

- Complete roadbed closure
- Continuous lane closure
- Weekend closure
- Nighttime closure

8.4.2 Equipment

Equipment requirements vary according to the treatment method and the material selected; and it will be described in more detail in Sections 8.4.3 through 8.4.11. Equipment may be required for:

- Sawing and material removal
- Cleaning
- Installation of load transfer devices
- Repair material placement
- Finishing
- Curing
- Joint sealing

8.4.3 Repair Locations

As mentioned in section 8.3.3, defining the location and boundaries of the repair needs to be performed by experienced personnel through a field survey. The field survey should be complemented with other measures such as coring or deflection testing to define the extent of the deterioration beneath the surface and determine the repair boundaries. This survey should be performed as close as possible to construction, and it should include additional distress areas that have occurred since the previous pavement inspection. Distress areas and repair boundaries should be marked on the pavement surface.

8.4.4 Concrete Sawing and Removal

Concrete sawing for full depth repairs can be accomplished by the two following transverse joint saw cutting procedures:

- **Rough-faced.** A diamond-bladed saw is employed to outline the repair boundaries. The saw cut should not penetrate more than 30% of the slab depth. Jackhammers are used to break the deteriorated slab allowing the resulting rough face to provide adequate aggregate interlock between the new repair material and the old pavement. A disadvantage of this procedure is the high potential of spalling beneath the slab during the concrete removal operation.
- **Smooth-faced.** The transverse joint is sawed to a full depth. No aggregate interlock is obtained with this procedure. The use of mechanical joint load transfer devices is highly recommended, especially for heavy trafficked pavements.

Caltrans specifies full-depth saw cuts around the entire perimeter of the distressed area that will be removed. The repaired area must be at least 6.5 ft (2 m) long. Additionally, any remaining concrete adjacent to the repaired area must also be at least 6.5 ft (2 m) long. Any repair that does not meet these requirements should be treated as a slab replacement and not as an isolated full depth repair (Caltrans, 2004).

Traffic loading must be limited between the time of sawing and the concrete removal to avoid pumping and erosion beneath the slab. No more than 2 days of traffic over the sawed repair areas before concrete removal begins is recommended (FHWA, 2001).

Saw Cutting Special Considerations

On hot days (temperatures greater than 100 F), a wide pressure relief cut will be needed to prevent spalling of the adjacent concrete during removal due to thermal expansion. The commonly used carbide-tipped wheel saw usually promotes excessive spalling along the joint. If a wheel saw is used, diamond sawcuts must be made at least 18 in. (460 mm) outside the wheel sawcuts. Additionally, the wheel saw should not intrude adjacent slabs, and must not be allowed to penetrate into the subbase more than 0.5 in. (13 mm). Another alternative, to avoid the need of pressure relief cuts, is to saw at night during cooler temperatures.

Caltrans provides the following guidelines for saw cutting (Caltrans, 2004):

- Saw the concrete in rectangular sections to simplify concrete removal
- Do not make notches or diagonal cuts in the pavement
- Each area of concrete to be replaced will receive a saw cut through the existing slab around its entire perimeter. Additional sawing of individual panels may be required for removal.
- Saw cuts through the existing slab are required to separate the removal area from the surrounding concrete.
- Water residue from concrete cutting should be removed immediately by vacuuming.
- Saw cuts made prior to the actual removal work shift should not include any cuts made closer than 1 m to another cut, joint, or crack, so as to avoid creating any small pieces that could be dislodged by traffic.

In areas with extensive deterioration, the repair costs can be reduced by removing and replacing large areas of concrete; this procedure is also called “slab replacement”. A slab replacement pay item should be additionally included for these larger area repairs.

Concrete Removal

Caltrans does not allow any removal techniques that may damage the remaining in-place pavement and base. Non-impact methods shall be used for concrete removal activities.

After the boundary cuts have been made, the deteriorated concrete can be removed by the **Lift out Method**. Lift pins are installed in the distressed slabs which are vertically lifted by the use of chains and a front-end loader or other equipment. Adequate equipment and procedures should be employed to avoid damaging adjacent slabs and disturbing the existing subbase. This method minimizes disturbances to the base, providing the best results and is vary effective (see Figure 7-5).

