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Full Depth Repair

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TECH BRIEF

This document is a brief technical summary of the MoDOT case study ***Full Depth Repair Case Study for California, Missouri and Other Leading States*** *which is included in a larger report,* ***Concrete Repair Best Practices: A Series of Case Studies****, Publication no. cmr 17-013, November 2017.*

Introduction

Full depth repair (FDR) is a well-established technique applied to existing jointed plain and jointed reinforced concrete pavements (JPCP and JRCP) that includes both partial slab replacement and full slab replacement to address any variety of serious distress. FDR provides for the long-term repair of structurally and/or functionally deteriorated joints, working cracks, shattered slabs, and multiple slab distress.

When combined with other needed concrete pavement restoration (CPR) techniques, FDR can significantly increase pavement service life before structural overlay or reconstruction is required. FDR can also increase the life of a pavement to be overlaid by providing high joint load transfer efficiency (LTE) to restore stability and control reflection cracking severity.

This case study report focuses on full depth repair in California for JPCP and in Missouri for JRCP, but also includes information from Georgia, Minnesota, Utah, and Washington. The "Case Study" report listed above provides a much more detailed summary of the States FDR practice and performance. This Tech Brief provides only a very brief summary of a few key points of FDR.

Pre-Construction FDR Considerations

California, Missouri, and other States have developed and refined FDR techniques and specifications over a long time period that are now producing 15+ year service lives for JPCP and JRCP projects. To achieve a long service life requires high-level pre-construction considerations.

Appropriate Existing Condition

Slab replacement in California is used to address severe deterioration (stage 3 cracking) of individual slabs in isolated areas when other strategies, including doing nothing, cannot extend the service life by at least 5 years or are not cost-effective.

- <10% stage 3 cracking (3 or more pieces) – individual slab replacement.
- 10-20% stage 3 cracking – life cycle cost analysis to determine replace slabs or lanes.
- >20% stage 3 cracking – lane replacement.

Missouri uses FDR for both JPCP and JRCP slabs. The extent of longitudinal cracking, transverse cracking, and JRCP joint spalling are used as criteria for selecting FDR.

Replacing Individual Distressed Slabs

In determining the need for slab replacement, California considers the extent and type of distress observed within a project. The following assessment criteria are used to determine if slabs need to be replaced: Slabs with two or more corner breaks, slabs with third-stage cracking, slabs with segments that are moving relative to each other, slabs damaged due to lack of support caused by settlement, base failure, or excessive curling, and slabs with longitudinal or transverse cracks more than ½ inch wide.

FDR Dowel Load Transfer Design

States' designs for dowel bar layout, dowel bar diameter, and length of FDR vary, as summarized in Table 1. Figure 1 shows the California layout of the dowels. The dowel bar diameter is perhaps the most critical factor, since a slight change in diameter dramatically affects the steel/concrete bearing stress under a wheel load, which greatly affects joint LTE, erosion, faulting, and roughness.

Many experimental tests have shown that larger diameter bars show less joint faulting in new JPCP and also in FDR. Given the fact that transverse joint faulting is always greater at the outer edge of the slab, the outer two or three dowel bars are most critical to provide long-term high LTE. Therefore, the diameter of these bars and spacing are most critical factors.

Table 1. State FDR dowel bar layout and diameter.

State	Slab Thick (in)	Dowel Locat-ion	Dowels At Joint, (in)	Dowel Dia-meter (in)
CA	=< 9	WP	8 @ 12	1.25
CA	>9	WP	8 @ 12	1.5
MO	All	WP	10@ 12	1.0
UT	All	WP	8@ 12	1.5
WA	All	Uni-form	11@ 12	1.5
MN	All	Uni-form	11@12	1.25
GA	=< 10	Uni-form	11 @ 16	1.25
GA	>10	Uni-form	11 @ 16	1.5

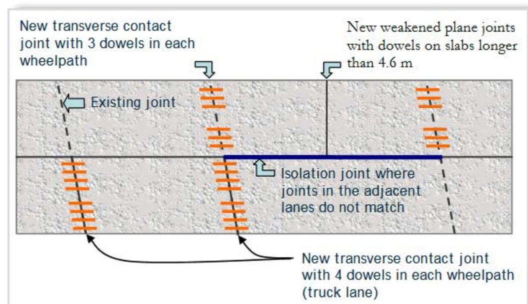

Figure 1. California FDR dowel layout.