Impact methods, such as the **Breakup and Cleanout Method**, may be allowed when the treated base needs to be removed. The deteriorated concrete is broken into smaller pieces by using a jackhammer, drop hammer, or hydraulic ram, and then removed by the use of a backhoe and hand tools. Demolition equipment should not be allowed near sawed joints. Breakup should begin at the center of the repair area and never at the edges. This method generally results in great disturbances to the subbase and subgrade, and usually requires either replacement of these layers or filling with concrete.



Figure 8-2 Concrete removal using lift out method (Caltrans, 2004)

8.4.5 Cleaning and Repair Area Preparation

The repair area should be clean of all debris from the demolition stage. If subbase and/or subgrade material has been disturbed or pockets of loose or missing material are identified, they should be removed and replaced with similar material or concrete. If excessive moisture is present, it should be dried out or removed and replaced before placement of the repair material. The need of lateral drainage should be evaluated before continuing the repair work. This procedure may not be practical for typical Caltrans work windows.

Compaction of granular material in confined areas is difficult. In these cases, replacement of damaged subbase material with concrete may be the best option. Caltrans recommends the use of rapid strength concrete (RSC) for base repairs, and a bond breaker shall be used to separate the treated base from the concrete pavement (Caltrans, 2004). In these cases, the treated base layer should be allowed to cure and gain sufficient strength before the new pavement slab is poured.

8.4.6 Provision of Load Transfer

Adequate installation of mechanical load transfer devices reduces differential movement between slabs and is critical to the performance of full depth repairs. Load transfer devices such as dowel bars can be employed to provide for load transfer across repair joints. At least one doweled joint should be provided to the repair to allow for horizontal movements.

Holes should be drilled at mid-depth of the exposed face of the existing slab with equipment that warrants proper horizontal and vertical alignment. Single hand-held drills are not allowed because of the likelihood of misalignment. Adequate hole alignment is critical to the repair performance. Standard pneumatic and hydraulic percussion drills are acceptable for drilling dowel holes. Electric-pneumatic drills should be avoided due to their inadequate production rate.

Hole diameter should be big enough to allow room for the dowel and for the anchoring material. Table 8-4 provides some recommendations for dowel hole diameter (Snyder et al, 1989).

Table 8-4 Anchoring materials and dowel hole recommendations

| Anchoring material | Dowel hole diameter | Comments |
|--------------------|----------------------------------|---|
| Cement grout | Dowel diameter + 0.25 in. (6 mm) | Plastic grout mixtures provide better support to dowels than fluid mixtures. |
| Epoxy material | Dowel bar + 1/6 in. (2 mm) | Due to epoxy materials' flexibility compare to the surrounding concrete, a thin layer is desirable to reduce mortar deformation and dowel deflection. |

Anchoring the dowels is critical to the performance of the repairs. The following procedure is recommended for anchoring dowel bars (See Figure 8-3) (FHWA, 1985, Snyder et al, 1989, ACPA, 1995):

1. Remove debris and dust from the dowel holes by blowing them out with air. If the holes are wet, they should be allowed to dry before installing dowels. Oil will prevent good bonding. Always check the air for oil and moisture contamination from the compressor.
2. Place quick-setting, non-shrinking cement grout or epoxy resin in the back of the dowel hole. The grout can be placed by using a flexible tube with a long nose that places the material in the back of the hole; epoxy-type materials can be placed using a cartridge with a long nozzle that dispenses the material to the rear of the hole.
3. Optionally, place a grout retention disk (a thin donut-shaped plastic disk) over the dowel and against the slab face, as illustrated in figure 8-3. This prevents the anchoring material from flowing out of the hole and helps create an effective face at the entrance of the dowel hole (the location of the critical bearing stress).

4. Insert the dowel into the hole with a slight twisting motion so that the material in the back of the hole is forced up and around the dowel bar. This ensures a uniform coating of the anchoring material over the dowel bar
5. The protruding end of the dowel should be slightly greased to facilitate horizontal movement.

Caltrans recommends using a long nozzle that feeds the cement grout or epoxy resin to the back of the dowel hole. This ensures that the anchoring material will flow forward along the entire dowel embedment length during insertion and decreases the likelihood of leaving voids between the dowel bar and the concrete (Caltrans, 2004).

Caltrans also recommends the use of a cap or grout retention disk, if a non-shrink cement mix is used. All cements that are not portland cement may be considered non-shrink. Dowel bars that are drilled and bonded with epoxy do not need caps on the side placed in the drilled hole (Caltrans, 2004).

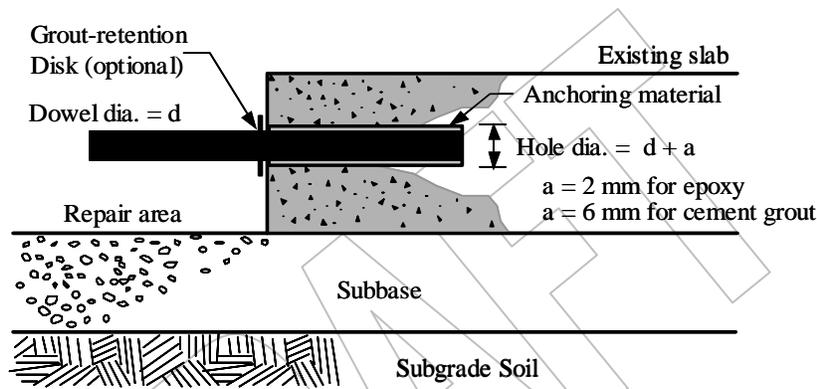


Figure 8-3 Dowel bar anchoring in slab face (FHWA, 2001)

FHWA recommends the use of tie bars for full slab replacement and full depth repairs longer than 15 ft. (4.6 m). Tie bars should be installed using the same procedures used for dowel installation. Typically, dowel bars are spaced along the longitudinal joint at 30 in. (750 mm). This information can be found at the Federal Highway Administration website at the following address:

<http://www.fhwa.dot.gov/pavement/concrete/full.cfm>

Caltrans requires tie bars between existing slabs and “newly placed” concrete, if the existing pavement has tie bars. Tie bars help mainly to keep lanes from separating (Caltrans, 2004).

8.4.7 Joint Preparation

Transverse Joints

Caltrans requires the installation of a ¼ in. (6 mm) thick, commercial quality polyethylene flexible foam expansion material across each transverse joint. This material must be securely placed and shall extend along the slab face, with the top of the expansion material flush with the top of the pavement. In addition, the expansion material must be cut to fit with the holes for drill-and-bond dowels (Caltrans, 2004).

Longitudinal Joint

Full depth repairs less than 15 ft (4.6 m) long would require a bond breaking board along the longitudinal face with an existing concrete lane or concrete shoulder. A 1/5 in. (5 mm) bond breaker should match the repair area length and depth and sit flush with the longitudinal face (FHWA <http://www.fhwa.dot.gov/pavement/concrete/full.cfm>).

Caltrans does not require the use of expansion materials along the longitudinal joint for pavement repairs, unless the joints of adjacent pavement slabs do not match. The expansion material must be placed securely across the entire length of the joint and extend along the height of the slab, with the top of the expansion material flush with the top of the pavement joint (Caltrans, 2004).

8.4.8 Bond Breaker

Caltrans recommends the application of a suitable bond breaker, such as plastic sheeting or curing paper, over the prepared base. The bond breaker will allow the slab and the base to move independently of one another. Other bond breaker materials may be used per contract specifications. The base replacement material and RSC pavement shall not be placed in a monolithic pour (Caltrans, 2004).

8.4.9 Materials Placement

Clean Surface

Before placing the bonding agent and the repair material, it is necessary to make sure the repair area is clean and dry.

Placement

A careful control of mixing times and water content is very important because of the quick setting nature of the material. Do not allow the addition of extra water to the concrete mix to achieve “greater workability” because it may result in reduction in concrete strength and increase of concrete shrinkage.

Portland cement concrete and most proprietary repair material should not be installed under adverse conditions, such as air or pavement temperature below 40 °F (4 °C) or in wet substrates. Placement under temperatures below 55 °F (13 °C) will require the use of warm water, insulation covers, and longer cure periods.

Consolidation usually is achieved more consistently by the use of vibrating screeds. High-frequency internal vibrators can also be used to consolidate RSC, but vibrators are not permitted for shifting of the mass of RSC. The use of vibrating screed parallel to the centerline of the pavement is recommended for full depth repairs.