Which is the best design? The larger diameter dowel bar should be the most effective in reducing long-term transverse joint faulting of FDR. California, Utah, Washington, and Georgia use 1.5-inch diameter dowels, and these States have four to five dowels per wheel path. These States have shown no significant faulting of FDR with these designs. Minnesota conducted a 2013 study on adequacy of anchoring dowels after some failures on a project and found a lack of bonding agent around the dowels from all contractors. They changed back from 8 dowels bars to 11 bars due to this problem with workmanship and increased the diameter to

1.25 inch, spread over 11 dowels uniformly spaced.

FDR PCC and Base Repair
The base course beneath the slab must provide adequate long-term support to the new FDR, just as in new design. If this is not provided, the FDR will fail no matter how well all the other construction steps are performed. Assessing the underlying base condition and determining when underlying base should be replaced is one of the more challenging aspects to slab replacements since the base layer is not visible until removal of the slab layer. Coring and ground penetrating radar can be used to investigate its condition, but these activities have limitations including time, expense, and accuracy (limited sampling).

An efficient method used by California for estimating base replacement during design is to use the surface distresses of the concrete slab to indicate base failure, considering that deteriorated base can extend beyond an individual slab into adjacent areas. Distress indicators include:

- Cracking with settlement > ¼ inch.
- Rocking slabs (typical with pumping fines).
- Spalling > 2 square feet total or > 2 inches wide over 75% of the crack length.

Length and Width of FDR
Another major design detail is FDR length (both minimum and maximum) that may have an effect on joint faulting and cracking. Nearly all States require full lane width for structural stability purposes. State recommendations for minimum length vary from 4, 5, and 6 feet. While most of these States require 6-ft minimum length, none report having excessive longitudinal cracking develop over time. Research has been somewhat inconclusive for doweled FDR, with some evidence that shorter slabs (especially 3 ft) tend to develop more longitudinal cracking. The maximum length of FDR is also important. Most States have maximum lengths to control transverse fatigue cracking. Missouri has a 15 + or – 5 ft maximum when the repair area equals or exceeds 30 feet. California has a maximum joint spacing of 15 feet.

Full-Depth Repair Specifications

All of the States included in this study have spent many years refining and improving these highly effective specifications for FDR. Table 2 summarizes their specifications, special provisions, and other documents.

Table 2. Summary of State specifications.

State	Specification
CA	Section 41-9: Individual Slab Replacement, ISR (2015) Concrete Pavement Guide
GA	GA 452, 504, 609
MN	MnDOT 2302 SP
MO	MoDOT Standard Specification 613.10. MoDOT Standard Drawing 613 (Sheet #1)
UT	UDOT: PCC 3055 Precast: SP 02757S, PB4, 2753
WA	Standard Plan A-60.10-03. WSDOT 5-01 Cement Concrete Pavement Rehab.

Dowel Bar Anchoring
Anchoring of the dowel bars into the existing slab is the most critical construction step for FDR. If this is not done adequately, the dowels will eventually become loose, the FDR joint will lose joint LTE, and pumping and faulting will develop along with cracking and settlements.

The process is to drill holes, clean with air, inject epoxy resin into the hole, rotate the bar during insertion, use grout retention rings (some States), place end caps on protruding dowels, and coat bars with lubricant. The grout retention rings are an important part of a system for anchoring dowels that includes the proper consistency and strength of anchor materials (cementitious grout or epoxy-based material), the right annular gap for the material being used, the proper injection of the material into the drilled hole, the proper technique for inserting and rotating the dowel to eliminate voids in the gap, and the grout retention ring to force full grout coverage at the joint face (the critical location) and hold it all in place until it sets.

Can dowels be anchored between existing dowel bars? Contractor feedback concludes that placement of dowels between existing dowels does not work. Practical solution is to extend the FDR about 12 inches to get past the existing dowels (e.g., move the transverse joint about 12 inches).

Concrete Materials

To reduce disruption to traffic, California carries out overnight repairs, limiting lane closures to the hours between 11 pm and 5 am. Severely distressed concrete panels are removed and replaced with rapid strength concrete (RSC). Only specialty or proprietary cement mixes are used that meet the early opening strength requirements within 2 to 4 hours after placement.