During placement, a slightly over-filling of the repair area should be allowed to account for the volume reduction during consolidation. It is also important to ensure that the concrete is well vibrated over the entire repair area and especially around the edges of the repair to avoid over finishing the repair area.

8.4.10 Finishing

A critical aspect of full depth repairs is to obtain a level finish of the repair area with the surrounding pavement. To provide adequate skid resistance and a smooth transition, the surface of the repair should be textured to match that of the existing pavement. In full depth repairs, the repair material should be struck off two or three times in a transverse direction to make it flush with the existing pavement.

8.4.11 Curing

Adequate attention to curing will reduce the development of shrinkage cracking and promote a more complete cement hydration, by preventing moisture loss from the concrete. Proper curing is even more important when accelerating admixtures are being used. Curing procedures shall be in conformance with Caltrans Standard Specifications Section 90-7 "Curing Concrete".

In hot weather (greater than 100 F), the use of pigmented curing compounds is highly recommended over other curing procedures (moist burlap and polyethylene). Caltrans recommends a nominal rate of application of 150 ft²/gal (4 m²/L), unless otherwise specified (Caltrans Standard Specifications Section 90-7). ACPA recommends an application rate of about 200 ft²/gal (5 m²/L). Insulation mats are not necessary in hot weather, and if used can result in concrete cracking (ACPA, 1989).

In cold weather (less than 50 F), the use of insulating blankets and tarps can accelerate hydration and promote higher early strength; allowing for earlier opening to traffic. Special care is required during the removal of insulation blankets, because rapid cooling of the pavement surface can cause cracking. When large temperature differences exist between concrete and air temperature, the insulation blankets should not be removed from the repair area.

Curing time and procedures for epoxy and proprietary materials should follow manufacturers' recommendations.

8.4.12 Joint Sealing

Joint sealing will reduce future spalling and minimize water infiltration. Both longitudinal and transverse repair joints should be sealed. The joints should be sawed or formed, sandblasted, air blasted, a backer rod should be inserted and the joint sealant applied. More detail information on joint sealing can be found in Chapter 4 of this document.

Timing for sawing of intermediate joints is critical. Sawing too early can lead to spalling along the cut or dislodging of aggregate particles; while sawing too late can result in random cracking in the repaired area.

8.4.13 Opening to Traffic

Repair materials must have gained sufficient strength before it is opened to traffic. Caltrans requires a minimum flexural strength of 406 psi (2.8 MPa), as determine in accordance with CTM 523, for slab replacement (Caltrans, 2004). The FHWA provides the following criteria for full depth repairs to specify when the pavement may be opened to traffic (FHWA, 2001):

- **Minimum strength.** An agency may stipulate that the repair attain a minimum strength before it is opened to traffic. Recommended minimum strength requirements are (Darter, Barenberg, and Yrjanson, 1985; Whiting et al, 1994):
 - Compressive Strength: 2,000 lbf/in² (13.8 MPa).
 - Modulus of Rupture: 300 lbf/in² (2.1 MPa) center-point loading, or 250 lbf/in² (1.7 MPa) third-point loading.
- **Minimum time to opening.** Minimum time to opening to traffic should be based on the mix design, curing procedure, the ambient temperature at placement, and slab thickness.

It is preferable to have a measure of the actual concrete strength before allowing the repair area to be opened to traffic, especially if very early opening is required (e.g., 4 hr or less curing time). On such projects, maturity meters or pulse-velocity devices can be used to monitor concrete strength (ACPA, 1995).

8.4.14 Job Review-Quality Issues

Quality control and workmanship are critical to the performance of full depth repairs. It should be a cooperative effort between the Caltrans and the contractor's representatives to conduct inspections of all construction procedures, materials, and project equipment before and during the project. Careful project inspections allow earlier detection and correction of deficiencies in workmanship, equipment, and materials, resulting in improved end product.

Improper construction, placement techniques, or material deficiencies has been the most frequent quality concerns related to poor performance of isolated full depth repairs. Frequent causes of failure include improper preparation of the repair areas, inadequate placement of load transfer devices, insufficient consolidation, as well as improper use of repair materials, and incompatibility in thermal expansion between the repair material and the original slab.

8.5 PROJECT CHECKLIST AND TROUBLESHOOTING GUIDE

The project checklist and the troubleshooting guide, included in this section, provide important information which can help troubleshooting and improve performance of the repair areas. The project checklist describes important aspects, such as preliminary responsibilities, material and equipment requirements, project inspection responsibilities, and cleanup responsibilities, which should be considered in order to promote a successful job. The troubleshooting guide describes common problems encountered during construction and their solutions.

8.5.1 Project Checklist

The following checklists were primarily based on guidelines from the FHWA Pavement Preservation Checklist Series (http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=351) and the FHWA NHI Course titled "Pavement Preservation Design and Construction of Quality Preventive Maintenance Treatments".

| Preliminary Responsibilities | |
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| Project Review | <ul style="list-style-type: none"> ✓ Verify that pavement conditions have not significantly changed since the project was designed and that full-depth repair is appropriate for the pavement. ✓ Check estimated number of full-depth repairs against the number specified in the contract. ✓ Agree on quantities to be placed, but allow flexibility if additional deterioration is found below the surface. |
| Document Review | <ul style="list-style-type: none"> ✓ Bid/project specifications and drawings ✓ Special provisions ✓ Traffic control plan ✓ Manufacturers' instructions and recommendations ✓ Material safety data sheets |
| Materials Checks | |
| Concrete patch material | <ul style="list-style-type: none"> ✓ Verify that concrete patch material is being produced as required by contract documents. ✓ Verify that the mix design for the material being supplied meets the criteria of the contract documents. ✓ Verify that concrete patch material has been sampled and tested prior to installation, and is not contaminated. |
| Load transfer devices | <ul style="list-style-type: none"> ✓ Verify that load transfer units (dowels) meet specifications and that dowels are properly coated with epoxy (or other approved material) and free of any minor surface damage in accordance with contract documents. ✓ Verify that dowel-hole cementing grout meets specifications. |
| Other materials | <ul style="list-style-type: none"> ✓ Verify that bond-breaking board meets specifications (typically asphalt-impregnated fiberboard). ✓ Verify that joint sealant material meets specifications. |
| General | <ul style="list-style-type: none"> ✓ Verify that sufficient quantities of materials are on hand for completion of the project. ✓ Ensure that all material certifications required by contract documents have been provided to the agency prior to construction. |
| Equipment Inspections | |
| Concrete Removal Equipment | <ul style="list-style-type: none"> ✓ Verify that concrete saws and blades are in good condition and of sufficient diameter and horsepower to adequately cut the required patch boundaries. ✓ Verify that required equipment used for concrete removal is all on-site and in proper working order and of sufficient size, weight, and horsepower to accomplish the removal process (including front-end loader, crane, fork lift, backhoe, skid steer, and jackhammers). |
| Patch Area Preparation Equipment | <ul style="list-style-type: none"> ✓ Verify that the plate compactor is working properly and capable of compacting subbase material. ✓ Verify that gang drills are calibrated, aligned, and sufficiently heavy and powerful enough to drill multiple holes for dowel bars. ✓ Verify that air compressors have oil and properly functioning moisture filters/traps. Prior to use, check the airstream for water and/or oil by passing the stream over a board, then examining the board for contaminants. |
| Testing Equipment | <ul style="list-style-type: none"> ✓ Verify that the concrete testing technician meets the requirements of the contract documents for training/certification. ✓ Ensure that all material test equipment required by the specifications is available onsite and in proper working condition (typically including rod, mallet, ruler, and 10 ft [3 m] straightedge). ✓ Ensure that sufficient storage area on the project site is specifically designated for the storage of concrete cylinders. |