Missouri's high early strength concrete is often used. However, early shrinkage cracking is a concern. The contractor interviewed for this study has had good experience with high early strength materials. These materials can increase the cost of a project greatly. Mobile mixers are commonly used because of early set up time.

Curing and Avoiding Temperature Extremes and Extreme Upward Curling

Each State addresses proper curing procedures for cold and hot weather paving. One key aspect of hot weather placement of FDR needs special attention—severe upward curling of the FDR. Such curling has occurred when the temperature of the slab when the concrete hardens is much higher than the overnight low temperature of the concrete. A large difference may result in an upward curled slab that will develop top-down longitudinal cracking. (Yu, Mallela & Darter, 2006)

Extreme temperatures require special actions that prevent an FDR from becoming significantly curled upward (saucer shape) due to temperature extremes on sunny day afternoons. Extreme temperature differences like this can be avoided simply by cooling the surface of the slab after placement with several sprays of cool water or wet burlap. Wet burlap prevents rapid loss of moisture and maintains reasonable levels of concrete temperature during hydration. Wet burlap significantly decreases the potential for built-in negative temperature gradients during daytime placements.

Inspection/Acceptance

Effective inspection and acceptance procedures are extremely important to long-term performance. The inspection and acceptance process for FDR focuses on proper removal of concrete, dowel alignment and anchoring, base course repair, smoothness, concrete strength, cracks and other observable distresses in the FDR, and distress in surrounding concrete. Since the success and failure of an FDR depends so highly on achieving proper dowel bar anchoring, an incentive could be placed on achieving this requirement. This can be accomplished in two ways:

- Through random coring of the dowels to check visual coverage, as in the DBR specifications and States describe above.
- Falling Weight Deflectometer load testing of the FDR joints for LTE. This test would be very easy

and quick to perform. The higher the FDR joint LTE, the greater the incentive. A standard load testing procedure would need to be specified.

As a further aid to inspection/acceptance, a checklist for FDR of portland cement concrete pavements is included in the case study report. (Titus-Glover & Darter, 2007)

Performance of FDR

FDR is considered a cost-effective treatment for many existing JPCP and JRCP that can help significantly extend pavement life before more costly treatments such as an overlay or reconstruction is required. Performance of FDR in California, Missouri, Georgia, Minnesota, Utah, and Washington has been good, providing a service life ranging from 10 to 20+ years for JPCP and JRCP. Properly doweled and anchored FDR minimizes the occurrence of joint faulting with subsequent roughness and cracking. A recent performance analysis in California indicated that a very high percentage of rapid strength concrete FDR (98.6 percent) are performing very well after 3 to 8 years on a dozen projects. The same has been true for FDR with conventional material in the other States included in this study. (Bhattacharya, Zola & Rawool, 2008)

FDR Summary

The full-depth repair technology has evolved into a reliable restoration technique that is essential to producing a significant increase in life for JPCP and JRCP. FDR, when combined with repairs such as dowel bar retrofit and diamond grinding, significantly enhances concrete pavement service life (> 15 years). The key factors to long life of full-depth repair include the following:

- Incorporating a dowel bar design that ensures joint faulting will not occur well into the future.
- Proper anchoring of the dowels into the slab.
- Proper construction of other FDR steps.

California, Missouri, and the other States mentioned herein have excellent specifications, special provisions, and standards that provide long-life FDR projects. With proper project selection, design, construction, and inspection of CPR projects involving FDR, these States have demonstrated that many restored pavements can last from 15 to beyond 20 years before another restoration or rehabilitation.

References

Bhattacharya, B., M. Zola, and S. Rawool. *Evaluation of Rapid Strength Concrete Slab Repairs*. Sacramento: California Department of Transportation, 2008.

Titus-Glover, L., and M. Darter. *Guidelines for Improving Full-Depth Repair of PCC Pavements in Wisconsin.* Madison: Wisconsin Department of Transportation, 2008. http://wisconsindot.gov/documents2/research/07-03fulldepthconcrete-fr1.pdf

Yu, T., J. Mallela, and M. Darter. *Early Opening of Full-Depth Pavement Repairs.* Washington: U.S. Federal Highway Administration, 2006. FHWA-RD-02-085. https://www.fhwa.dot.gov/pavement/pub_details.cfm?id=407

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