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| Placing and Finishing Equipment | <ul style="list-style-type: none"> ✓ Verify that handheld concrete vibrators are the proper diameter and operating correctly. ✓ Verify that all floats and screeds are straight, free of defects, and capable of producing the desired finish. ✓ Verify that sufficient polyethylene sheeting is readily available on-site for immediate deployment as rain protection of freshly placed concrete, should it be required. |
| Others | |
| Weather Requirements | <ul style="list-style-type: none"> ✓ Verify that air and surface temperatures meet contract document requirements (typically a minimum of 40 °F [4 °C] and rising) for concrete placement. ✓ Patching should not proceed if rain is imminent. Patches that have been completed should be covered with polyethylene sheeting to prevent rain damage. |
| Traffic Control | <ul style="list-style-type: none"> ✓ Verify that signs and devices match the traffic control plan presented in the contract documents. ✓ Verify that the setup complies with the Federal Manual on Uniform Traffic Control Devices or local agency traffic control procedures. ✓ Verify that traffic control personnel are trained/qualified in accordance with contract documents and agency requirements. ✓ Ensure that the repaired pavement is not opened to traffic until the patch material has met the minimum strength specified in the contract documents. ✓ Ensure that signs are removed or covered when they are no longer needed. ✓ Verify that any unsafe conditions are reported to a supervisor (contractor or agency). |
| Project Inspection Responsibilities | |
| Concrete Removal and Cleanup | <ul style="list-style-type: none"> ✓ Verify that the boundaries of the removal areas are clearly marked on the pavement surface and the cumulative area of the pavement to be removed is consistent with quantities in the contract documents. ✓ Verify that the patch size is large enough to accommodate a gang-mounted dowel drilling rig, if one is being used. Note: The minimum longitudinal length of patch is usually 6 ft (1.8 m). ✓ Verify that boundaries are sawed vertically the full thickness of the pavement. ✓ Verify that concrete is removed using the lift-out method and minimizing disturbance to the base or subbase as much as possible. ✓ Verify that after concrete removal, disturbed base or subbase is re-compacted, and additional subbase material is added and compacted if necessary. ✓ Verify that concrete adjoining the patch is not damaged or undercut by the concrete-removal operation. ✓ Ensure that removed concrete is disposed of in the manner described in the contract documents. |
| Patch Preparation | <ul style="list-style-type: none"> ✓ Verify that dowel holes are drilled perpendicular to the vertical edge of the remaining concrete pavement using a gangmounted drill rig. ✓ Verify that holes are thoroughly cleaned using compressed air. ✓ Verify that approved cement grout or epoxy is placed in dowel holes, from back to front. ✓ Verify that dowels are inserted with a twisting motion, spreading the grout along the bar inside the hole. A grout-retention disk can be used to keep the grout from seeping out of the hole. ✓ Verify that dowels are installed in transverse joints to the proper depth of insertion and at the proper orientation (parallel to the centerline and |

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| | <p>perpendicular to the vertical face of the sawcut excavation) in accordance with contract specifications. Typical tolerances measured perpendicularly to the sawed faced are 1/4 in. (6 mm) misalignment per 12 in. (300 mm) of dowel bar length.</p> <ul style="list-style-type: none"> ✓ Verify that tiebars are installed at the proper location, to the proper depth of insertion, and to the proper orientation in accordance with contract documents. When the length of the longitudinal joint is 15 ft (4.5 m) or greater, tiebars are typically installed in the manner used for dowels. When the length of the longitudinal joint is less than 15 ft (4.5 m), a bond-breaker board is placed along the length of the patch to isolate it from the adjacent slab. ✓ Ensure that tiebars are checked for location, depth of insertion, and orientation (perpendicular to centerline and parallel to slab surface). |
| <p>Placing, Finishing, and Curing Concrete</p> | <ul style="list-style-type: none"> ✓ Concrete is typically placed from ready-mix trucks or mobile mixing vehicles in accordance with contract specifications. ✓ Verify that the fresh concrete is properly consolidated using several vertical penetrations of the concrete surface with a handheld concrete vibrator. ✓ Verify that the surface of the concrete patch is level with the adjacent slab using a straightedge or vibratory screed in accordance with contract documents. ✓ Verify that the surface of the fresh concrete patch is finished and textured to match adjacent surfaces. ✓ Verify that adequate curing compound is applied to the surface of the fresh concrete immediately following finishing and texturing in accordance with contract documents. Note: Best practice suggests that two applications of curing compound be applied to the finished and textured surface, one perpendicular to the other. ✓ Ensure that insulation blankets are used when ambient temperatures are expected to fall below 40 °F (4 °C). Maintain blanket cover until concrete attains the strength required in the contract documents. |
| <p>Resealing Joints and Cracks</p> | <ul style="list-style-type: none"> ✓ Verify that patches have attained adequate strength to support concrete saws, patch perimeters and other unsealed joints are awed off to specified joint reservoir dimensions. ✓ Verify that joints are cleaned and resealed according to contract documents. |
| <p>Cleanup Responsibilities</p> | |
| <p>General</p> | <ul style="list-style-type: none"> ✓ Verify that all concrete pieces and loose debris are removed from the pavement surface. ✓ Verify that old concrete is disposed of according to contract documents. ✓ Verify that mixing, placement, and finishing equipment is properly cleaned for the next use. ✓ Verify that all construction-related signs are removed when opening pavement to normal traffic. |

8.5.2 Troubleshooting Guides

The following guides were primarily based on guidelines from the FHWA Pavement Preservation Checklist Series (http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=351) and the FHWA NHI Course titled “Pavement Preservation Design and Construction of Quality Preventive Maintenance Treatments”.

| Problem | Description and solution |
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| Undercut spalling | <p>Description: deterioration on bottom of slab on sound concrete surrounding the patch area, evident after removal of deteriorated concrete from the patch.</p> <p>Solution:</p> <ul style="list-style-type: none"> • Saw back into adjacent slab until sound concrete is encountered. • Make double saw cuts, 6 in. (150 mm) apart, around patch area to reduce damage to adjacent slabs during concrete removal. • Use a carbide-tipped wheel saw to make pressure-relief cuts 4 in. (100 mm) wide inside the area to be removed. |
| Saw binds | <p>Description: saw blade getting stuck to pavement when cutting full depth exterior cuts.</p> <p>Solution:</p> <ul style="list-style-type: none"> • Shut down saw and remove blade from saw. • Wait for slab to cool, then release blade if possible, or make another cut inside the area to be removed to provide a small pie-shaped piece adjacent to the stuck saw blade. • Make transverse saw cuts when the pavement is cool. • Use a carbide-tipped wheel saw to make pressure-relief cuts 4 in. (100 mm) wide inside the area to be removed. |
| Adjacent slab damage | <p>Description: lifting out a patch for a full depth repair damages adjacent slab.</p> <p>Solution:</p> <ul style="list-style-type: none"> • Adjust lifting cables and re-position lifting device to assure a vertical pull. • Re-saw and remove broken section of adjacent slab. • Use a forklift or crane instead of a front-end loader. |
| Slab disintegration | <p>Description: slabs disintegrates when attempts are made to lift it out</p> <p>Solution:</p> <ul style="list-style-type: none"> • Complete removal of patch area with backhoe or shovels. • Angle the lift pins and position the cables so that fragmented pieces are bound together during liftout. • Keep lift height to an absolute minimum on fragmented slabs. |
| Patch filled with water | <p>Description: patches become filled with rainwater or groundwater seepage, saturating the subbase.</p> <p>Solution:</p> <ul style="list-style-type: none"> • Pump the water from the patch area, or drain it through a trench cut into the shoulder. • Re-compact subbase if necessary to a density consistent with contract |

| Problem | Description and solution |
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| | documents, adding material as necessary. <ul style="list-style-type: none"> • Allow small depressions in subbase to be filled with aggregate dust or fine sand before patch material is placed. Permit the use of aggregate dust or fine sand to level small surface irregularities (1/2 in. [12 mm]) in surface of subbase before concrete patch is placed. |
| Grout flow out of dowel holes | Description: grout around dowel bars flows back out of the holes after dowels are inserted. Solution: <ul style="list-style-type: none"> • Pump grout to the back of the hole first. • Use a twisting motion when inserting the dowel. • Add a grout retention disk around the bar to prevent grout from leaking out. |
| Misaligned dowels | Description: dowels appear to be misaligned once they are inserted into holes Solution: <ul style="list-style-type: none"> • If misalignment is less than 6 mm (1/4 in.) per 300 mm (12 in.) of dowel bar length, do nothing. • If misalignment is greater than 1/4 in. (6 mm) per 12 in. (300 mm) of dowel bar length on more than three bars, re-saw patch boundaries beyond dowels and re-drill holes. • Use a gang-mounted drill rig referenced off the slab surface to drill dowel holes. |

8.6 KEY REFERENCES

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